PROCEEDINGS

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Nuclear Power in Developing Countries: Its Potential Role and Strategies for its Deployment

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

The demand for energy, especially electricity, in developing countries is expected to grow rapidly in the coming decades as they seek to improve the living standards of their growing populations. Substantial growth in developing country energy demand plus a continued heavy reliance of the power sector on fossil fuels is likely to result in an increased dependence of these countries on energy imports and thus to potential deterioration of their terms-of-trade, reduced energy security and, in the absence of costly mitigation measures, severe degradation of the environment and public health, and will also lead to increasing emissions of greenhouse gases. If supply security, health and environmental protection and climate change become pressing policy issues, nuclear power is, in the short to medium term, the only viable non-fossil base load electricity generating alternative (other than hydro where growth potential is limited) that is already meeting 17% of global electricity needs and contributing more than 30% of electricity supplies in 14 countries. It is in the above context that the International Atomic Energy Agency organized this seminar to explore the role of nuclear power in meeting the growing demand for electricity in the developing world, and to identify and discuss suitable ways and means for proper implementation of nuclear power programmes in these countries. Several issues were discussed, in particular, the need and role of nuclear power; economic and financial aspects; technology transfer and national participation; safety, regulation and safeguards; and public acceptance.

The seminar was hosted by the Government of India at the Bhabha Atomic Research Centre, Mumbai, and the excellent support facilities provided by the hosts significantly contributed to its success. The IAEA officers responsible for this publication were A.M. Khan, K.V.M. Rao and H.H. Rogner of the Division of Nuclear Power.

This publication provides a summary of the proceedings of the seminar and includes the papers presented, by session, as well as the panel discussion.

EDITORIAL NOTE

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SUMMARY

The demand for energy, especially electricity, in developing countries of the world is expected to grow rapidly in the coming decades as they undergo industrialization, experience increased urbanization and improve the living standards of growing populations. International agencies project electricity requirements of these countries to increase by a factor of 2.5 to 3 over the next 20 years and 5 to 7 fold by 2050. The fraction of primary energy for electricity generation will increase from about 26 per cent now to some 30–35 per cent during this period.

At present about 73 per cent of the electricity needs of developing countries is met through fossil fuels, with hydro and nuclear power contributing 22 per cent and 4 per cent respectively. Continued heavy reliance on fossil fuels will increase dependence on energy imports for a number of these countries, with consequent balance of payments difficulties and reduced energy security. Such reliance can also severely degrade the local and regional environment, and lead to increased emissions of greenhouse gases. Increasing hydropower is constrained by the limited potential of hydro resources and environmental considerations. At the same time, because of their intermittent nature, status of technological development and/or unfavorable economics, other renewable energy technologies such as solar heat, photovoltaic and wind power are not expected to be significant in the commercial base load supply of electricity in the foreseeable future. If supply security, health and environmental protection and climate change become pressing policy issues, nuclear power is, in the short to medium term, the only viable non-fossil base load electricity generating alternative (other than hydro where growth potential is limited) that is already meeting 17% of global electricity needs and contributing more than 30% of electricity supplies in 14 countries.

It is in this context that the IAEA organized this seminar to explore the role of nuclear power in meeting the growing demand for electricity in the developing world, and to identify and discuss ways and means for implementation. The seminar provided a forum for the exchange of information between experts and policy makers from both developed and developing countries, the nuclear industry and international organizations.

Several issues, in particular, the need and role, economics, financing, technology transfer, safety, regulation, safeguards and public acceptance aspects of nuclear power in relation to the prevailing situation in developing countries, were discussed during the seminar. In order to provide adequate coverage of these issues, five key issue papers, together with several supplementary papers and five country case studies were prepared by leading experts and policy makers under the overall guidance of the seminar steering committee.

The seminar was attended by 94 participants from 29 countries and the IAEA. The countries represented were Armenia, Bangladesh, Belarus, Canada, Chile, China, Croatia, Cuba, Egypt, France, Georgia, Ghana, India, Indonesia, Iran, Kazakhstan, the Republic of Korea, Kuwait, Lithuania, Mexico, Philippines, Romania, the Russian Federation, Slovakia, Sudan, the Syrian Arab Republic, Tunisia, Turkey, and Ukraine.

S.R. Hatcher of Canada, president of the American Nuclear Society from 1997 to 1998, was seminar chairperson. The chief guest at the opening ceremony was R. Chidambaram, chairperson of the Atomic Energy Commission of India. V.M. Mourogov, Deputy Director General and Head of the Department of Nuclear Energy, IAEA, represented the IAEA at the opening and closing ceremonies.

A total of 46 papers were presented in the technical programme, which comprised seven sessions directed toward:

(1) Need and Role of Nuclear Power
(2) Economic and Financial Aspects
(3) Nuclear Technology Transfer and National Participation
(4) Country Presentations
(5) Safety, Regulation and Safeguards
(6) Public Acceptance
(7) Experience with Nuclear Power in India.

The seminar concluded with a panel of nine experts from the IAEA (3), India (2), Canada, France, the Republic of Korea, and the Russian Federation. There was very active participation by those present throughout the seminar, and particularly during the concluding panel session.

The message from the developing countries at this seminar was that there is significant interest in nuclear power as part of their future energy strategy. It was recognized that considerable infrastructure must be in place for regulation, training, operations, public communications, etc. Technology transfer is vital in these areas as well as in design and construction. Waste management appears to be important primarily due to public concern, not because of technical or economic issues.

Without doubt, the biggest hurdle to implementing nuclear power programmes in developing countries is the high capital costs and severe difficulties in financing. Unless capital cost is reduced or profitability improved, there is little hope that nuclear power will make more than an incidental contribution to energy supplies in developing countries.

Public acceptance remains a significant hurdle to the rapid expansion of nuclear power. Despite many years focusing on the issue, there is no pattern of success for convincing the public or decision-makers that nuclear power is safe and economic. New approaches are necessary to overcome this problem.

Recommendations

(1) Since selection of the most cost effective nuclear power plant is a complex task for many developing countries, participants recommended the preparation of an international utility requirements document. This could be based on the IAEA guide for preparation of user requirements documents for small and medium reactors and their applications in developing countries, and be prepared jointly by interested utilities from developing countries. They might also invite the Electric Power Research Institute to provide input, based on their experience with US documents. The document could be the basis for international co-operation to develop an appropriate sized unit for mass production, and would be a natural follow-on to current studies of small and medium reactors.

(2) Launching of an international project to advance nuclear power in developing countries was recommended. One possibility would be a small, modular, high temperature, helium cooled reactor with an integral gas turbine. Another specific suggestion was the development of a fast breeder reactor, cooled by heavy metal and

optimized, not for breeding, but for economics, safety, non-proliferation, and waste minimization. Further definition of the nature and scope of such a project is needed.

(3) Regional co-operation in reactor design and construction and in fuel cycle facilities should be promoted as such a co-operation can play a key role in the deployment of nuclear power by developing countries. It will have an added advantage of easing the technology transfer difficulties while, at the same time, meeting the requirements of international safeguards against nuclear weapons proliferation.

(4) Consideration should be given to the feasibility of a regional international electrical grid serving several countries, using large central generating stations. This could reduce costs to individual countries through economies of scale, simplified financing, risk sharing among many partners, consolidation of regulatory activities, and more efficient operation. It could also provide training in nuclear power plant operation and maintenance for future projects.

(5) Full cost accounting should be used to prioritize energy investment decisions. This would level the playing field for those options, such as nuclear, that already include the costs of all externalities, such as management of wastes, health effects, and environmental effects.

(6) Developing countries should set electricity prices so as to cover the full costs of generation. This would improve cash flow for investment in new units.

(7) Debate is now under way among medical experts and health physicists on assumptions of a linear, non-threshold model for the health effects of low level radiation. Research and analysis in this field by independent experts should be encouraged.

SUMMARY OF THE SESSIONS

1. TECHNICAL SESSIONS

1.1. Need and role of nuclear power

The papers in this scene-setting session left no doubt that there is indeed a pressing need for nuclear power worldwide. As we look to the next century, the developing nations must have cheap and abundant energy to advance the welfare of their citizens. Energy demand will be particularly strong in developing countries because of their continued high population growth, coupled with rapid economic development. Furthermore, electricity demand is growing at an even faster rate than economic growth and energy demand in general. Some countries have few indigenous energy resources, and nuclear power offers strategic energy security. The environment is a concern as regional problems of acidification from acid gases arise from coal and oil combustion. On a global scale, there is mounting belief that carbon dioxide in the atmosphere may lead to global warming and industrialized countries have committed themselves to reducing carbon dioxide emissions. The developing countries are similarly concerned and would like economic alternatives to fossil fuels. These points indicate a growing need for nuclear power to provide energy in an environmentally benign manner.

Several papers pointed out that nuclear technology is already advanced and capable of filling this role if economically competitive. Selecting the best electricity generating options is difficult because of current costs, pricing policies and financial ground rules.

Under the IAEA project on Comparative Assessment of Energy Sources, methodologies and databases have been developed which facilitate objective comparison of different energy options in terms of their technical, economic, environmental and human health aspects on full energy chain basis, under prevailing regional economic and financial conditions. There appears to be a market for a sizable number of small and medium reactors if competitive with other energy options.

1.2. Economic and financial aspects

This issue is highest on the list of concerns of most developing countries. Cost comparisons of nuclear electricity from various sources illustrate the wide range of costs, depending upon such factors as initial capital cost and discount rate on the investment; higher discount rates favor fossils fuels such as gas, oil and coal. However, it is increasingly clear that nuclear power will not enjoy any special status when investment decisions are made. If the return on investment is competitive, there is no shortage of capital available for major projects, including nuclear power. The key is the rate of return. Discount rates can be misleading since they suggest that interest rates for nuclear power must be low for the plants to be competitive. Financial markets are not interested in lending money at low interest rates when they can obtain better rates for other projects. Thus, the use of low discount rates bears little relation to the market; capital is available if the return is good. That means that unless the capital costs of nuclear power are reduced, few plants will be built, and then only with government subsidies. To build financial credibility and attract foreign investment, utilities must improve their credit ratings. This may be best achieved by invoking full pricing of electricity, rather than having subsidies or preferential interest rates.

It would benefit developing countries if economically competitive smaller reactors could be built to match the grid sizes of many countries.

Capital costs may be reduced through standardization and/or modular designs and by reducing construction times. In the Russian Federation, a molten lead-cooled fast reactor is proposed as an economic alternative that will have the strategic benefit of resource extension.

1.3. Nuclear technology transfer and national participation

There was a strong consensus on the need for technology transfer, to move nuclear power forward in developing countries. Both buyers and vendors have already recognized this and there are several examples of effective technology transfer resulting in successful nuclear programmes in the buyer countries. Successful technology transfer occurs only when there is a commitment by both parties to a programme of assimilation of the technology through training, technical assistance, and hands-on application by the receiver. Technology transfer is a continuing need for new national nuclear programmes.

1.4. Country presentations

Presentations were made from twelve developing countries, many of which have no nuclear programmes at present. These provided an important update on current thinking and planning in these countries. In a number of presentations, national energy security was mentioned as one of the reasons for considering nuclear power. This is especially true in countries with few indigenous energy resources who are forced to import energy supplies. Environmental advantages, particularly the benefits of reducing carbon dioxide emissions, were frequently quoted as a reason for consideration of nuclear power. Analysis of renewable energies will likely continue but indications are that capital costs are too high. One analysis indicated very low capacity factors for solar and wind installations, resulting in diseconomies at capital costs above 200–250 US $/kW(e). For distributed load and remote locations, solar and wind power can still be competitive if the avoidance cost of transmission is included.

In general, the priorities are aimed at building the infrastructure in preparation for acquiring nuclear power plants.

In countries with Soviet-installed plants, considerable attention is being given to upgrading the safety of operation.

The theme of high capital cost and difficulties of financing recurred in many presentations, although some countries found economic advantages for nuclear under their specific financial conditions. High capital cost and difficulties in financing were a frequent topic of discussion outside the main meeting room. This appears to be the principal stumbling block to obtaining plants.

1.5. Safety, regulation and safeguards

The necessity of safe operation was strongly emphasized. Good regulation is an essential element in ensuring safe operation. However, this is a complex issue and needs an appropriate balance between the level of safety to be achieved and the cost of achieving it. There is considerable experience in the industrialized countries as well as a growing body of experience in some developing countries that have embarked upon nuclear power programmes. This is an area where there is a strong need for international co-operation. The IAEA safety standards are an important contribution to international safety. The IAEA safeguards programme to provide assurance that nuclear materials in civilian use are not diverted from their peaceful purpose, was presented without comment by the participants.

1.6. Public acceptance

Some papers discussed the continuing dilemma of public acceptance and public communication. It was recognized that more effort must be devoted to public communication, because previous methods have not solved the problem. The public is interested in the spectacular, whether accidents, murder or natural disaster; it is not interested where everything is going well. While problems of communication are common to all nuclear projects, nothing was identified unique to the developing countries.

1.7. Experience with nuclear power in India

This session gave participants an excellent review of the Indian nuclear programme. It is a vibrant, major strategic energy programme planned well into the future, with the ultimate goal of development of fast breeder reactors to improve the use of uranium resources. Performance of existing units continues to improve steadily and there are well developed plans for future expansion and the introduction of larger units, and PWRs as well as PHWRs.

Despite the need for a massive expansion of electricity generation to bring India up to the world average per capita level, there are severe financial constraints. The programme is government funded and must take its place in the national priorities for capital allocations. The high capital cost of new nuclear plants means that much of the electricity expansion will be done with natural gas.

2. PANEL DISCUSSION

To introduce the panel discussion, the chairperson S.R. Hatcher first summarized issues raised in the technical papers and the discussions of those sessions. He then reviewed the conclusions he had drawn from the seminar up to this point.

The participants in the panel discussion are listed below:

- R. de Préneuf (France)
- K.I. Han (Republic of Korea)
- P.E. Juhn (IAEA)
- V. Nadkarni (India)
- Y.S.R. Prasad (India)
- H.-H. Rogner (IAEA)
- M. Rosen (IAEA)
- A.V. Zrodnikov (Russian Federation).

2.1. Seminar chairperson's review of the sessions

The presentations left no doubt that there is a pressing need for nuclear power worldwide. The developing countries must have cheap and abundant energy to cope with high population growth and advance the welfare of their citizens through economic development. The demand for electricity is growing at an even faster rate than economic growth and the demand for energy in general. Some countries have few indigenous energy resources and these are often far from load centers and expensive. For these countries, nuclear power offers strategic security of energy supply. There are also growing concerns over environmental quality, especially in large urban centers, where the combination of heating, industrial activity and traffic congestion cause severe atmospheric pollution from fossil fuel combustion, particularly in the winter season. Developing countries are also concerned about the possibility of global warming and looking for economic alternatives to fossil fuels to increase energy use while minimizing carbon dioxide emissions.

These points indicate a growing need for nuclear power as an environmentally benign energy supply. Several papers pointed out that nuclear technology is well advanced and capable of fulfilling this need, provided it is economically competitive.

Selecting the best electricity generating option is not easy because capital requirements and fuel costs vary widely for different options. Capital costs and financial ground rules differ from country to country. The IAEA DECADES project is a useful tool to analyze the economic impacts of various national energy options.

The large units currently built in the industrialized world are beyond the financial capability of the utilities in many developing countries. There is a need for economically competitive, smaller sized units matching the size of their electrical systems.

Capital costs and financing seemed highest on the list of concerns of the developing countries. Considerable discussion had taken place, both in the formal sessions and in the halls of the seminar, regarding financing of nuclear power plants. While the developing countries expressed their need for attractive financing terms and foreign investment, it was also emphasized that capital is available and flows automatically to projects providing the best return on investment. Nuclear power does not enjoy any special status when investment decisions are made. If the return on investment is competitive, there will be no shortage of capital available for major projects, including nuclear power. Analyses clearly indicated the importance of the discount rate, or the cost of money, in comparing different energy options. Low discount rates clearly favor higher capital cost projects with low fueling and operating costs, such as nuclear power, whereas high discount rates favor low capital cost projects, such as gas, oil and coal fired generators. However, low discount rates and long write-off periods traditionally used for nuclear projects may no longer be valid in light of the global trend towards deregulation and privatization of electric utilities. It can be misleading to conclude that low discount rates are necessary for nuclear projects, because financial markets and governments direct their capital to projects providing the best return on their investment. This emphasized again the importance of reducing the cost of nuclear plants so they can attract capital at normal investment terms.

There was a strong consensus that technology transfer is essential for a successful nuclear programme. Successful technology transfer occurs only when there is a commitment by both parties to the absorption and assimilation of the technology, through hands-on training and practical application.

Twelve countries, many of which have no nuclear programmes at present, made presentations on their national programmes. These provided an important update on thinking and planning in those countries. National energy security is a reason for interest in nuclear power in a number of them, particularly those with few indigenous energy resources. Environmental benefits, including the reduction in carbon dioxide emissions were mentioned several times. Analyses of renewables have been done in several countries and indications are that the capital costs are too high to consider them on a large scale. One analysis indicated that the capacity factors are low for solar and wind installations with the result that they would not be competitive at capital costs above US $250/kW(e). However, for remote locations and distributed load, the competitiveness of solar and wind power may improve considerably due to the avoidance of the cost of transmission.

In general, building the infrastructure for acquiring nuclear power plants is the priority in these countries. Countries that already have installed Soviet plants are paying considerable attention to the safety of their operations.

The theme of high capital cost and the difficulties of financing recurred in many presentations. However, some analyses found economic advantages for nuclear under their own financial parameters. Outside the main meeting room, high capital cost and difficulties in financing were frequent topics of discussion. This is the principal stumbling block to new nuclear plants in developing countries.

In the discussions on safety, there was clear recognition of the need for international co-operation. The International Atomic Energy Agency safety standards were recognized as an important contributor to safe operation.

Communication with the public is a key factor in winning public acceptance. However, it is an area where, despite more than thirty years of work, the industry has not yet been effective and the public remains concerned in many countries. The problem is that it is difficult to attract the public's attention unless the story is spectacular or deals with a disaster. Stories of continuing success and routine operation are of no interest. The challenge is to make the material more interesting to the public. The problems are common across the world and there do not appear to be any unique issues for the developing countries.

There was an excellent review of the Indian nuclear programme. It remains an ambitious programme with a strong forward looking and strategic approach. There is much that other developing countries could learn from this example of industrialization. India has well-developed plans for expansion of its nuclear power programme with the introduction of larger units. But once again, participants noted constraints of capital cost, with the result that natural gas would increasingly be used to meet new demands.

It emerged that there is considerable interest in nuclear power by developing countries as part of their future energy strategy. There was recognition that a considerable infrastructure in regulation, operations, training, and public communication must be in place. Technology transfer is vital in those areas as well as in the design and construction of the power plants. Waste management appears to be of concern primarily as a result of public concern rather than because of technical or economic questions. Without doubt, the biggest hurdle to implementing nuclear power in the developing countries is the high capital cost, which in turn leads to severe difficulties in financing. Unless capital costs can be significantly reduced, there is little hope for nuclear power to make more than an incidental contribution to world energy supplies.

What recommendations could participants make towards improving the prospects for nuclear power in developing countries? A number of suggestions surfaced during the week. The chairperson mentioned some of these, and invited further discussion of these and other suggestions, so the final report to the Agency could provide guidance for the future.

2.2. Presentations of the panelists

The chairperson then invited each panelist to make a brief statement, indicating which was the most important issue raised by the seminar and recommendations for dealing with it.

R. de Préneuf (France) said that the three key conditions for success are safety, economic competitiveness, and strong government support. He emphasized that another accident of the scale of Chernobyl would make it impossible to continue with nuclear power. Economic competitiveness remains a key issue, and it is important that the comparison be made with local alternatives, which may vary from country to country and even within larger countries, such as China and India. For example, coal may be more competitive than nuclear near coal pits, whereas nuclear may be more competitive when the transportation lines are extended. The French have demonstrated that economic competitiveness can be achieved by increasing scale and reducing unit costs, although smaller units may be competitive in some situations. Economies are also achieved by standardization and series production, with any changes made on all units. Large reductions of cost can also be achieved by increasing local input, when a series of units is built. Societal costs, such as consideration of pollution effects, will not be sufficient to sell nuclear power plants if the economics are unfavorable. Government support is essential, not to subsidize the cost, but for the infrastructure to support a nuclear power programme, such as commitment to a long term programme, regulatory infrastructure, guarantee of loans and adherence to international conventions.

K.I. Han (Republic of Korea) emphasized that it is unnecessary to develop independent nuclear regulatory requirements for a country's first nuclear power plant. To start with, one can adopt the IAEA or supplementary regulations, or regulatory requirements of the supplier country. He stressed the need for balanced regulatory requirements, so the cost of compliance does not have unacceptable economic impacts. A very important aspect is the attitude and will of the country's policy makers for a successful nuclear programme. Nuclear power offers energy independence, particularly for countries with few natural resources, such as coal and oil. Now is a good time for prospective customers to enter the business because it is a buyer's market. Help from the developed countries is necessary. The spin-off of a nuclear programme is very important because of the strict quality requirements, which can then be applied to other manufacturing and boost the industry of a country. However, this cannot be done without the help of the donor country. The industrialized countries should help in technology transfer through favorable financial terms for the transfer. We must show the public that nuclear power is safe and cost competitive. Developed countries should provide favorable financing for developing countries, increase local participation, and transfer technology.

P.E. Juhn (IAEA) reiterated the need for nuclear power in developing countries and urged them to take full advantage of the current buyer's market. Governments should improve manpower skills and build industry by acquiring technology transfer from suppliers. A national research institute can provide manpower training and receive the technology from supplier countries. Architect engineer companies and constructor companies can render a major role. Local manufacturers must also receive and use the technology. The government is important to initiate this. It is unnecessary for developing countries to develop their own technology but local industry should benefit to the maximum extent from technology transfer arrangements. The IAEA is willing to provide support to member states to facilitate technology transfer and manpower training.

V. Nadkarni (India) stressed the importance of building confidence with the public. He felt that the most important issue is winning the confidence of consumers and vendors in the future of nuclear power. Winning consumer confidence involves demonstrating the safety and need for nuclear power and making nuclear power cost effective. Communication with the public is important and a transparent system is evidence of openness. Confidence of investors on the return on investment is equally important. There is a consensus that nuclear power will be called upon increasingly to contribute to energy supply, but the task is winning consumer confidence, and making it as attractive as any other investment to public and private capital.

Y.S.R. Prasad (India) pointed out that nuclear power is more difficult to initiate in developing countries than in developed countries. Financing is important but there are also political problems. It is essential to show the public that nuclear power is beneficial and that the operations are safe, otherwise people will not accept it. Safety is a most important issue, but returns on safety are low considering the input of effort. There is no such thing as absolute safety and we should not be excessively conservative in setting safety standards or the system will be uneconomic. One problem is that advanced countries have not shared safety technology, but have kept it totally commercial. An important role for the IAEA is to disseminate information on safety to developing countries. Standardization of safety regulation is important and plant design standardization could make it easier to regulate. A long-term commitment is needed and good performance must be demonstrated. In all these areas, developing countries need the help of the developed countries.

M. Rosen (IAEA) stressed the need for nuclear power, saying the real issue is the dramatic global increase in energy demand - an increase of 150 per cent in the next 50 years. Electricity growth will be even more dramatic, because electricity is clean at the point of use. Developing countries now have a very low per capita energy use and their demand will grow fastest, due to industrialization and increases in population. Economics is certainly key in the choice of energy sources, but environmental issues can also be a key argument. Urbanization is increasing and 80 per cent of the world will live in urban areas. It will require clean energy sources at the point of use. Economic surcharges on greenhouse gases and health effects can make the economics of nuclear power more attractive.

The second issue is public misunderstanding regarding nuclear power. We should clarify these issues, especially with respect to the economic and environmental sectors. We must explain the realities of radiation — that we are surrounded by radiation, that the nuclear industry has stringent regulations, basically a zero health effect policy, uncommon to any other industrial enterprise. We need better understanding of accidents in comparison to other industries. All energy resources, including hydroelectric, have major consequences. Perhaps the most misunderstood issue is waste management. We discuss the hazard, but we do not emphasize that the magnitude is small, because the quantities of waste are so small. The debate will be difficult, but must be engaged. Seminars are one way, but we need smaller meetings, with the media and decision-makers to clarify issues and misunderstandings.

A.V. Zrodnikov (Russian Federation) felt the most important problem is ways to satisfy the tremendous, and growing, energy needs of the developing countries, with limited natural resources, and environmental concerns. One of the theories of growth now is to look into the future, take from it the appropriate technology, and launch development work toward this technology, today. Plan so that when the future comes, the technology will be available. Looking into the future of nuclear energy production, there is only one technology capable, not just of using natural resources, but producing new ones. This is nuclear power with a portion of fast breeder reactors and special fuel cycles. They can meet all requirements on safety, economics, ecology and non-proliferation. He recommended launching an international project, joining scientific efforts and minds to solve energy production problems, not only for developing countries, but for mankind. The IAEA can play a central role in such a project.

2.3. Remarks by the session co-chairperson

The chairperson then invited the panel co-chairperson, *H.-H. Rogner (IAEA)* to present his conclusions. Mr. Rogner stressed that the key to success for the developing countries lies in the economics of nuclear power. If the economics are unattractive, then all the other issues do not matter. There is no need to worry about public acceptance if nuclear power is not economic. We must be sure nuclear power is economic in its own right.

Security of energy supply is an important feature of nuclear power because it avoids use of large amounts of imported fuel, requiring only small amounts of an open commodity, uranium. There is enough inexpensive uranium in the world, so development of the fast breeder reactor is premature. Strategic security of supply is a valid reason to pay a premium, so subsidies to nuclear power are not necessarily bad when applied for strategic purposes.

The external costs of all energy supply options should be included in the cost of the power generated, but are not at present. For example environmental and health effects should be included for all forms of energy. If such costs were included, the economics of nuclear power would be improved. Energy must be affordable to developing countries and environmental concern is something that must be affordable. So without economic development, countries do not reach the point where they can exercise good stewardship of the environment. We must go through the cycle and minimize the ecological burden created by energy production. In industrial settings, external costs could now tilt the balance in favor of nuclear power, but we should not bank on it. In the long term, climate change may collaterally benefit nuclear power, but cannot be the sole justification. More important is the TINA (there is no alternative) approach - that really equates the cost of not supplying energy to the economy and to society. As to breeders, eventually we will need the breeder, but we usually talk 50 to 70 years in the future. For most countries it is not an immediate question. There is enough inexpensive uranium for at least the same order of time as conventional energy reserves. So it is premature to argue that we must go into breeding if we go nuclear. Such an argument might deter some developing countries from adopting nuclear power.

2.4. Open discussion: Highlights

The chairperson then invited comment from the floor, and there was a spirited discussion period involving many of the participants. Because so many important points were raised, the discussion is reported in detail in the Panel Session. The principal points are summarized here.

There was a consensus that the developing countries will need energy as a part of their industrialization and that nuclear power will be an important component, provided conditions are right. One opinion was that the need is more important than the cost, but most felt that nuclear must compete economically.

The most difficult issue for developing countries is cost and financing. The developing countries are typically short of capital, making financing a particular burden. This is made more acute by the capital-intensive nature of nuclear power plants. This can be compounded when the scarcity of capital leads to construction delays, which in turn increase the interest during construction, resulting in higher capital costs by the time the unit starts to produce revenue. Furthermore, the traditional capital markets are not generally available to capital scarce countries, which must turn to export credits and government financing. These are difficult to secure unless the country is economically healthy, a situation rarely found in developing countries. It is a classical case of bootstrapping the economy of a country.

Economics is then a central issue not only for developing countries, but also for the developed countries, who now find that pipeline natural gas is the economic competition. Furthermore, as deregulation of the electricity industry occurs, especially in the developed countries, the emphasis is more and more on short-term economics, and a rapid return on investments. Projects such as nuclear power with high capital cost and low fuel and operating costs are at a disadvantage compared with projects such as gas-fired generators, with low capital and high fuel costs. Short-term economics always lead to the selection of gas as the preferred energy option. It was argued that strategic issues such as security of supply, environmental impact, and resource depletion should carry heavier weight than economics, but most countries find these arguments hard to sustain when faced with investment decisions and scarcity of capital. Economic competitiveness appears to be the key for all countries.

There was general agreement that the capital cost of nuclear plants must be reduced if they are to compete with natural gas. Provided the need for power is clear and the capital cost is low enough to give competitively priced electricity, there will be capital available to build nuclear plants. Although some countries are exploring mass production of small and medium sized plants, there was a caution that matching the grid is important and larger units may be cheaper and easier to operate.

Another attack on the cost of nuclear power was the suggestion of an international electrical grid to serve several countries, using large central generating stations operated solely for the participants. This would bring economies of scale, simplified financing, risk sharing among more partners, consolidation of regulatory activities, more efficient operation and the opportunity for training nationals in operation and maintenance of nuclear plants.

There was recognition that the externalities of environment, particularly carbon dioxide emissions, should be included and all energy options evaluated on a level playing field. However, governments appear to have little appetite for introducing carbon taxes or non-carbon incentives, despite commitments to the Kyoto Protocol. Without such quantitative treatment of these externalities, it is unlikely that environmental factors will have much impact in stimulating the use of nuclear power instead of fossil fuels.

Many participants identified the need to improve communication with the public to allay concerns about nuclear power. It was noted several times that decision makers must be convinced of the benefits and safety of nuclear power, notwithstanding the fact that politicians follow public opinion in most instances, rather than exercising leadership in decision making. The media are an important element in communication, but are more interested in sensational stories than in promotional pieces from the industry. To be effective, the industry must learn to present material in a way that will interest the public and that they can readily understand. A differing point of view was also expressed, that public acceptance doesn't really matter if the decision-makers are prepared to be leaders, to make hard decisions and live with them. One approach that seems successful is to ensure that local communities obtain clear and tangible benefits, such as decreased taxes, better community projects, schools, sports facilities and improved roads, from the presence of a nearby nuclear power plant. In some cases, local communities will then object if projects are delayed, because benefits are also delayed.

An important issue in communication is safety. Public concerns over the safety of nuclear plants stem primarily from fear of radiation. There was a general feeling that, in an effort to overcome this fear, regulators, designers and operators have gone to excess in adding more and more complex elements to plants to increase safety levels. It is not clear that the objective is always achieved, and there was some feeling that the added complexity increases costs, but does not improve safety. The most important action industry can take is to avoid another Chernobyl-type accident, for it would almost certainly spell the end of nuclear power.

Another important feature of safety and radiation protection is the tightening of ICRP recommendations. This conveys a sense of danger to the public. Debate is now under way among medical experts and health physicists over the assumption of a linear, non-threshold model for the health effects of low level radiation. This is an area in which the IAEA can stimulate research and analysis by independent experts.

For many developing countries, selection of the most cost effective nuclear power plant is a complex task. There was further discussion of the merits of preparing a joint international utility requirements document based on the IAEA guide for the preparation of User Requirements Documents for Small and Medium Reactors and their Applications in Developing Countries (technical document, now in draft form). This publcaton would be prepared jointly by interested utilities from developing countries, under the guidance of the IAEA. The Electric Power Research Institute might be invited for input based on experiences with US documents.

Several participants suggested that the time has come to launch an international project on nuclear power development under the auspices of the IAEA. One specific suggestion was development of a fast breeder reactor, cooled by heavy metal and optimized for economics, safety, non-proliferation, and waste minimization. Another would be a small, modular, high temperature, helium-cooled reactor with an integral gas turbine. Further definition of the nature and scope of such a project is needed.

Finally, there was further discussion of the possibility of developing regional fuel cycle facilities. Recognizing that it not sensible for small countries to set up their own facilities for the fuel cycle, it was suggested contemplating a regional fuel cycle center by constructing and operating a high level waste management facility. This could initially be a storage facility, with the prospect for long-term, permanent disposal. Other features of the fuel cycle could be added as desired and justified economically.

NEED AND ROLE OF NUCLEAR POWER

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Key Issue Paper No. 1

NUCLEAR POWER FOR DEVELOPING COUNTRIES

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Abstract

Is there a rationale for developing countries to adopt nuclear power? This paper explores this rationale and the suitability of nuclear power for developing countries by surveying the prerequisites for and implications of developing a nuclear power program: infrastructure availability, economics and finance, environment, the needs for technology transfer, the regulatory and institutional frameworks required and the awareness of public concerns.

1. INTRODUCTION

Providing adequate energy services - and especially the availability of abundant and inexpensive electricity - are essential for economic development, human welfare, and higher standards of living. Electricity shortages or lack of reliability can be a bottleneck to economic development and human welfare. Without economic development, it is difficult to address the environmental challenges associated with poverty.

Since the onset of the industrial revolution in the 19th century, production and the accumulation of wealth in the industrialized North has been principally driven by the increasing use of fossil fuels. Between 1960 and 1997, global energy use increased about three fold. Since electricity is a clean and versatile form of energy, its demand has grown even faster and the world consumption of electricity increased more than five fold over the 1960 to 1997 period. The fraction for electricity generation increased from 17% to 27%. As the 20th century draws to a close, some two billion people living in developing countries do not yet have access to modern, commercial energy services, especially those provided by electricity. Per capita energy and electricity use mirror the level of economic development and welfare, measured in income per capita. The economic and energy disparities between the industrialized and developing countries[1] are put into perspective in Figure 1. Three quarters of the global population live in the developing South but account for a mere one quarter of the global economic output.

More specifically, the average annual commercial energy and electricity consumption in developing countries are about 0.6 tons of oil equivalent/per capita (toe/cap) and 800 kilowatt hours/per capita (kWh/cap), corresponding to about one-ninth of those in the Organization for Economic Cooperation and Development (OECD) countries and one-twelfth of those in North America. Hidden in these statistics are the aforementioned two billion people, without access to electricity or other commercial forms of energy. In countries like Bangladesh and Tanzania, the average annual consumption of energy and electricity are less than 0.1 toe/cap and 100 kWh/cap and the per capita income is among the lowest in the world. In addition, because the energy needs are largely met from non-commercial forms (foraged agricultural

[1] In this paper, the term "developing countries" covers all the countries of the world except the following: Australia, Canada, Japan, New Zealand, the USA and the countries of West and East Europe, including all those countries previously part of the former USSR.

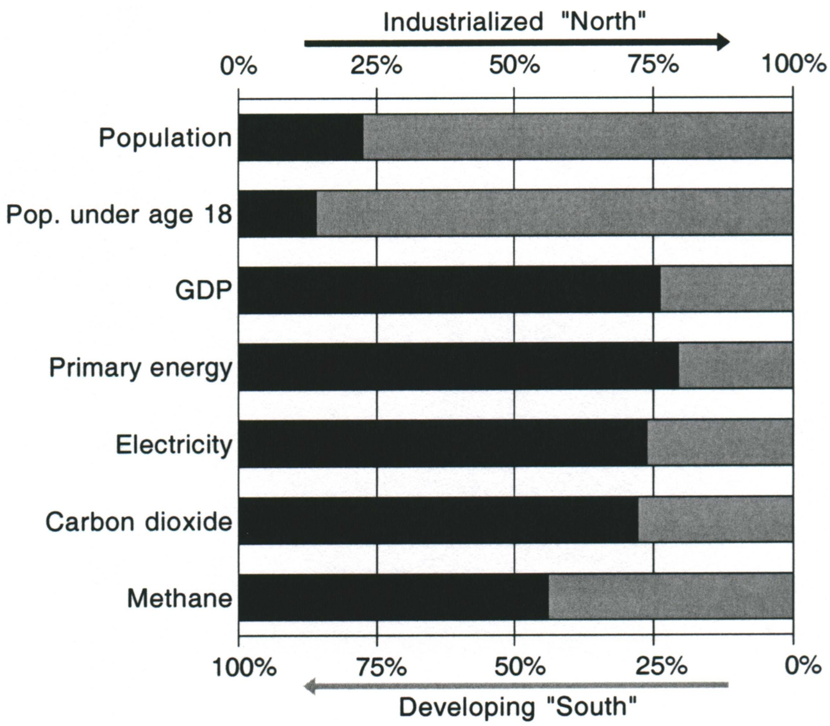

FIG. 1. North-South disparities, 1997.

waste and firewood), these countries also experience serious deforestation, top soil erosion and subsiding water table problems.

Material wealth accumulated in the industrialized countries and fed by fossil fuel combustion did not occur without pain, i.e., local and regional environmental degradation partly undermined the economic gains. With increasing standards of living, modern societies also began to express a preference for non-material values and quality of life: cleaner air, pristine rivers and lakes, and healthy forests. In essence, the question arose as to the environmental sustainability of "business-as-usual" development. Clearly, environmental stewardship is first of all a matter of affordability; secondly, it is a matter of knowledge. Measures have been implemented in most OECD countries to correct some obvious environmental disturbances but others remain obscure. Alterations to the composition of the atmosphere, largely caused by fossil fuel combustion and land-use changes, may already have caused a discernible human impact on climate (IPCC, 1996). Although the extent of anthropogenic greenhouse gas (GHG) emissions and potential climate change are not yet fully understood, caution led world leaders to agree in 1997 in Kyoto to curb future GHG emissions from industrialized countries.

To date, environment burdens in the developing countries are primarily local and regional. However, this burden is likely to be more severe and more damaging than that in the industrialized countries, due to the sheer size of the demographic explosion. It is projected that world population will grow from about 5.8 billion people to over 10 billion by the year 2050 (UN, 1998), with some 95% of the increase in developing countries. Because short-term economics necessarily take precedence over environmental protection, the transition from unsustainable non-commercial energy to commercial energy supply in the developing countries is likely to require using low cost fossil technologies (predominantly coal) with little or no pollution abatement. This will lead to a rapidly degrading local and regional environment and drastically increase greenhouse gas emissions.

Economic development and demographic dynamics will reverse the regional disparities in aggregate energy consumption within the coming two to three decades (although because of high population growth, this does not translate into drastically improved per capita energy use in developing countries). The economies of the industrialized countries have now slowed, having reached near saturation in energy consumption, and further increases in energy service are expected to be offset to a large extent by future gains in efficiency. Contrarily, the demand for energy, especially electricity, in developing countries is expected to increase as they industrialize, accompanied by increased urbanization, and as they seek to improve the quality of life for their fast growing populations.

According to projections made in early 1998 by the International Energy Agency of OECD (IEA/OECD, 1998), the primary energy demand in developing countries is expected to increase by a factor of more than two, with demand for electricity increasing by a factor of almost three between 1998 and 2020. Corresponding increases projected for the industrialized countries are by factors of 1.1 and 1.3, respectively. By 2020, aggregate primary energy use and GHG emissions in the developing countries will be nearly the same as those in the industrialized world.

A relatively longer term perspective is provided by the joint study of the International Institute for Applied System Analysis and the World Energy Council (Nakicenovic *et al*., 1998). The study projects that, depending on economic growth and the extent to which efficiency is improved, the demand for primary energy in developing countries will increase 3 to 5 fold by 2050, with an accompanying 5-7 fold increase in electricity demand. This significant expansion of global energy production and use will require the utilization of all available energy supply options, including nuclear power, as well as stepped-up efforts to further improve energy efficiencies throughout the energy system. To dismiss a particular option a priori would be imprudent.

Figure 2 puts the prospects of future demand into perspective, comparing cross-country data of 1997 per capita income and per capita electricity use. Despite the numerous and widely different factors that determine demand in individual countries, the income effect is striking: Electricity makes possible economic development which, when compounded with population growth, inevitably leads to substantially increased needs for electricity.

2. ELECTRICITY SUPPLY OPTIONS

Capital stock turn-over in energy supply in general, and particularly in the electricity sector, has been slow compared with capacity expansion. To date, most existing generating capacity was put in place to meet demand growth rather than to replace old capacity. Global electricity generation expanded more than five-fold over the last 40 years - a time period comparable to the life times of most generating stations. Consequently, this means that change in the electricity supply structure is not only inherently slow, but investment decisions today will impact the generating mix until the mid 21st century. This is of special importance for greenhouse gas considerations. Investments in fossil fuel infrastructure and fossil-source electricity generation locks this capacity into the system for half a century or so. Premature retirement due to GHG mitigation pressures may prove quite costly. Figure 3 depicts changes in global electricity generation between 1971 and 1995. Clearly, fossil fuels continue to dominate, holding at a market share of 62% (down from 75% in 1971). Reduced oil use for generation accounts for the lion's share of this decline, brought about by the oil price hikes of the 1970s and supply assurance considerations. Coal use also declined from 41% to 37%, which was almost offset by a corresponding increase in natural gas use. The overall decarbonization of the global electricity system, however, would not have materialized without the rapid commercialization of nuclear power during the 1970s. The market share of nuclear power grew from just 2% in 1971 to 17% in 1997. Over that period, hydropower did not keep pace with total electricity generation and its market share declined from 23% to 19%. Renewables - solar, wind, commercial biomass, and geothermal energy - practically non-existent some 25 years ago, now supply 2% of global electricity (the bulk of which emerged in North America since 1990 as the result of strong incentive programs).

The electricity supply pattern in developing countries like that of industrialized countries (see Figure 4), is heavily dominated by fossil fuels (73%), while hydropower contributes some 22% and nuclear power about 4% to electricity generation. The share of geothermal and other renewable, is about 1%. Unlike industrialized countries, developing countries as a group have not made much use of nuclear power so far. At present, only 9 developing countries operate nuclear power plants, one in Africa (South Africa), five in Asia (China, India, Pakistan, Republic of Korea, and Taiwan China) and three in Latin America (Argentina, Brazil and Mexico). The nuclear share in these three sub-groups is 2.2% in Africa, 4.7% in Asia and 1.5% in Latin America. The corresponding shares in the OECD countries and reforming countries[2] 24% and 18%, respectively.

Fossil fuels, hydropower and nuclear power, will remain the main energy options for supply of electricity in the foreseeable future. Modern renewables will expand as their techno-economic performance improves with investment and experience. In areas distant from existing transmission grids, wind and solar electricity can be economically feasible alternatives, especially when avoided transmission costs are factored into the equation. Where peak demand coincides with availability of an intermittent energy source, e.g., solar electricity with peak air conditioning demand, renewable energy may well supplement base-load. However, only minor contributions to base-load supply can be expected from renewable sources of energy other than hydropower, since these are, in one way or another, constrained: geothermal energy is unavailable in most parts of the world; wind power, photovoltaics and solar thermoelectric conversion are intermittent sources of energy that are not yet economically if provided with energy storage or back-up; and biomass-based generation requires large quantities of land, putting it in direct competition with food production, especially in thickly populated developing countries with limited arable land. The 1998 study of IEA/OECD projects renewables (other than hydropower) to contribute some 1% to total electricity supplies in developing countries by the year 2020.

2.1. Hydropower

Hydropower is an energy resource with essentially zero fuel costs and low operating costs. Considerable hydropower potential exists in many developing countries. But further exploitation is increasingly constrained by the high cost of constructing dams in remote sites in difficult terrain, where most remaining potential lies, and by the adverse environmental impacts of building large dams. Still, it is expected that sufficient new hydropower will be developed in the coming decades to maintain the share of hydro at about the same as at present, 20-30%, in electricity supplies of developing countries. Latin American developing countries are expected to continue to meet 70-80% of their electricity needs through hydropower.

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[2] Reforming countries are the countries currently undergoing the transition from centralized economic planning to market economies. Essentially they include the states of the Former Soviet Union and Eastern Europe.

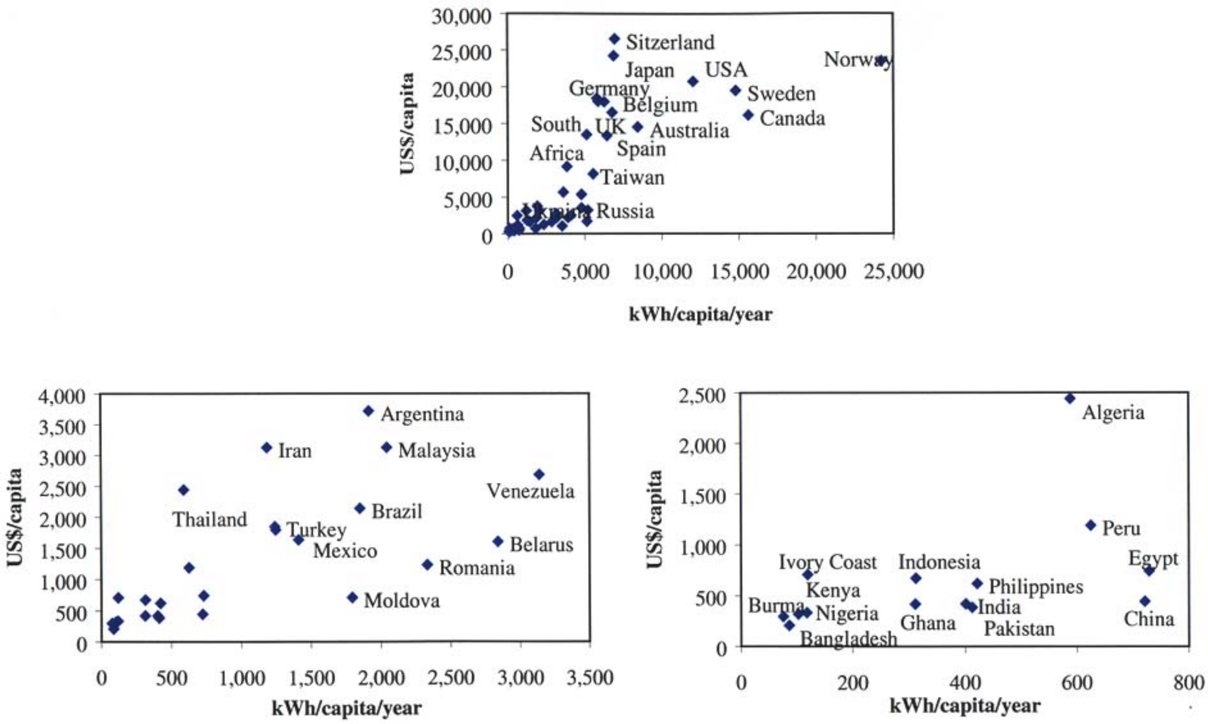

FIG. 2. Electricity use per capita versus income (GDP) per capita at 1995 market prices and exchange rates.

2.2. Fossil fuels

Besides being the main source of electricity generation, these fuels are essentially the only means (other than electricity) of providing commercial energy for transportation, process heat in industry and heating and cooking in households. (Biomass-based noncommercial fuels are also used in households of developing countries.) Thus, the use of fossil fuels for electricity generation must compete with other applications for which no viable alternative exists now or in the foreseeable future. However, the concerns of the 1970s and early 1980s that fossil fuels are running out have now disappeared (Rogner, 1997). Thanks to technological progress, even the proven global reserves of fossil fuels are so large that, at present production rates, oil will last for more than four decades, gas for more than six decades and coal for more than two centuries. Add to this the enormous occurrences of unconventional oil and gas and the potential extends well through the 21st century (IPCC, 1996). At the same time, concern has increased about adverse environmental impacts - at local, regional and global levels - from continued reliance on fossil fuels.

Although developing countries as a group are well endowed with fossil fuels (90% of world proven reserves of conventional oil, 50% of natural gas and 30% of coal), these resources are very unevenly distributed (BPAmoco, 1999). In fact, the vast majority of developing countries are net importers of energy, with many meeting 30-50% of their energy needs, or even 60-90% (e.g., Philippines, South Korea, Taiwan China, Thailand), through the import of oil and gas.

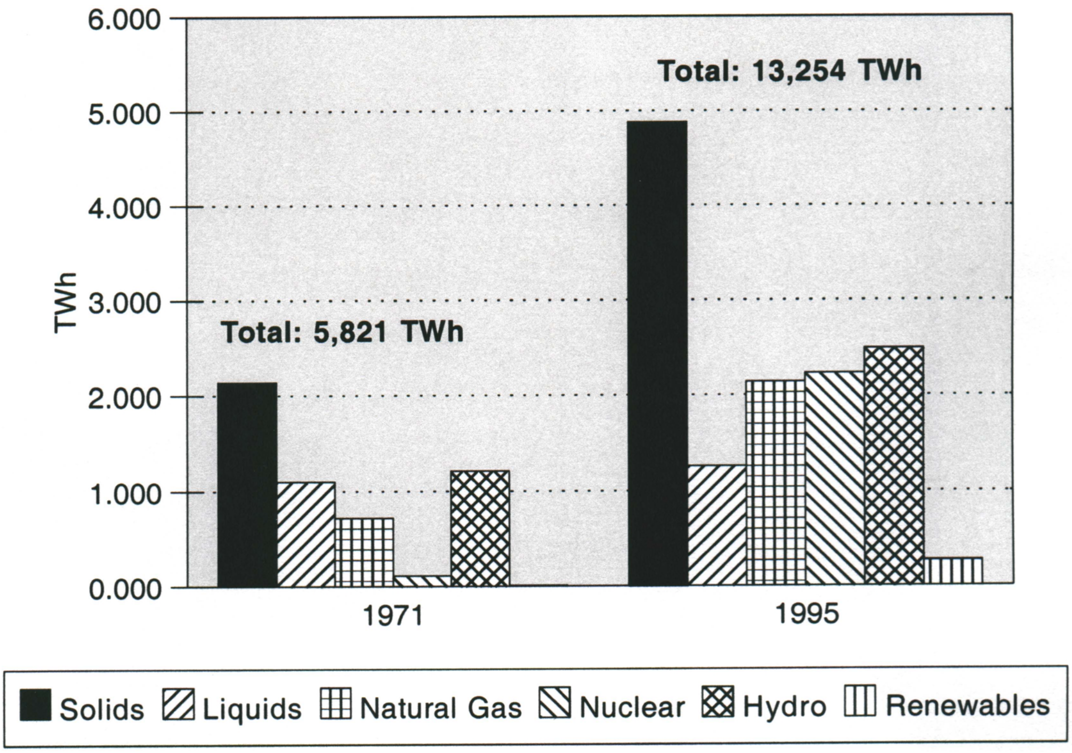

FIG. 3. Changes in the structure of the global electricity generation mix, 1971-1995. Source: EIA, 1998

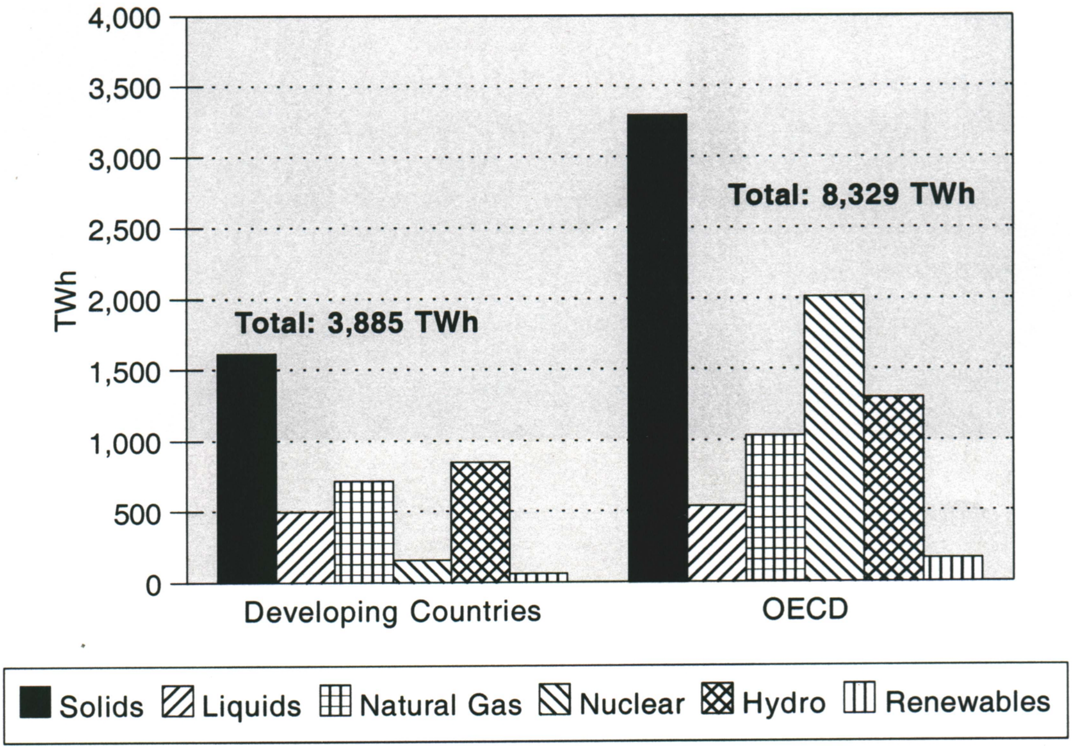

FIG. 4. Electricity generating structure for developing countries and OECD. Source: Adapted from EIA, 1998 and EC, 1998.

2.3. Nuclear power

Nuclear power is an economically proven and well established energy option and an important component of the electricity supply system of many countries today. In spite of thefact that it entered the market only four decades ago, it now generates some 2,300 Tera Watt hours (TWh) of electricity per annum and commands an impressive 17% share of the global electricity. Figure 5 shows the evolution of nuclear electricity generation and growth of the nuclear share in global electricity between 1970 and 1998 (IAEA, 1999a). In 1998, the nuclear share was more than 40% in 9 countries and more than 25% in 18 countries, but as high as 77% in Lithuania and 76% in France. Among the developing countries, South Korea and Taiwan China also meet between one fourth to one third of their electricity requirements through nuclear power.

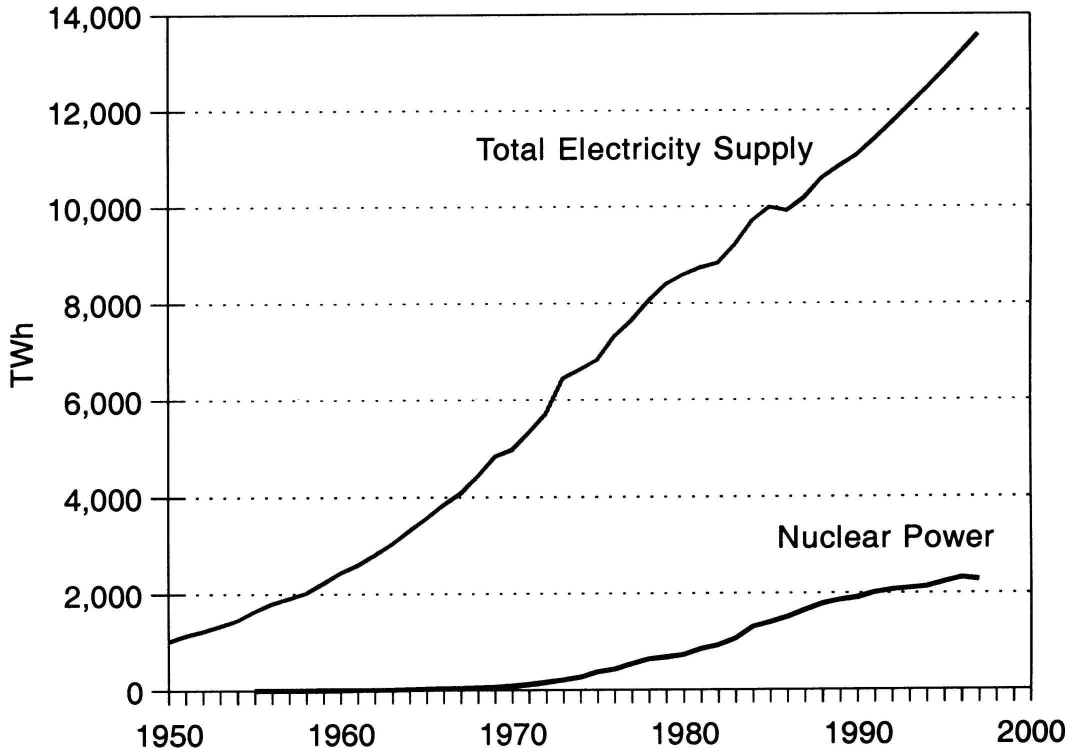

FIG. 5. Nuclear power contribution to global electricity supply, 1950 to 1998.

By the end of 1998, 434 nuclear power plants with a total generating capacity of 349 Giga Watts electric (GWe) were operating in 32 countries and another 36 units with a generating capacity of 27 GWe were under construction in 14 countries. Nine developing countries now using nuclear power, have 39 operating reactors with a total capacity of some 23 GWe. Of the 36 units under construction by the close of 1998, 19 were in developing countries, including two in a country (Iran) without an operating nuclear power plant. The total accumulated operating experience of nuclear power plants by the end of 1998 amounted to over 9000 years, corresponding to an average operating period of almost 20 years per plant (see Table I). Besides the 10 developing countries which have nuclear plants operating or under construction, others have shown an interest in using it. These are:

Africa	Algeria, Egypt, Libya, Morocco, Tunisia
Middle East	Israel, Saudi Arabia, Syria, Turkey
South and East Asia	Bangladesh, Indonesia, Malaysia, North Korea, Philippines[3], Thailand, Vietnam
Latin America:	Chile, Cuba[4], Peru, Uruguay

Nuclear power has the potential to meet a much larger share of future electricity needs than is currently forecast, in an environmentally friendly manner, for both industrialized and developing countries. The use of nuclear power for non-electric applications has been limited however, nuclear power has the potential to replace fossil fuels for a substantial part of this market as well. For example, nuclear power can produce heat and steam for industry and district heating. Processes requiring temperatures of up to 300ºC can be supplied by the current generation of water cooled reactors, while temperatures of up to 950ºC can be produced from breeders and high temperature, gas cooled reactors. Since severe shortages of fresh water are expected in many areas of the world - including coastal areas - nuclear power might become important in the desalination of seawater. A number of developing countries are showing increased interest in this application.

3. FACTORS AFFECTING THE CHOICE OF NUCLEAR POWER

The extent to which developing countries use nuclear power to meet their future electricity needs depends on factors such as:

- fossil fuel and hydropower resources and constraints on their exploitation,
- the need to reduce energy imports and ensure national energy security,
- the need for diversification of supply sources,
- the economic competitiveness of nuclear power,
- environmental considerations,
- size of the national grid and availability of appropriate nuclear plant capacities,
- the technological capability to assimilate an advanced and demanding technology,
- public acceptance of nuclear technology,
- the availability of financing for a capital intensive technology,
- the desire to reap spin-off benefits from an advanced technology,
- the tenor of the international environment for or against nuclear power, and
- international cooperation in the field of nuclear technology.

[3] In the Philippines, a 600 MW(e) plant was mothballed in 1986 owing to political and legal difficulties between the manufacturers and the Government of the Philippines.

[4] The work on the construction of two 408 MW(e) units was stopped in 1992 due to financial difficulties.

TABLE I. NUCLEAR POWER REACTORS IN OPERATION AND UNDER CONSTRUCTION, 31 DEC. 1998. Source: IAEA, 1999b

Country	Reactors in operation		Reactors under construction		Nuclear electricity supplied in 1998		Total Operating Experience to 31 Dec. 1998	
	No of units	Total MW(e)	No of units	Total MW(e)	TW(e).h	% of total	Years	Months
Argentina	2	935	1	692	6.9	10.0	40	7
Armenia	1	376			1.4	24.7	31	3
Belgium	7	5,712			43.9	55.2	156	7
Brazil	1	626	1	1,229	3.3	1.1	16	9
Bulgaria	6	3,538			15.5	41.5	101	1
Canada	14	9,998			67.5	12.4	405	2
China	3	2,167	6	4,420	13.5	1.2	17	5
Czech Republic	4	1,648	2	1,824	12.4	20.5	50	8
Finland	4	2,656			21.0	27.4	79	4
France	58	61,653	1	1,450	368.4	75.8	1,052	1
Germany	20	22,282			145.2	28.3	570	7
Hungary	4	1,729			13.1	35.6	54	2
India	10	1,695	4	808	10.2	2.5	159	1
Iran			2	2,111				
Japan	53	43,691	2	1,863	306.9	35.9	863	5
Kazakhstan	1	70			0.1	0.2	25	6
Korea Republic	15	12,340	3	2,550	85.2	41.4	137	5
Lithuania	2	2,370			12.3	77.2	26	6
Mexico	2	1,308			8.8	5.4	13	11
Netherlands	1	449			3.6	4.1	54	
Pakistan	1	125	1	300	0.3	0.7	27	3
Romania	1	650	1	650	4.9	10.4	2	6
Russia	29	19,843	4	3,375	95.4	13.1	613	6
South Africa	2	1,842			13.6	7.3	28	3
Slovak Republic	5	2,020	3	1,164	11.4	43.8	73	11
Slovenia	1	632			4.8	38.3	17	3
Spain	9	7,350			59.0	37.2	174	2
Sweden	12	10,040			70.0	45.8	255	2
Switzerland	5	3,079			24.4	41.1	118	10
United Kingdom	35	12,968			91.1	27.1	1,168	4
Ukraine	16	13,765	4	3,800	70.6	45.4	222	1
USA	104	96,423			673.7	18.7	2,351	8
Total	434	348,864	36	27,536	2,293.7		9,012	6

Note: The total includes the following data in Taiwan, China:

- 6 units, 4884 MW(e) in operation;
- 1 unit 1300 MW(e) under construction;
- 35.4 TWhe of nuclear electricity generation, representing 24.8% of the total electricity generated there;
- 104 years 1 month of total operating experience.

3.1. Energy security and the need for diversification of supplies

Developing countries without large, easily exploitable hydropower and short of fossil fuel, not only face economic hardships and balance of payment difficulties due high cost energy imports, they are also the most vulnerable group with respect to energy security. Nuclear power can benefit them by reducing their energy import bill and by providing a certain measure of energy security through diversification of supply. These considerations have been key in the decision of developing countries like South Korea and Taiwan China, as well as of industrialized countries like France and Japan, to go nuclear on a large scale. In all likelihood, these will also be determinants in the decision of countries in similar situations.

The annual fueling cost of a nuclear power plant is lower than that of an equivalent fossil fuel fired plant by a factor of 3-4. Thus, nuclear power can substantially save recurring annual fuel costs over the 30-40 year working life of the plant, thereby reducing the energy bill even of countries needing to import nuclear fuel.

The uranium fuel required for annual operation of a 1,000 Mega Watt electric (MW(e)) nuclear plant is about 30 tons. About 60,000 tons of natural uranium a year are required to operate all the nuclear reactors in the world, compared to some 1.5-3 million tons of fossil fuel to operate only 1,000 MW(e) capacity oil or coal fired plant. Several years supply of uranium fuel for a nuclear plant may be kept in reserve as a precaution against possible future disruption. Such disruptions are also unlikely since uranium resources are widely distributed in the world. In any case, building a nuclear fuel reserve for several years supply, does not pose a storage problem.

There are sufficient known uranium reserves worldwide to last for at least 75 years at current levels of once-through use, without reprocessing spent fuel. In addition, there exist enormous uranium occurrences at lower geological concentrations that can be mined at higher than today's costs but with little effect on total electricity costs given the typically low share of fuel costs in nuclear generating costs. As well, recycling plutonium from reprocessed spent fuel in thermal reactors and introduction of fast breeder reactors would increase the energy potential of today's known uranium reserves by up to 70 times, enough for more than 5000 years at today's levels of use. There is no imminent danger of uranium scarcity or of a rapid increase in uranium prices.

3.2. Economic aspects

The economics of electricity is the single most important factor in the choice of electricity generation technologies. Compared to fossil fuel fired plants, nuclear plants are more expensive to build but much less expensive to operate. The capital cost of a nuclear power plant is typically three to four times that of an equivalent oil or gas fired plant and one and a half to two times that of an equivalent coal fired plant. The operation and maintenance costs of all the plants are comparable but the fueling cost of nuclear plant is much lower — only one quarter to one third as much as that of a fossil fuel fired plant. The net result is that electricity generation costs per kWh from all the four types of plants are roughly comparable. The relative economics of electricity generation from nuclear, coal, gas and oil fired plants vary in different countries with the plant construction cost, localization factor, plant site, environmental regulation, interest rate, O&M costs and fuel cost for each type of plant.

For example, since the early 1990s, the principal incremental electricity capacity addition in industrialized countries with a natural gas infrastructure in place, is based on natural gas and the highly efficient combined cycle gas turbine. Short construction time, low capital costs compared to coal or nuclear, smaller incremental unit sizes, considerably lower emissions compared to coal and oil, and inexpensive natural gas make it the fuel of choice. However, where a natural gas infrastructure is lacking - which includes most developing countries - this is not an option, at least in the short to medium run. Further performance gains are expected in the efficiency of combined cycle technology, resulting in reduced fuel requirements and capital costs, and hence lower generation costs. Natural gas or coal sourced fuel cells in the 10 to 200 MW(e) range are other high-efficiency generating options rapidly approaching commercialization, with the potential to challenge combined cycle technology.

Because of high capital costs and long lead times, the competitiveness of nuclear power is highly sensitive to interest rates. At relatively low interest rates, e.g. 5%, nuclear power is competitive with some coal power plants and even some natural gas combined cycle plants (see Figure 6). At a higher interest rates[5], e.g. 10%, gas fired combined cycle units are much more attractive investments (Figure 7). Within this range, there can be substantial differences in relative plant costs depending on the technologies and pollution abatement schemes required.

The competitiveness of natural gas combined cycles (NGCC) is highly sensitive to gas prices which may vary greatly even within one country and might enter a period of high volatility if gas demand grows substantially.

Figure 8 depicts the greater sensitivity of fossil-sourced electricity generating costs for France. These data reflect the change in incremental generating costs caused by technical performance/efficiency improvements (especially for NGCC), fuel cost differences within France, and prevailing short-term fuel import prices. In 1997, natural gas represented a least-cost alternative but only within a small margin. Slightly higher gas prices could quickly undermine its competitiveness while nuclear power generating costs are quite stable over a wide range of fuel price scenarios.

Nuclear generated electricity remains competitive with coal generation for base load supply in many countries which have developed and implemented nuclear programs (see Figure 6 and Figure 7). However, its competitiveness is challenged by continued high costs, by relatively low long-term fossil fuel prices, and improved efficiencies in coal and natural gas conversion technologies which are being made far faster than comparable gains in the efficiencies of nuclear plants.

Technological progress and changes in environmental protection and safety regulations continue to affect the competitiveness of both nuclear and fossil fueled power generation. While technological progress improves the economics of power generation, environmental protection policies and measures, including more stringent atmospheric emission limits are likely to increase the costs of fossil fueled power plants that must comply with regulations by adding pollutant abatement and/or by relying on higher quality, more expensive fuels (e.g., low sulfur coal). The cost of nuclear generated electricity is not affected by such measures but might increase due to more severe safety and radiation protection standards.

[5] The commercial sector tends to demand a premium on interest rates for projects with longer amortization periods or when the return-on-investment may be subject to abnormal risk perceptions.

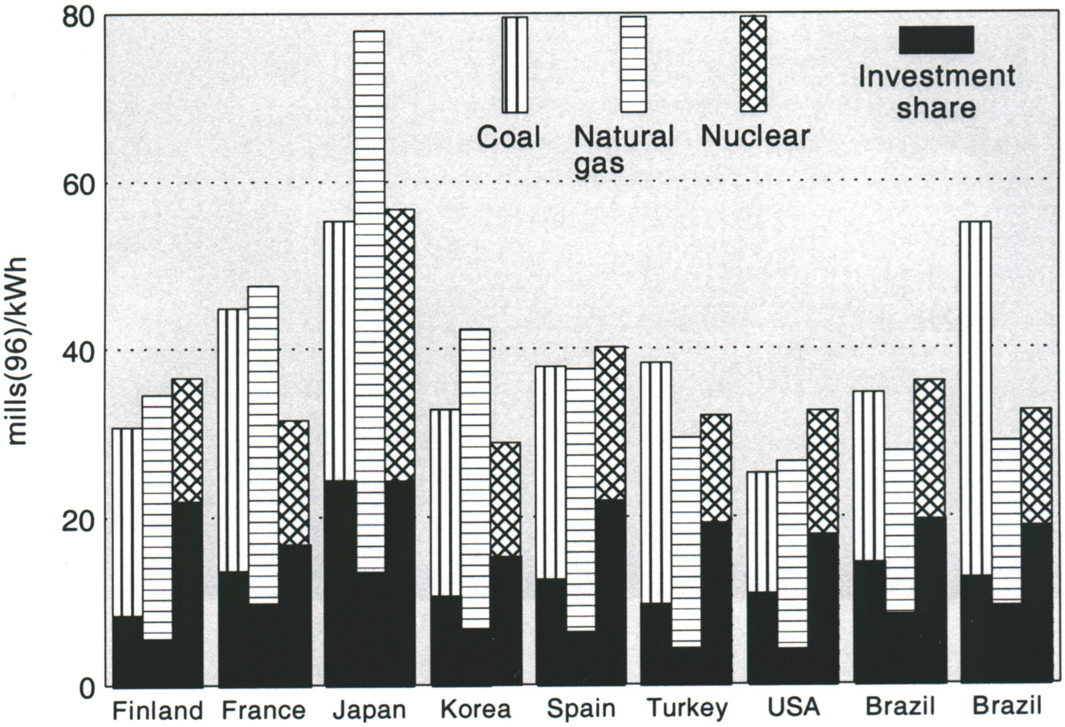

Fig. 6. Economic performance of nuclear power versus coal and gas-sourced electricity generation (5% interest rate). Source: OECD, 1998.

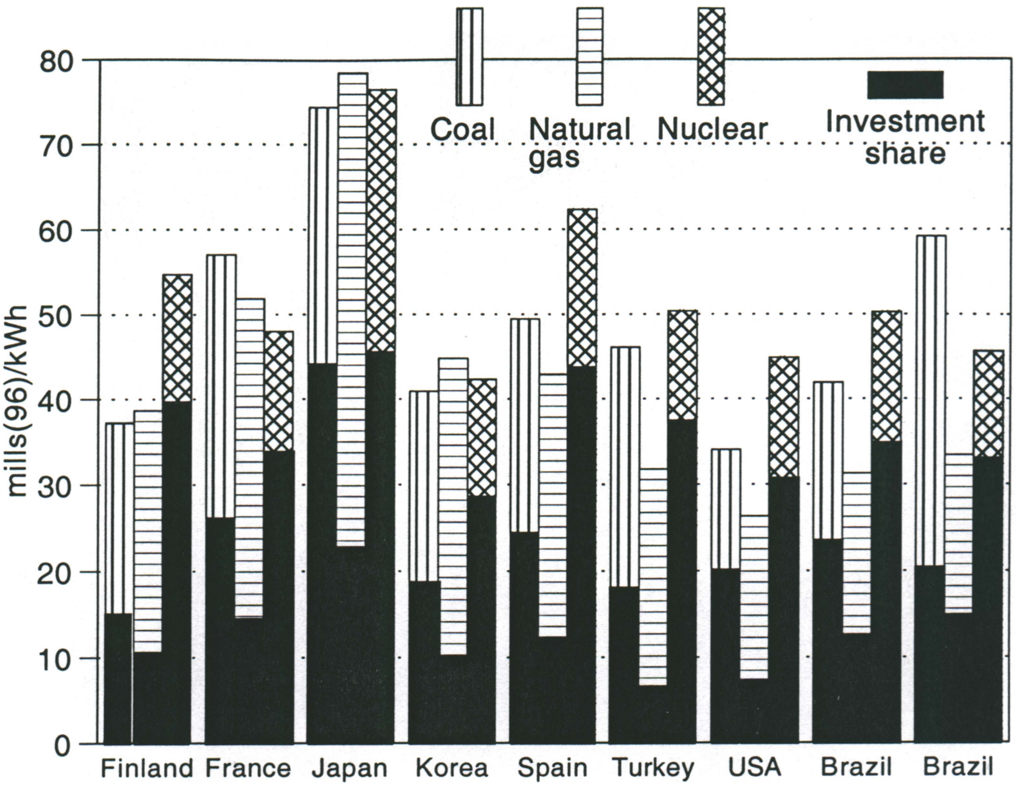

Fig. 7. Economic performance of nuclear power versus coal and gas-sourced electricity generation (10% interest rate). Source: OECD, 1998.

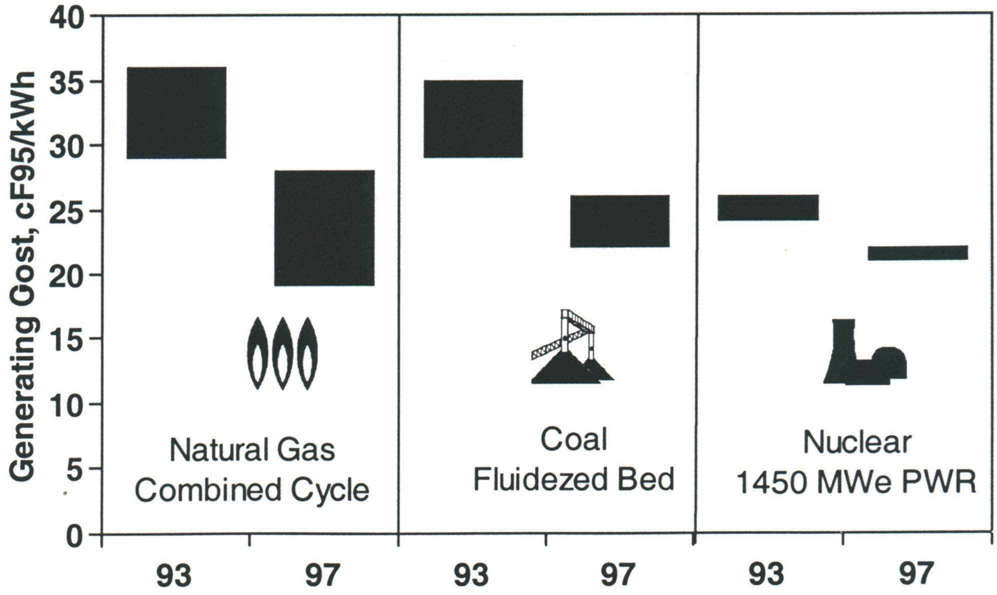

Fig. 8. Fuel price sensitivity of different incremental electricity generating options in France.

3.3. Financing[6]

The high up-front cost of nuclear power is a serious deterrent for countries short of capital (both developing and industrialized), even where nuclear power has clear economic merit and is attractive for energy security and environmental reasons. Because of higher investment costs compared to equivalent fossil fired plants, a nuclear plant competes for scarce financial resources with obligate investments in other essentials such as education and health. This delayed nuclear power projects in several countries, prolonged construction in many (e.g., Argentina, Brazil and India, as well as the Czech Republic, Romania, Slovak Republic, and Ukraine) and, in one case (Cuba), necessitated abandoning work on partly completed projects.

Until recently, power in most developing countries was an exclusive, state-owned monopoly and still is in many cases. State-owned utilities are usually required to provide electricity to under-privileged sectors of the economy at subsidized rates. Besides reducing the self-financing capacity of the utilities, this undermines their credit worthiness for raising foreign capital. The net result is that capital intensive projects must be abandoned in favor of less costly projects, irrespective of their relative life-cycle economics.

The trend to deregulate and privatize electricity markets places great emphasis on competitive returns on investment and on risk minimization. Utilities will increasingly need to adopt (the generally higher) market interest rates as discount rates, especially if privatization stems from decreasing finance support from the public sector for energy infrastructure. Because of high up-front costs and long licensing and construction times, financing nuclear power plants in general, and especially in developing countries, is becoming more difficult. Private investors are usually more interested in quick, low risk returns than in long-term socio-economic advantages. Local, regional or global environmental benefits are not an issue of immediate concern, at least under current national regulations and policies. Investors' environmental concerns focus on minimizing liabilities, and on the cost of pollution abatement to meet government standards, which serves to highlight the importance of

[6] See also Key Issue Paper No. 2.

adequate government environmental regulation. From the perspective of the private sector, ideally, generating technologies should have the following characteristics: low capital costs, modular and small unit sizes, short construction schedules, short amortization times, capacity closely matching load, siting flexibility, and minimal regulatory/public acceptance problems; i.e., attributes largely met by natural gas combined-cycle (NGCC) plants but not necessarily by contemporary nuclear plants.

The challenge to the nuclear industry is to develop advanced reactors with these characteristics without compromising safety. Reactors of advanced designs now under development are expected to meet some of these goals: load following capabilities, shorter construction times, lower capital costs, improved fuel cycle efficiencies all leading to more competitive costs for nuclear generation. The financing environment for nuclear power, even in a deregulated and privatized power regime, would become more favorable once these new smaller, modularized reactors become available and if governments include environmental externalities in the cost of generation. However, commercial use of the new designs, will require adjustments in licensing, which has a tendency to stymie and frustrate innovation.

Besides a lack of credit worthiness of their utilities, such factors as political stability, inconsistent national policies and high external indebtedness may also deter the inflow of foreign capital into developing countries. The recent financial crises in developing countries of East Asia underscores the uncertainty and high risk factor that foreign investors assign investments in all developing countries. In spite of this, the nuclear industry in industrialized countries, now short of domestic markets, might be willing to provide sufficient levels of supplier credit for power plant construction under suitable guaranties. To exploit these opportunities, developing countries must implement fiscal and regulatory policies to build vendor confidence. At the same time, international monetary establishments should facilitate confidence by financial back-up of the national guarantees. Whether such changes can occur in international financing within the next two decades is highly uncertain.

3.4. Environmental considerations

Besides its merit as a cost effective generating option and a means to provide energy security to energy resource-poor developing countries, nuclear power is also attractive because it is essentially pollution free. Today, fossil fuels are a major source of worldwide environmental degradation, with coal the most polluting followed by oil and then gas. Fossil fuel combustion causes the atmospheric release of large quantities of the oxides of nitrogen, sulfur dioxide, carbon dioxide and particulates and have serious adverse environmental impacts at local, regional and global levels. For example, the type of pulverized coal plants that will meet a large part of the incremental electricity demand in China and other developing countries for the coming one to two decades will, on average, release the following pollutants per kWh generated (without emission mitigation)[7]: 9.1 grams of sulfur dioxide (SO_2), 3 grams of nitrogen oxides (NO_x), 0.2 gram of particulates and 321 grams of carbon as carbon dioxide (CO_2). Assuming equivalent full power operation of 6,500 hours per year of such a 600 MW(e) plant, the annual emissions amount to 35,500 tons of SO_2, 11,700 tons of NO_x, 780 tons of particulates, 1.25 million tons of carbon and 148 tons of heavy metals including radionuclides. Nuclear plants do not directly produce such emissions, and those from the operation of the rest of the nuclear fuel cycle are negligible.

[7] Assuming coal with the following characteristics: 1% sulfur, 12% ash, 8% moisture (all by weight), and a heating value of 22 MJ/kg.

3.4.1. Local and regional environmental degradation

The degradation of their local and regional environment is of immediate concern to developing countries. A number of large cities in developing countries now face increasing levels of smog caused by NO_x emissions and regional acidification from emissions of sulfur and nitrogen oxides is already a serious problem in parts of major coal consuming countries, China and India. This problem is expected to spread to countries in South and East Asia as fossil fuel consumption increases in these densely populated countries. Based on local and regional environmental considerations, nuclear power will become even more attractive to these countries than it is today.

Flue gas desulfurization and de-noxing equipment or more highly efficient plants would lower emissions of SO_2 and NO_x by as much as a factor of 10 and more. But these abatement measures do incur cost penalties of up to 25%. Table II compares two types of pulverized coal plants, the Chinese capacity expansion model and a modern European plant designed to meet current air emission codes. The 25 percent increase in generating costs may tilt the economics of generation toward nuclear even where it is not otherwise economically competitive.

Although some radioactive materials are released to the environment during operation of a nuclear power plant and other fuel cycle facilities, the amounts are small and strictly limited to levels far below those of health significance, by regulations laid down by international organizations (ICRP[8] and IAEA). The quantity of such releases may be judged by the fact that, in some cases, radioactivity released from a coal fired plant exceeds that from the normal operation of an equivalent nuclear plant. Coal, like most natural materials, contains natural radionuclides that are released during combustion. In coal there is an average of 2.08 parts per million (ppm) of uranium, 4.58 ppm of thorium and 0.054 ppm of potassium-40. Most of the more than 4 tonnes of uranium, 9 tonnes of thorium and 0.1 tonne of potassium-40 contained in the coal burnt annually in 1,000 MW(e) coal fired plant (40% efficiency, load factor of 6,500 hours/year, average US bituminous coal) end in the fly ash and are disposed of "uncontrolled"[9].

3.4.2. Climate change concerns

While the fear of global warming from increasing concentrations of GHGs in the atmosphere, especially carbon dioxide, is a major global concern, the industrialized countries are responsible for more than two thirds of the current CO_2 emissions. These countries agreed at the Third Conference of the Parties (CoP 3) held at Kyoto last year to binding commitments to reduce the emissions of six GHG gases, of which CO_2 is the single most important, by at least 5% below 1990 levels during the commitment period 2008 - 2012.

Although developing countries were spared from similar commitments, the stabilization of atmospheric GHG at acceptable levels will be impossible unless they too try to contain emissions, especially from fossil fuel combustion. Thus, with time, developing countries are likely to feel increasing international pressure to slow down and gradually stabilize emissions

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[8] International Commission on Radiological Protection.

[9] The determination of the impact on human health of these radioactive material emissions is very complex and depends on numerous factors including the concentration in the coal, combustion temperature, the portion of fly ash in total ash, the efficiency of the emission control devices, the actual composition of radionuclides generated, their half-life times, the location of the emission source, population density, etc. Thus, radiation exposure comparisons are difficult to generalize. But it is fair to say that electricity generation from coal may result in radiation exposures to the public that exceed those associated with the full nuclear fuel cycle chain.

of CO_2, notwithstanding the obvious need for increased energy to support socio-economic development.

Developing countries must then make full use of the three main options available for reducing CO_2 emissions, namely, improved energy efficiency, a shift to low carbon fossil fuels and increased use of non-carbon energy sources. Improvement of energy efficiency is a welcome option every where as it decreases energy requirements, reduces emission of all pollutants, not just CO_2, and reduces costs. But there is a limit to which efficiency may be improved cost-effectively. Going beyond that could be counter productive for economic development. Among the fossil fuels, a shift from coal to oil may reduce CO_2 emissions by 20% and that to gas by 40-45%. But since industrialized countries also seek to shift to less carbon intensive fossil fuels, developing countries short of petroleum resources may well find themselves outbid in securing a sufficient share at acceptable costs in the international oil and

TABLE II. TECHNO-ECONOMIC PERFORMANCE COMPARISON BETWEEN TWO INCREMENTAL COAL-FIRED ELECTRICITY GENERATING STATIONS

Characteristics		PC 600[a] China	PC 600[4] Europe	Ratio
1. Technical				
Net Capacity	MW(e)	600	600	1
Load factor	hours/year	6,500	6,500	1
Net efficiency	% (LHV[b])	33.8	47.5	1.4
Sulfur abatement (SO_2)	%	0	90	
Nitrogen oxides (NO_x)	%	0	80	
Particulates	%	99.5	99.5	1
2. Economic				
Overnight investment costs	US$/kW(e)[c]	700	1329	1.9
Localization	%	100	30	n.a.
Discount rate	%	8	8	n.a.
O&M costs	US$/kW(e).year	21.13	43.87	2.08
Fuel costs	US$/GJ	1.7	1.7	1
Total generating costs[d]	mills/kWhe	24.09	30.02	1.25
3. Emissions				
Heavy metals[e]	gHM/kWh	0.038	0.027	1.4
Sulfur dioxide SO_2	g/kWh	9.09	0.65	0.07
Nitrogen oxides NO_x	g/kWh	3.01	0.43	0.14
Carbon monoxide CO	g/kWh	1.08	0.77	0.71
Nitrous oxide N_2O	g/kWh	0.02	0.02	1
Particulates	g/kWh	0.20	0.14	0.7
Carbon dioxide CO_2	g C/kWh	321	230	0.71
Total GHG emissions	g C/kWh equiv.	325	233	0.72

[a] PC 600 is a 600 MW pulverized coal fuelled power plant.
[b] LHV = Lower heating value.
[c] At 1995 prices and exchange rates.
[d] Including interest during construction.
[e] Including uranium, thorium, potassium, arsenic, cadmium, lead, mercury, selenium, zinc. Not considered are non-toxic materials such as aluminium, magnesium, titanium or vanadium which would another 15g/kWh of metal emissions.

gas markets. Thus, with increasing energy requirements, increased use of nuclear power and other non-fossil energy sources, whenever feasible, by developing countries may be part of their response to the climate change challenge.

In this connection, it is instructive to note that by increasing the nuclear share of electricity generation from some 25% in 1980 to over 78% in 1997, France was able to reduce its CO_2 emissions from the power sector by a factor of four, in spite of a two fold increase in generation during this period. It may also be pointed out that the current use of nuclear power is helping the world avoid some 700 million tonnes of carbon emissions (Mt C)[10], equivalent to about 8% of the present global GHG emissions from use of fossil fuels. By contrast, the Kyoto Protocol envisages a 5% reduction from 1990 emission levels in industrialized countries only.

3.5. Special needs of countries with small grids

Most of the nuclear power plants started or completed in industrialized countries in recent years are large units in the range of 700 – 1,500 MW(e) because of economies of scale. However, grids in a large number of developing countries are quite small and cannot accept reactor units of 700 MW(e) size or more. Many cannot even accommodate unit sizes in the range 300-700[11]. At present, nuclear power plants below 300 MW(e) are not considered economically competitive with fossil fired alternatives. The use in India of the 220 MW(e) unit of domestic design is an exception, but even they now plan in favor of a larger unit of 500 MW(e) capacity. Units in the 700 – 1,500 MW(e) size range were also built or are now under construction in some developing countries with large interconnected grids (Brazil, China, Iran, South Africa, South Korea, Taiwan China). Smaller units on which construction started since the beginning of 1990 are of sizes 600-700 MW(e) (three in South Korea and four in China), 300 MW(e) (one in Pakistan) and 220 MW(e) (two in India).

There seems to be a revival of interest in the design of medium and small reactors (SMRs) from 700 MW(e) down to a few tens of MW(e). The design purpose of SMRs in unit sizes above 150 MW(e) is base load generation in an interconnected grid but it is possible to use most of them as co-generation plants supplying both electricity and heat. Very small reactors (< 150 MW(e)) are not economically attractive for grid applications because of their relatively higher electricity generation costs. They are intended for specific applications such as captive generation of electricity and/or heat in industries, district heating, desalination, oil extraction, propulsion of vessels or for energy supply of concentrated loads in remote areas. As many as 50 new SMRs are in different design stages at present; these new designs seek improvements in reactor safety, reliability and economics. However, with a few exceptions, little development effort is being directed to bring these new designs to fruition.

3.6. Public acceptance[12]

Following the Three Mile Island accident in 1979 and the Chernobyl accident in 1986, nuclear power has faced increasing opposition in countries of North America and Europe. Although other factors, including slow growth of demand, surplus capacity, reduction in fossil prices, availability of gas and development of more efficient combined cycle gas and cleaner

[10] In terms of carbon dioxide the emissions avoided by nuclear power amount to 2,600 million tonnes (Mt CO_2)

[11] System operational considerations limit the size of the largest unit in an interconnected electric grid to about one tenth to one sixth of the grid size. The optimal size may be even smaller.

[12] See also Key Issue Paper No. 5.

coal technologies are also responsible for the stagnation, the effect of adverse public opinion in the slow down, moratorium or even abandonment of nuclear power cannot be downplayed.

Public opposition to nuclear power in industrialized countries stems from three main issues, namely, reactor safety, safe disposal of high level radioactive waste and risk of nuclear proliferation. Only the first of these is a direct consequence of the Three Mile Island and Chernobyl accidents. The other two were simply raised by those opposed to nuclear power, to help mobilize public opposition to the technology.

Regarding operational safety, the performance record of nuclear power is better than any other major generation technology including hydropower. Without going into detail, suffice it to say that an objective, comparative assessment of nuclear power and other major options for electricity generation puts nuclear among the least-risk technologies with respect to human health impacts associated with the operation of their full energy chains. Still, fear of a nuclear accident and the release of radioactivity, is on the minds of many. The only workable remedy is prolonged nuclear power operation without other serious accidents or major releases of radioactivity into the environment and the nuclear industry is working hard toward this end. The safety of all operational reactors and those under construction has already, and is continuously being upgraded, although this may have a negative impact on capital costs. Advanced reactors based on evolutionary and innovative designs now under development, will have even greater operational safety due to the incorporation of inherent or passive nuclear safety features.

The long-term, safe disposal of high level radioactive waste from a nuclear power plant and associated fuel cycle facilities should not pose an insurmountable problem even for present day technology. Temporary storage of high level radioactive waste in spent fuel has been carried out for over 40 years in storage pools, storage tanks and, in some cases, in dry storage facilities, normally at power stations which produced the spent fuel. The quantities are quite small - only some 30-40 tons per year for a 1,000 MW(e) capacity operation, compared to three to four hundred thousand tons of ash containing several hundred tons of toxic heavy metals (e.g., arsenic, cadmium, lead, mercury) produced annually by a 1,000 MW(e) coal fired plant. The storage of highly radioactive spent nuclear fuel material has not presented any technical problem, nor has it caused any significant environmental damage or damage to public health. Technical solutions to the safe disposal of this high level radioactive waste on a permanent basis have already been the subject of extensive research and development and are ready for implementation. It is due to public skepticism or opposition coupled with lack of political will that these solutions are not yet practiced. Until appropriate policy decisions are taken, temporary storage of such waste above or below ground will continue.

The risk of nuclear proliferation is a political and military problem that developed independently from nuclear power. No established nuclear weapon state evolved its weapons through the development and use of nuclear power. The world environment towards non-proliferation has improved since the end of the Cold War and accelerated dismantling of nuclear weapons in the USA and the Russian Federation. Nuclear weapon-free zones were established in Latin America, Africa, the South Pacific and South East Asia, the Non-Proliferation Treaty was extended for an indefinite period, and the Complete Test Ban Treaty was approved by the United Nations last year. For years, the IAEA has operated safeguards, checking for possible misuse of nuclear materials from facilities submitted to that system under its purview, to prevent illicit trafficking of nuclear materials and to ensure strict adherence to treaties related to international non-proliferation. It is hoped that these measures, further strengthened if necessary, minimize the risk of nuclear proliferation.

Present public opinion in developing countries is generally not averse to nuclear power. However, it is possible that, in time, public opinion there will oppose it influenced by strong lobbying by NGOs. Such a shift, should it occur, could have a negative effect on the decision of governments in developing countries to accept or increase nuclear power use. On the other hand, a revived interest in nuclear power in industrialized countries could increase support by the governments and public in developing countries.

3.7. Advanced technology[13]

Nuclear power is an advanced technology with many spin-off benefits for developing countries, such as the improvement of domestic technological capability, improved quality control in local industries, introduction of a safety culture in technology, development of skilled manpower, greater emphasis on science and technology in the educational system and enhanced public awareness of related issues. However, important as these benefits may be, they are unlikely to affect decisions toward adopting nuclear power unless the need is already justified based on economics, environment, security, and diversification of energy supply.

Being an advanced and demanding multi-disciplinary technology may deter its use in developing countries without the technological infrastructure and human resources to assimilate it. Technology transfer can overcome some of these problems, especially through joint ventures, preferably in terms of risk allocation, local responsibilities and long term effectiveness.

3.8. International cooperation[14]

Enhanced international cooperation in technology transfer and financing of nuclear projects will be key in its deployment or increased use in many developing countries. This technology was largely developed in industrialized countries and it is they who possess and control most of the expertise. This is changing: a few developing countries, most notably the Republic of Korea, China and India, have acquired/developed a sufficiently high level of self-reliance in technological aspects of nuclear power plants and related fuel cycles. But cooperation between developing countries in the field of nuclear power is rare; a notable exception is the 300 MW(e) plant under construction in Pakistan with the help of China.

New entrants in the field need international assistance/cooperation in practically all aspects of nuclear power technology: plant design and construction, manpower training for operation and maintenance, supply of spare parts, services for the front-end of the fuel cycle, local fabrication of fuel, establishing an appropriate regulatory regime etc. Those already using but now interested in greater deployment of this technology need similar support to a varying degree. But, even more important, they need international cooperation to develop self-reliance through a transfer of expertise at reasonable terms. With public opinion in many industrialized vendor countries now unfavorable to nuclear power, it is difficult to determine if such cooperation will be forthcoming. It is likewise too early to assess the extent of mutual cooperation between developing countries themselves to facilitate greater deployment of nuclear power there.

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[13] See also Key Issue Papers No. 3 and 4.
[14] See also Key Issue Papers No. 3 and 4.

4. CONCLUDING REMARKS

Electrification and the supply of affordable energy remain the single most important prerequisite for industrialization and socio-economic development. In countries with limited domestic resources or with resources distant from demand centres, nuclear power offers a proven and economically viable option for base load electricity generation.

Fossil fuels, particularly coal, remain attractive fuels for electricity generation for many developing countries. Several have sizable domestic coal resources or access to the international coal market with very attractive current prices. The economics of coal-fired generation and nuclear power are largely comparable and in the final analysis, depend on local (infrastructure related), regulatory and institutional factors. For countries without domestic fossil resources, nuclear power creates long term price stability by buffering against potential market volatility. Probably more important is that its use resolves problems of air quality and regional acidification with little or no incremental costs for pollution control. When air pollution related environmental and health damage costs are factored into an economic comparison between nuclear and other generating options, the environmental advantages of nuclear are clear. Nuclear power, in its life cycle emits lower GHG by orders of magnitude, than fossil fueled generation, requiring essentially no additional abatement costs. Although nuclear power may seem a distant prospect for some developing countries now, the stabilization of atmospheric GHG will likely require them to control GHG emissions in the future. Nuclear power is one avenue for doing so. Indeed, from today's perspective, nuclear power appears to be one of the most economically viable and environmentally benign alternatives for GHG mitigation for base load electricity generation.

“Public concerns” about reactor safety, safe radioactive waste disposal and nuclear proliferation are not written in stone and may change within the span of a decade or less when the public is better informed about the realities, and risks of the various options. Many views on nuclear power reflect a lack of knowledge and the nuclear community must respond with objective public information. In the past, the nuclear industry has been secretive about its affairs which is, to a large extent, at the root of public opposition. Open and honest information is a necessity in addressing public concerns.

This does not suggest that nuclear power is the solution to all global energy problems, but it is clearly already part of the solution. Nuclear power alone cannot ensure secure and sustainable electricity supply worldwide, nor is it the only means of air borne pollution control. But with clean fossil technologies, renewables and improvements in energy efficiency throughout the energy systems, nuclear power can play a strategic role in providing sustainable energy services.

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NUCLEAR POWER DEVELOPMENT ON THE BASIS OF NEW CONCEPTS OF NUCLEAR REACTORS AND FUEL CYCLE

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Abstract

Current state of nuclear power in the world has been discussed and the reasons for its falling short of the great expectations relating to its vigorous development in the outgoing century are considered. Anticipated energy demand of the mankind in the next century is evaluated, suggesting that with exhausted resources of cheap fossil fuel and ecological restrictions it can be satisfied by means of a new nuclear technology meeting the requirements of large-scale power generation in terms of safety and economic indices, moreover, the technology can be elaborated in the context of achievements made in civil and military nuclear engineering. Since the developing countries are the most interested parties, it is just their initiative in the development of nuclear technology at the next stage that could provide an impetus for its actual advance. It is shown that large-scale development of nuclear power, being adequate to increase in energy demand, is possible even if solely large NPP equipped with breeders providing BR≥l are constructed. Requirements for the reactor and fuel cycle technologies are made, their major aspects being: efficient utilization of Pu accumulated and reduction of U specific consumption by at least an order of magnitude, natural inherent safety and deterministic elimination of accidents involving high radioactive releases, assurance of a balance between radiation hazard posed by radioactive wastes disposed and uranium extracted from the ground, nuclear weapons non-proliferation due to fuel reprocessing ruling out potentiality of Pu diversion, reduction of the new generation reactor costs below the costs of today's LWR.

1. INTRODUCTION

The doubling of the global population expected by the mid-century, mostly due to the developing countries, and the ever-increasing number of nations taking the course of industrial development are bound to cause at least doubling of the world's demand for primary energy and trebling of the demand for electricity.

The growth of energy production will he in all probability accompanied by gradual depletion of cheap hydrocarbon reserves and by a rise of their prices. The world fuel market is likely to be increasingly affected by the endeavours of various countries to preserve their national hydrocarbon resources as a chief item of export, for many of them, and as fuel for transport and raw materials for chemical synthesis.

The looming hazard of international conflicts around oil and gas sources is another factor to be reckoned with.

Use of fossil fuels, including huge coal resources, can prove to be closer to its end than is currently expected, on account of the emissions of combustion products and global climatic changes. Besides the rise of fuel prices, measures taken to minimize harmful releases are bound to add to the capital costs of the energy sector.

The main provision of the long scale and reliable energy supply would be the development of new energy technologies capable of large-scale and economical replacement of fossil fuels.

With half a century of practical experience behind them, fission reactors might seem to be an eligible and realistic alternative to the conventional energy sources. But deployment of thermal reactors fuelled With ^{235}U is limited by the resources of cheap uranium reactors are assessed at somewhat more than 10^7 t, which in terms of the energy equivalent is less than the estimated resources of oil and gas, let alone coal. This means that ^{235}U-fueled reactors are incapable of having a greater effect on the 'global consumption of conventional fuels. With its current share in electricity production, nuclear power based on traditional reactors, mostly LWR, can go ahead for another ~40 years to supply the demands of fuel-deficient countries and regions. Nuclear power can be deployed on a much larger scale, using fast reactors - which only some 20 or 30 years ago was believed attainable within this century. However, contrary to expectations, the first generation of fast reactors proved to be much more expensive than LWRs. It is only to be regretted now that the root causes thereof were never brought to light - with the result of an ingrained prejudice against fast reactors stamped as inevitably costly machines. The hazard of proliferation of nuclear weapons is also associated with fast reactors and the closed fuel cycle.

For these reasons as well as the grave accidents at TMI and Chernobyl, energy saving measures and others the expected large-scale deployment of nuclear power was never brought into effect, deferred till some not entirely definite time in the future.

2. ENERGY TECHNOLOGY OF THE NEXT CENTURY

Meanwhile, studies show that it is possible to create a nuclear technology which will meet the safety and economy requirements of large-scale power production without going too far from the achievements of civil and military nuclear engineering. If in the next few years, the States concerned recognize the vital need for resolving the problem, and doing so in good time, and if they succeed in adopting a definite concept, the engineering development and demonstration of the latter can be carried out within a reasonable period of about 20 years. Thus the stage would be set for a new nuclear power which in the next century could take on a major part - say, half - of the increase in the global demands for fuel and energy. This means that nuclear power should grow by an order of magnitude from its present-day level of ~340 GWe by the mid-century and then double or treble its capacity before the end of the century.

Nuclear technology development has long since acquired the traits of an international effort and in the century to come will be guided by the global energy requirements, with countries concerned joining forces to carry it on. In so far as such a need is now greatest in the developing countries, it is their initiative in developing a nuclear technology for the next stage that can really give a practical turn to this work.

Such an initiative would undoubtedly find support with Russian nuclear experts whose vast experience and capabilities are currently in poor demand in the country, as well as with specialists from other countries seeking applications for their expertise.

Creation of a new nuclear technology would also answer the fundamental needs of industrialized nations and ought to be supported by their governments with the understanding that this technology would not add to the risk of a sprawl of nuclear weapons.

The criteria for adopting a nuclear technology for the next stage stem from the fairly general view of the future nuclear power discussed below.

3. LONG TERM SCENARIO OF NUCLEAR POWER DEVELOPMENT

A long term scenario of nuclear power development, which is of course a most tentative job, is presented in Fig.1. Curve I describes the continued advancement of nuclear power on traditional thermal reactors with ^{235}U fuel - mostly LWRS.

Consuming ~200 t of natural uranium a year per 1 GWe and given 10^7 t of cheap uranium, LWRs will have a total output of ~5 10^4 Gwe yr, with their operation in reactor-years making roughly the same figure, and will produce ~10^4 t of fissile Pu (-200 kg/yr. per 1 GWe). Reuse, of Pu, recovered now at the facilities built in France, UK and Russia, could increase the fuel resources of thermal reactors by 20 to 25%. But the low cost-effectiveness of using MOX fuel in these reactors offers no incentive to expansion of these facilities, while the spread of this technology in the world would add to the hazard of proliferation of nuclear weapons. Pu burning in thermal reactors, which has a low efficiency, would constrain or even bar the way to large-scale deployment of breeders at the next stage. That is why this scenario assumes that the thermal reactors of the first stage will continue operating mostly in the open fuel cycle.

Many developing countries are showing interest in heavy-water reactors, which allow using natural uranium and can give them independence from the suppliers of enriched uranium. Increasing their share in the nuclear energy mix of the first stage (from today's ~5%) offers certain saving of natural uranium (a factor of 1.5 reduction of consumption per reactor) and an increase in Pu production (roughly twofold per reactor). Fuel burnup reduced by a factor of 4 to 6, as compared to LWRs, results in greater build-up of spent fuel and added storage requirements.

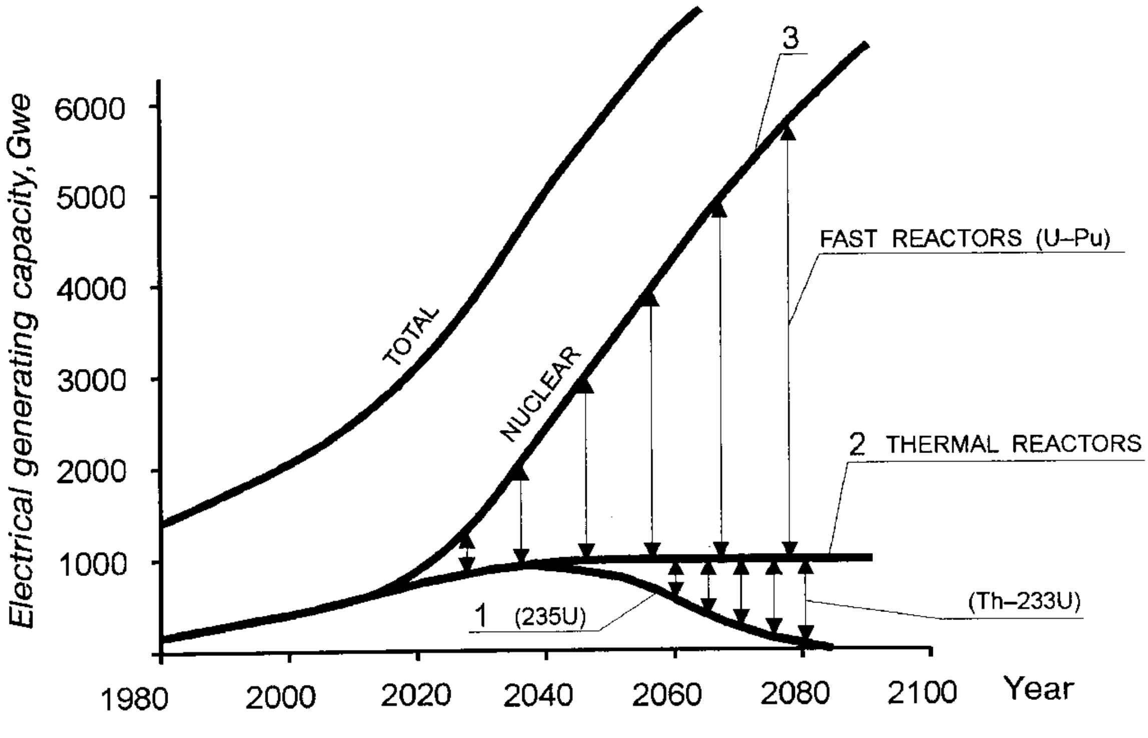

FIG. 1. Tentative scenario of nuclear capacity growth.

Thermal reactors of different types are most likely to find application in a longer term as well, owing to their advantages in some areas of energy production: small and medium nuclear plants (tens and hundreds of MWth) are well suited to meet local heat and electricity needs of remote regions where construction of transmission lines and fuel delivery are difficult and costly, or to provide high-grade heat for some processes. But to do so, thermal reactors will subsequently have to, shift to the Th-^{233}U fuel cycle and a BR of ~0.8 to 1 (curve 2), with the ^{233}U deficit covered by breeders.

But centralized electricity production at large NPPs (of GWe capacity), with power transmission over hundreds of kilometres to regions with a million-size population, will in all probability remain the main sphere of nuclear energy application. Electricity is still the most universal and convenient form of energy, well suited for transmission and final uses; its generation grows at the quickest rate and will account for the predominant part of fuel consumption in the next century (its current share being roughly 1/3).

The experience with high-voltage transmission lines amassed in Russia among other countries and the anticipated advent of economical superconducting lines in the next century, open up possibilities for transmitting electricity from large NPPs over thousands of kilometres and for expanding its export. The trend toward miniaturisation observed in other industries is opposed here by the indivisibility of the technological process and by the increase in specific costs with reduction of power, especially for NPPs.

Electricity being a standardized and universal product, changes in the market demand do not entail reorganization of the production process, which together with the ease of long-distance transportation is another point in favour of large power plants and reactor units. This does not preclude the use of nuclear energy for heat supply, while utilization of waste heat from NPPs remains an important problem yet to be solved.

On these grounds, large-scale nuclear power deployment, represented by curve 3 with a conventional start in 2020, is assumed to involve construction of mostly large NPPs. Such a scale can be provided only by breeders with BR≥1.

An essential objective of this stage is the cost-effective and safe utilization of ~Pu produced both by the reactors of the first stage (10^4 t) and as a result of nuclear arms reduction (possibly over 200 t). With the use of Pu, BR≥l is attainable only with fast reactors, which predetermines their principal role at this stage.

There is one fundamental advantage of the Th-U cycle, which lies in a good neutron and fuel balance in thermal reactors to the extent of their reaching BR~1. This advantage would be a decisive factor, if the high costs proved to be characteristic of not only the first generation but also of all fast reactors. However, there is no serious evidence to just this view. Quite on the contrary, by the physical and engineering principles of their design and control, large fast reactors with a liquid metal coolant are inherently simpler than LWRs and other thermal reactors; besides, they have a higher fuel and energy efficiency and, hence, can be cheaper too, provided better solutions are found for their design. There are apparently no reasons for the high cost of the first fast reactors, other than the use of the highly chemically active sodium. Prevention of its contact with water and air under normal operation and during accidents requires a 3-circuit cooling configuration, a safeguard vessel, sophisticated systems for monitoring and protection of steam .generators, and for refuelling, and affects the auxiliary equipment and structures of the NPP. The possibility of sodium taking fire or coming to the boil during accidents, with consideration for the positive - at least locally - void effect of reactivity, prevents fast reactors from taking full advantage of their inherent safety properties.

One of the main reasons for using light-weight and heat-conducting sodium as a coolant in the first fast reactors, was its capability to remove high heat fluxes from the fuel, with a resultant decrease in the fuel inventory and in the Pu doubling time, T_2. In the post-war decades, the annual rate of energy production growth reached 6 to 7% (up to 12% in the USSR) and short doubling time, T_2, was regarded as an important criterion in fast reactor development. Along with high power density, another associated requirement was a high breeding gain (BR~1), for which purpose a uranium blanket was provided. Studied as long term options were high-density and heat-conducting fuels, such as metal alloys, monocarbides and mononitrides, which afforded a simultaneous rise in the BR and the power density.

The situation is dramatically different now. The growth rates have dropped (a threefold increase of electricity production over slightly more than 50 years corresponds to an average rate of 2% a year), Pu is building up in large quantities, so short $T_2$is no longer needed. The scenario depicted in Fig. 1 can be fulfilled by fast reactors with BR~l and moderate power density. The 10^4 t of Pu and ~$1.5.10^4$ t of ^{235}U in the spent fuel of the first-stage reactors allow bringing in fast reactors ~4000 GWe in capacity, using Pu mixed with slightly enriched (1 to 4%) uranium (additionally enriched regenerated fuel of thermal reactors). As nuclear power settles on an even keel, these reactors will move into the ordinary U-Flu cycle. With an optimum CBR of 1.05 (minimum reactivity variations), nuclear generating capacities can reach ~8000 GWe due to Pu breeding in the early 22~nd century. Therefore, their development should be governed exclusively by the safety and economy criteria. These goals can be met by replacing sodium with a chemically passive high-boiling coolant, eliminating the uranium blanket with assured in-core breeding CBR=BR~1, and using high-density, heat-conducting fuel instead of oxide fuel (for the purpose of attaining CBR~1 and reducing reactivity margins, rather than increasing power density). It will be shown below that these and other measures result in an economically efficient high-power fast reactor with an essentially higher level of safety.

Excess neutrons in a fast reactor without a U blanket in the U-Pu cycle and a high flux of fast neutrons endow fast reactors with the advantage of transmutation of long-lived radionuclides to resolve the problem of radwaste without creating special burners. The equilibrium fuel composition (CBR~1) opens the way for the use of a reprocessing technology which consists basically in rather limited removal of fission products and rules out Pu extraction in this process. Use of such a technology in "non-nuclear" countries would afford a certain degree of their independence from nuclear nations without violating the international non-proliferation regime.

This discussion leads us to the conclusion that the choice of fast reactors in the U-Pu cycle as a basis for large-scale nuclear power, made by its founders back in the 1940s-50s, remains valid in the new conditions as well. But these conditions and the experience amassed call for new approaches to the creation of such reactors.

It was already mentioned above that thermal reactors also have some scope for long term development in certain fields of power production with a switch-over to the Th-U cycle in the future. With their contribution to the future nuclear power assessed at 10 to 20%, it can be shown that the ^{233}U deficit in these reactors may be covered without too much trouble by providing fast reactors with a small thorium blanket to utilize part of the leakage neutrons.

With breeding well established and the problems of radwaste settled - mainly through transmutation of long-lived actinides - there seem to be no constraints on the duration of nuclear power operation from the viewpoint of cheap fuel resources and radwaste accumulation. But a complete concept of nuclear development should incorporate, among other things, the final stage with phase-out of NPPs and elimination of large quantities of radioactive material from the reactor inventories. This suggests the need for effective burners without nuclear fuel reproduction, which makes the ongoing quest and studies in this area meaningful. However, even if our hopes for the reasonably early advent of economical and safe breeders do come true, the engineering development of such burners will not be started until some more remote time in the future.

4. REQUIREMENTS TO REACTOR AND TECHNOLOGY, CHOICE OF REACTOR TYPE

4.1. Uranium consumption

Efficient utilization of stockpiled Pu, reduction of specific uranium consumption by no less than an order of magnitude with no need to provide short doubling time.

High-power fast reactor in the U-Pu cycle, moderate power density, CB=CBR~1, no uranium blanket.

Reactor with CBR~1 should have the power of no less than ~300 MW(e). CBR~1 also dictates the use of high-density fuel. For many reasons, UN-FuN fuel appears to be an optimum choice.

4.2. NPP safety

Exclusion of severe accidents which may result in fuel failure and large radioactive releases (fast runaway, loss of coolant, fire, steam and hydrogen explosions).

If the operation period of nuclear power in the next stage of its development exceeds 106 reactor-years ' the probability of the above accidents should be kept well below 10^{-6} per reactor-year. Probabilities of such a level obtained by PSA methods have neither operational experience (the existing nuclear power has operated for about 10^4 reactor-years) nor convincing theoretical data to support them. PSA techniques are useful for planning safety improvements at NPPs and allow quite dependable predictions related to the near term nuclear power development, but they are unsuitable for preparing a really strong safety case for large-scale nuclear power.

Therefore, reactors, of the next stage should present no risk of such accidents under whatever human errors, failures or damages to equipment and safety barriers, i.e. these accidents should be deterministically excluded owing to the intrinsic physical and chemical properties and behaviour of the fuel, coolant and other reactor components (natural safety).

Needless to say, there is no way to avoid radioactive releases in case of total reactor and plant destruction as a result of a nuclear attack or a fall of a large asteroid, and these events should be mentioned in the design documentation as exceptions. All potential accidents in a naturally safe reactor, except for those mentioned above, are treated as design-basis events.

Fast reactors with high-density fuel, operating in the U-Pu cycle, can be designed to have optimum CBR~1, no Xe and Sm poisoning, small power reactivity effect due to the use of fuel with high heat conductivity, and small effect of delayed Np decay, so as to keep the total reactivity margin at the level of $\Delta K_{TOT} < \beta_{eff}$ and hence exclude fast runaway under any erroneous actions or accidents in the reactivity control system. Without uranium blanket, a fast reactor has a deeply negative integral void effect. Passive control and cooling elements, feedbacks including large negative temperature coefficient dK/dT, a high level of natural circulation of coolant, prevent dangerous temperature growth under off-normal conditions.

Sodium interaction with air and water, which may cause hydrogen generation and lead to a loss of coolant, and the possibility of a local positive void effect showing up during boiling of this coolant, suggest that it should be traded for another, chemically inert, coolant which boils at a much higher temperature. With no necessity to provide high power density in the core and short doubling time T_2, it becomes possible to use, for instance, the heavy coolant which has been successfully employed in Russian naval reactors, namely PbBi eutectic - or Pb which is close to the former in all physical and chemical characteristics but for the melting point. Use of Pb settles the problems of the high cost and small resources of Bi, and of volatile ^{210}Po With its high alpha activity, produced from Bi. The problems caused by high melting temperature of Pb (327°C) can be resolved through the use of proper temperature conditions and reactor cooling so as to stay within acceptable steel temperatures and to exclude blockage of lead paths under off-normal conditions.

The deterministic safety requirement implies that the ultimate design-basis accident (UDBA) - i.e. the accident which covers any event resulting from human errors or multiple failures of equipment, including loss of forced cooling, failure of the scram function, insertion of full reactivity margin, damage to outer barriers such as containment and reactor vessel - should not cause fuel failure and radioactive releases such that would require evacuation of people from the territory around the plant.

Analysis of hypothetical (non-credible) accidents including large rapid reactivity addition, fuel failure and collapse with resultant secondary criticality, has been performed optionally, with a view to obtaining ultimate estimates.

Extreme external impacts leading to destruction of the plant, reactor and its vault will be mentioned in the design documentation, but their analyses are also optional.

4.3. Radwaste

Any predictions concerning safe disposal of large amounts of radwaste for tens of thousands of years give rise to doubts about the validity of geological and especially "historical" forecasts for such remote future.

These doubts can be removed if the radiation hazard from buried radwaste is brought into balance with that of uranium extracted from the earth (radiation-equivalent radwaste disposal), and this is adopted as a requirement for nuclear technology.

– The requirement can be satisfied in the following way: long-lived products of U decay (Th, Ra) can be co-extracted with uranium and then handled together with actinides. This step will also facilitate rehabilitation of U mining areas on completion of the work there;

- U, Pu, and other actinides produced during reactor operation, first of all Am, can be returned to reactor to be transmuted by fast neutrons into fission products;
- radwaste can be subjected to treatment with a view to removing actinides so that it contain only $\sim 10^{-3}$ of Pu;
- after cooling, radwaste can be brought into a mineral-like state or some other physical and chemical form not prone to migration in soil;
- radwaste can be buried in naturally radioactive geological formations remaining after U mining, in such amounts that they will be equivalent to extracted U in terms of their radiation hazard.

It should be pointed out that long-lived Np produced in reactors has low activity, and can be dumped untransmuted without disturbing the radiation equivalence. Moreover, if returned to reactors Np adds to the fuel activity since it produces highly active ^{238}Pu and ^{236}Pu which decays to ^{232}U.

Cm, whose main isotopes have a relatively short half-life and a high activity, especially neutronics, can also significantly increase fuel activity if returned to reactor for transmutation, thus impeding fuel refabrication. Therefore, it would be better if Cm were separated from fuel during reprocessing, cooled for some 50-70 years and then returned to reactor in the form of decay products, i.e. Pu isotopes.

Attainment of radiation equivalence between radwaste and mined uranium would also benefit from separation of Sr and Cs so that only l-10% of them will remain in radwaste. Extracted Sr and Cs could then be utilized as radiation or heat sources. Long-lived I and Tc (with 1-10% of them going to wastes), if extracted, can be returned to reactors for transmutation. The remaining radwaste (with the activity of about 10^4 Ci/l) can be stored in casks cooled by dry air under natural circulation. The activity of radwaste stored in this way would fall by three to four orders of magnitude in 200 years, which simplifies the technology of final disposal of radwaste and enhances its safety. Analysis shows that such storage can be designed to be simple and not very expensive.

There would be no problems or risk associated with long-distance transport of radwaste if fuel cycle facilities and radwaste storage were set up on NPP sites.

4.4. Nonproliferation

A fast reactor with CBR~1 and no uranium blanket operates with fuel of equilibrium composition and has no need for Pu separation or addition during fuel fabrication. To adjust the fuel composition, it is sufficient to add ^{238}U to compensate for its burnup.

This fact allows putting forth the following requirement: reprocessing technology should be such as to rule out Pu separation. In this case, reprocessing will boil down essentially to removing fission products from the fuel. In the context of their influence on reactivity, it is acceptable to remove FPs so that ~1-10% of them remain in the fuel, which would simplify the above technology and facilitate its choice, though increasing the fuel activity, in particular during refabrication. This is not a major complication, however, since the process is remote anyway. Besides, a high activity of fuel is another warranty against its theft.

The main point here is that such a technology will not add to the risk of proliferation and hence way find world-wide application.

Needless to say, there is no way in which any new fuel cycle technology can rule out illegal application of existing techniques of Pu separation, in particular from LWR fuel, or uranium enrichment for the purpose of obtaining weapon-grade materials. This problem can be successfully dealt with only by political steps meant to enhance the non-proliferation regime and improve the safeguards. Moreover, it has to be resolved irrespective of the further route of nuclear power and nuclear technology.

Promotion of the breeding technology appears to be the most cost-effective way of utilizing Pu accumulated in spent fuel from modern reactors. With this option, Pu would be taken from cooling ponds and put into reactors and fuel facilities, which affords maximum safeguarding and reduces the risk of illegal plutonium separation and utilization.

Fast reactors without uranium blanket, with CBR~1 and moderate power density, have many traits and possibilities essential for attaining this goal:

- there is no U blanket to produce weapon-grade Pu and with a small reactivity margin in these reactors, it is no longer possible to put U assemblies in the core for Pu accumulation;
- small reactivity variations during refuelling, moderate power density and on-site fuel cycle allow quasicontinuous on-load refuelling. Spent fuel can be cooled during 3 to 12 months in an in-vessel storage facility and then sent directly for reprocessing and refabrication. Hence there will be no need for out-of-pile storages for spent and fresh fuel. Such fuel handling can largely simplify supervision and practically excludes fuel thefts.

Initial reprocessing of spent fuel from thermal reactors and fabrication of first cores for fast reactors will have to be done at facilities available in the nuclear countries, but this dependence will not be so strong as in case of regular supply of enriched uranium. Consideration may be given to setting up nuclear technology centres on the basis of these facilities under international jurisdiction.

The aqueous technology widely used now and other options being studied at the moment, is tailored to existing reactors, which require Pu separation. To meet the above requirement, it is necessary to alter the existing reprocessing technologies or to develop a new one, and this is one of the major challenges along with the development of new reactors. Physical methods of fuel treatment, in which FP removal relies on a factor of two differences in atomic weights, may prove to be the most effective and simple solution.

No concept of a closed fuel cycle satisfying the requirements of large-scale nuclear power, has been suggested yet. It will not fail to appear, however, once the objective is properly defined, and then the requisite technology can be developed and demonstrated within the period of the reactor development.

4.5. Economics

With cheap fuel, it is the NPP cost, which has grown considerably during the last years on account of safety improvements, that is largely responsible for the cost of nuclear energy generation. NPPs of the next stage should be cheaper than modern LWRs, to be economically competitive in many countries and regions.

As is the case with most of the sophisticated technological systems, many things determine NPP cost. No separate improvement in one area (for instance, use of natural water circulation instead of pumps in BWR~S) can reduce this cost by more than a few per cent. NPPs with fast reactors should be made at least twice cheaper, which calls for some basic solution extending to the main equipment, systems and structures, whose high costs stem from safety requirements. The answer in this case comes from the natural safety philosophy.

High safety level of new plants, achieved mostly owing to elimination of potentially dangerous design solutions and due to the use of the laws of nature, will make it possible to simplify plant design, lower requirements for basic and auxiliary systems, structures and personnel, and will obviate the need for additional safety systems. These potentialities can be translated into plant design based on consistent application of the natural safety philosophy.

5. AN EXAMPLE OF A NATURALLY SAFE FAST REACTOR

The conceptual design of a fast reactor with UN-PuN fuel and lead coolant (BREST), developed not so long ago, proves that it is possible to meet all the above requirements keeping to a proven technology.

Design and analytical studies were performed and then optimized for reactors with the power in the range from 300 MW(e) to 1200 MW(e). Experiments carried out at U-Pu-Pb critical assemblies sought to validate reactor physics and revise the nuclear data. Steels were subjected to long term corrosion testing in Pb circulation loops. Experiments were performed to study Pb interaction with air and water of high parameters, interaction of nitride fuel with Pb and steel claddings, and other things.

Calculations on the ultimate design-basis accident, as it was defined above, showed that this reactor can survive it without fuel failure and with moderate radioactive releases. Investigations into hypothetical accidents confirmed that the reactivity addition of up to several β_{eff} at a rate of up to 50 β/s does not cause lead boiling and large release of mechanical energy. According to these studies, lead density, which is close to that of fuel, and convective flows prevent fuel collapse which may otherwise result in the formation of a secondary critical mass.

Lead-cooled fast reactor has a simpler design than LMFR-Na:

– single vessel or pool-type arrangement without a metal vessel (reactor is placed directly in a concrete vault with thermal insulation between concrete and lead);
– two circuits in the main and emergency cooling systems; decay heat removed by natural circulation of air in tubes located in the lead coolant of the primary circuit;
– no special system to wash coolant off FAs during refuelling;
– reactivity control provided mostly by lead in tubes located in the side blanket; lead level in tubes is regulated by gas pressure;
– passive control and protection features with threshold response; high level of natural circulation of coolant; less stringent requirements to the speed of operation with simplification of control and protection systems;
– simpler design of steam generators, with no need for fast-acting leak detection systems and quick-response valves;
– less sophisticated fire protection, ventilation and other support systems and components; simpler rooms in the cooling circuits and other NPP constructions.

Cost estimations and comparisons confirm that it is possible to reduce capital costs of such NPPs and the cost of their electricity, as compared to those at VVER plants.

Operating experience of reactors with a heavy coolant, extensive in-pile testing of nitride fuel, calculations and experiments performed in the course of the conceptual design, made the basic aspects of the concept clear enough to embark on engineering development. Considering that the latter will require additional studies and tests, it will take some 10 to 15 years to develop and build an experimental reactor or a demonstration unit which can be put into demonstration operation in about 20 years.

SUSTAINABLE DEVELOPMENT AND NUCLEAR POWER

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Abstract

The substantial increase in global energy consumption in coming decades will be driven principally by the developing world. Although there is some awareness on both the technical and political levels of the advantages of nuclear power, it is not a globally favored option in a sustainable energy future. This paper, after discussion of rising energy consumption, concentrates on a comparison of the environmental impacts of the available energy options.

1. INTRODUCTION

With projections of sharply rising energy consumption and continuing global dependence on fossil fuel sources, environmental pollution and greenhouse gas emissions could reach severely damaging levels. The global challenge is to develop strategies that foster a sustainable energy future less dependent on fossil fuels. Low environmental impacts and a vast fuel resource potential should allow nuclear power to have a meaningful role in the supply of energy during the next century.

Although there is some awareness on both the technical and political level of the advantages of nuclear power, it is not a globally favored option in a sustainable energy future. A sizeable sector of the public remains hesitant or opposed to its increased use, some even to continuation at present levels. This paper, after discussion of rising energy consumption, concentrates on a comparison of the environmental impacts of the available energy options.

2. RISING ENERGY CONSUMPTION

The substantial increase in global energy consumption in coming decades will be driven principally by the developing world. Today's developing countries, with some three-quarters of the world's inhabitants, consume only one-fourth of global energy. Current annual per capita energy consumption differs markedly by country and region. Canada in the high energy use region of North America has a per capita consumption close to 8 tons of oil equivalent (toe), eight times greater than Brazil where consumption is fifteen times more than in Tanzania or in Bangladesh.

Strong economic growth in many developing countries is already leading to sharp increases in per capita energy consumption. Consumption will continue to rise driven also by the projected two fold expansion in world population during the 21st century that will occur overwhelmingly in the developing world. Although progress is evident in restraining global population growth, currently at 80 million per year, the medium projection from the UN *World Population Prospects: 1996 Revision* forecasts a 50% increase by the middle of the next century with India likely exceeding China's projected more than 1.5 billion population and populations greater than 250 million inhabiting Brazil, Indonesia, Nigeria and Pakistan. Half of the world's people now live in intensive energy consuming urban areas and this percentage will increase as urbanization in some regions expands to include 80% of the population.

A 1995 study by the World Energy Council (WEC) - a leading non-governmental voice in energy matters - and the International Institute for Applied Systems Analysis (IIASA) considered three global energy scenarios for the next century - a high, middle and ecologically driven low economic growth scenario. The study projects by mid-century a range of energy demand increase of some 50% for the low economic growth case to more than 150% for the high growth case, with the latter showing a 50% increase before 2020.

The United States Department of Energy (DOE) in its recently released *International Energy Outlook 1997* projects a 54% increase in global energy demand as early as 2015 - less than 18 years from now - some half of this increase due to rising demand in the newly emerging Asian economies, including China and India. It warns that if the transport sector demand in China follows that seen in Thailand and the Republic of Korea, energy demand could be dramatically underestimated.

2.1. A shift from fossils

To limit environmental pollution and to slow the rate of increase of CO_2 concentration, responsive long-term energy strategies exploiting the maximum potential of non-greenhouse gas emitting energy sources need to be developed and implemented as rapidly as possible. The future energy mix that evolves will depend not only on environmental considerations, but also on economic, technological, supply and political factors. It is generally accepted that for many decades fossil fuels will continue to be the major energy source with natural gas, the lowest fossil fuel greenhouse gas emitter, likely becoming the major component. Countries having or exporting fossil fuels cannot easily turn away from their use and likewise, the economically dynamic countries of Asia cannot easily turn from fossil fuels toward uncertain and costly renewables for growing baseload power needs.

The 1995 WEC and IIASA middle economic growth Case B Scenario projects at mid-century more than a two-fold increase in fossil fuel consumption and a continuing fossil dominance with a two-thirds share of global energy - some 20% less than today. Nuclear power and renewables including hydroelectric each will more than double their current 6% shares.

National and regional factors govern the energy mix in each country. They differ considerably today and they will in the future. Today, China is 98% dependent on fossil fuels while France and Sweden have reduced their dependence to some 50% and 35% respectively through use of nuclear and hydroelectric power.

On the global level, difficult policy decisions lie ahead to foster a shift away from fossil fuel dominance. There is little consensus on how to proceed. There is general support for *cost-effective* energy efficiency techniques to somewhat slow demand, and on the supply side, an endorsement of increased use of renewables. Both efforts are necessary, but with limited potential over the near term. In the developed countries, the significant energy efficiency gains seen over the past two decades, such as in the industrial and residential sectors, will not likely be seen in the decades to come.

The supply potential of renewables is difficult to assess since they are only emerging technologies and currently unsuitable for meeting large baseload energy demand. With differing relevance for the various renewables, technological improvements are needed and basic challenges exist in reducing costs, improving efficiency and reliability, solving energy storage problems and integrating the technologies into existing energy systems.

2.2. The prospects of renewables

Both the WEC and the International Energy Agency (IEA) of the Organization for Economic Cooperation and Development (OECD) predict that non-hydroelectric renewables will not be economically competitive for large scale production in the foreseeable future and that they will play only a limited role in the decades to come. The WEC *Message for 1997* indicates that even with adequate support and subsidies, the share of renewables could reach only 5% to 8% of primary energy supply by 2020, this figure including a 2% non-commercial energy share. Hydroelectric has already been extensively developed in Europe and North America - some 50% of the estimated maximum economic potential. Its greatest potential lies primarily in Asia, South America and Africa where the trend will likely be towards small capacity units as concerns grow about the damaging environmental and social impacts of large dams. The hydroelectric share is forecast to remain around the current 6% level.

The ecologically driven low economic Case C scenario in the 1995 WEC and IIASA study, which focuses on a shift away from fossil fuels, considers a major share of energy supply from renewables, in one variant some 39% by 2050 and as much as 81% by 2100. A second variant assumes a somewhat smaller renewable contribution with nuclear power assisting the shift away from fossil fuels through a 33% contribution to global electricity needs by 2050 and some 38% by 2100. However, the ecologically driven scenario - as with any scenario that assumes a huge shift away from fossil fuels principally through renewables and an excessively low energy demand - requires an unlikely rapidly reoriented global energy system focused explicitly on the environment and on developing countries.

2.3. The nuclear power potential

The 6% contribution of nuclear power to global primary energy supply is almost entirely in the rapidly increasing electricity sector where 17% of global electricity is generated by 442 nuclear power reactors in 32 countries. There are 36 units currently under construction in 14 countries. The first commercial nuclear power reactor began operation some 40 years ago with a rapid expansion in reactor units taking place during the 1970s and early 1980s. Today, nuclear power is a mature and highly developed technology.

In terms of the total quantity of nuclear electricity generated, the five largest producers are the United States, France, Japan, Germany and Russia. Globally, the nuclear share of electricity is more than 20% in 19 countries. Regionally, in 1996 Western Europe with a 33% share had the highest percentage of nuclear electricity - the nuclear share in France, Belgium and Sweden being 77%, 57% and 52% respectively. Two large nuclear power units in Lithuania supplied almost 85% of the country's electricity requirements.

With a continuation of the current trend, the next century will see global electricity demand grow faster than overall energy demand as it provides the greatest flexibility in use at the point of consumption. Already Turkey, an example of a rapidly industrializing developing country, has seen its electricity capacity increase 10 times in the past 25 years from some 2,200 megawatts electric (MW(e)) to 21,000 MW(e). The 1997 DOE energy outlook report projects a possible 75% global increase in electricity demand from 1995 to 2015 - equivalent to 1500 new 1000 MW(e) plants.

Although nuclear power is currently a significant source of global electricity supply, there is no consensus concerning its future role. While nuclear power stagnates in much of Europe and in North America, it continues as a strong option in a number of Asian countries. Economy and security of supply have been principal considerations in the choice of nuclear power along with an awareness of its environmental benefits - from mining to waste disposal and decommissioning, it produces remarkably little environmental pollution and greenhouse gas emissions. These three factors - economics, security of supply and the environment will determine the long-term role of nuclear power in a sustainable energy future.

All three energy scenarios of the 1995 WEC and IIASA study - as well as those developed by the IPCC for its climate change studies - assume a significant nuclear power contribution over the next several decades, but the assumptions for nuclear power after 2020 vary considerably due to uncertainty about its future. For the six variants in the study, the range of the nuclear power contribution varies from some twenty-fold increase to a total phase out by the end of the next century.

3. COMPARATIVE ASSESSMENTS

To assist energy planners, over the years the IAEA has carried out comparative assessments of the alternative energy sources. Full energy chain analyses that consider elements beyond the direct power generation stage reveal a wide variety of significant environmental issues and impacts linked to energy options.

Emissions to the environment are commonly the principal focus of energy impact studies. Other significant environmental impacts such as land disturbance and population displacement together with their economic and social implications are less emphasized. Major impacts such as depletion of natural resources and large fuel and transport requirements that influence a wide range of areas, including occupational and public safety as well as national transport systems, are mostly ignored.

In general, *fossil fuels* can have significant damaging impacts locally, regionally and globally through,

- Global climate change
- Air quality degradation (coal, oil)
- Lake acidification and forest damage (coal, oil)
- Toxic waste contamination (coal ash and slag, abatement residues)
- Groundwater contamination
- Marine and coastal pollution (oil)
- Land disturbance
- Large fuel and transport requirements
- Resource depletion.

Hydroelectric while relatively kind to the atmosphere can be much less considerate to the earth and its inhabitants both locally and regionally through,

- Population displacement
- Land loss and change in use
- Ecosystem changes and health effects
- Loss of bio-diversity
- Dam failure
- Decommissioning.

Renewables (solar, wind, geothermal, biomass) are not without their impact although they are more local in nature such as through,

- Air quality degradation (geothermal, biomass)
- Extensive land use
- Ecosystem changes
- Fabrication impact (solar photovoltaic cells)
- Noise pollution (wind).

Nuclear power under normal operation is benign to the atmosphere and to the earth and its inhabitants locally, regionally and globally. As discussed subsequently, due principally to small nuclear fuel requirements there are limited environmental impacts for the full energy chain from mining to waste disposal and decommissioning. A significant environmental impact arises only from *potential* abnormal events such as through,

- Severe reactor accident impact
- Waste repository impact.

3.1. Fuel and land requirements

Generally, the quantity of fuel used to produce a given amount of energy - the energy density - determines in a large measure the magnitude of environmental impacts as it influences the fuel extraction activities, transport requirements, and the quantities of environmental releases and waste. The extraordinarily high energy density of nuclear fuel comparated to fossil fuels is an advantageous physical characteristic.

One kilogram (kg) of firewood can generate 1 kilowatt-hour (KW(h)) of electricity. The values for the other solid fossil fuels and for nuclear power are:

1 kg coal	-	3 KW(h)
1 kg oil	-	4 KW(h)
1 kg uranium	-	50,000 KW(h) (4,000,000 KW(h) if reprocessed**)**

Consequently, a 1000 MW(e) plant requires the following tonnes (t) of fuel annually:

2,600,000 t coal	-	2000 train cars (1300 t each)
2,000,000 t oil	-	10 supertankers
30 t uranium	-	α of a reactor core (10 cubic meters)

The energy density of fossil and of nuclear fuel allows relatively small power plant areas of some several square kilometers (km^2). The low energy density of renewables, measured by land requirements per unit of energy produced, is demonstrated by the large land areas required for a 1000 MW(e) system with values determined by local requirements and climate conditions (solar and wind availability factors ranging from 20% to 40%):

Fossil and nuclear *sites*	-	1 to 4 km^2
Solar thermal or PV *parks*	-	20 to 50 km^2 (a small city)
Wind *fields*	-	50 to 150 km^2
Biomass *plantations*	-	4,000 to 6,000 km^2 (a province)

3.2. Environmental pollutants

Due to the vast fuel requirements, the quantity of toxic pollutants and waste generated from fossil fuel plants dwarfs the quantities from other energy options. In general, pollution depends on the fuel's impurity level, with natural gas cleaner than oil and oil cleaner than coal. A 1000 MW(e) coal plant without abatement technology produces an annual average of 44,000 t of sulfur oxides and 22,000 t of nitrous oxides that are dispersed into the atmosphere. Additionally, there are 320,000 t of ash containing 400 t of heavy metals - arsenic, cadmium, cobalt, lead, mercury, nickel and vanadium - these quantities without considering energy chain activities such as mining and transportation.

Fossil fuel plants using modern abatement technology can decrease noxious gas releases as much as ten-fold, but significant quantities of solid waste are produced in the process. Depending on sulphur content, solid waste from sulphur abatement procedures for a 1000 MW(e) plant are as much as 500,000 t annually from coal, more than 300,000 t from oil and some 200,000 t from natural gas sweetening procedures. The waste, containing small quantities of toxic substances, is commonly stored in ponds or used for landfill or other purposes. Regulatory bodies increasingly categorize such waste as hazardous.

A 1000 MW(e) nuclear power plant does not release noxious gases or other pollutants and produces only some 30 t of discharged high level radioactive spent fuel annually, along with 800 t of low and intermediate level radioactive waste. In the United States, low-level solid waste from nuclear power plants has been reduced tenfold over the past decade through compaction to 30 cubic meters of waste per plant annually - a total of some 3000 cubic meters from all operating plants. For perspective, industrial operations in the United States are estimated to produce more than 50,000,000 cubic meters of solid toxic waste annually.

3.3. Confinement vs. dispersion of waste

There is continuous public concern that nuclear waste cannot be safely managed. However, nuclear waste has distinct advantages as quantities are remarkably small relative to the energy produced. The small quantities permit a *confinement* strategy with the radioactive material beginning with the nuclear fission process through waste disposal essentially isolated from the environment. Disposal techniques exist and the hazard decreases with time due to radioactive decay. The main disposal options are simple near surface, engineered structures, mined cavities, and deep geological repositories. Some thirty countries currently operate licensed depositories for low and intermediate level radioactive waste.

In sharp contrast, disposal of the large quantities of fossil fuel waste follows an alternative *dispersion* strategy. Most of the waste (noxious gases and many toxic pollutants) is dispersed directly into the atmosphere, while some solid waste containing toxic pollutants is buried in shallow ground, there being no practical alternative. The waste is dispersed or buried at concentrations considered unharmful. While the resulting impact can be small, the accumulation over many years from a large number of waste producing activities can easily overburden the natural environment, locally as well as globally.

Confinement is preferable to dispersion, but is economically feasible only when waste volumes are small and arise under easily controlled conditions. Most nuclear waste consists of relatively short lived low and intermediate level waste, annually some 450 and 350 t respectively from a 1000 MW(e) plant. Low level waste, consisting largely of minimally contaminated clothing, machine parts and industrial resins, can be placed in containers with disposal in trenches covered by soil. Intermediate level waste, including reactor parts and contaminated equipment, is packaged in cement inside steel drums. Similar to low-level waste, it can be safely disposed of in near surface facilities.

3.4. High level waste

High level waste consists of liquid from reprocessing after recovering uranium and plutonium or spent fuel for ultimate disposal, if it is not to be reprocessed. The spent fuel, some 12,000 t annually from all operating plants, can be readily stored above or below ground awaiting decisions on long-term disposal. An interim storage period is necessary to allow the residual heat generated in the spent fuel to decrease, disposal being more practical after several decades. The volume of high level liquid waste from reprocessing 30 t of spent fuel released annually from a 1000 MW(e) plant, containing more than 99% of the radioactivity, is some 10 cubic meters. The waste can be vitrified to a glass solid and stored awaiting long term disposal.

To date, no long term disposal site has been licensed in any country. Deep underground geologic formations undisturbed for many millions and even billions of years are being considered. Solid salt domes or granite tunnels several hundred meters below the surface are impervious to water ingress, which is the potential mechanism for material transport to the surface. A number of barriers would prevent the release and transport of disposed radioactive material; the canisters containing the vitrified waste, a surrounding absorbent clay backfill and the solid host material. A number of countries are developing repository concepts to handle vitrified waste as well as spent fuel. Startup times for repositories are likely at least a decade away. Disposal is blocked not by technical, but by political obstacles.

A common apprehension about radioactive waste concerns its long lived nature. Waste from reprocessing facilities, where much of the very long lived materials such as plutonium are removed, would decay to radioactive levels below that of natural uranium ore in less than one thousand years compared to more than ten thousand years without reprocessing. Waste pollutants from coal such as cadmium, lead or mercury - much of which are dispersed or disposed of in near surface facilities - remain toxic indefinitely. There is a growing recognition that management of indefinitely toxic waste and radioactive waste warrant a harmonized approach. However, managing toxic wastes from fossil fuels to standards proposed for high level radioactive wastes is not economically feasible.

Indicators to compare radioactive waste hazards with fossil fuel waste hazards have been developed. One such indicator is based on admissible concentrations of radioactive and toxic pollutants in water. For similar amounts of energy generated, in some one hundred years the amount of water necessary to dilute reprocessed radioactive waste to admissible concentrations would be less than the amount to dilute lignite waste to admissible concentrations - the reason being the relatively small quantity of radioactive material and the relatively rapid decay of reprocessing waste due to the removal of long lived elements.

3.5. Greenhouse gas emissions

Turning now to greenhouse gas emissions, a single 1000 MW(e) coal plant emits some 6,000,000 tons of CO_2 annually. There is no economically viable technology to abate or segregate the large quantities emitted. Segregation and storage underground are theoretically possible, but technologies are only in very early stages of study. Some may require high energy input and environmental impacts have not been assessed.

Countries with significant nuclear power and hydroelectric capacity have markedly lower CO_2 emissions per unit of energy produced than countries with high fossil fuel shares. Through a rapid expansion in nuclear power, France has lowered its CO_2 emissions by more than 80 %over the past 30 years. In contrast, countries that have rejected or sharply curtailed nuclear power programmes have increased greenhouse gas emissions by turning to fossil fuels. Globally, the use of nuclear power and hydroelectric as an alternative to fossil fuels has helped restrain CO_2 emissions over the past several decades. Today nuclear power and hydroelectric each avoid some 8% of global CO_2 emissions annually from energy production.

Efforts to reduce greenhouse gas emissions require attention to the full energy chain emissions as significant fuel extraction, transport, manufacturing and construction activities can be involved. Full chain analyses require identifying all emission sources. Burning natural gas with a low carbon content produces less CO_2 than burning coal or oil. But leakage's during extraction and pipeline transport, which are more than 5% in some areas, can offset much of this advantage since the escaping methane is a more effective greenhouse gas. In terms of equivalent grams of carbon per KW(h), a quantity used for comparative purposes, some natural gas chains can have emissions similar to coal energy chains.

Full chain hydroelectric assessments generally show comparatively low greenhouse emissions despite massive construction activities. However, if methane gas released from decomposition of inundated organic material at the bottom of some water reservoirs is included, emissions could approach natural gas values. Nuclear power and wind are on the low side of full chain emissions with solar photovoltaic releases higher due to various greenhouse gases released during silicon chip manufacturing. Although biomass can be low in emissions, full chain analyses can be extremely complex and currently provide uncertain results as they involve non-energy byproducts as well as growth and harvesting time periods.

3.6. Natural resources

Depletion of natural resources is an environmental issue. There are proven reserves of coal sufficient for more than 200 years, of natural gas for 60 years and of oil for 40 years at current levels of use. Efforts are underway to increase oil and gas resources through improved recovery techniques and oil-shale and tar-sand processing that are estimated to be capable of at least doubling the resource base. Depending on their specific economics, new technologies to further increase fossil fuel extraction could be developed. But, financing investments and price volatility could then become leading concerns.

Known uranium reserves with reactors operating primarily on a once through cycle without reprocessing spent fuel, assure a sufficient fuel supply for at least 50 years at current levels of use, the same order of magnitude as today's proven resources of natural gas and oil.

Estimates of additional undiscovered (speculative) resources could add more than 100 years. Unconventional uranium resources are also available such as the uranium contained in sea water and phosphates that could increase resources by many multiples of current reserves, but as with speculative fossil reserves, it would not necessarily be an economic energy resource.

Over the long term, recycling plutonium from reprocessed spent fuel in thermal reactors as mixed oxide fuel and introduction of fast breeder reactors also to convert non-fissionable uranium into plutonium would increase the energy potential of today’s known uranium reserves by up to 70 times, enough for more than 3,000 years at today's usage. Uranium used in a complete fuel cycle not only maintains, but also significantly increases the resource base.

Additionally, thorium, which like uranium has no significant use other than as a reactor fuel, is another energy resource although it does not contain a fissionable isotope as does uranium. It can be used in a breeding fuel cycle with either fissionable uranium or plutonium and converted to a fissionable isotope of uranium. Indigenous thorium in a number of countries with limited uranium deposits could make this an attractive option.

3.7. External costs

While environmental and energy supply considerations show significant advantages to nuclear power, economic justification is a central factor. As a capital intensive undertaking with relatively long construction periods, the competitiveness of nuclear power depends on investment conditions, particularly interest and payback period of loans. In today's liberalized electricity markets and radically changing financial environment, initial capital investments involving high discount rates must be recovered in excessively short time periods. For discount rates in the order of 5%, nuclear power is competitive with fossil fuels. At higher rates it is difficult to be competitive with gas - particularly with combined cycle - and at 10% not with coal. The economic competitiveness of large hydroelectric projects and capital intensive renewables such as solar have also been adversely affected.

In the long term, nuclear power’s economic competitiveness could significantly increase if *externalities* - the considerable indirect and external environmental costs of energy generation and use not usually included in the market price of energy - were weighed. Indirect costs, such as for waste management and decommissioning are already components of nuclear generation costs. For fossil fuels, these costs are not yet fully included and could become significant under more stringent environmental policies.

There would be even greater impact if external costs for local and regional health and environmental impacts were included, perhaps through more stringent regulations or the ecological surcharges some countries already use in the transport and industrial sectors. For nuclear power, most environmental externalities have essentially been internalized in the generating costs by the imposition of numerous costly systems that prevent virtually all radioactive material including waste from entering the environment.

3.8. Carbon tax

With international commitments in place to reduce global greenhouse gas emissions, economic instruments could be considered. Such instruments could include so called carbon trading that in essence allows emission reductions to be accomplished by a third party at a price - a difficult mechanism at the global level - or a more direct carbon value tax.

A carbon value would favor less carbon intensive fossil fuels, particularly natural gas but nuclear, hydroelectric and some renewable systems would be unaffected. To illustrate, if coal generated electricity were 20% cheaper than nuclear, addition of a carbon value of $30 per ton to a coal price of $60 would eliminate the advantage. If natural gas generated electricity were 40% cheaper than nuclear, a carbon value of $200 per ton would make nuclear power competitive.

3.9. Environmental costs

The assessment of environmental externalities must include the entire fuel chain and consider occupational as well as public effects on a local, regional and global scale. For equivalent amounts of energy generation, coal and oil plants, due to greater emissions and fuel and transport requirements, have the highest external costs and equivalent lives lost. The external costs are some ten times higher than for the nuclear power plant and can be a significant fraction of generation costs.

For nuclear power, the impact of routine radioactive releases is negligible and occupational exposures are very low due to small mining requirements. Severe accident impact could be expected to have a great effect on externalities. However, an infrequent event has a small impact per unit of energy generated as its consequences are proportionate to the total amount of energy generated during a period without a severe accident. For example, the Chernobyl accident's projected consequences of 3,500 cancer deaths late in life must be apportioned to the 442 reactors that have operated to date, on average for 20 years each.

4. CONCLUSION

For over 40 years nuclear power has contributed significantly to world energy needs, by providing more than 6% of primary energy and 17% of global electricity. Low environmental impacts and a vast fuel resource potential should allow it to contribute substantially to meeting the sustainable energy challenge. But today’s energy planners are confronted by public apprehension about nuclear power and unrealistic expectations for new energy sources. Will future generations applaud us for retarding and perhaps even abandoning nuclear power, or will they condemn us for not fully utilizing it? Clearly, in view of nuclear power’s contribution to date and its significant potential, it should be fully considered. Comparative assessments of energy options will help to clarify the issues limiting its full use.

SELECTING FUTURE ELECTRICITY GENERATION OPTIONS IN CONFORMITY WITH SUSTAINABLE DEVELOPMENT OBJECTIVES

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Abstract

The complexity facing today's energy planners and decision-makers, particularly in electricity sector, has increased. They must take into account many elements in selecting technologies and strategies that will impact near term energy development and applications in their countries. While costs remain a key factor, tradeoffs between the demands of environmental protection and economic development will have to be made. This fact, together with the needs of many countries to define their energy and electricity programmes in a sustainable manner, has resulted in a growing interest in the application of improved data, tools and techniques for comparative assessment of different electricity generation options, particularly from an environmental and human health viewpoint. Although global emissions of greenhouse gases and other pollutants, e.g. SO_2, NO_x and particulate, must be reduced, the reality today is that these emissions are increasing and are expected to continue increasing. In examining the air pollutants, as well as water effluents and solid waste generated by electricity production, it is necessary to assess the full energy chain from fuel extraction to waste disposal, including the production of construction and auxiliary materials. The paper describes this concept and illustrates its implementation for assessing and comparing electricity generation costs, emissions, wastes and other environmental burdens from different energy sources.

1. INTRODUCTION

The supply of adequate and affordable energy services is an essential element of sustainable development. For the energy system in general and for the electricity sector in particular the challenge is to provide the energy services required for supporting economic development and improving quality of life, especially in developing countries, while simultaneously minimizing health and environmental impacts of anthropogenic activities. All technology chains for electricity generation encompass a certain level of health risk. As well, all technology chains--form resource extraction to the production of energy services--interact with the environment causing varying degrees of damage to the environment. Health and environmental impacts associated with current energy production and use are increasingly felt in many countries.

The need to design and implement sustainable strategies in the electricity sector has been repeatedly stressed during international fora such as the Senior Expert Symposium on Electricity and the Environment (Helsinki, 1991), the United Nations Conference on Environment and Development (UNCED, Rio de Janeiro, 1992) or the 16th Conference of the World Energy Council (Tokyo, 1995). Agenda 21, adopted by UNCED, emphasizes that environment and development concerns should be integrated into the decision making process. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) emphasizes that mitigation options for alleviating the risks of global climate change should be comprehensively assessed and adequate policies be implemented to promote the installation of the most environmentally benign energy conversion technologies.

2. THE DECADES PROJECT

The joint inter-agency project on Databases and mEthodologies for Comparative Assessment of Different Energy Sources for electricity generation, in short DECADES [1], was established at the end of 1992, when nine international organizations (EC, ESCAP, IAEA, IIASA, IBRD, OECD/NEA, OPEC, UNIDO and WMO) agreed to join efforts to enhance data bases and methodologies for comparative assessment of different energy sources and conversion technologies. The aim of the project is to facilitate the development of sustainable energy strategies as an integral part of contemporary planning and decision making in the electricity sector.

The DECADES Computer Tools developed in the first phase of the project, consist of databases and analytical software (DECPAC). These tools can be used for evaluating the always existing trade-offs between technical, economic and environmental features of different electricity generation technologies, chains and systems at the national, regional and international levels.

2.1. Databases

A comprehensive, up-to-date and consistent set of technology, economic and environmental data is a necessary prerequisite for any comparative assessment of different electricity generating pathways. For DECADES two types of technology databases were developed: the Reference Technology Database (RTDB) and Country Specific Databases (CSDBs).

2.1.1. Reference technology database

The Reference Technology Database (RTDB) provides a comprehensive, harmonized set of technical, economic and environmental data for energy chains that use fossil fuels, nuclear power, and renewable energy sources for electricity generation. RTDB addresses all stages of the source-to service chain, i.e., from energy source extraction to electricity services and waste disposal (Figure 1). The database has built in checks to verify the accuracy of information provided by the users (eg, fuel heating value or facility emission factors). The Agency has circulated the RTDB for peer review and organized several Advisory Group Meetings to verify the accuracy of information contained in the database. At present, the RTDB contains data for about 300 technologies, characterized according to their level of maturity (e.g., matured, commercially deployed, demonstration stage, etc.).

2.1.2. Country specific databases

Country specific databases (CSDBs) store data on electricity generation technologies for various countries or regions for the purpose of carrying out case studies with the DECADES analytical software or other national planning tools. The CSDBs accommodate site-specific data, which are not stored in the RTDB. More than twenty-five countries have developed CSDBs, containing a total of more than 2,500 technologies.

The DECADES databases have a flexible structure which not only allows users to modify values for a predefined set of characteristics but also to add new characteristics to the facilities and energy forms. Hence, the DECADES database management system can be used to transfer data to and from analytical tools (e.g., DECPAC, ENPEP, WASP, or other national planning or impact assessment tools).

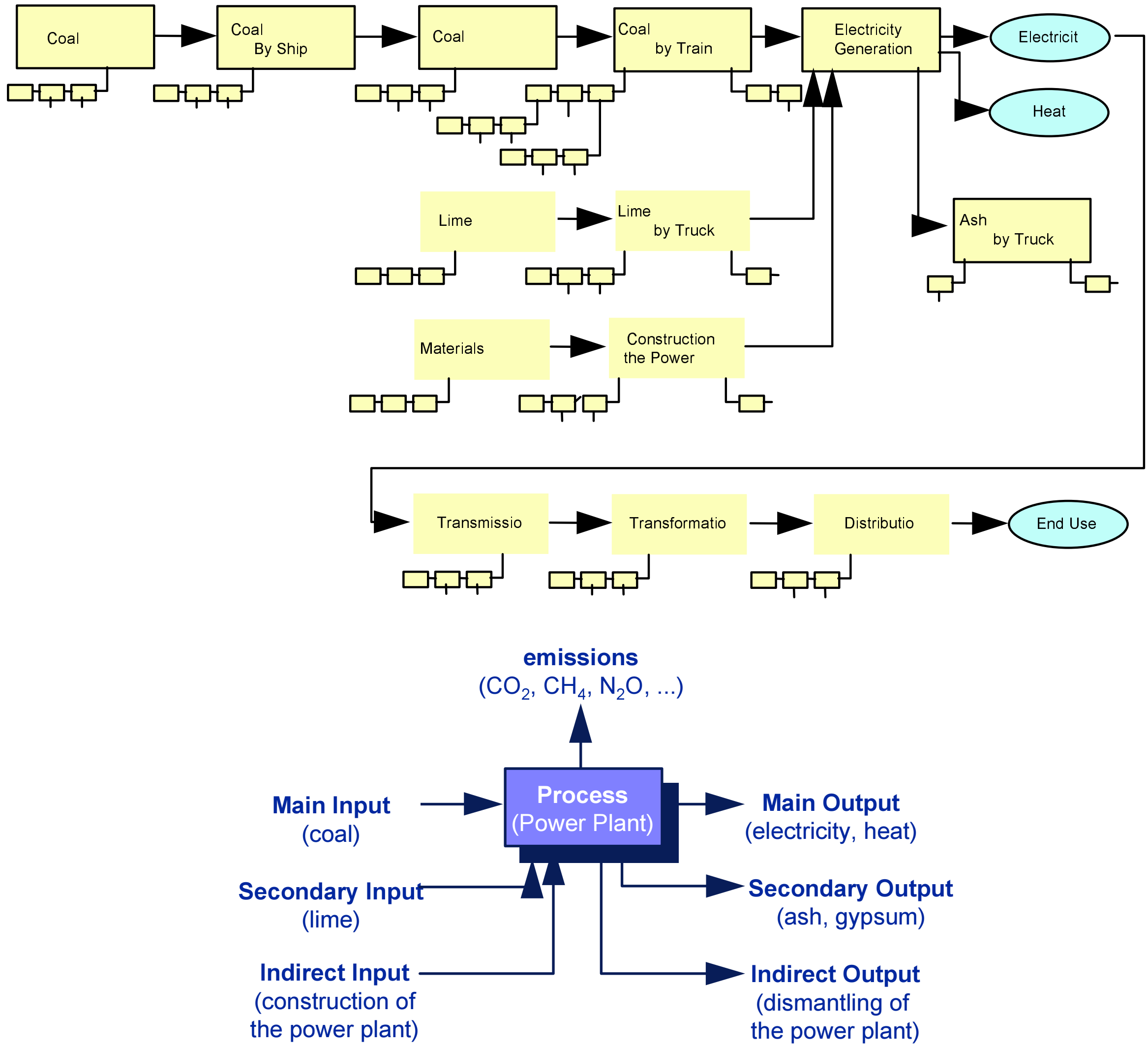

FIG. 1. A graphical representation of a coal source-to-service chain [2].

2.2. Analytical software

The specific objective of the DECADES software is to provide the users with an easy to use tool for carrying out decision support studies for the power sector. The DECADES analytical software is designed to access information stored in the technology databases for analysis and comparison of costs and environmental burdens at the power plant, energy chain and electric system levels. Its design focuses on user friendliness, short turn-around time for the optimization of electricity system expansion strategies and extensive reporting capabilities.

2.2.1. Plant level analysis

Plant Level Analysis adjusts power plant characteristics automatically based on the type of fuel and pollution abatement technology specified by the user. It also estimates air emission factors for main pollutants as well as electricity generation costs and calculates technical, economic and environmental performance changes resulting from adding a control device to a plant.

2.2.2. Chain level analysis

Chain level analysis supports the comparative assessment of full energy chains for electricity generation, from resource extraction to electricity service generation and waste disposal. A flexible interface facilitates rapid construction of energy chains and ensures the validity of energy chain representations. Chain level results include: Levelized generating costs, mass flow of fuels and waste, total greenhouse gas emissions (CO_2 equivalent), pollutants affecting local air quality and regional acidification, water effluents, solid waste generation and land use. Emissions from auxiliary material inputs and materials for construction and dismantling of generating stations are also calculated.

2.2.3. System level analysis

System level analysis allows users to quickly screen electricity system expansion strategies and to conduct comprehensive studies. The system planning tool, DECPAC, contains three analysis options, ranging from preliminary analysis tools based on screening curves to sophisticated least-cost optimization with dynamic programming. DECPAC has core features derived from the IAEA's WASP and ENPEP models with an enhanced graphical interface, improved computation of environmental residuals (e.g., air pollutant emissions, land use and waste generation) and extensive reporting capabilities.

3. SOME ILLUSTRATIVE APPLICATIONS OF THE DECADES COMPUTER TOOLS

The following section illustrates some applications of the databases and software developed in the Phase I of the DECADES project for comparative assessment studies.

3.1. Comparison of power plants

Figure 2 compares the net generating efficiency values of several types of power plants (conventional as well as those under development) included in RTDB. It may be noted that while significant improvements in the generating efficiency may be obtained for the conventional technologies based on gas, the expected efficiency improvements for the other conventional technologies are less impressive. However, new technologies, with conversion processes other than combustion and advanced power cycles, will eventually surpass the best performance of current technologies.

The generating efficiency data are strongly influenced by the characteristics of the fuel used, maintenance of the power plant and other local conditions. Plant efficiencies vary from country to country and in many countries are lower than the values presented in Figure 2 for coal, oil and gas fueled electricity generation technologies.

Figure 3 illustrates a comparison of the CO_2 emission factors for the following types of power plants: pulverized coal with flue gas desulphurization (PC+FGD), pressurized fluidized bed coal combustion (PFBC), integrated coal gasification combined cycle (IGCC), gas turbine combined cycle (GTCC), oil fired steam turbine (OSB). The power plants have the same size (500 MW) and the coal fired plants use similar coals. The highest CO_2 emissions result from the coal-fired options. These technologies display a considerable range of CO_2 emissions as a result of variations in efficiency of power generation. The CO_2 emissions obtained from the GTCC plant are less that half of those from coal. The emissions from oil fired units are within

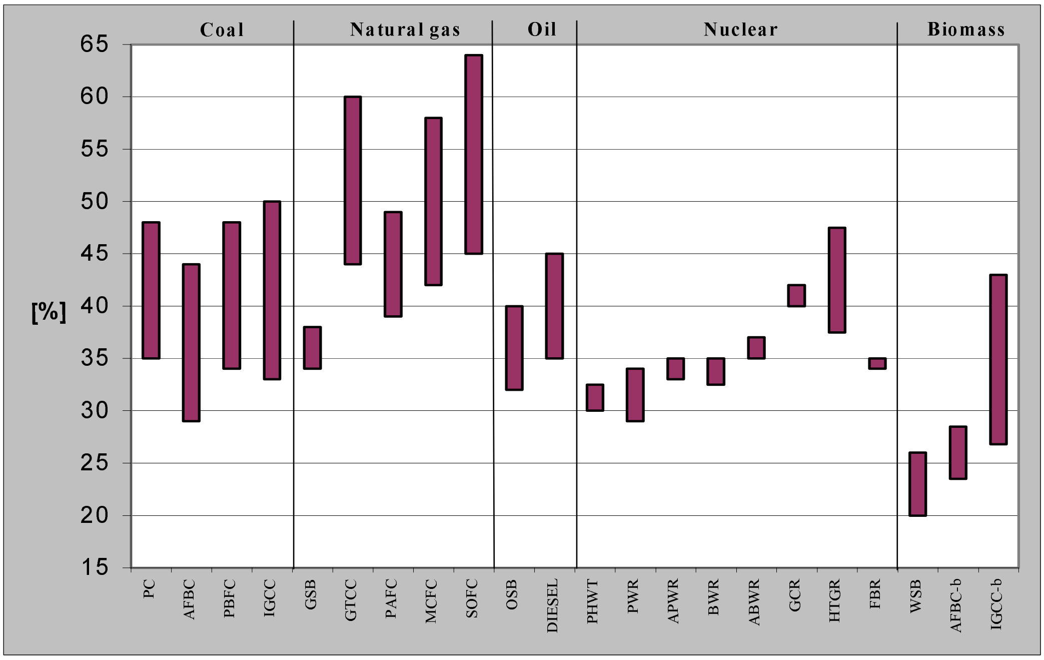

FIG. 2. Comparisons of net generating efficiency for RTDB technologies[1] *(Source: RTDB).*

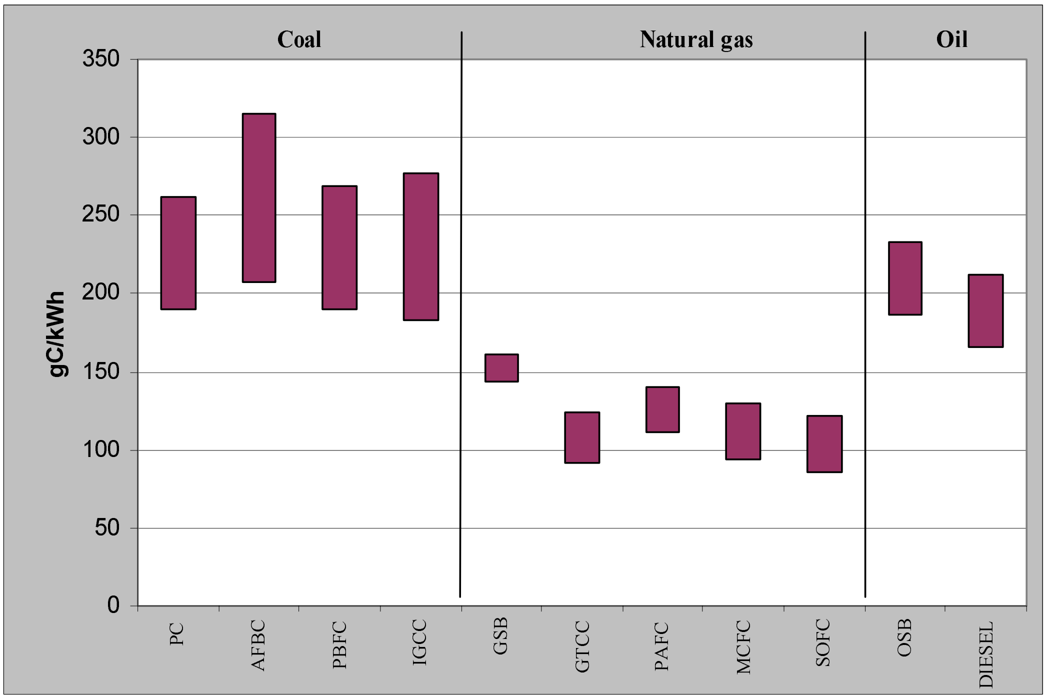

FIG. 3. Plant emissions of fossil-sourced electricity generation (Source: RTDB).

[1] **PC**- Pulverized Coal, **AFBC**- Atmospheric Fluidized Bed Combustion, **PFBC**-Pressurized Fluidized Bed Combustion, **IGCC**-Integrated Gasification Combined Cycle, **GSB**-Gas Steam Boiler, **GTCC**-Gas Turbine Combined Cycle, **PAFC**-Phosphoric Acid Fuel Cell, **MCFC**-Molten Carbonate Fuel Cell, **SOFC**-Solid Oxide Fuel Cell, **OSB**-Oils Steam Boiler, **DIESEL**- Diesel Engine, **PHWR**-Pressurized Heavy Water Reactor, **PWR**-Pressurized Water Reactor, **APWR**- Advanced PWR, **BWR**-Boiling Water Reactor, **ABWR**- Advanced BWR, **GCR**-Gas Cooled Reactor, **HGCR**-High Temperature Gas Cooled Reactor, **LMR**-Liquid Metal Reactor, **FBR**- Fast Breeder Reactor, **WSB**-Wood Steam Boiler, **AFBC-b** - Atmospheric Fluidized Bed Combustion using biomass, **IGCC-b** - Integrated Gasification Combined Cycle using biomass, **ST**-Solar Thermal, **PT**-Parabolic trough, **PD**-Parabolic dish/Sterling, **PVAm**-Photovoltaic Amorphous, **PVTf**-Photovoltaic Thin Film

the spread of the natural gas and coal, and depend upon the quality of heavy oil used. The emissions depend on the fuels' carbon contents (highest for coal, lowest for natural gas), technologies' generating efficiencies, pollution control measures included in different designs, and other factors. The emission factors presented in Figure 3 are given for currently best available technologies and good quality fuels. Similar comparisons [3] can be carried out for other pollutants such as SO_2, NO_x, particulates, etc.

The economic comparative assessments carried out at the power plant level using RTDB and CSDB data show that nuclear power is a competitive option for generating electricity in many countries. Figure 4 displays the total capital requirements for pulverized coal fired plants (PC), oil steam boiler plants (OSB), gas turbine combined cycle plants (GTCC) and nuclear (PWR, PHWR) plants in several countries. As expected, the total capital requirements per unit capacity vary from country to country, but the range is not large for similar technologies.

Figure 5 illustrates the variation of electricity generation costs for the several candidates for generating capacity expansion for an energy importing developing country (Pakistan). Here nuclear power appears to be a least-cost option for base load electricity supply. Algorithms were developed to support a modular approach to air pollution abatement technologies. This allows analysis of the impact of pollution abatements on the emissions and costs of a power plant. The analysis is based on the data stored in RTDB/CSDBs and includes: capital and overnight costs, fixed and variable operation and maintenance (O&M) costs, reagent consumption, if any, internal electricity consumption, and the impact on efficiency of adding abatement devices to the power plant.

3.2. Comparison of chains

Figure 6 illustrates maximum and minimum GHG emissions for solid, liquid, gaseous, hydro, nuclear, wind, solar and renewable electricity generation pathways. Taking into account the entire up-stream and down-stream energy chains for electricity generation, nuclear power emits 40 to 100 times less carbon dioxide than currently used fossil-fuel chains. Greenhouse gas emissions from the nuclear chain are due mainly to the use of fossil fuels in the extraction, processing, and enrichment of uranium and to fuels used in the production of

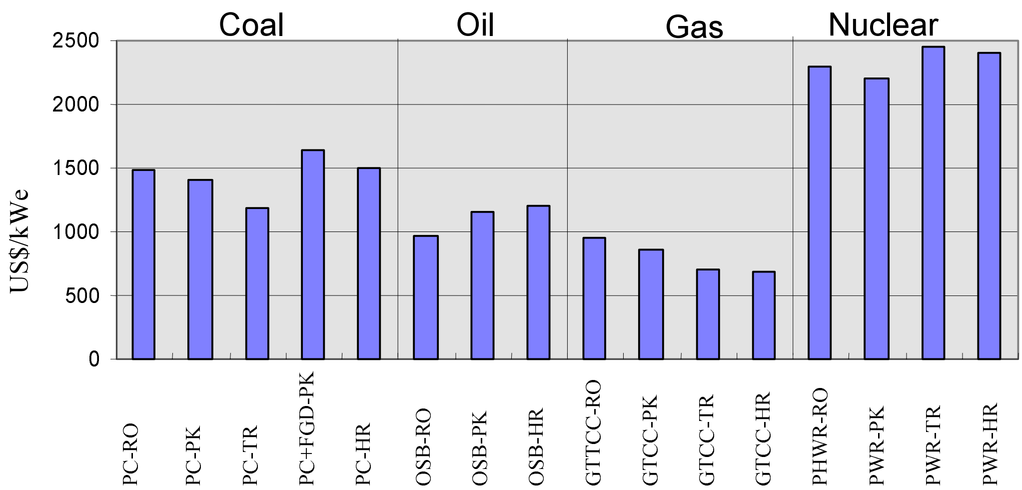

FIG. 4. Investment costs - power plant level (RO - Romania, PK - Pakistan, TR - Turkey, HR - Croatia) (Source: CSDBs)

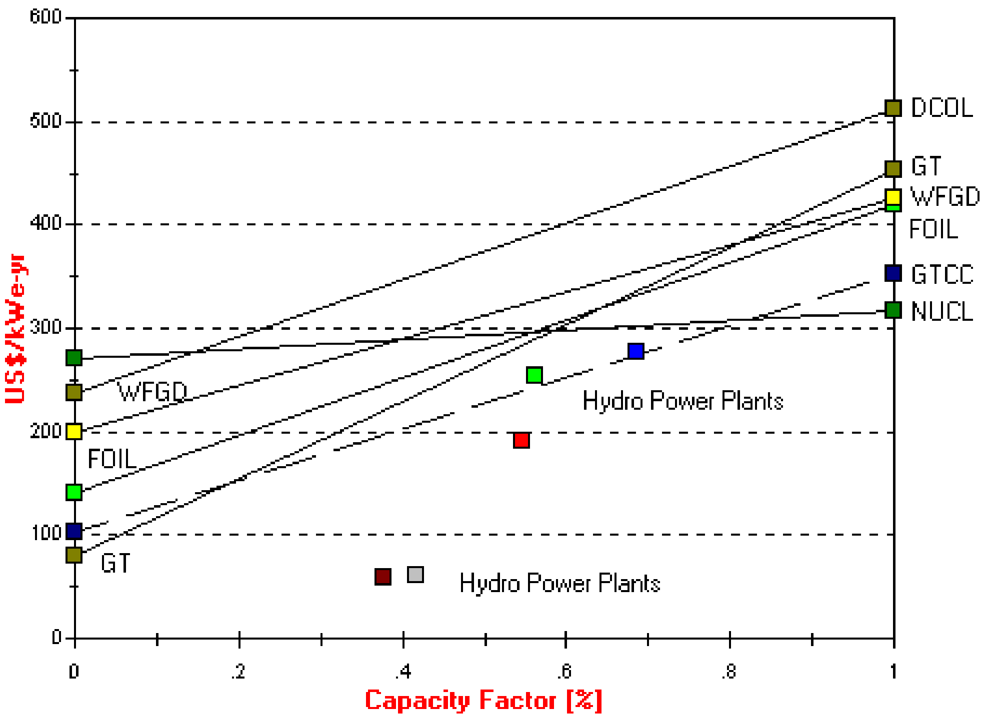

FIG. 5. Electricity generation costs[2] at 10% discount rate.

steel and cement for the construction of reactors and fuel cycle facilities. These emissions, which are negligible relative to those from the direct use of fossil fuels for electricity generation, can be reduced even further by energy efficiency improvements. Such improvements at the enrichment step include, for example, replacing the gaseous diffusion process by less energy-intensive processes such as centrifugation or laser isotope separation. Figure 6 also shows uncertainty ranges. Among the fossil fuel chains, natural gas has the widest uncertainty, mainly due to different assumption concerning methane releases to the atmosphere during drilling, extraction and transportation of natural gas.

The emissions listed here are calculated for full load power operation of a particular power plant without considering possible interaction with other chains or load dispatch impacts. Significant differences may result when such interactions are taken into consideration, as is provided at system level analysis.

It may be also pointed out here that the very low levels of radioactive emissions from routine operation of nuclear energy facilities are generally considered to be harmless for human health and the environment as the public exposure due to these emissions are far below those from the natural background. Furthermore, in the case of nuclear power, the external costs arising from ensuring safety, and for radioactive waste management and decommissioning of facilities, are internalised by including them explicitly in the price of electricity generated from nuclear power [4]. On the other hand the external costs arising from

[2] DCOAL: Domestic coal; FOIL: Fuel Oil; GT: Gas Turbine; GTCC: Natural Gas Combined Cycle;WFGD: Imported coal pulverized Coal + Wet Scrubber, NUCL: Nuclear (Source: CSDBs)

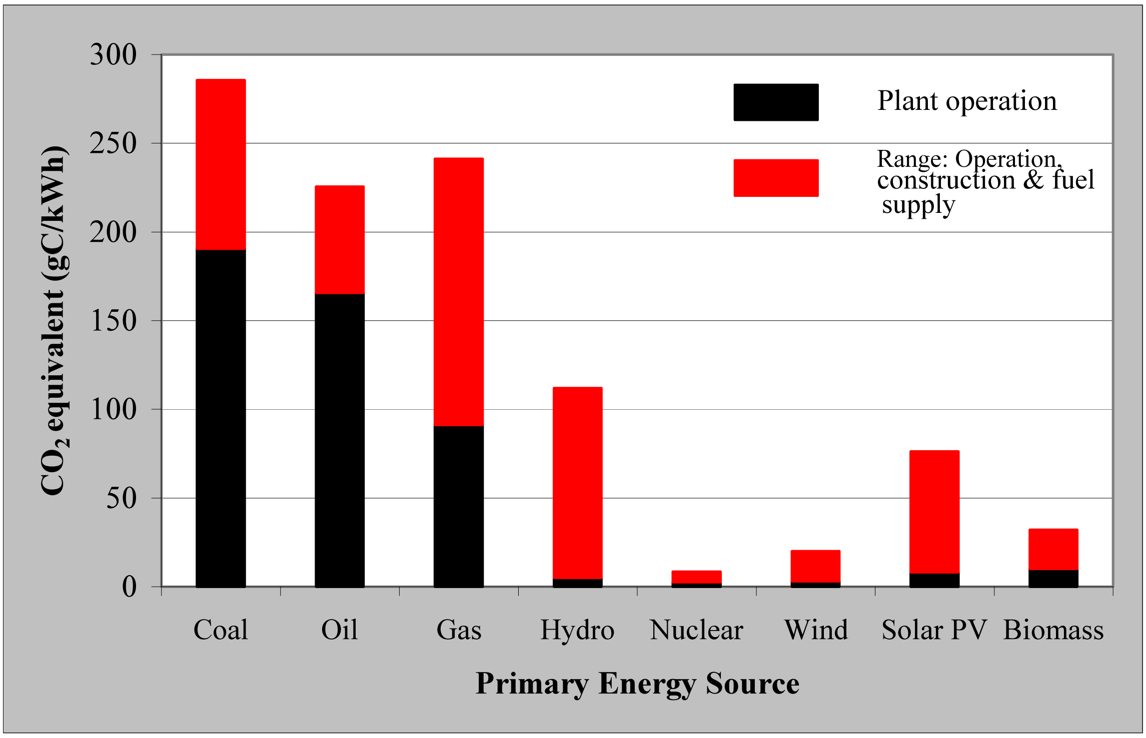

FIG. 6. CO_2 equivalent emissions - full chain (maximum and minimum values) [5]

the adverse environmental and health impacts of other electricity generating pathways have not yet been properly estimated and, as such, still remain to be fully internalised.

3.3. Power system expansion

The DECPAC software can be used to determine environmentally sound least-cost expansion plans for electricity generation systems or to analyze whether a particular project fits into the robust long-range least-cost development plan for a country or region. It can also be used in an iterative manner to investigate least-cost methods to reduce environmental burdens (e.g., minimum system costs to meet targets for reducing sulfur dioxide or greenhouse gas emissions).

The optimization of the expansion plan is performed taking into consideration the capital investment costs, the operation and maintenance cost, the fuel cost, the fuel inventory cost and the cost of energy not served.

Once the optimum expansion plan has been developed, DECPAC allows for the calculation of air emissions, land requirements and production of solid wastes, year by year and step by step, for every energy chain included in the system, so that the totals for the entire electricity system are given.

3.4. Comparative assessment case studies

Under the DECADES project, twenty-two country case studies on comparative assessment of alternative strategies and policies for the electrical power sector were carried out, supported by the IAEA through a Coordinated Research Programme (CRP). The case studies sought to identify electricity generation strategies that would meet the objectives of environmental protection, in particular reduction of atmospheric emissions at acceptable cost. A broad range of issues such as: assessing the potential role of nuclear power in reducing the greenhouse gas emissions; effects of CO_2 taxation and/or emission constraints on future generation mix and impact of privatization and deregulation of electricity sector on electricity system expansion strategies and others have been addressed in these case studies.

Significant reductions of emissions and other environmental burdens can be obtained by improving the efficiency of existing facilities at different levels of the energy chains. The rehabilitation of existing power plants, in particular by adding pollution control technologies, was often found a cost effective measure for mitigating local air quality and regional acidification impacts. Improving the overall efficiency of energy systems by promoting co-generation was identified as a cost-effective option in many countries, especially where heat distribution networks already exist for district heating. In most of the studies addressing capacity expansion, nuclear power proved cost-effective for reducing emissions of SO_2, NO_x, CO_2 and other greenhouse gases. Figure 7 illustrates the results obtained for a gas expansion scenario versus a nuclear expansion scenario in Romania. Large reduction of CO_2 emissions may be obtained by using nuclear power plants in the power system expansion without any significant increase in the total system expansion cost. For the gas scenario, although the CO_2 emissions are reduced in comparison with coal dominated scenarios they are significantly increasing over the study period. The SO_2 and NO_x emissions (see Figures 8 and 9) will decrease in both scenario but, in the nuclear expansion scenario, the decrease is approximately 30% higher that in the gas scenario.

Some studies also showed that, although CO_2 emission reduction targets could be achieved without nuclear power, its use would lead to significantly lower costs. It may be pointed out here that the implementation of environmental protection measures and policies, including more stringent atmospheric emission limits are likely to increase the cost of electricity from fossil-fueled power plants that will have to comply with these regulations by adding pollution abatement technologies and/or switching to higher quality fuels (e.g. low sulfur coal) that are generally more expensive. Furthermore, global climate change concerns are leading many countries to consider policy such as carbon taxes, that would affect the competitiveness, and /or limit the use of fossil fuels for electricity generation. In the Romanian case, CO_2 abatement costs based on the accelerated use of nuclear power are approximately US$5/ton CO_2 or US$18/ton C which is at the bottom end of the range US$0 to US$120/ton C reported in IPCC [6].

In most of the case studies carried out the natural gas combined cycle power plants which are very attractive from the point of view of generating efficiency (58% or higher), capital requirements and short construction periods were considered as candidates for electric system expansion. However, operating experience for 1995 shows problems in the reliability of such plants. Furthermore, the limited resources of natural gas and the escalation of the natural gas price, the losses of methane during pipeline transportation as well as the service and technical support problems in developing countries are additional reasons to be taken into account when considering this option.

The cooperation that has been established through this CRP, involving experts from different countries and having different scientific backgrounds, has proven to be extremely valuable and effective. In particular, the cooperation and exchange of information and

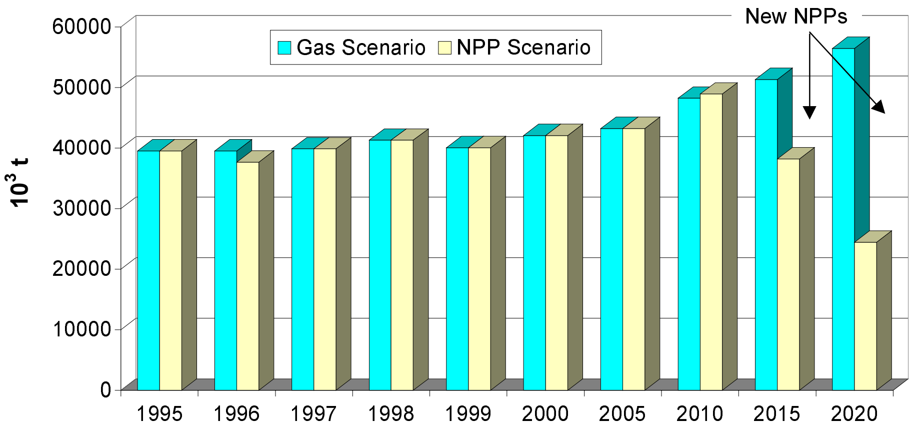

FIG. 7. CO_2 emissions in Romania over the study period (Source: DECADES Case Studies).

experience between different teams who are confronted with similar difficulties, such as datacollection, technology description, fuel chain definition and comparison, and electric generation system analysis, resulted in identifying and implementing common approaches for solving such problems. The participation of experts in the fields of electricity system analysis, macro-economics and environmental impact assessment led to a recognition of the need to reconcile various concerns and priorities - e.g., alleviating local and global environmental impacts and also addressing economic, social and security of supply issues - within a comprehensive assessment of alternatives.

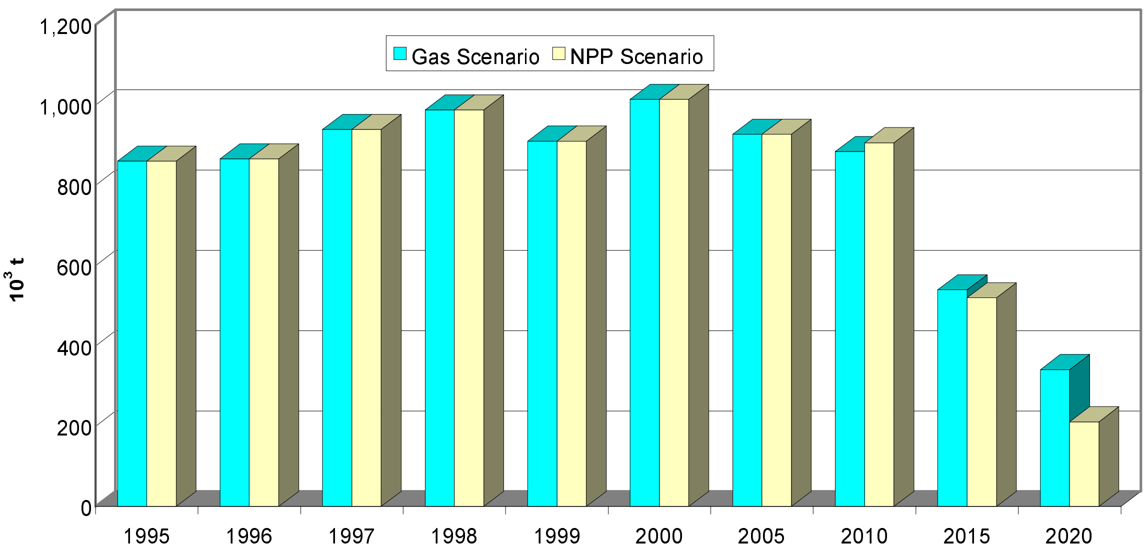

FIG. 8. SO_2 emissions in Romania over the study period. (Source: DECADES Case Studies).

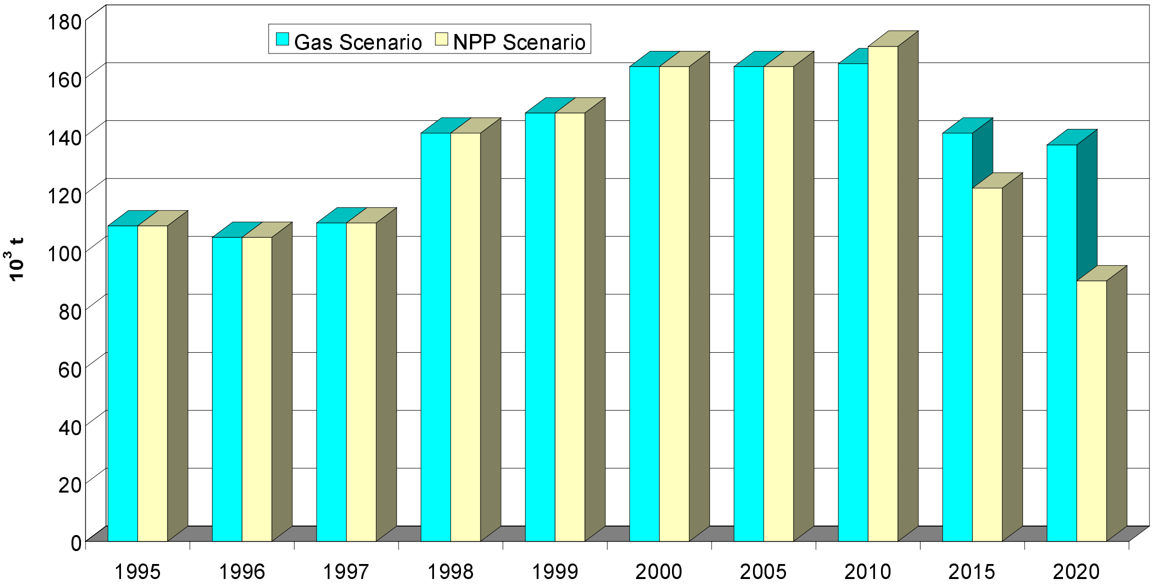

FIG. 9. NO_x emissions in Romania over the study period. (Source: DECADES Case Studies).

4. CONCLUDING REMARKS

The comparative assessment of comprehensive source-to-service pathways of different energy sources and conversion technologies is key to the development of sustainable energy supply strategies. The DECADES project provides the necessary methodology and tools for performing such assessments. The dissemination of the DECADES activities and results to Member States is an ongoing process. Inter-regional workshops on the use of the DECADES Computer Tools were held at Argonne National Laboratory (ANL) in USA (1995 and 1996), in Poland (1996) and in Brazil (1997). Also, seminars and workshops were held in Canada, USA, UK, Brazil and Republic of Korea. The high interest manifested by institutes, organizations and universities in Member States in participating in these events is a good indicator for the usefulness of the DECADES approach.

The comparative assessment studies based on DECADES show that nuclear power is economically competitive with other base load generation options and generates significantly lower emissions of SO_2, NO_x and CO_2 than any fossil-sourced option. While coal and/or gas fired power plants may be attractive in countries having access to inexpensive domestic fossil sources, their economic competitiveness might become questionable in the context of more stringent environmental protection regulations and standards requiring the implementation of pollution control devices and limitations to greenhouse gas emissions. Most renewable energy sources offer interesting prospects for environmentally friendly electricity generation systems. However, the potential role of renewable energy sources, other than conventional hydro power, for large scale electricity generation, may be limited by physical constraints in some regions and, moreover, they are unlikely to be economically competitive with fossil fuels and nuclear power in the short and medium term.

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NUCLEAR POWER TECHNOLOGIES FOR APPLICATION IN DEVELOPING COUNTRIES

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Abstract

The tremendous social and political changes which have occurred during the recent decade in the former USSR made it possible to launch the process of commercialization of defense-related technologies in Russia. The so-called dual-use technologies are meant initially developed by the state for defense needs, but having a high commercial potential as well. To date, the process of such technology transfer from the state sector to private one has been limited primarily by insufficient progress of the national private sector. Essentially, the main economic problem still remains the attraction of private capital for the promotion of dual-use technologies to the point at where they acquire commercially viable. A large number of advanced technologies are waiting to be commercialized. The report presented considers the prospects of civil use of some technologies related to nuclear power area: space nuclear power systems, nuclear powered submarines and rector-pumped lasers.

1. SPACE NUCLEAR POWER TECHNOLOGY

The former Soviet Union has conducted extensive R&D works to create space nuclear power systems (SNPS).

More than 30 reactor-powered satellites with thermoelectric SNPS (known in the West as RORSAT) have been orbited before 1987.

The thermoelectric SNPS unit consists of small size fast 100 kW thermal power reactor, two-loop Na-K system with 3kW$_e$ remote semiconductor battery, electromagnetic pump and radiator.

Two TOPAZ-type SNPS units were successfully tested in space both using thermionic principle of heat energy conversion into electricity (Fig. 1). In reactor-converter cores the fuel elements are combined with thermionic converters which generate almost 10 kW of electric power.

Three nuclear power propulsion units were designed and ground-tested.

In the course of these works very sophisticated scientific and engineering problems were resolved and unique experience was gained in the field of high technology development, including:

– fuel composition development (metal, oxide, nitride and carbonitride fuel)
– thermionic reactor-converter design (geometry optimization, electrode material selection, fission product withdrawal, electrical insulation availability, etc.)

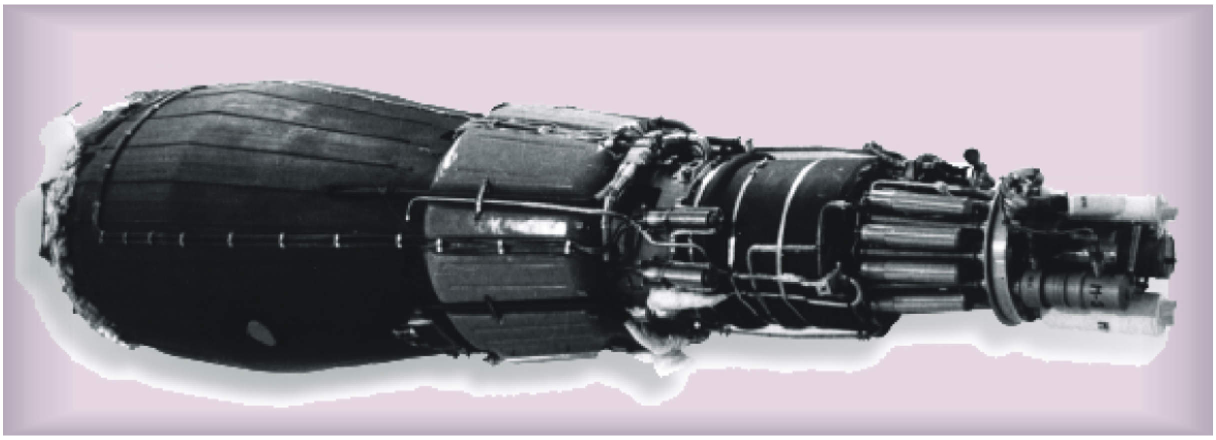


FIG.1. "TOPAZ" space nuclear power system.

- reactor structural material development (moderator, reflector, thermo-and electro-insulator, metal-ceramic connections, etc.)
- liquid-metal coolant technology (mass transfer and corrosion processes, compatibility, methods and means of impurities control, etc.)
- waste heat removal techniques (heat pipes, advanced radiator design, drop radiator, etc.)

Some proven technologies have been already used and most of other can be used for civil applications. Possible areas of the applications are described below.

1.1. Space nuclear power system technology

1.1.1. Industry

- Hydrogen (special purity) technologies for metallurgy and chemistry
- Super-pure gases and de-ionized water (Kr, Xe, N_2, Ar, H_2; purity >99,9999%)
- High temperature devices and equipment for vehicle and tractor industry.

1.1.2. Medicine

- Medical equipment using new structural materials (implants made of super pure zirconium alloys)
- Specialized medical reactor
- Diagnostic equipment.

1.1.3. Power engineering

- Nuclear power technology complex for ecologically safe production of synthetic fuel
- Co-generation thermal electric and thermionic systems using natural gas and liquid fuel
- New kinds of thermal and refrigerating equipment (conditioners and micro-refrigerators based on thermoelectric elements).

1.2. Nuclear power technology complex

1.2.1. Application for processing of low brown coals

- to petrol, diesel fuel, fuel for ships and propulsion engines
- to chemical products (phenols, nitrogen bases, non-finite and aromatic hydrocarbons) of quality corresponding to that of oil processing products(Figure 2).

1.2.2. Principal difference

- the use of extremely safe nuclear power source with liquid metal coolant, its high thermal potential (~550°C) completely meeting the technological needs of the production of liquid fuel.

1.2.3. Advantages

- low pressure (10 MPa) in hydrogenization compared to similar technologies (30-70 MPa) developed by Coppers (USA), Ruhrkohle (Germany) and other companies
- a two-fold decrease of expenses for coal mining.
- decrease of areas withdrawn from economic use
- considerable decrease of organic fuel fume releases (CO, SO_2, NO_x, etc.) into atmosphere
- possibility to concentrate more production enterprises for coal processing in one region because of a low environmental burden

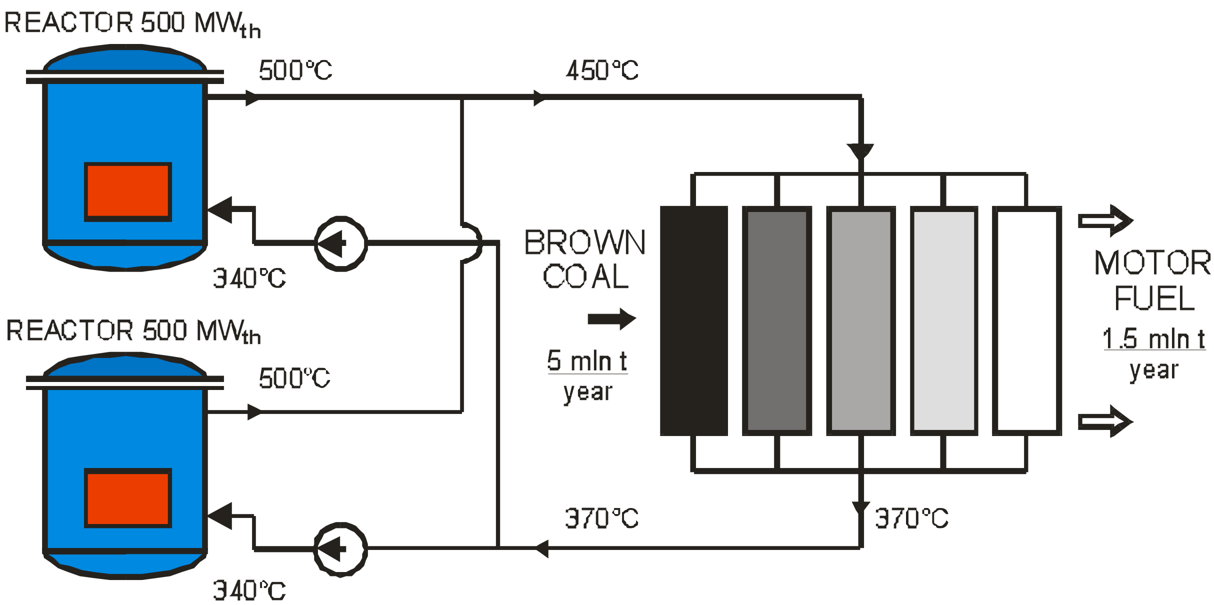


FIG. 2. Example of a nuclear power technology complex.

1.3. Specialized medical reactor (SMR)

Specialized medical reactor has a wide application of beam therapy methods used for treatment of cancers. SMR are simple, reliable, inexpensive, transported as self-contained units, reactor intended purely for medical purposes using convection under double-planimetry circuit as a heat removal (Figure 3).

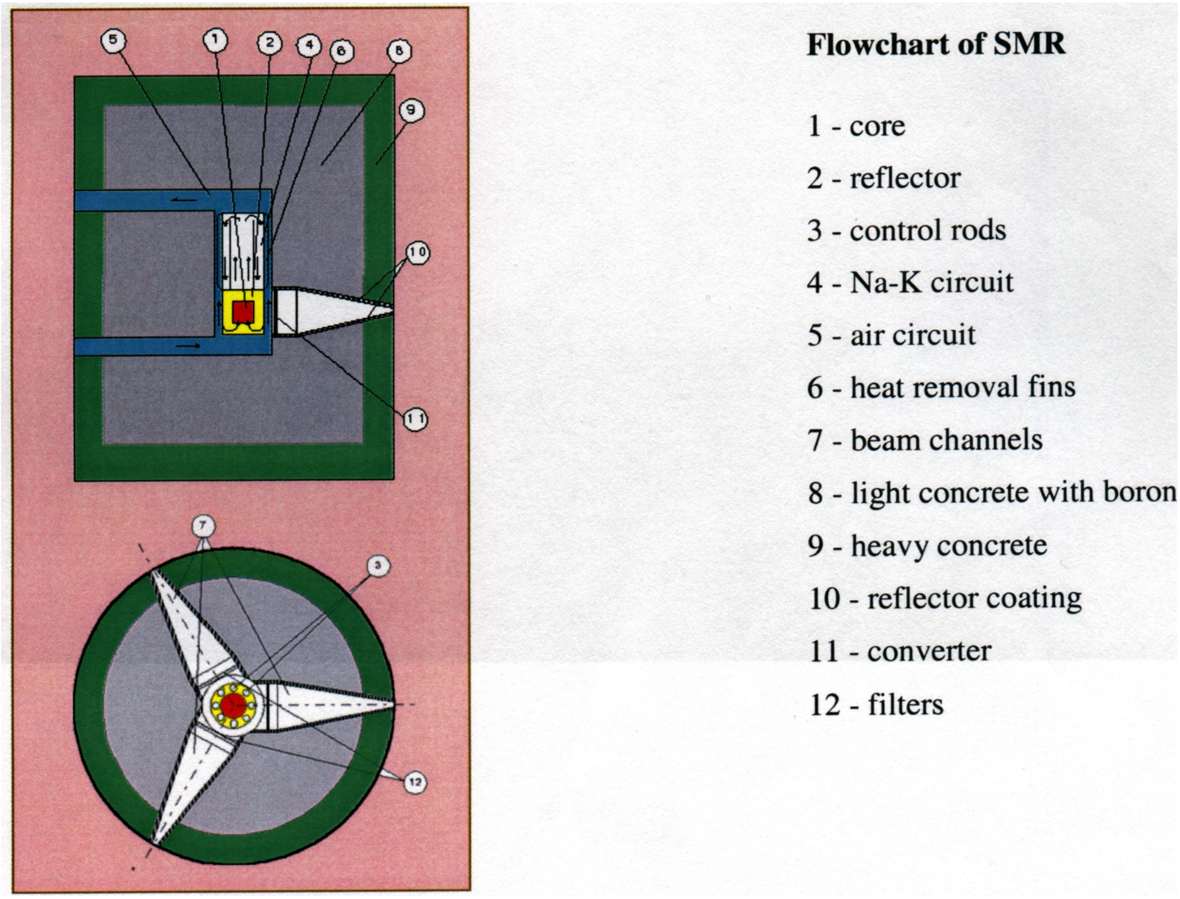


FIG. 3. Specialized medical reactor.

Specialized medical reactors provides three irradiation channels:

- for therapy in fast neutron beams
- for neutron capture therapy
- for therapy in mixed gamma-neutron beams

Reactor is simple in operation and does not require large expenses for construction due to a convection heat removal and rather small dimensions.

1.4. Natural gas-fueled cogeneration installation for cathodic corrosion protection systems

This system has the following advantages:

- Use in all climatic zones
- Integration into high pressure pipelines
- High level automation and safety
- Adaptation to customer’s demands for heat and electricity production
- Convenient operation and servicing

Technical Data:

Natural gas flow rate, m^3(n)/hr		2.5
Inlet gas pressure, atm	max	100
Gas pressure upstream of burners, atm		0.1
Thermal power obtained by conversion from the heat recovery system, kW		17
Electrical power at load, W	min	500
Output voltage (DC), W		12…48
Ambient temperature, °C		-50…+30
Dimensions:		
cogen. plant (w/o heat recovery system), mm	w*d*h	500*500*2,000
heat recovery system, m		500*500*1,500
Weight:		
cogen. plant (w/o heat recovery system), kg	max	150
heat recovery system, kg		
Life time, years	min	10
No. of thermal cycles	min	1,000

2. LEAD-BISMUTH TECHNOLOGIES

The works on development of chemically inert high-boiling led-bismuth coolant for nuclear powered submarine have been started in our country more than 40 years ago (Fig.5).

The Institute of Physics and Power Engineering, Research and Development Bureau "Gidropress" and other Russian institutions have gained extensive experience in the development, construction and operation of nuclear power reactor with lead-bismuth coolant. Ground nuclear facilities and 8 nuclear-powered submarines were built and tested, total operation time of such systems was about 80 reactor-years.

In the course of development and construction of NPP with lead-bismuth coolant, complex research works were carried out, and related engineering problems were resolved in the following areas:

– hydrodynamics and heat exchange
– monitoring and technology for maintenance of coolant quality
– structural material

– radiation safety
– problem of solidifying and remitting coolant in the primary circuit.

Low chemical activity of lead-bismuth, high boiling point (1670°C), high neutron yield by proton impact, comparatively small cross-section of neutron absorption make lead-bismuth a perspective coolant for both reactors and accelerator-driven systems.

2.1. Nuclear powered submarine technology

2.1.1. Power engineering

– Modernization of old nuclear power plants
– Liquid-metal target for electronuclear systems
– High-grade gallium generation

2.1.2. Liquid filtration:

– Liquid metals (Pb, Bi, Ga, Al, etc.)
– Organic liquids (fuel, alcohol)
– Water suspensions (H_2O; milk; acid, alkali and salt solutions; medical solutions)

2.1.3. Gas filtration

– Aerosols of radioactive waste disposal process
– High-temperature gas processing aerosols
– Radioactive aerosols ventilation systems
– Sodium burning aerosols

2.2. Modernization of reactor steam generator module

An example of a modernized reactor steam generator module is shown in Figure 6.

2.3. Lead-Bismuth cooled reactor with enhanced safety

These reactors are characterized by negative temperature and power feedbacks, as well as negative void and steam-gas reactivity affect. Absence of poisoning affects and a high breeding factor provide operative reactivity reserve below β_{eff} at any moment of the life time, the reactivity-related accidents with fast reactor runaway on prompt neutrons being thus excluded. According to the computation studies carried out, core melting and destruction of the reactor vessel can be excluded in the most improbable beyond the design-basis accidents with heat removal failure, explosions and fires. High boiling point of coolant excludes overpressurising of the primary circuit and coolant leakage as a result of its boiling up or evaporation after the circuit break-down. Low chemical activity of coolant makes hydrogen formation impossible in any accidents (leakages in steam generators, high overheating, etc.).

BRUS-150 multipurpose reactor system (150-170 MWe) has been developed on the basis of this concept. It can be transported by railway in operational readiness form. This reactor can be used to generate electricity or produce mean potential heat for chemical technologies of obtaining motor fuel from brown coals.

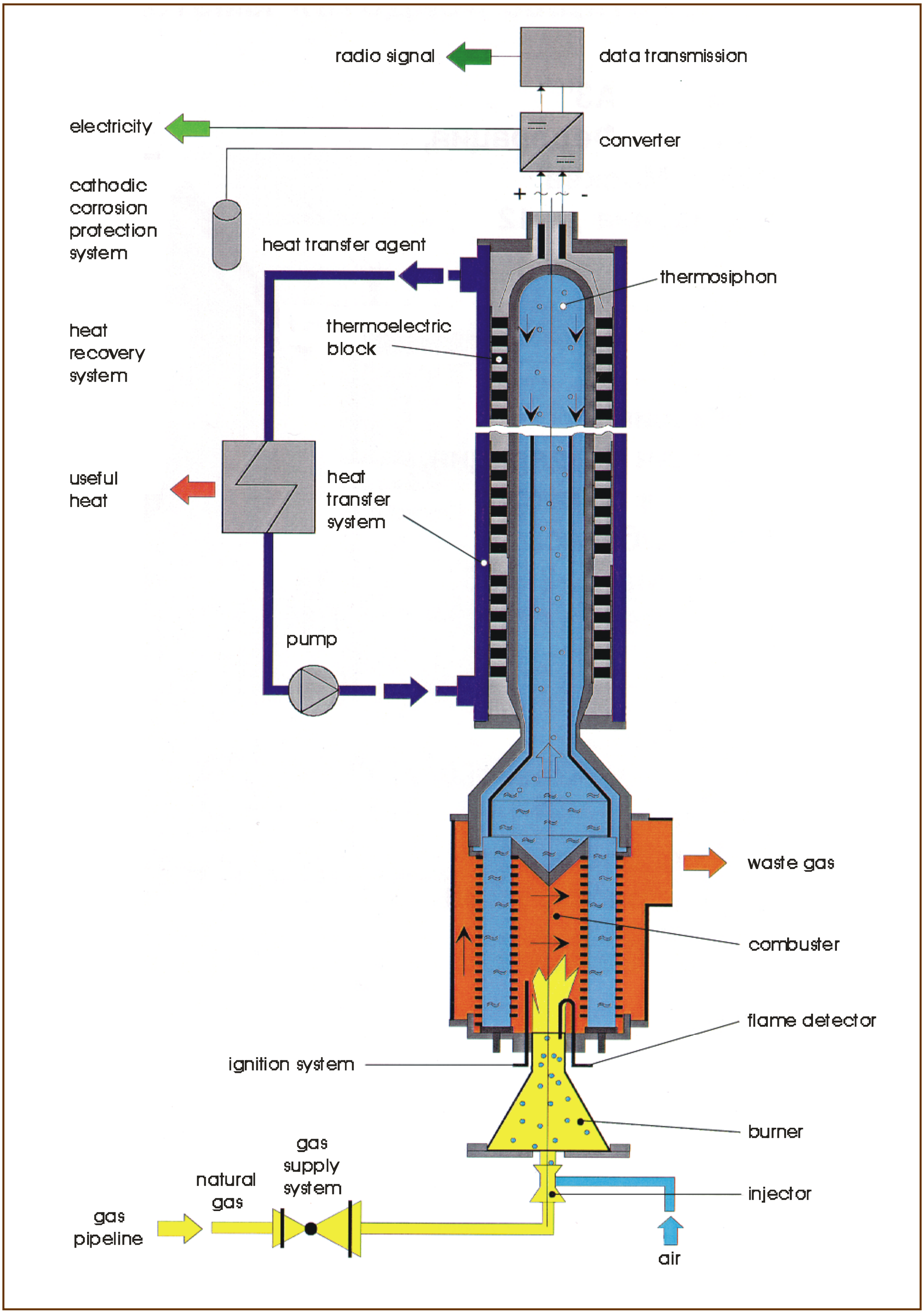


FIG. 4. Natural gas-fueled cogeneration installation for cathodic corrosion protection systems. design and operational mode.

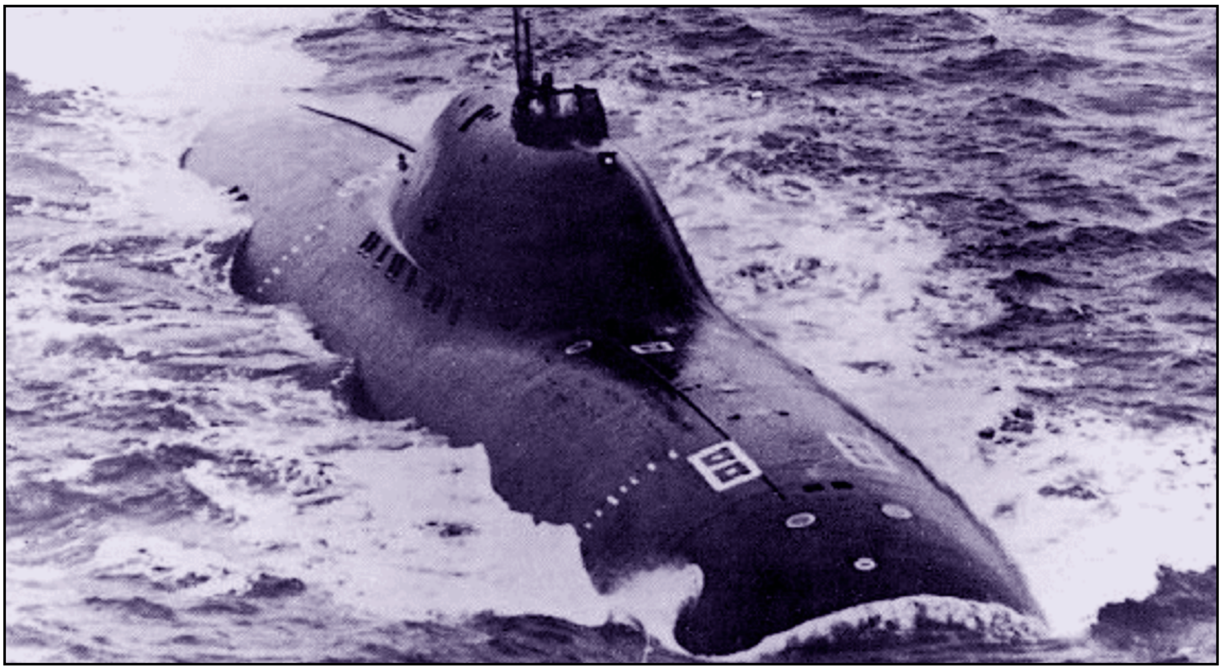


FIG. 5. Nuclear powered submarine. (Lead-Bismuth cooled reactor).

In addition to BRUS-150, a design of module-transportable “Angstrem” Nuclear Power and Heat Generating Plant (NPHGP) has been developed (electric power of 6 MW and 12 Gcal/h heat production). Dimensions of unit meet the railway standards. Units can be delivered to the operation site by any mode of transport, including air crafts. NPHGP can operate in various regions, including the North and deserts.

2.4. Accelerator-driven systems

At present a feasibility of creating subcritical accelerator-driven systems is actively discussed, mainly for transmutation of long-lived radioactive waste.

An accelerator-driven system consists of accelerator ions (usually protons), target where neutrons are generated under ion impact, and subcritical reactor-blanket.

Advanced systems (~10^{16}n/cm^2·sec neutron flux in the blanket and several tens MW proton beam power) are feasible only when a liquid lead-bismuth or lead target is used. In this case, unlike that of solid target, the problem of the target assembly cooling seems to be resolved naturally, and injection of proton beams is in principle possible without special membrane (“window”) providing vacuum conditions in the ion guide.

As an example, some other civil applications of this technology for gas and liquid filtration are given Sections 2.4.1-3.

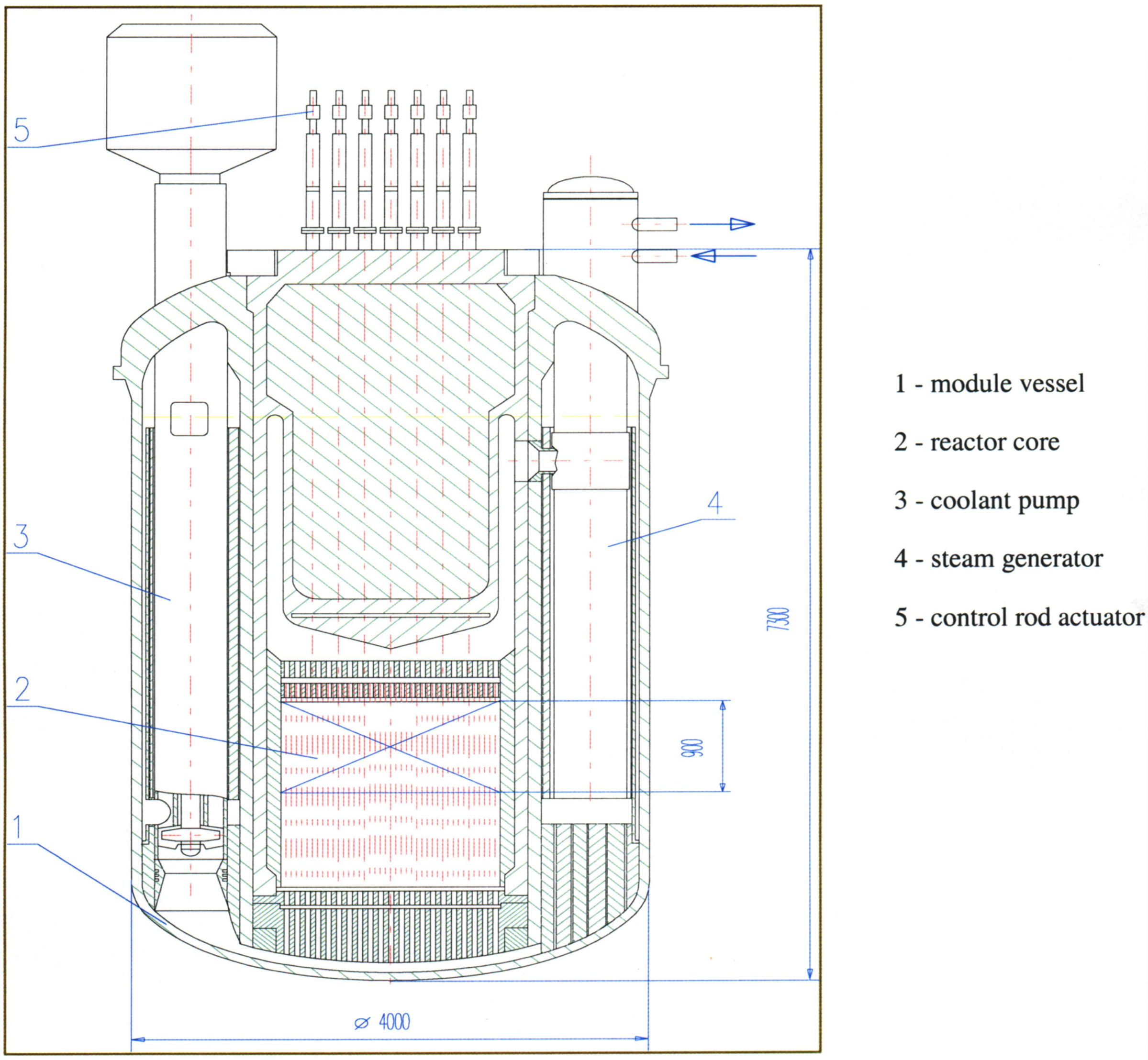


FIG. 6. Modernized reactor steam generator module.

2.4.1. Aerosol filter

There are several applications of the aerosol filter (Fig. 7) as:

- preventing radioactive aerosol release through ventilation, purification and discharge systems;
- preventing environmental pollution from chemical, metallurgical and other industries.

Advantages of the aeosol filter are given below:

- high purification efficiency, up to 99.995%
- high specific dust capacity, up to 500 gr/m^2
- improved aerodynamic and mechanical characteristics
- high thermal and chemical resistance
- operation in the conditions of high air humidity, up to 100%.

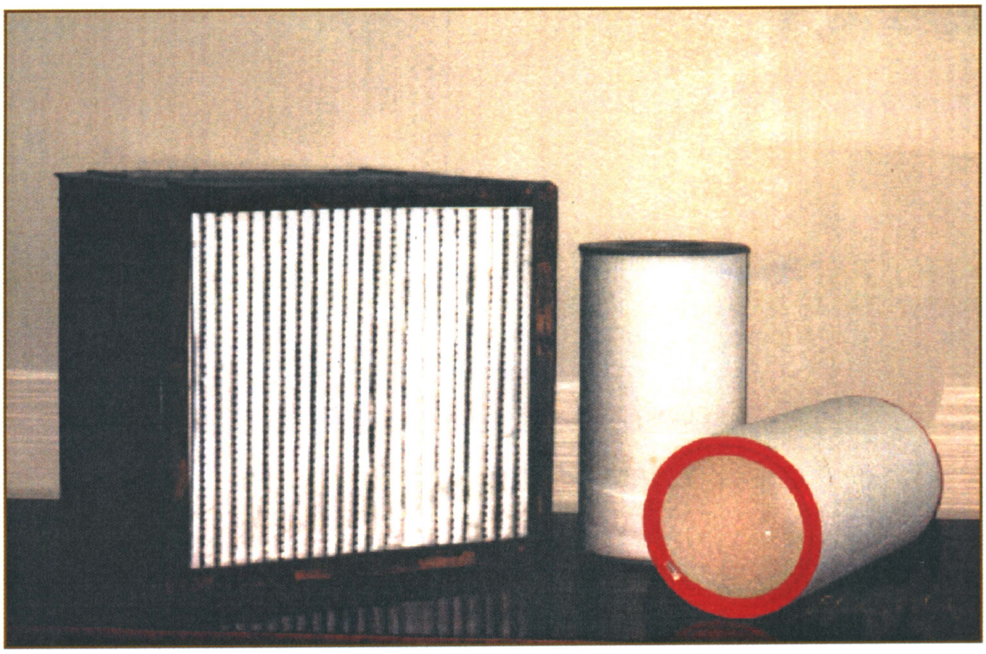


FIG. 7. Aerosol filter.

FIG. 8. Filter for process and portable water purification.

2.4.2. *Filter for process and portable water purification*

These filters (Fig. 8) are used for purification of water and other liquids from suspension impurities of ≥ 0,1 μm; achieving an efficiency of operation by using filtering element with plasmochemical filtering coating from oxides, nitrides and carbides of Ti, Zr, Al and other metals on a porous base. The advantages of these filter are high mechanical and corrosion resistance of filtering elements having capability of many-fold (>1000 times) hydrodynamic regeneration of filter without dismantling. The capacity is (5-10)10^3 liter per hour, depending on filtering elements' size and number.

2.4.3. Milk granular filter

The milk granular filter are abroad used for milk purification from mechanical impurities, having as a specific features the two stage cleaning. Several advantages as high efficiency of purification, long time of filter's structural material (more than 5 years), regeneration of filter element without dismantling, low maintenance cost, easy attendance and unlimited service life of the filter can be meet.

2.5. Reactor-pumped lasers

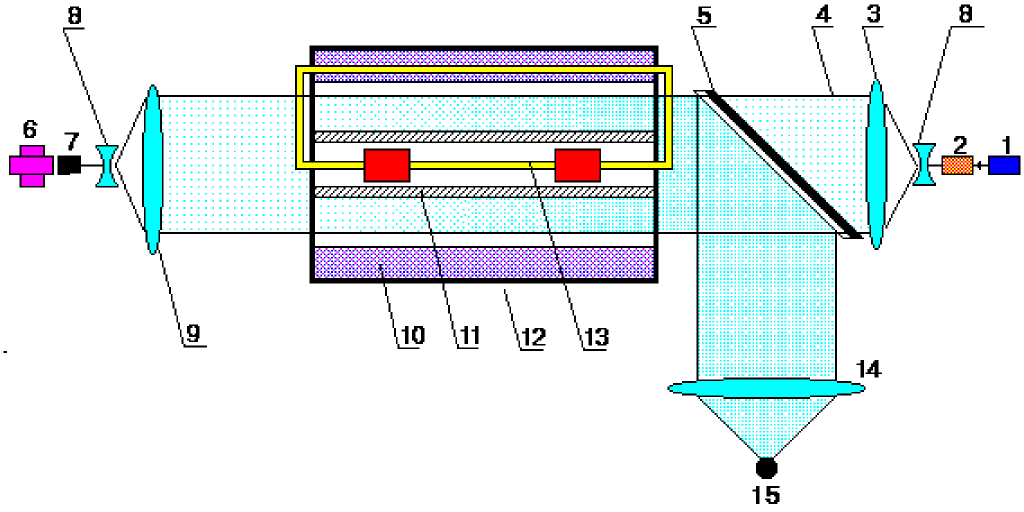
Prospects for lasers of this type are determined by unique features of the pumping source based on a chain fission reactions, namely: high energy capacity, autonomy, compact form, possibility of pumping a large active medium volume owing to a high penetration ability of neutrons in multiplication systems, etc. Practical application of these lasers could result in qualitative changes of the most important areas of human activity.

There are two recognized concepts of powerful nuclear-laser systems. The first one - quasi-stationary reactor-laser, - was proposed in fact simultaneously by Sandia Laboratories and Russian Research Institute of Experimental Physics in late 70-ies. The second concept - pulsed-periodical nuclear-laser system named "Optical Quantum Reactor-Pumped Amplifier" (OKUYAN) - was proposed in the middle of 1980s by the Institute for Physics and Power Engineering, Obninsk. The pulse reactor and laser modules are separated both functionally and spatially; "master oscillator amplifier" principle is used in optical scheme. Hopefully, the OKUYAN will make it possible to achieve power and beam quality, as well as pulse repetition unique for lasers.

In 1994, as a result of joint efforts of three institutions (IPPE, All-Russian Research Institute of Technical Physics, both of Minatom, and Institute of General Physics of Russian Academy of Sciences), a power model of OKUYAN was prepared for operation at IPPE, Obninsk. Its basic units are: an ignition reactor module in the form of pulsed fast-burst reactor "BARS-6" and thermal subcritical laser module Ar-Xe laser-active medium.

The scheme of the power model is given Figure 9.

It should be pointed out that demonstration of feasibility of unique energy characteristics of the laser beam in nuclear pumped systems has been one of the most urgent problems up to now and is a subject of further research in the field of direct conversion of nuclear energy into laser radiation.



1,2 - master oscillator system
3,8,9,14 - beam expander systems
4 - input beam
5 - polarizer
6 - conjugation cell
7 - Faraday cell
10 - neutron reflector
11 - boron coating
12 - initial burst reactor
13 - reactor's cooling system
15 - target

FIG. 9. Scheme of a power model.

The reactor-pumped laser technology has a broad application. In the science field is used in fundamental physics and fusion plasma experiments; burning plasma experiments and laser fusion energy driver. In industrial application the reactor-pumped laser technology is used for cutting and welding of thick pieces, surface hardening of wide areas, application of ceramics to metals, cutting of fiber composites, 3-D ceramic lithography and heavy oil spill removal.

However, the reactor-pumped laser technology is also used for space application mainly, extension of satellite life, orbital transfer vehicles, space debris removal and microsat launch. A scheme of a laser-initiated hybrid fission-fusion power plant is shown in Figure 10.

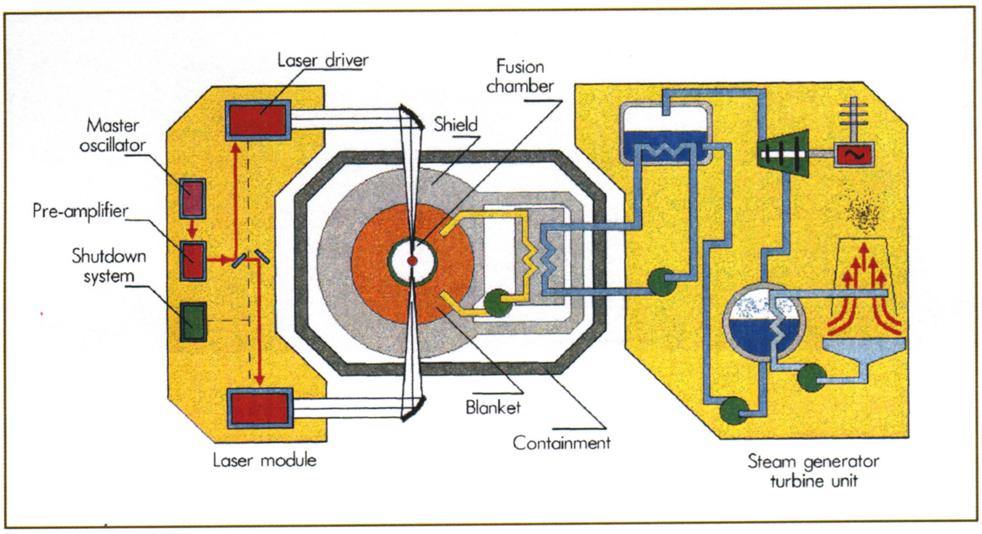


FIG. 10. Laser-initiated hybrid fission-fusion power plant.

3. CONCLUSION

The unique experience accumulated in the course of development of dual-use technologies can be applied validly to the civil needs.

It is now necessary to develop a mechanism for technology transfer process. It is also necessary to seek and find new ways to make these technologies commercially viable.

The best way to achieve these aims is a progressive development through experience and practice.

CHOOSING THE NUCLEAR POWER OPTION: FACTORS TO BE CONSIDERED

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Abstract

To plan and develop a nuclear power program, policies must be formulated and decided at different stages and at different levels by the government and its organizations, by the utility and by other organizations in industry and research and education, each within its sphere of interest and influence. The purpose of this paper is to highlight areas where policy decisions are needed, the options available, what they mean and the contexts in which they should be considered.

1. INTRODUCTION

A reliable and adequate supply of energy, and especially of electricity, is indispensable for economic development. Thus providing safe, reliable energy in economically acceptable ways is an essential political, economic and social requirement. Planning and decision making for energy and electricity supply are important for governments; it is assumed that energy policy occupies a central role in the general policy structure of governments in those developing countries, which may consider the nuclear power option.

2. ECONOMICS OF NUCLEAR POWER

In most countries with nuclear power plants, base loaded nuclear electricity competes favorably with other options, particularly coal and oil. With recent developments in many countries to introduce competition into electricity markets, the costs of fuel and of operation and maintenance for nuclear power plants must be kept lower than the corresponding costs for fossil fuelled plants to remain competitive, without jeopardizing plant safety in any way.

The potential benefits of nuclear power include a certain buffering against escalating fossil fuel prices, which helps maintain the long term stability of electricity prices. However, because of the importance of capital costs in nuclear power, the financing of a nuclear program is sensitive to inflation. Financing schemes and the related issue of supply contracts are therefore essential considerations. Three types of supply contracts have commonly been used in the past: turnkey, split package and multiple package. In recent years, two new supply mechanisms have been used for fossil fuelled power plants: build–own–operate (BOO) and build–operate–transfer (BOT).

In the overall context, there are economic benefits from a nuclear power programme going beyond the mere comparison of electricity costs between alternatives. An important consideration in many developing countries has been the positive influence of a nuclear programme on the technological sophistication of the country. On the other hand, certain additional costs are directly related to the introduction of nuclear power, such as the cost of establishing a regulatory infrastructure. It would be desirable if these costs could be distributed over a number of plants, leading to the conclusion that a nuclear programme must be large enough to enable spreading of costs to yield economies of scale.

3. NUCLEAR SAFETY AND RADIATION PROTECTION

3.1. Nuclear safety

A nuclear power plant is allowed to operate only if adequate measures to prevent accidents are in place. Nevertheless, if an accident occurs, it is necessary to be able to limit its escalation and to mitigate the consequences, particularly with regard to the release of radioactive materials, to reduce the potential exposure of the public and of plant personnel. A low probability of accidents with potentially severe consequences must be demonstrated through safety assessments, safety research, sound design, high quality construction, good operating practices and procedures, proper staff selection and training, etc. Appropriate reviews and assessments should be conducted by the regulatory body.

To provide support at the international level, the IAEA has published fundamental safety concepts as well as Codes and Safety Guides as part of its Nuclear Safety Standards (NUSS) programme. It is important that only one organization, the owner/operator, has primary responsibility for the safety of a plant. As a prerequisite for obtaining an operating license the owner/operator must accept this responsibility, which cannot be shared either with the plant designer or constructor or with the authority which regulates safety in the country.

3.1.1. Defense in depth

A publication of the International Nuclear Safety Advisory Group (INSAG) entitled *Basic Safety Principles for Nuclear Power Plants* discusses the need for a defense in depth concept centered on several levels of protection, including successive barriers to prevent the release of radioactive materials to the environment. The objectives are:

- To compensate for potential human and component failures,
- To maintain the effectiveness of the barriers by averting damage to the plant and to the barriers themselves,
- To protect the public and the environment from harm in the event that these barriers are not fully effective.

INSAG has further developed requirements for a defense in depth strategy in a more recent publication. In this strategy, accident prevention is the first priority. However, if preventive measures fail, mitigating measures, in particular a well designed confinement system, can provide additional protection for the public and the environment.

3.1.2. Quality assurance

It is important to achieve the highest levels of quality in all stages of a nuclear power project, from site selection through design, construction and commissioning to operation and decommissioning. This is indicated by the fact that quality assurance (QA) is one of the five main topics of the Codes and Safety Guides issued in the IAEA's NUSS program. Quality assurance is defined as: "all those planned and systematic actions necessary to provide adequate confidence that an item or service will satisfy given requirements for quality".

The recently revised NUSS Code and Safety Guides on QA put greater emphasis on the responsibility of everyone concerned to achieve their performance objectives.

(1) Management is responsible and accountable for all aspects of quality of performance, including planning, organization, direction, control and support

(2) The line unit is responsible and accountable for achieving quality of performance to ensure safety and reliability.

(3) The assessment unit evaluates the effectiveness of the management and line units in carrying out their responsibilities to achieve quality of performance, and identifies and ensures removal of barriers which may hinder the ability of the plant organization to function effectively in carrying out its responsibilities.

3.1.3. Safety culture

Safety culture is a concept which can be described as inculcating in all personnel a pervasive safety consciousness, a commitment to excellence and personal accountability. A safety culture should be established in all countries which operate nuclear power plants and codified in laws, regulations and standards for nuclear safety. Many IAEA Member States have already shown their commitment to this idea by consenting to be bound by the Convention on Nuclear Safety, which entered into force in October 1996.

3.2. Radiation protection

3.2.1. Health effects of radiation exposure

Ionizing radiation and radioactive substances are natural and permanent features of the environment, and low level radiation is part of our surroundings. Exposure to radiation has associated health risks. As we are always exposed to radiation, this risk can only be minimized but not entirely eliminated. Through use of nuclear reactors for power as well as research, the quantity of radioactive materials requiring control have greatly increased. Very strict radiation protection standards have been formulated and experience has shown that risks can be kept under control.

3.2.2. Radiation protection standards

Since 1929 the International Commission on Radiological Protection (ICRP) has worked on the establishment of scientific principles for radiation protection. The recommendations of the ICRP are kept under continuous review to consider all information which becomes available. The stochastic effects, i.e., the risk of cancer induction, determine the protection norms for occupational as well as public exposure. In 1990, the ICRP issued new recommendations based on the most recent re-evaluation of the doses to the atomic bomb survivors, corresponding to reductions in earlier recommended dose limits. The *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources* (BSS), issued by the IAEA in cooperation with the Food and Agriculture Organization of the United Nations (FAO), the International Labor Organization (ILO), the Organization for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA), the Pan American Health Organization (PAHO) and the World Health Organization (WHO), constitute a translation of the ICRP recommendations into practical standards of radiation protection for the public and radiation workers. The BSS have been updated several times in response to changed ICRP recommendations, most recently in 1996. The severity of these standards is indicated by the fact that the limits for additional doses to the public are below levels of background radiation found in different parts of the world.

Experience from well managed nuclear power plants shows that occupational and public exposures were kept to a fraction of the annual dose limits stipulated by safety standards .

4. NUCLEAR FUEL CYCLE

The nuclear fuel cycle consists of a number of distinct industrial activities which can be separated into two sections: the front end, comprising those steps prior to fuel irradiation in the plant; and the back end, including the activities concerning the irradiated, spent fuel.

4.1. Front end

Acquisition of its first nuclear power plant by a country involves a major degree of dependence on external suppliers, with associated commitments to non-proliferation and international cooperation. The power plant is usually provided with fuel for one to four years of operation but it must be re-supplied over its lifetime of 40 or more years. When the type of power plant is decided, the choice of the form of the fuel is made:

A desire to assure fuel supplies over the lifetime of a reactor (40 years or more) leads to considering establishing a domestic fuel supply and fuel production technology to guarantee continual operation of the plant. With the exception of enrichment, front end technologies are available for transfer, usually on commercial terms through licensing. The counter-argument to domestic front end fuel services is that at present it is hardly economic. It is normally cheaper and as reliable to use the international market for fuel supplies.

Commercial enrichment services are available to any prospective buyer with good non-proliferation standing. Services to convert uranium to chemical forms required for enrichment are also widely available and competitively priced. Thus, in all aspects of the front end of the fuel cycle, security of supply is not a serious concern.

4.2. Back end

In the back end of the fuel cycle there are three policy options for management of the spent fuel:

- Reprocessing for fabrication of mixed oxide fuels (MOX) fuel to be recycled in light water reactors (LWR),
- Storage for 30–50 years and subsequent disposal as high level waste (HLW) (the once-through cycle),
- Deferral of the decision on whether to reprocess or dispose of the spent fuel.

Reprocessing is now offered by three countries, but at least two (France and the UK) require that the resulting HLW be returned to the client country with the separated uranium and plutonium. Thus, plans must be made for domestic HLW disposal, whichever back end option is chosen. Experience has shown that international transport and storage of both plutonium and vitrified HLW can be highly problematic as they have become focal points for public and international opposition, even though a high level of safety can be ensured.

The second option of storage and final disposal of the spent fuel without reprocessing is chosen by many countries at present (e.g., Germany, Sweden and the USA) and HLW disposal technology is being developed to meet future requirements. In Canada, the decision not to reprocess fuel from its CANDU type PHWRs was taken long ago. Power plants in some countries were designed for ten years of spent fuel storage, with extra storage added later. This has sometimes been provided through lower cost dry storage facilities.

The third option, chosen by many countries, of deferring the back end decision is the cheapest as it permits deferral of decisions on HLW disposal and siting. However, it could be an easy opening for attack by those in opposition maintaining that there is an unsolved waste problem.

5. MANAGING RADIOACTIVE WASTE AND DECOMMISSIONING NUCLEAR FACILITIES

5.1. Waste management and disposal

Radioactive waste has become a focus of environmental concerns related to nuclear power. The main feature of wastes from nuclear power plants is that they occur in small quantities, and can therefore be more easily managed and disposed of. Radioactive wastes are divided into three categories:

- Low level waste (LLW) arises from nuclear plants and from applications of radioisotopes in medicine, industry and research, and must be isolated for a periods of up to about 200 years.
- Intermediate level waste (ILW) consists to a great extent of operational wastes from power plants, such as ion exchange resins, and can usually be treated and disposed of in the same general manner as LLW.
- High level waste (HLW) consists of fission products and plutonium contained in spent fuel elements and must be safely isolated from the environment for very long periods, possibly hundreds of thousands of years. HLW also generates heat, which can be significant for the first 30–50 years.

Safe waste management involves the application of technology and resources to limit the exposure of the public and workers to ionizing radiation and to protect the environment from radioactive releases, in accordance with national regulations and international standards.

Further international progress was made in this area with the adoption of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

To assist national regulatory bodies, the IAEA is revising its Safety Series publications to be issued within the Radioactive Waste Safety Standards (RADWASS) program so that the structure is equivalent to that of the NUSS programme.

In each country where radioactive materials are handled, a national waste management program must be established. It should also ensure continuing communication between the regulatory authorities, the operators and the public.

5.2. Decommissioning nuclear facilities

A nuclear power plant must be decommissioned at the end of its useful life. A useful life of 30 years is often referred to but plants are usually designed for 40 years of operation. This lifetime can be extended beyond 40 years with suitable management including control of degradation processes, maintenance, repair and refurbishing and/or replacement of plant components and systems. There are essentially two options for decommissioning a plant:

– The plant is dismantled after operation ceases and the site is restored or adapted for reuse.
– Fuel is discharged to a storage facility and non-radioactive components are dismantled but radioactive parts are mothballed for 30-50 years or longer before dismantling.

The first option has the benefit of freeing potentially valuable sites for other purposes, notably for new power plants, as early as possible. It also neutralizes continuing public concern about whether the reactor remains a threat to public health and safety.

The second option has the benefit of reducing the total radiation dose to decommissioning workers as radioactivity will have decayed substantially in the 30–50 year mothball period. This also reduces the cost of dismantling, though the saving may be offset by the cost of maintenance and surveillance during the mothballing period. Technology is available for dismantling radioactive reactors but new technology may be developed over the next 30–50 years to allow further reduction of costs and worker exposure. In both cases, some radioactive materials will have to be managed as waste as a result of dismantling. Three prerequisites must be satisfied to decommission a nuclear power plant

– Well trained personnel with appropriate technical skills,
– A licensed storage or disposal facility to accommodate decommissioning wastes,
– A regulatory basis for implementing a decommissioning project.

The IAEA has published decommissioning guidelines for research reactors and small facilities but they can, to a great extent, also apply to large facilities. There is now a need for more specific guidance on the development of decommissioning regulations. IAEA safety standards on decommissioning are therefore being developed as part of the RADWASS program.

6. ENVIRONMENTAL ASPECTS

The increasing use of energy worldwide has become a major environmental concern since energy use has environmental impacts at all levels:

– Locally, e.g., through use of primitive cooking stoves in many developing countries, smog formation in urban areas, and local flooding and resettlement as a result of new hydropower schemes;
– Regionally, through acid rain caused by emissions of sulphur dioxide and nitrogen oxides;
– Globally, through the contributions of carbon dioxide and methane to the atmosphere.

The greenhouse effect and global warming now seem to be a major subject for discussion. Emissions of sulphur dioxide and nitrogen oxides from fossil fuelled power plants can be limited by flue gas cleaning, though at a cost; carbon dioxide emissions are only limited by reducing fossil fuel use, which will influence electricity supply systems.

Regardless of international environmental goals, all countries must protect the environment in their national energy policies by reduction or at least control of emissions.

Nuclear power can contribute in this context as emissions from normal operation are very small.

7. LEGAL AND REGULATORY ASPECTS

Responsibility for development of the structures to create, regulate and maintain a nuclear power program rests with the government, national organizations and institutions. Establishment of a nuclear power program entails legal requirements at both the national and international level.

7.1. National legal requirements

Responsibility for the safety of nuclear installations and radiation protection must be defined by law, as must the responsibility of the plant operator and the regulatory authority or authorities (where radiation protection and nuclear safety regulatory bodies are separate).

7.1.1. Nuclear safety regulatory authority

The government must establish a system to develop nuclear safety regulations, issue operating licenses and perform inspections so regulations are met and standards are followed. Legislation must be enacted to create and empower a nuclear safety regulatory authority. This regulatory authority must be independent of the operator and have the legal power to:

- Formulate rules and regulations to be followed by the owner/operator;
- Issue licenses or permits for siting, construction, commissioning, operation and decommissioning of nuclear power plants;
- Supervise measures ensuring that rules and regulations are followed by owner/operators;
- Ensure that the licensee understands its obligations and is competent to fulfill them;
- Enforce laws.

The Convention on Nuclear Safety stipulates that other parties to the Convention in the vicinity of a proposed installation be given enough information to enable them to make their own assessment of the likely safety impact on their own territory.

The adequacy of regulatory authorities can be reviewed upon government request by an IAEA International Regulatory Review Team (IRRT). The Convention on Nuclear Safety foresees that signatory States will report on measures taken to maintain a high level of safety and that these reports will be discussed in periodic review meetings.

7.1.2. Radiation protection regulatory authority

A national system for radiation protection is a precondition for nuclear activities in a country. If this does not exist, the first step is for the government to enact legislation and empower a regulatory authority and establish regulations and standards for radiation protection. The regulatory authority licenses users of radioactive materials and radiation sources and ensures that regulations are followed. The Convention on Nuclear Safety addresses these issues. The adequacy of the system can be checked by an IAEA Radiation Protection Advisory Team (RAPAT) on government request.

Basic Safety Standards published by the IAEA are the only international standards available in the area of radiation safety. Therefore, many countries accept the BSS in extenso as national standards. The IAEA has a statutory right and obligation to require that the BSS be used in all projects it supports in a particular country. A number of countries have their own standards which differ from the BSS in some respects.

Within the radiation protection regime a policy should be defined for managing radiation emergencies. This is needed not only for nuclear power plants but also for accidents with radiation sources, which can have considerable local impact.

7.2. Third party liability

Liability for nuclear damage is part of the legal framework that has developed around the peaceful uses of nuclear energy. The present international liability regime is embodied primarily in two instruments: the Vienna Convention on Civil Liability for Nuclear Damage (1963) and the Paris Convention on Third Party Liability in the Field of Nuclear Energy (1960). These are linked by a Joint Protocol adopted in 1988. The Paris Convention was later extended by the 1963 Brussels Supplementary Convention. These Conventions are based on concepts of civil law and share the following main principles:

- The international liability regime applies to nuclear installations defined in the Conventions, e.g., civil, land based nuclear reactors and reprocessing and storage facilities, as well as nuclear materials transported to or from such installations.
- Liability is channeled exclusively to the operator of the nuclear installation.
- Liability of the operator is absolute, i.e., the operator is held liable irrespective of fault.
- Liability is limited in amount.
- Liability is limited in time.
- There will be no discrimination of victims on the grounds of nationality, domicile or residence.

Following several years of preparation, a diplomatic conference held at the IAEA Headquarters in September 1997 adopted a protocol to amend the Vienna Convention and a Convention on Supplementary Compensation for Nuclear Damage.

7.3. Non-proliferation regime

Since the first international transfer of nuclear fuel, equipment and technology, assurances of exclusively peaceful use have generally been a condition for supplies under bilateral agreements between a recipient and a supplier State. These agreements generally permitted verification by the authorities of the supplier State. Since the early 1960s, this verification of specific supplies has been in most cases delegated to the IAEA through its safeguards system, a function which had been foreseen in its Statute.

Subsequently, an international non-proliferation regime came into existence. The basis of this regime is the Treaty on the Non-Proliferation of Nuclear Weapons (Non-Proliferation Treaty, NPT), which entered into force in 1970. As of 7 January 1997, 184 States were parties to this Treaty. Any State (with the exception of the five proclaimed nuclear weapon States, China, France, Russia, the UK and the USA) which becomes a party to the NPT makes the commitment not to receive, manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices and to accept IAEA safeguards on all of its nuclear materials in all of its current and future peaceful nuclear activities (known as full scope or comprehensive safeguards). A conference held in 1995 reviewed the operation of the Treaty and decided on its indefinite extension.

Supplier States started to discuss in various forums (e.g. the Zangger Committee and the Nuclear Suppliers Group, NSG) common conditions for supplies during the late 1970s. States participating in the NSG have agreed that a condition for nuclear supplies will be acceptance of full scope safeguards under the terms of international agreements such as the NPT, the Treaty for the Prohibition of Nuclear Weapons in Latin America (Tlatelolco Treaty), the South Pacific Nuclear Free Zone Treaty (Rarotonga Treaty), the African Nuclear-Weapon-Free Zone Treaty (Pelindaba Treaty) or the Southeast Asia Nuclear-Weapon-Free Zone Treaty (Bangkok Treaty). Earlier, specific supplies could be obtained under a safeguards agreement which covered only the supplies in question but this is no longer possible from any of the NSG countries. In some cases a bilateral agreement between the supplier State and the purchasing country is also required.

8. FINANCING OF NUCLEAR POWER

8.1. Role of Government

The commitment of the government to a nuclear power programme, together with strong policy support, is of paramount importance in order to reduce the uncertainties and associated risks and improve the overall climate for financing. The government should prepare long term plans for nuclear power development, clearly describing the role of nuclear power in the national energy plan, as well as the associated financial and economic plans. The government should also ensure that the necessary infrastructure is developed to support the introduction of nuclear power. A regulatory system for licensing nuclear power plants must be in place.

The investment climate is improved if the government and the owner/operator achieve good records of consistent and fair dealing with lenders and investors. Only countries with acceptable credit ratings would qualify for bank loans and other credits for financing a nuclear power project. The development of sound economic policies as well as good debt management and appropriate sharing of project risks would all contribute to this end.

8.2. Key criteria

For successfully financing a nuclear power project in a developing country, it is essential for the government as well as the utility to do the following:

- Commit itself to the nuclear power programme.
- Make a thorough financial analysis together with an economic analysis for evaluating the feasibility of the project.
- Ensure that the construction programme is well planned and regulatory issues are fully addressed before construction starts in order to minimize the risk of expensive delays.
- Maintain generally acceptable credit ratings in order to obtain investments and debt financing.
- Finance as much as possible of the local cost component of the project in local currency from sources within the host country itself. The importance and complexity of this are often underestimated.

- Set electricity tariffs at a level necessary for a sound financial position.
- Build up strong management capabilities and utilize thoroughly a full range of expertise to deal with the financial complexities.

9. PUBLIC ACCEPTANCE AND PARTICIPATION IN DECISION MAKING

9.1. Public acceptance of nuclear power

Public acceptance is a very important issue for nuclear power. Attitudes vary from country to country. In some countries there is acceptance of nuclear power. In other countries, both industrialized and developing, public opinion has turned against nuclear power and this is often cited as a major obstacle to its further development. The arguments used against nuclear power focus on three issues:

- The risk of repetition of a serious reactor accident with consequences like those of the Chernobyl accident,
- The claim that the waste presents a problem that has no solution,
- The alleged close link between civilian nuclear power and nuclear weapons.

There should be no doubt that these arguments have caused fear among the public but, at the same time, it appears that very often the public has been neither well informed nor directly concerned, with side issues sometimes dominating the debate. Experience has shown that the only way to influence public opinion is through a carefully designed long term education programme based on correct, neutral information. Such a programme requires a major effort but its importance should not be underestimated.

9.2. Public participation in decision making

With industrial development, governments and parliaments became the guardians of public safety and took the decisions needed to establish new plants and carry through programmes. This led to the creation of local consultation procedures which were to be carried out before decisions could be taken on the siting of new and potentially hazardous industries. Under all circumstances it is important that there be a process of local consultation and that it be accessible and transparent.

At the local level the role of politicians in public participation has often been very useful. At this level they have more direct contact with their electorate, see the importance of local issues and can serve as a channel for information to their constituency. This has led some countries (e.g. France, Hungary and Sweden) to establish local information or safety committees which have direct insight into the safety, operation and emergency planning at a plant.

9.3. Public information and education

In many countries nuclear power is encountering strong public opposition. Gaining public acceptance will require informing and educating the public correctly and neutrally. Therefore, a carefully planned information and education strategy would need to be formulated and implemented at an early stage, on the basis of an understanding of the level of public knowledge and of the public concerns.

Local benefits will accrue from the introduction of a large industrial plant and are likely to increase local support for such a project. Benefits may include added employment opportunities, improved education possibilities and greater local commerce.

10. NATIONAL POLICIES OF IMPORTANCE TO NUCLEAR POWER DEVELOPMENT

National governments will probably have laid down policies in such sectors as national development (including goals and priorities), energy development (including supply) and international relations. These policies would be of a long term nature and where they are the result of consensus they would not be expected to change with political changes in the country..

10.1. National energy policy

A country considering a nuclear power programme would have a national energy plan specifying the objectives for the national energy policy. The objectives include:

- Improved energy independence
- Development of indigenous energy resources
- Economic optimization of energy and electricity supply
- Stability of electric grid system
- Availability of energy at prices which support general development
- Environmental protection
- Opening of competition in electricity market.

Some of the above objectives are, of course, overlapping and may yield the same energy policy. Some of the policy options could preclude the use of nuclear power in a country. For example, if a primary objective is to use indigenous energy sources this would not favour the introduction of nuclear power plants. It would be necessary for a nuclear power programme to have a well defined role within the overall energy policy.

10.2. National development policy

Most countries have a national development plan, which is periodically updated. This plan sets priorities for development and targets for production, education and achievements in various sectors. It provides an important background for the development of electricity generation plans and for any nuclear power programme as it will also give priorities for investments.

10.2.1. Level of national participation

Each country will decide on the level and extent of national participation desired at each stage in its nuclear power programme. However, it must be emphasized that there is a minimum level necessary. First, the future owner organization must be well informed and the regulatory authority must know what its responsibilities will be. This means that there must exist a group of well qualified and trained staff with experience, which they will have acquired most often from abroad. Secondly, a country must be able to accept the responsibility to reach the minimum level of national participation to achieve an acceptable and assured level of safety as well as to make nuclear power a viable energy option. The desirable level of participation must be seen against the existing infrastructures in the country and the levels to which it is possible and appropriate to develop these. In this context infrastructures have been defined as: organizational and regulatory frameworks; qualified personnel, and education and training capabilities for acquiring such personnel; financial capabilities; industrial capabilities; and R&D capabilities.

A more common approach has been that the first plant is ordered under a turnkey contract and steady progress is then made with subsequent plant orders towards split package and multiple package contracts, each step placing increasing demands on the domestic infrastructures.

10.2.2. Development of human resources

The technological, safety and reliability requirements of a nuclear power programme dictate the careful selection and recruitment of highly qualified and competent personnel by plant owners as well as by regulatory organizations. This can prove to be a national asset and also give an impetus for raising the level of national technical education and training capabilities, which will be beneficial for other industries.

10.3. Regional policy

Policy concerning relations with neighbouring countries within a region is increasing in importance, as shown by the number of regional associations and alliances being formed for various purposes. This applies also in the case of nuclear power programmes as there are many areas, including the following, in which regional co-operation could yield direct benefits:

- Electric grid integration
- Nuclear safety
- Environmental protection
- Sharing of plant services
- General R&D and human resources development
- Nuclear fuel cycle
- Non-proliferation assurances.

It is not necessary that all parties to a regional co-operation agreement share an interest in nuclear power and its development. For example, while Sweden and Finland have important nuclear power programmes, Denmark is opposed to nuclear power. This has not prevented good and rewarding co-operation on nuclear safety matters.

11. CONCLUSION

Several areas have been highlighted in the above discussion, where policy decisions are needed and available options along with their implications need to be considered prior to establishing a nuclear power programme. The IAEA could provide technical assistance and expert services to requesting member states in planning and implementing their nuclear power programmes.

STATUS AND PROSPECTS FOR SMALL AND MEDIUM SIZED REACTORS

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Abstract

Member States have evinced interest in the continued development of small and medium sized reactors (SMRs) as an energy source for the future. Support for this programme was recently reaffirmed at the IAEA 1997 General Conference. Although the generation of electricity is the predominant focus of existing SMRs, there is increasing interest in using these plants for desalination, district heating and high temperature industrial process heat applications. Here is a review of SMR development within selected Member States, an overview of the IAEA's SMR programme and a discussion of selected SMR designs with emphasis on safety attributes.

1. INTRODUCTION

For the past two decades, a major focus for nuclear power was the design and construction of generating plants of continually increasing size. This suited many industrialized countries which could readily increase their electrical grids in 1000 MW(e) increments. However, many developing countries are developing their energy infrastructure to improve the standard of living for their citizens. Often, the size of the electrical grids servicing these countries is incapable of accepting the additional capacity of a large plant, so nuclear power has not been a viable option. Also, there is emerging interest in nuclear power for co-generation of electricity and heat for industrial processes, such as desalination of seawater or district heating.

2. CHARACTERISTICS OF ENERGY USE

About 33% of total primary energy is used worldwide to produce electricity. Most of the remaining amount is either used for transportation or converted into hot water, steam and heat. Nuclear energy now produces about 16% of the world's electricity. This includes 437 nuclear reactors, with a total capacity of 352 gigawatts-electric (GW(e)). Yet, only a few of these plants are being used to supply hot water and steam. The total capacity of these plants is about 5 GW thermal (th), and they operate in just a few countries, mostly in Canada, China, Kazakhstan, Russian Federation, Slovak Republic, Switzerland and Ukraine.

Specific temperature requirements vary greatly for heat applications (Fig. 1). They range from about room temperature, for use as hot water and steam for agro-industry, district heating, and seawater desalination, to up to 1000°C for process steam and heat for the chemical industry and high-pressure injection steam for enhanced oil recovery, oil shale and oil sand processing, oil refinery processes and refinement of coal and lignite. Water splitting for the production of hydrogen is at the upper end. Up to about 550°C, heat can be supplied by steam; above that, requirements must be served directly by process heat, since

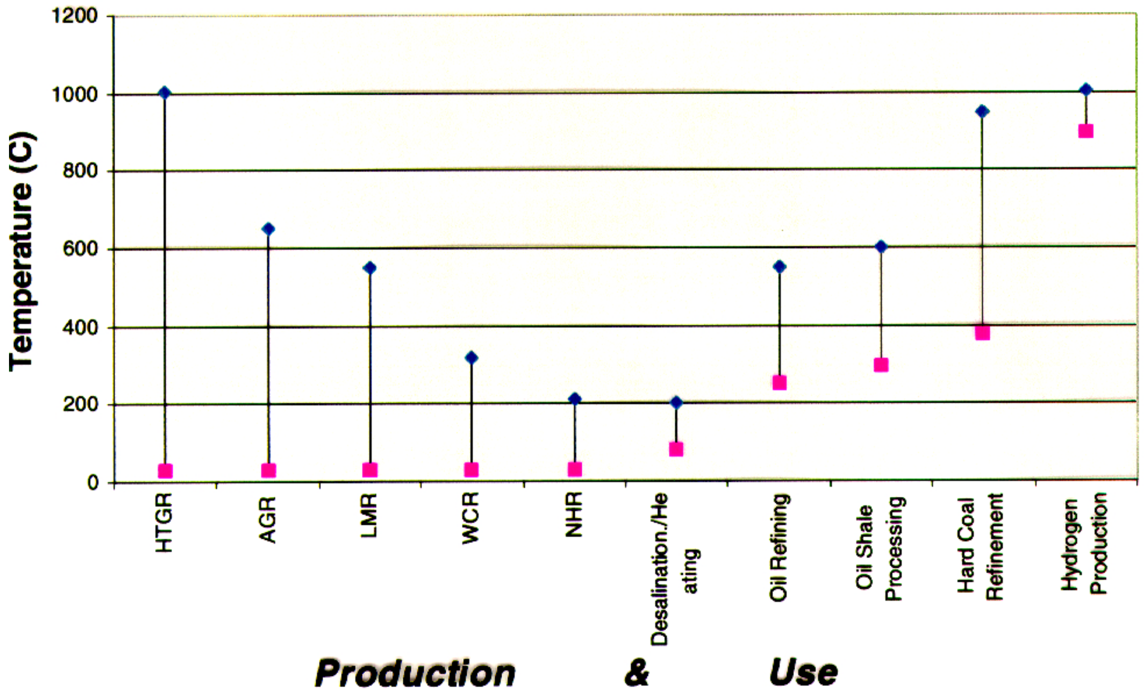

FIG. 1. Production and use of heat.

steam pressures become too high above 550°. An upper limit of 1000° for nuclear-supplied process heat is set based the long-term strength capabilities of metallic reactor materials.

Water cooled reactors offer heat up to 300°C. These include pressurized water reactors (PWRs), boiling water reactors (BWRs), pressurized heavy water reactors (PHWRs) and light water cooled, graphite-moderated reactors (LWGRs). Liquid-metal cooled fast reactors (LMFRs) produce heat up to 540°C. Gas cooled reactors reach even higher temperatures, about 650°C for the advanced gas cooled, graphite-moderated reactor (AGR), and 950°C for the high temperature gas cooled, graphite-moderated reactor (HTGR).

The primary conversion in a nuclear reactor is from nuclear energy into heat. This can be used in a "dedicated" mode for direct heating, while no electricity is produced.

Another mode is co-generation of heat and electricity. Parallel co-generation is achieved by extracting some of the steam from the secondary side of the steam generator, before entering the turbine. Series co-generation is achieved by extracting steam at some point during its expansion in the turbine, when it is the right temperature for the intended application. During this cycle, the extracted steam has also been used for electricity production. Series co-generation is ideally suited to industrial processes related to district heating, desalination and agriculture.

More than 80% of the world's energy use is from fossil sources, namely coal, oil and gas. Burning these fuels causes serious environmental problems from emissions of sulphur oxides, nitrogen oxides and carbon dioxide into the atmosphere.

One approach to contribute to solving these problems is to use nuclear energy in integrated energy systems. A typical example for the future is application of nuclear heat to reform natural gas. Using what is known as the HTGR-reforming process, synthesis gas, methanol, hydrogen, heat and electricity are produced from natural gas and uranium. In the process, natural gas is decomposed mainly into hydrogen and carbon monoxide with the main products methanol, a liquid carbohydron, and hydrogen; side products are heat and electricity.

Another example of integration is in the oil industry. Several studies have been made on the use of nuclear power as a heat source for heavy oil exploitation. They show that under favorable oil market conditions, the nuclear option benefits economics and the environment, compared to conventional methods.

A third example is integration of coal and nuclear energy in the steel industry. Technologically, this is the most ambitious integration, involving gasification of hard coal heated by hot helium from an HTGR. The intermediate products are synthesis gas and coke, used for iron ore reduction. The final products are methanol and pig iron [1].

3. REACTOR SIZE RANGES

It is the usual practice to take the upper limit of the SMR range as approximately half the power of the largest reactors in operation. Accordingly, reactors up to about 700 MW(e) are currently considered SMRs. Reactors up to 300 MW(e), or a thermal equivalent of up to about 1000 MW(e), correspond to the small size range. Sometimes the power range of up to 150 MW(e) is designated as the "very small" size range.

The above ranges expressed in power levels (MW(e) or MW(th)), are interpreted as orders of magnitude and not as precise numbers. Note that the large variety of reactors with different characteristics included in each of these ranges, are intended to respond to different requirements and uses, which need to be considered to facilitate assessment of the potential market [2].

4. PROGRAMMES FOR SMR DEVELOPMENT IN MEMBER STATES

Nuclear energy supplies a significant portion of the world electricity demand. Supply of heat produced in nuclear reactors is used in several parts of the world for district heating, process heat application, and seawater desalination. It should be noted that over 50% of the world energy demand is for either hot water or steam production. Such processes could be more efficient and clean utilizing nuclear energy. In spite of the slow down or stoppage of nuclear programmes in some Member States in the last decade, utilization of nuclear power is picking up momentum in others.

Several Asian countries strongly believe nuclear power will be a principle energy source in the future. Small and medium reactors have a major role in this regard. The People's Republic of China has a well developed nuclear capability having designed, constructed and operated reactors. These are SMRs and the skills needed to implement them are the same as those needed for larger power plants. There is special interest in district heating reactors to help ease the enormous logistical problems of distributing 11 billion tons of coal around the country each year. In the SMR range, a 300 MW(e) PWR is in operation and two 600 MW(e) PWR reactors are under construction. Longer term plans call for development of a 600 MW(e) passive PWR system. A 5 MW(th) integrated water cooled reactor was built and operated for several winter seasons for district heating. A 200 MW(th) demonstration heating reactor project has begun. A 10 MW(th) high temperature gas cooled reactor is under construction for process heat application. The test Module HTR is been constructed at INET and is expected to go critical by 1999. The system is used to accumulate experience in plant design, construction, and operation. Several applications, such as electricity generation, steam and district heat generation are planned for the first phase; a process heat application, "methane forming", is planned for the second. China is also constructing a 300 MW(e) PWR in Pakistan.

India has some early reactors of the CANDU type developed by Canada, but has adopted a policy target of self reliance in nuclear power based on heavy water moderated reactors. Four units of the 220 MW(e) PHWR type are under construction, and the first two units of a scaled up 500 MW(e) type, planned. The main objective is maximize economical use of uranium resources in the first phase of the Indian nuclear power programme; in the second phase of the Indian nuclear power programme, the plan is for fast breeder reactors fueled by plutonium generated in phase one. India also has large reserves of thorium exceeding their uranium reserves. The heavy water reactor with good neutron economics is well suited to the thorium/U233 cycle and a programme of R&D has been initiated for phase three, aimed at using the U-233/Th cycle in an advanced heavy water reactor,.

Japan has a high population density and a shortage of suitable sites for nuclear reactors due to the large fraction of the landmass existing as mountainous terrain. This has led to a preference for large reactors on the available sites to maximize power output. In spite of this, there is a very strong and diverse programme of reactor development supported both by the big industrial companies, by the national laboratory and by the universities. Three large industrial companies developed their own LWR designs in the SMR range and the Japan Atomic Energy Research Institute (JAERI) has several innovative designs. The MONJU fast breeder reactor (280 MW(e)), a prototype plant, is currently undergoing safety review as a follow up of an incident in 1995. Several different designs are currently underway in the SMR range; namely SPWR, MRX, MS 300/600, HSBWR, MDP, 4S and RAPID. SPWR and the marine reactor MRX are integrated PWRs. The MS series are simplified PWRs. HSBWR is a simplified BWR. MDP, 4S and RAPID are small sodium cooled fast reactors. Preliminary investigations show a high level of safety, operability and maintenance. The economics of these systems are promising. These systems are expected to be part of Japan's next generation reactors.

Japan also has a development programme for the gas cooled reactor in the small and medium size range. A High Temperature Engineering Test Reactor (HTTR) has been under construction since 1991 at Oarai. The 30 MW(th) reactor will be the first of its kind to be connected to a high temperature process heat utilization system with an outlet temperature of 850 C. The system will be a test and irradiation facility and also utilized to establish the basic technology for advanced HTGR for nuclear process heat applications. The system is expected to go critical in 1998. However, the main trend in power generation is still pursuit of larger (1000-1300 MW(e)) evolutionary light water reactors. The guidelines of the programme put user-friendliness, improvement in operability, and flexibility of core design as prime design objectives.

The Republic of Korea has twelve nuclear power plants (10 PWRs, 2 PHWRs) in operation and has an ambitious programme for the further deployment of nuclear power. The country is not well blessed with indigenous sources of fossil fuel and relies on imports. Furthermore, 80% of the countryside is mountainous encouraging the installation of large stations to optimize use of the available sites. Most of the existing plants are of the PWR type, but, since 1983, PHWRs have been added to the grid. Four large size PWRs (1000 MW(e) each) and two medium size PHWRs (700 MW(e)) are under construction. Large size PWRs are expected to form the main component of nuclear power installation in Korea until well into the next century. The optimal combination of PWRs and PHWRs will help maximize the use of uranium resources through the future utilization of spent fuel. This choice has been the first phase of a strategy of reactor development in Korea.

The mid size PHWR would be part of the Korean power source, but the standard nuclear power plant, KSNP, with 1000 MW(e) rating, is expected to form the main stream of power generation in Korea. On the basis of PWR technology, an advanced integral reactor (SMART: System Integrated Modular Advanced Reactor) is being developed. The power output of the reactor will be in the SMR range and will be used for desalination and power generation. It is expected that export of nuclear technology will form part of Korean trade. Streamlining of standardization, modularization, prefabrication, and substantial reduction in construction schedules of small and medium size reactors will make Korea a potential nuclear power exporter in the 21st century.

In the Russian Federation there is substantial experience from the development, design, construction and operation of several reactors in the small and medium size category. These reactors are used for electricity, heat production and ship propulsion. Reactors used for icebreakers are planned to be made available for other applications not only within the Russian Federation, but also in other countries interested in their application for electricity generation in remote locations or for non-electric application.

Currently a project is being implemented consisting of two reactors (KLT-40) mounted on a barge. These reactors used earlier for propulsion of icebreakers, are supposed to provide electricity to Perek in Northern Siberia. Barge mounted reactors may be a near term solution for other countries needing energy but presently without infrastructure for the introduction of large plants. Barge mounted reactors could be operated under the supervision of the vendor and be returned to the vendor's location for maintenance and refueling. Besides KLT-40 (up to about 160 MW(th)h) there are other small sized reactors under design for mounting on barges including the NIKA 75 (75 MW(th)), UNITHERM (15 MW(th)) and RUTA-TE (70 M(th)).

The CAREM-25 reactor is under development in Argentina by the Atomic Energy Commission (CNEA), which has subcontracted the design and development of the reactor to INVAP. The design and development of the fuel elements is carried out by CNEA.

The power level of CAREM is 100 MW(th) , approximately 25 MW(e). The intended use of the reactor is electricity generation, industrial steam production, seawater desalting or district heating. The reactor is also intended to bridge the gap between a research reactor and a larger nuclear power plant, by serving as a focal project for infrastructure development and the transfer of technology. This will facilitate launching of a nuclear power programme in a country without previous nuclear power experience. The main features of the reactor are light water cooling by natural circulation, low enriched uranium fuel, integrated and self pressurized primary system, and passive heat removal system. The achievement of high levels of safety, simplicity and reliability are the main design criteria.

The basic design of CAREM-25 has been completed. The detailed design of the reactor is underway, and there is a comprehensive research and development effort. This consists of relevant studies and testing rigs and installations, such as a critical facility, natural convection loop, full scale hydraulic control rod drives, protection system simulator, etc. A preliminary safety analysis report has been completed and presented to the national Regulatory Authority. The first project is intended for construction in Argentina.

5. SMR ACTIVITIES OF THE IAEA

The IAEA, has a dedicated SMR project. The Division of Nuclear Power is coordinating this activity and its basic objective is to provide the venue for the international exchange of information on development of technology and designs of SMRs, to enhance their performance, safety and economics.

This project includes development of an educational simulator operating on a personal computer and simulating the responses of a number of reactor types to operating and accident conditions. The purpose of this simulator is to provide students and young engineers, particularly from developing countries, with a visual aid to compare the operational characteristics of different reactor types. This simulator is not meant to be a detailed operator training tool nor is to be used in licensing. This computer simulator is being expanded, but presently includes a number of light and heavy water power reactor types in the SMR range. A series of technical committee meetings/workshops and expert missions are underway to provide input to Member States on this simulator.

The IAEA is also coordinating development of a users guide aimed specifically at the introduction of SMRs, in developing countries. A document containing guidance for the preparation of users requirements by developing countries, is soon to be published. This work is being closely coordinated with the IAEA's nuclear power desalination programmeme due to the significant co-generation potential for these plants.

Corresponding operating costs and the technical infrastructure required to support the programme are of significant concern to a Member State initiating an SMR project. In this regard, Advisory Group and Consultancy meetings are ongoing to collect SMR operating experiences, including O&M costs and to secure information on staffing requirements from existing SMRs and from vendors to guide members on numbers, disciplines and qualifications of staff required.

Member States are giving greater attention to the need for the IAEA to place priority and to strengthen SMR activities. An example of this increased interest was the incorporation of the SMR programme in General Resolution GC(41)RES/14 of the 1997 General Conference, which coupled application of SMRs with the desalination of water. The SMR programme is being closely coordinated with the IAEA's desalination programme. It is also evaluating the possibilities of a broader choice of nuclear power options to meet the needs and applications of individual Member States. Included in this evaluation are power reactors originally designed for ship propulsion, for possible co-generation of electricity generation and desalination; the introduction of reactors which can be periodically returned to the vendor for off-site refueling, to control non-proliferation of nuclear materials; and the development of small gas cooled reactors coupled directly to gas turbines. Also under consideration is the development of a comprehensive report on the status and emerging prospects for the international development and application of SMRs.

6. CONCLUSIONS

The IAEA has witnessed renewal of interest by Member States in the development of SMRs. This is particularly evident in the developing countries where large power plants are not a viable consideration due to the size of the existing electrical grid. This interest was strongly expressed in the 1997 IAEA General Conference and subsequently reaffirmed at the March 1998 Board of Governors meeting.

Many Member States have active programs associated with nuclear power development in the SMR size range. These programmes involve a wide variety of reactor designs and include plants whose status ranges from being in long term operation to undergoing initial conceptual design. The majority of these plants are intended for the production of electricity.

Although nuclear power seems to be focused predominantly on the generation of electricity, the wide range of plant types provides the possibility for nuclear power as an energy source for other applications such as desalination, district heating, and industrial processes such as hydrogen production through the reforming of methane.

The IAEA has an extensive programme to help support Member States in their national SMR efforts. This programme has, as its basic objective, the requirement to provide a venue for international exchange of information on the development of technology and designs of SMRs in order to enhance their performance, safety and economics.

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Annex 1

EXAMPLES OF SMR DESIGNS

AP-600

The Westinghouse Advanced Passive PWR AP-600 is a 600 MW(e) design conservatively based on proven technology, but with an emphasis on passive safety features. It was designed by Westinghouse under sponsorship of the US Department of Energy (DOE) and the Electric Power Research Institute (EPRI). The design team includes a number of US and foreign companies and organizations. The AP-600 passive safety-related systems include the passive core cooling system (PXS), the passive containment cooling system (PCS), and the main control room habitability system (VES).

The passive core cooling system (PXS) (Fig. 2) protects the plant against reactor coolant system (RCS) breaks, providing the safety functions of core residual heat removal, safety injection, and depressurization.

The PXS uses three passive sources of water for safety injection: the core makeup tanks (CMTs), the accumulators, and the in-containment refueling water storage tank (IRWST). These injection sources are directly connected to nozzles on the reactor vessel. Long-term injection water is provided by gravity from the IRWST, which is normally isolated from the RCS by check valves.

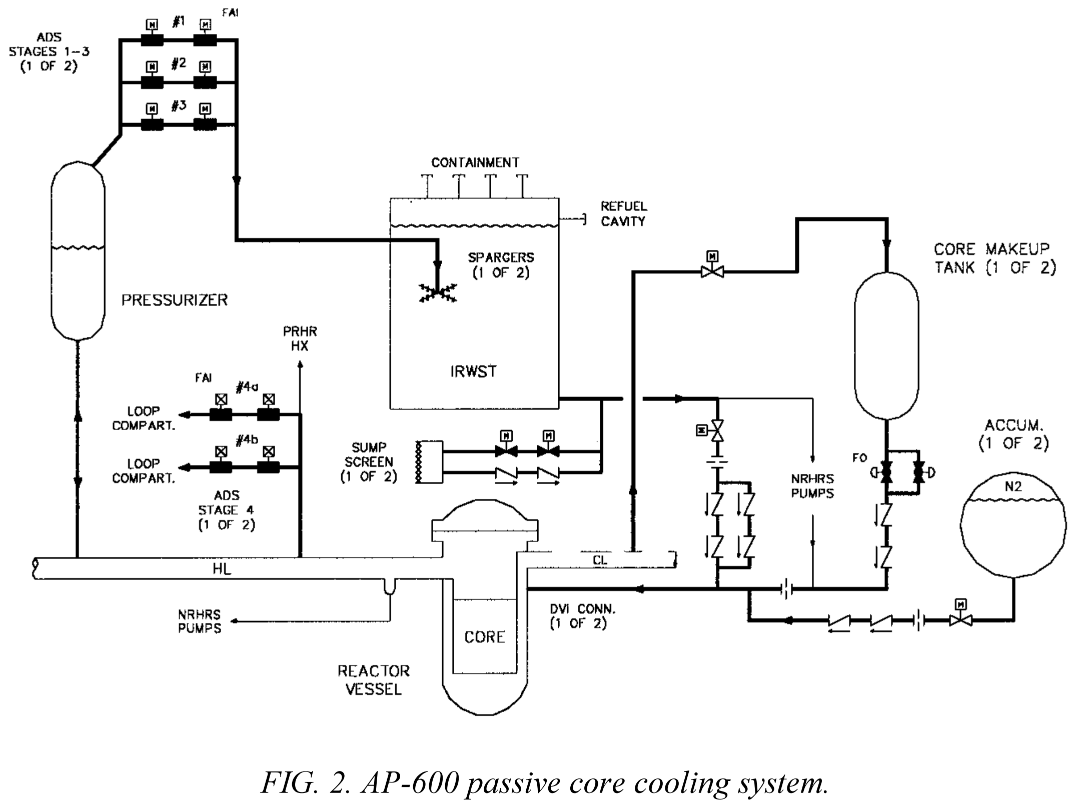

FIG. 2. AP-600 passive core cooling system.

The PXS includes a 100% capacity passive residual heat removal heat exchanger (PRHR HX), (Fig. 3) which is connected through inlet and outlet lines to one RCS loop. The IRWST provides the heat sink for the PRHR HX. Once boiling starts in the IRWST, steam passes to the containment. This steam condenses on the steel containment vessel and after collection, drains by gravity back into the IRWST. The PRHR HX and the passive containment cooling system provide indefinite decay heat removal capability.

The passive containment cooling system (PCS), shown in Figure 4, provides the ultimate heat sink for the plant. The steel containment vessel provides the heat transfer surface that removes heat from inside the containment and rejects it to the atmosphere. Heat is removed from the outer surface of the containment vessel by natural circulation of air. During an accident, air cooling is supplemented by evaporation of water which drains by gravity from a tank located on top of the containment shield building.

To contain core damage, the AP-600 design provides the operators the ability to drain the in-containment refueling water storage tank (IRWST) water into the reactor cavity, in the event that the core has uncovered and is melting. The objective is to prevent reactor vessel failure and relocation of the molten core debris into the containment.

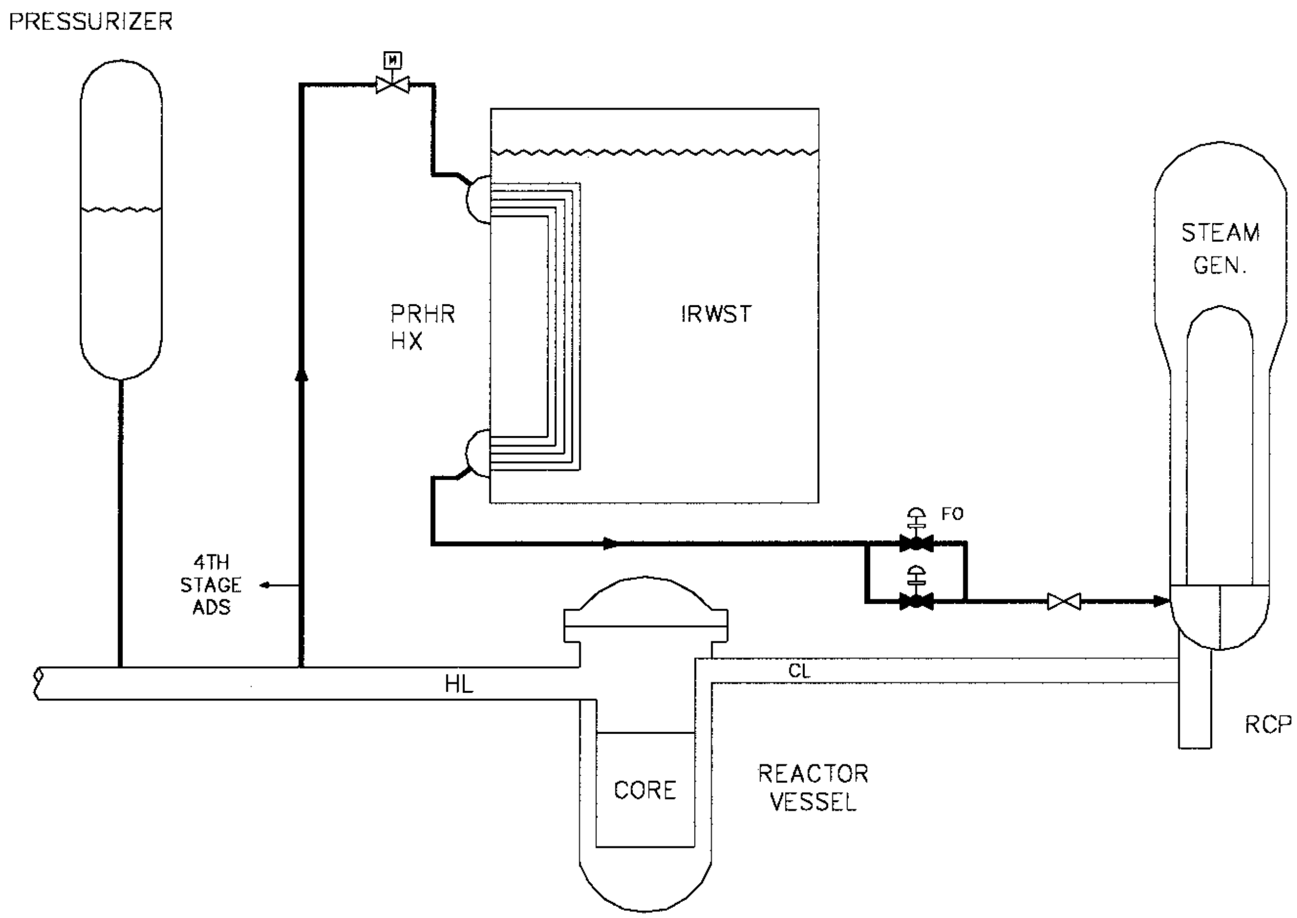

FIG. 3. AP-600 Passive residual heat removal system.

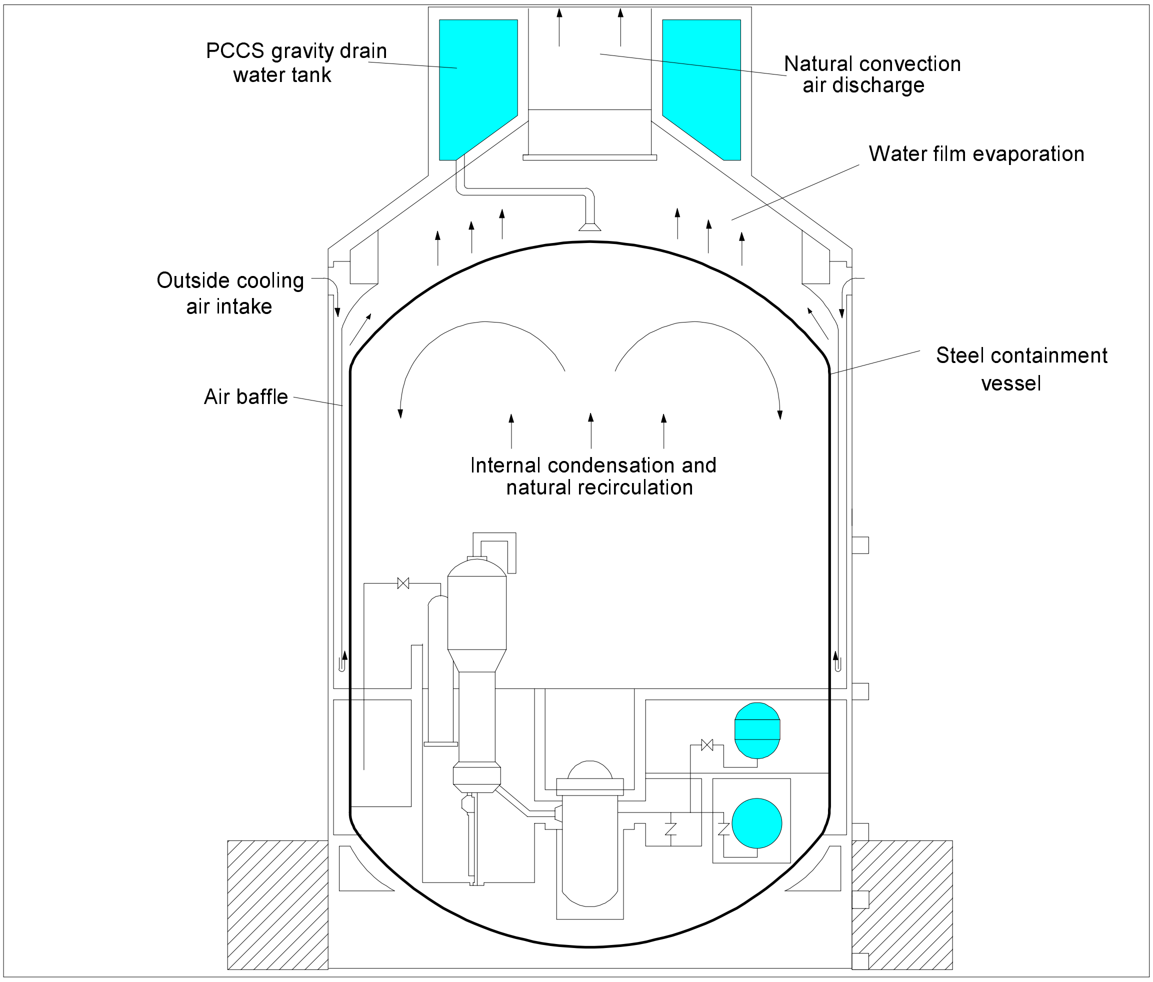

FIG. 4. AP-600 Passive containment cooling system.

WWER-640

The organizations involved in the design of the WWER-640 (V-407), shown in Figure 5, are: OKB "Gidropress", the Russian National Research Centre "Kurchatov Institute" and LIAEP.

The WWER emergency core cooling system (ECCS) includes the following automatic subsystems:

- subsystem of hydrotanks with nitrogen under pressure,
- subsystem of hydrotanks under atmospheric pressure,
- subsystem of deliberate emergency depressurization.

The passive emergency core cooling system provides long-term residual heat removal in LOCA accidents accompanied by a station blackout. In the first stage, the nitrogen-pressurised hydrotanks will be actuated. When these are empty, the tanks holding cooling water under atmospheric pressure begin to operate. Active elements of the system needed for the function of emergency heat removal are provided with electric power from storage batteries.

The design basis for the passive residual heat removal system (PHRS) is also for a station blackout situation, including loss of emergency power. The PHRS consists of four independent trains, each comprising: a steam water heat exchanger, piping for steam supply and condensate return, and battery-operated valves. The heat exchangers are installed in a tank of demineralized water. They are connected to the secondary side of the steam generators in such a way that the steam from the steam generator will flow to the heat exchanger where it condenses, transferring its heat to the water. The condensate will flow back to the steam generator. Coolant motion occurs by natural circulation.

The system for passive heat removal from the containment includes coolers, storage tanks of cooling water and connecting pipelines. Steam released to the containment condenses on the heat exchange surface of the cooler giving heat to the water of a storage tank via natural circulation.

Construction of a first pilot plant at the Sosnovy Bor site, the Leningrad nuclear power station site, outside St. Petersburg is under consideration.

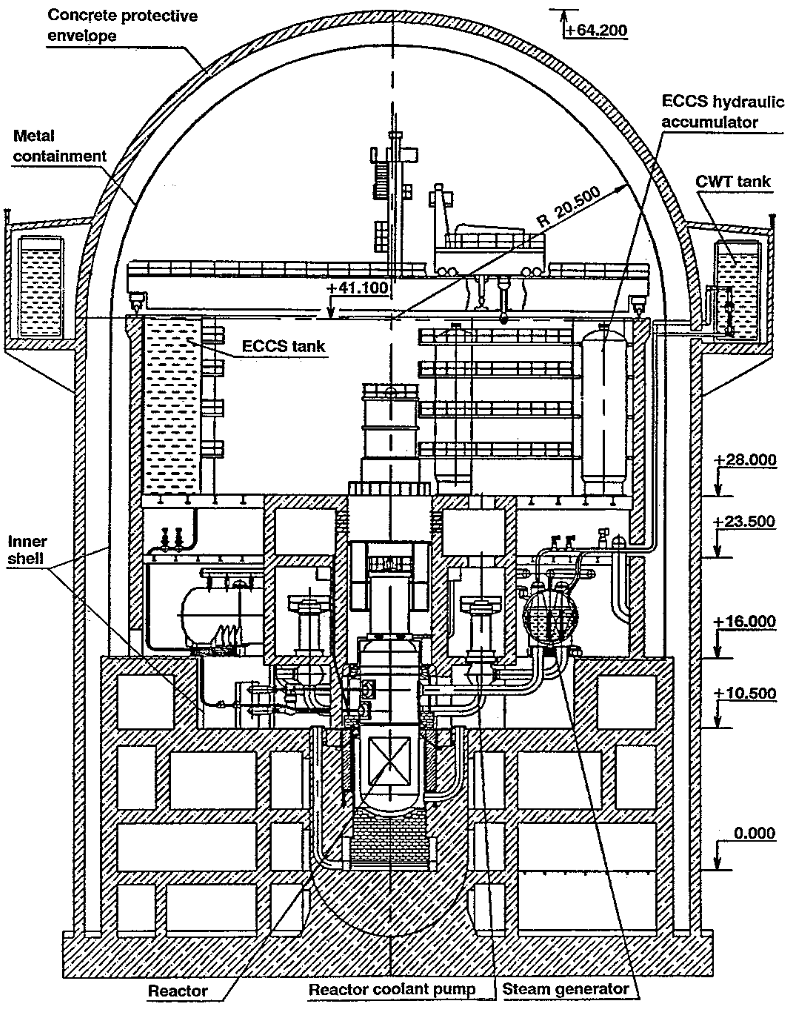

FIG. 5. WWER-640 reactor building.

Indian AHWR

A 220 MW(e) Advanced Heavy Water Reactor (AHWR) is being developed at the Bhabha Atomic Research Centre in India. The AHWR (Fig. 6) utilizes a heavy water moderator and light water coolant with a fuel cycle based on thorium, and a safety approach based on passive safety systems.

Boiling light water in vertical tubes in the reactor core permits heat removal through natural circulation so primary circuit pumps are unnecessary. The required flow rate is achieved by locating the steam drums about 32 m above the center of the core. An experimental programme is underway to confirm the analysis leading to the loop height and to study the thermal-hydraulic stability of the primary heat transport system (PHT).

The top of the primary containment shell contains the Gravity-Driven Water Pool (GDWP). The inventory in the GDWP is sufficient to cool the reactor for three days following an accident. The GDWP inventory is connected to the core through a series of rupture discs and does not involve the use of external power, moving parts or instrumentation.

Isolation Condensers (IC) positioned in the GDWP will transfer decay heat to the GDWP during short, planned reactor shutdowns or following a reactor trip. This is achieved by diversion of the steam flow between the steam drums and the turbine to the IC condensers. Another set of condensers in the GDWP will cool the primary containment following a Loss of Coolant Accident (LOCA). Simple experiments have demonstrated the feasibility of the passive containment cooling system and more detailed experiments are in progress.

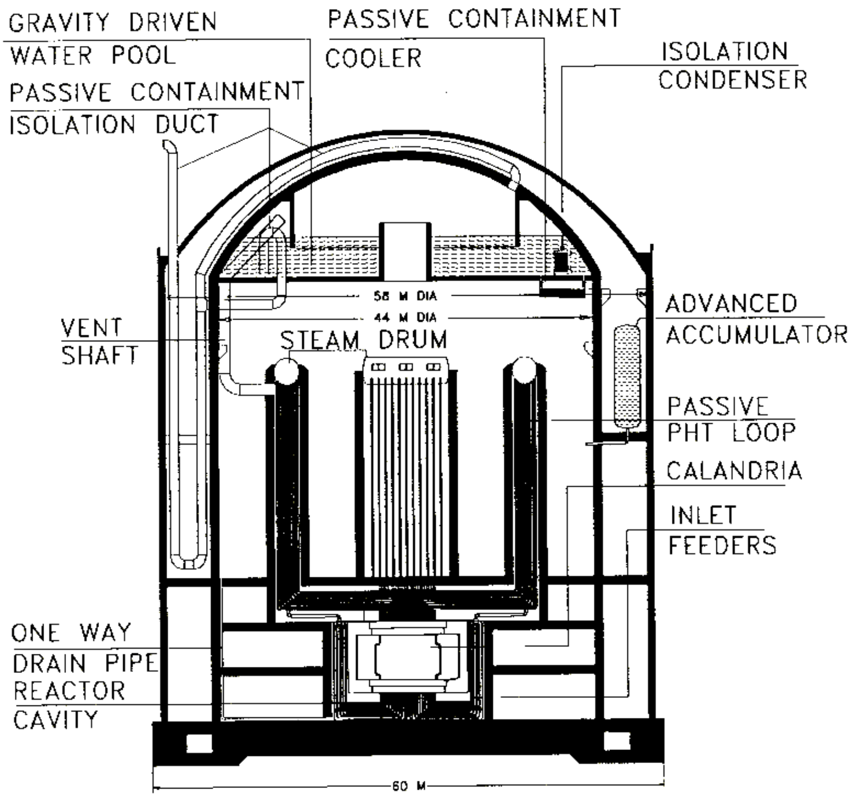

FIG. 6. Advanced HWR.

Emergency core cooling is provided by accumulators pressurized with nitrogen, with separation from the PHT system achieved with discs that rupture when post LOCA depressurization of the PHT reaches a pre-set level.

Passive containment isolation following a LOCA is achieved by U-bends in the reactor building air supply and exhaust ducts. In the event of a LOCA, pressure acts on the GDWP inventory and pours water, by establishment of a siphon, into the ventilation duct U-bends, thus providing seals. Experiments have confirmed the effectiveness of this innovation.

South African PBMR

Eskom, the state electric utility of South Africa, initiated a detailed economic and technical evaluation of the Pebble Bed Modular Reactor (PBMR) as a potential candidate for additions to its electric generation system. The requirements set by Eskom for the installation of new generation capacity include a capital and operation cost matching (or improving upon) that being achieved by their large coal stations. This currently represents a retail power cost to the customer of approximately two US cents per KWh. Other requirements for the plant include availability approaching 90%, location and plant size to match the load, public acceptance and environmental cleanliness.

High temperature gas cooled reactors (HTGRs) feature a high degree of safety through passive safety features. All HTGRs incorporate ceramic coated fuel capable of handling temperatures exceeding 1600°C with core helium outlet temperatures approaching 950°C under normal operating conditions. Consequently, the primary focus for this reactor type is to investigate the generation of electricity via direct coupling of a gas turbine to the HTGR (resulting in a net plant efficiency approaching 47%), and to evaluate the application of this high temperature primary coolant for industrial applications such as steam and CO_2-reforming of methane for the production of hydrogen and synthesis to other fuels such as methanol.

The conceptual design of the South African PBMR features a helium cooled pebble bed reactor with a power output of 103 MW(e)(228MW(th)) coupled to a closed cycle gas turbine power conversion system consisting of two turbo-compressors, a turbo-generator, a recuperator, precooler and an intercooler all located within three steel pressure vessels. The three turbomachines are equipped with magnetic bearings and the recuperator has a fin-plate design for compactness. The net efficiency of this Brayton cycle system is expected to be ~45% based on a reactor outlet helium temperature of 900°C and a maximum system pressure of 70 bars (Figure 7).

The PBMR reactor basically builds on German reactor designs utilizing the experience from the Thorium High Temperature Reactor and the AVR. These plants utilize a steam cycle in contrast to the Eskom design for a direct cycle helium turbine. The choice for a core design limited to 228 MW(th) with a diameter of 3.5 meters and the use of graphite constrictions for nuclear control and shutdown outside of the pebble bed provides conservatism in maintaining the maximum accident fuel temperature to 1600°C. Also, the PBMR is to use a multiple pass regime for on-line constant fueling of the reactor.

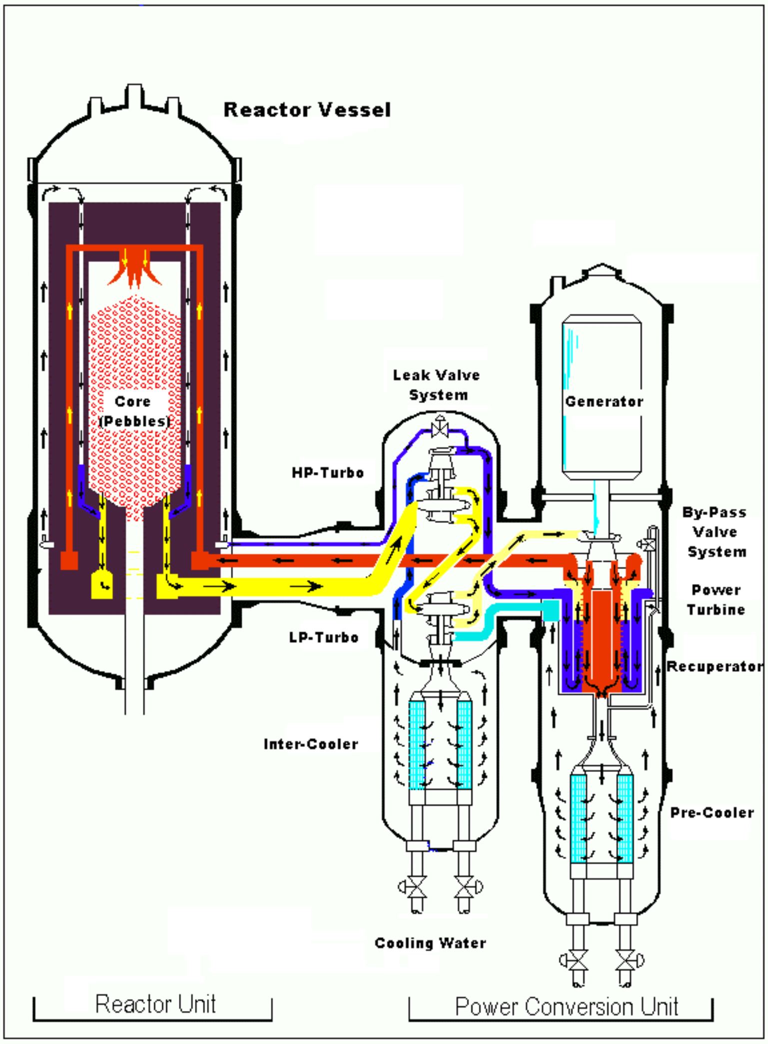

FIG. 7. Pebble bed modular high temperature gas cooled reactor.

Other design considerations for the PBMR include components for the power conversion unit (PCU). The Atomic Energy Corporation (AEC) of South Africa, in conjunction with IST, is developing the initial design for the two turbo-compressors and the power turbine. GEC Alsthom of France is providing the preliminary design of the electric generator and the associated exciter. The three rotating shafts of the PCU are to be supported by magnetic bearings. The recuperator is of the compact perforated fin-plate type with the precooler and intercooler of conventional finned tube design. The thermodynamic loadings of the precooler and intercooler are anticipated to be nearly identical, which may allow interchangability of components. The electrical generator will basically be of standard design with the additional requirements of operating in a vertical configuration on magnetic bearings and in a high pressure helium atmosphere. However, these requirements are not considered to represent significant design concerns.

STATUS AND PROSPECTS OF NUCLEAR DESALINATION

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Abstract

While availability of potable water is an important prerequisite for socio-economic development, about 1/3 of the world's population is suffering from inadequate potable water supplies. Seawater desalination with nuclear energy could help to cope with the fresh water shortages and several countries are investigating nuclear desalination. Status and future prospects of nuclear desalination and the role of the IAEA in this area are discussed in this paper.

1. INTRODUCTION

In many parts of the world, water resources are insufficient to meet the needs of people living there. In many cases, natural sources of fresh water supply are threatened by pollution and increasing salinity. At the same time, the demand for clean, potable water is growing, particularly in areas of high population growth [1].

Concern over the global implications of water problems was voiced as early as 1972, at the United Nations Conference on the Human Environment in Stockholm and since then, other meetings have reinforced these concerns. Most recently, the Committee on Natural Resources noted with alarm that some 80 countries, with 40% of the world's population, were already suffering from serious water shortages and, in many cases, the scarcity of water resources has become the limiting factor to economic and social development. At its second session in 1994, the Commission on Sustainable Development, noted that in many countries a rapid deterioration of water quality, serious water shortages and reduced availability of freshwater are severely affecting human health, important ecosystems and economic development [2].

Part of the answer to pressing water problems may come from the abundant resources of the sea. Desalination is one of the most promising alternatives for supplying potable water. The world's collective desalination capacity has increased steadily in the past decades, and the trend is expected to continue into the next century. Nuclear power plants could be an important part of the picture, and more countries are interested in using nuclear energy to desalt seawater.

2. TECHNICAL BACKGROUND

The reasons behind nuclear power's use for electricity generation also apply to its potential use for seawater desalination. These reasons are, for example, economic competitiveness in areas lacking cheap hydropower or fossil fuel resources, energy supply diversification, conservation of fossil fuel resources, the promotion of technological development, and environmental protection by avoiding emissions of air pollutants and greenhouse gases.

The IAEA surveyed the feasibility of using nuclear energy for seawater desalination as early as the 1960s and 1970s but at that time, the main interest was directed at its use for electricity generation, district heating, and industrial process heat. Since 1989, the IAEA's Member States have shown renewed interest in nuclear desalination[1], adopting a number of resolutions on the subject. Responding to requests in these resolutions, the IAEA performed studies to assess the technical and economic potential of nuclear reactors for seawater desalination, e.g., state-of-the-art desalination technologies were reviewed [3], and costs for different types of combinations of nuclear reactors and desalination processes were generically examined [4].

One study, The Potential for Nuclear Desalination as a Source of Low Cost Potable Water in North Africa, was completed in 1996 [5]. It analyzed the electricity and potable water demands and the available energy and water resources in five countries: Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, and Tunisia. The scope included the selection of representative sites, analysis of various combinations of energy sources and desalination processes appropriate for each site, economic factors, financial aspects, local participation, infrastructure requirements, and institutional and environmental aspects.

Seawater desalination is an energy intensive process. For standard seawater (25°C, 34500 ppm Total Dissolved Solids), the lowest energy consumption including that for seawater pumps and water pre-treatment is currently obtained with Reverse Osmosis (RO) plants. It amounts to 4 to 7 kW(e)·h/m^3 of electrical energy, depending on the requirements for fresh water quality, seawater salinity and plant configuration. The heat and electricity consumption of commercial multi-effect distillation (MED) plants is in the range of 30 to 120 kW(th)·h/m^3 and 1.5 to 2.5 kW(e)·h/m^3 respectively depending on the design and the seawater temperature difference. Today, multi-stage flash (MSF) plants have reached a mature and reliable stage of development. The thermal heat and electricity consumption is in the range of 45 to 120 kW(th)·h/m^3 and 3 to 6 kW(e)·h/m^3 respectively. Generic studies show that energy cost accounts for one third to one half the cost of the final product, depending on the desalination process. The combination of vapor compression systems with MED systems is often selected for the efficiency improvement. It consumes an additional 7-10 kW(e)·h/m^3 but the productivity is significantly improved by the reduced number of effects.

Nuclear economics are usually improved for large units due to the size effect. This has led to the development and deployment of large-size reactors in industrialized countries with large interconnected electrical grid systems. However, arid zones and water short countries are often equipped with smaller interconnected electrical grid systems and integration of large reactors is not viable. Thus, there has been and continues to be a need for small- and medium-sized reactors (SMRs). The largest power unit which can be integrated into an electric grid is

[1] *Nuclear desalination* is defined to be the production of potable water from seawater in a facility in which a nuclear reactor is used as the source of energy for the desalination process. Electrical and/or thermal energy may be used in the desalination process. The facility may be dedicated solely to the production of potable water, or may be used for the generation of electricity and the production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. In either case, the notion of nuclear desalination is taken to mean an integrated facility in which both the reactor and the desalination system are located on a common site and energy is produced on-site for use in the desalination system. It also involves at least some degree of common or shared facilities, services, staff, operating strategies, outage planning, and possibly control facilities and seawater intake and outfall structures. Non nuclear desalination is understood to be the production of potable water from seawater in a facility in which a fossil-fuelled plant and/or the electrical grid is used as the source of energy for the desalination process.

defined through economic optimization for certain goals of system reliability (usually well above 99%). In practice, the size of the largest unit for most of the potential countries or regions for large scale seawater desalination is limited to about 500-900 MW(e). Most SMR designs under development are not scaled down versions of large commercial reactors, and are claimed to be economically competitive [6]. SMRs in many cases fit the requirements of countries with small or medium electric grids and nuclear heat applications better than large reactors [7].

In areas without the possibility of suitable grid connections, the reactors would be dedicated to supplying energy to the desalination plant, leading to small nuclear units. Such small reactors could be installed on shore to supply adjacent desalination plants, or as barge-mounted self-sufficient floating plants. This can only be analyzed on a case by case basis. According to studies, floating MED plants could supply water in the range of about 20,000 m^3/d up to 120,000 m^3/d. Floating RO plants may even reach 250,000 m^3/d. Floating desalination plants could be attractive for supplying temporary demands of potable water.

Nuclear reactors could provide electricity or heat, or both, as required by the desalination processes. Regarding nuclear safety, the same principles, criteria, and measures apply to any nuclear plant. An additional requirement is that the product water must be adequately protected against any conceivable contamination.

3. EXPERIENCE AND PRESENT STATUS OF NUCLEAR HEAT APPLICATIONS

There are now about 60 reactors and over 500 reactor years of operational experience with nuclear heat applications: district heating, industrial processes and seawater desalination. There appear to be no major technical or safety concerns with nuclear heat application systems. Design precautions to prevent the carry-over of radioactivity into the heating network or into the desalted water have proven effective. These findings are important for future applications of nuclear heat for seawater desalination [8].

Nuclear energy has been used for seawater desalination at locations in Kazakhstan and in Japan. While in Japan the desalination plants are mostly for on-site water supply; the Aktau desalination complex in Kazakhstan supplies water to a nearby population centre.

In Aktau, Kazakhstan, the liquid metal cooled fast reactor BN-350 has been operating as an energy source for a multi-purpose energy complex since 1973, supplying regional industry and population with electricity, potable water and heat. The complex consists of a nuclear reactor, a gas and/or oil fuelled thermal power station, and MED and MSF desalination units. Seawater is taken from the Caspian Sea and the nuclear desalination capacity is about 80 000 m^3/d. A part of this capacity has now been disconnected.

In Japan, all of the nuclear power plants are located at the seaside. Several plants of the electric power companies of Kansai, Shikoku and Kyushu have seawater desalination systems using heat and/or electricity from the nuclear plant to produce feedwater for the steam generators and for on-site supply of potable water. MED, MSF and RO desalination processes are used. Individual desalination capacities range from about 1000 to 3000 m^3/d and the experience gained so far with nuclear desalination is encouraging.

A significant number of Member States have shown interest in this option and ongoing or planned national and bilateral projects will contribute to international experience in nuclear desalination. Such projects should be useful for commercial deployment, contributing to the solution of potable water supply problems in the next century. Canada is promoting the coupling of an RO desalination facility with feedwater preheating to a CANDU reactor. In China a feasibility study has been initiated for a heating reactor combined with a desalination unit that could produce 150 000 m^3/d of potable water. Morocco and China are studying the use of a small 10 MW(th) heating reactor from China for the production of about 8000 m^3 of potable water per day in Morocco via an MED process. Egypt is studying the feasibility of nuclear desalination on its Mediterranean coast. In the Republic of Korea, design of a 330 MW(th) advanced reactor is in progress as a cogeneration demonstration nuclear plant for electricity and seawater desalination. In India construction work is underway to couple a hybrid MSF/RO desalination unit producing 6300 m^3/d to an existing PHWR at Kalpakkam. In the Russian Federation, a small floating nuclear desalination plant is under development using a nuclear reactor originally developed for icebreakers. Argentina is developing a small water-cooled reactor (CAREM) with an output of about 100 MW(th). The reactor is supposed to serve for electricity production and seawater desalination. Several countries offer their projects for international co-operation and participation.

These projects, as well as studies and research and development in other interested Member States, can contribute to a universal demonstration program. They can be considered a basis for international co-operation and support, beneficial for other interested countries. It is important to use the experience gained from these programs, and not to duplicate activities.

4. PRACTICAL OPTIONS FOR DEMONSTRATION

Studies to date show that seawater desalination using nuclear energy is a realistic option for many countries. The continuing expansion of seawater desalination installations offers a potential market for the introduction and commercial deployment of nuclear desalination systems. However, some issues, in particular technical features with a major impact on economic competitiveness and on the overall economics, need demonstration to confirm assumptions and estimates.

Following resolutions of the IAEA General Conference, the IAEA has focused on activities to identify options to demonstrate nuclear desalination. A demonstration program would aim to build confidence, through the design, construction, operation, and maintenance of appropriate facilities, that nuclear desalination can be technically and economically feasible, while meeting criteria for safety and reliability. To this end, a two-year "Options Identification Programme (OIP)" was conducted from 1994 to 1996 with participation by representatives from interested Member States [9].

The purpose of the OIP was to select from a wide range of possible choices of desalination technologies and reactor types, the few most practical candidates for demonstration[2]. Demonstration options are based on reactor and desalination technologies readily available without significant further development being required.

[2] For an option to be "*practical*", it was regarded to have fulfilled the following conditions: there is no technical impediment to implementation and a suitable site exists; it is technically feasible to be implemented on a certain predetermined schedule; and the investment cost can be estimated within an acceptable range.

In the course of identifying practical options for demonstration, the list of available reactors was reviewed and several reactors identified as being most appropriate. Screening criteria based on design and licensing status were used as a filter and available reactor technologies or those, which might become available within approximately the next ten years were identified. Additional screening factors were then considered, ruling out some options. These included reactor designs not commercially offered; liquid metal-cooled reactors and high temperature gas-cooled reactors, which are unlikely to be commercially available in the near term; large reactors, unlikely to fit the electricity grids of most countries facing water shortages; small reactors which currently appear to be less economically competitive (however, they may be feasible at sites with low water demand where alternative systems for potable water production are also expensive); and boiling-water reactors, which are likely to require installation of additional systems to prevent radioactive release to the heat recipient systems.

Consideration was also given to desalination technologies suitable for coupling to a nuclear reactor. Desalination by the processes of reverse osmosis (RO) and multi-effect distillation (MED) appear to be most promising, due to relatively low energy consumption and investment costs and high reliability. Originally, the multi-stage flash (MSF) process was also a candidate. However, the MED process has lower energy consumption and appears to be less sensitive to corrosion and scaling than the MSF process. Also, its partial load operability is more flexible. Therefore, MSF has been excluded, having no inherent advantages over MED.

Demonstration desalination processes need not be implemented at the large-scale commercial production level. Two or three trains or units could provide design and operational characteristics fully representative of larger scale production facilities, as larger plants are simply multiple trains or units operated in parallel.

Compatibility was considered in the selection process to combine nuclear reactor and desalination process to form an integrated facility. Scheduling, infrastructure, and investment were considered in identifying practical options for demonstration. As a result, three options were identified as recommendable, practical candidates for demonstration. These options use well-proven water-cooled reactors and desalination technologies.

Option 1: RO desalination in combination with a nuclear power reactor being constructed or in an advanced design stage, with construction expected in the near term. The preferred capacity of the reactor is in the medium-size range. Two or three RO trains, up to 10,000 cubic meters per day each, would provide a suitable demonstration. A newly constructed reactor would offer the best opportunity to fully integrate the RO and reactor systems, including feedwater preheating and optimization of system design. Such demonstration could readily be extrapolated to larger scale commercial production facilities.

Option 2: RO desalination, as above, in combination with an operating reactor. Some minor design modifications may be required to the periphery of the existing nuclear system. Advantages include a short implementation period, a broad choice of reactor sizes, and the availability of nuclear infrastructures. A reactor in the medium-size range is preferred, as it provides a system close to that most likely be used in commercial facilities.

Option 3: MED desalination in combination with a small reactor. This is suitable for the demonstration of nuclear desalination for capacities of up to 80 000 m^3/d.

The identifying and characterizing demonstration candidates during the OIP required considering many issues which must be addressed for the demonstration of nuclear desalination as well as for commercial deployment. A demonstration program is intended to promote confidence and to confirm specific characteristics or parameters considered important in the design, construction, operation, and maintenance of the facility. A number of subjects were identified for more thorough examination and evaluation, covering technical, safety, and economic issues. Such specific subjects for investigation include the interaction between nuclear reactors and desalination systems; nuclear safety requirements specific to nuclear desalination systems; and the impact of feedwater preheating on performance of RO systems.

5. FUTURE PROSPECTS

Growing global interest in nuclear desalination led the IAEA to organize an international symposium on "Desalination of Seawater with Nuclear Energy" in Taejon, Republic of Korea, in May 1997 [10]. The Symposium was organized in co-operation with the International Desalination Association and the Global Technology Development Center. About 250 participants attended the Symposium from about 30 Member States and international organizations. An overview of activities on desalination was given by participants from selected organizations; experiences from existing nuclear desalination plants and relevant conventional desalination facilities were reported; national and bilateral activities including research, design and development of nuclear seawater desalination were presented; and forecasts and challenges lying ahead were discussed. With large attendance from the nuclear power and the desalination sectors, the Symposium proved a useful forum for the exchange of information and technical and economic aspects of different desalination processes. It was stressed that the IAEA should continue to involve itself in international and regional co-operation and information exchange, including activities dealing with public acceptance and demonstration of the economic feasibility of nuclear seawater desalination. There was consensus that nuclear seawater desalination is technically feasible. Cost and social acceptability were identified as major issues to be addressed by future programmes.

Regarding economics at co-generation plants, which constitute the vast majority of nuclear heat supplying plants, the main product is electricity. Heat delivery usually amounts to less than 10% of the total thermal power. The cost of the nuclear electricity will thus be decisive for the economic viability of a nuclear co-generation project, with heat supply as a by-product. The energy cost attributable to heat supply is usually calculated from the lost electricity and the electricity generation cost. This power credit method is also applied in a computer spreadsheet developed at the IAEA [4]. Besides the heat and/or water production cost, transport cost must be evaluated and compared to alternatives. The cost of distribution will be the same for the alternatives.

Nuclear heat applications were found economic in a number of study cases, but not under all circumstances. The energy cost due to lost electricity production in co-generation plants is usually low, but the heat transport system and other necessary installations may be quite costly. Among other conditions, a large and fairly steady demand for heat or desalted water is favorable for economic nuclear heat application.

When the nuclear desalination option is considered, the question of infrastructure requirements for nuclear plants is a major issue, especially for Member States with no nuclear experience. A demonstration project in such a country, could be an effective framework for developing its nuclear infrastructure, especially a nuclear regulatory structure.

Over the coming years, it will be important to continue and deepen studies and assist Member States in building their nuclear infrastructures, e.g., through demonstration programs. The IAEA will continue to support activities that encourage the participation of countries, and that emphasize sharing technical expertise and effective use of financial resources. To facilitate sharing knowledge and experience, an International Nuclear Desalination Advisory Group (INDAG) was established in 1997 with participation from Member States operating, developing, designing, planning, or with interest in nuclear desalination.

The main functions of INDAG are:

(1) To provide advice and guidance on IAEA activities in nuclear seawater desalination and review progress;
(2) To identify important topics for status reports, CRPs, technical meetings and topical conferences;
(3) To provide a forum for the exchange of information on the progress of national and international programs in this field; and
(4) To provide advice on action to concerned Member States for implementing nuclear seawater desalination demonstration projects.

The second meeting of INDAG held in June 1998, reviewed IAEA progress in nuclear seawater desalination and recommended the IAEA, among other items:

(1) validate and improve the computer software Cogeneration Desalination Economic Evaluation (CDEE) for economic assessment of energy options for seawater desalination,
(2) provide assistance for countries aiming at implementing demonstration projects, including preparation of a Guidebook on "Introduction of Nuclear Desalination" and the conduct of a CRP on "Optimization of Nuclear-coupled Seawater Desalination Systems",
(3) provide a forum for review and discussions of selected topics and identify frameworks for facilitating international co-operation.

Compilation of a Guidebook on "Introduction of Nuclear Desalination" has begun. The Guidebook will comprise three major parts:

(1) Overview of nuclear desalination,
(2) Special aspects and considerations of the introduction of nuclear desalination, and
(3) Steps to introduce nuclear desalination.

The Guidebook will be published in 2000.

The IAEA's Coordinated Research Project (CRP) on "Optimization of Nuclear-coupled Seawater Desalination Systems" has begun, to tackle technical aspects for nuclear desalination. With the participation of eleven institutes from nine Member States, the CRP encompasses research and development programs focused on optimized coupling of nuclear and desalination systems in the following major areas:

(1) Nuclear reactor design intended for coupling with desalination systems,
(2) Optimization of thermal coupling of NSSS and desalination systems,

(3) Performance improvement of desalination systems for coupling, and
(4) Advance desalination technologies for nuclear desalination.

6. CONCLUSIONS

Results of international co-operation so far illustrate that there are practical options for the application of nuclear energy to seawater desalination. To realize them, it is important to convince the public and to gain the confidence of investors. Means toward these goals include continued safe and reliable operation of nuclear plants, factual information on the comparative risks and benefits of all energy sources, and conservative cost estimates for nuclear desalination facilities. This will provide a sound basis for proceeding with development, demonstration, and final large-scale applications of nuclear desalination plants.

Recent IAEA activities have focused on helping countries assess the economic feasibility of using nuclear plants for desalination. Methods have been developed that enable site-specific economic evaluation [11, 12]. A computer program is available for use in such analyses, and experts have been trained on the program's use. Development of a more detailed computer program to allocate the costs of dual-purpose plants and determine their optimum coupling is now envisaged.

The IAEA is also assisting Member States in implementing demonstration projects. It is expected that these national and international activities on seawater desalination using nuclear energy will help solving the potable water shortage problems in the next century.

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ASSESSMENT OF THE WORLD MARKET FOR SMALL AND MEDIUM REACTORS

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Abstract

In the past decades, the major focus for nuclear power has been the design and construction of nuclear plants of ever increasing size. This was appropriate for many industrialized countries, which could readily add generation capability to their electrical grids in large increments. However, recently there has been an increasing emphasis on the development of small and medium reactors especially to meet needs in developing countries where electrical grids cannot accept the additional capacity of a large nuclear plant. The paper presents an estimation of the wold market for small and medium sized reactors giving the basic assumptions, criteria, scope, methods and important factors.

1. INTRODUCTION

Nuclear power has been used over the last four decades and is one of the fastest growing energy options. At present, about 17% of electricity worldwide is generated by nuclear power. Although the rate at which nuclear power is penetrating the world energy market has declined, it has retained a substantial share of the market, and is expected to continue as a viable option well into the future.

The present generation of nuclear power plants was developed primarily to satisfy the largest market for these plants, which means supplying electricity to industrialized countries with interconnected grids permitting the introduction of large units. However, the worldwide market for nuclear power is not limited to large reactors; small and medium reactors (SMRs) always had a share of this market and this is expected to prevail for the foreseeable future.

A substantial number of nuclear reactor designs have been developed within the small and medium power range. Some have been built or are under construction, others are still in the conceptual, basic or detailed design stage. Few of the design stage reactors are under active development, most are "on hold", waiting for potential customers to express their interest All the advanced designs under development share the common goals of improving safety, reliability and economics, with different degrees of emphasis on each aspect. It is also recognized that technology thresholds allow some technical solutions within the limits of size and which contribute to the above goals, but which cannot be used in larger reactors.

What is offered on the market is relatively easy to assess. Designers and vendors are willing and interested in providing information on their concepts, especially regarding technical aspects. The recent TECDOC-881 published by the International Atomic Energy Agency (IAEA)[1] reviews most of the designs pursued. There are several additional designs under development, and it can be concluded that there is certainly no lack of potential vendors.

While the appraisal of market offerings is basically a status review, the assessment of demand is directed toward the future, that is, it has the character of a forecast. This is a more difficult task, and the results strongly depend on the assumptions, criteria and methods adopted. Forecasts are directed toward predicting the future but based necessarily on past experience and current knowledge. To achieve reasonably reliable results, it is essential to base the predictions on real and objective expectations, and not on what one wishes or would like to happen.

For an overview of the nuclear power market, the IAEA annually performs a forecast, which consists of energy, electricity and nuclear power estimates for the future. [2]. The nuclear generating capacity estimates are derived from a country by country, bottom-up approach, and includes reactors of all size ranges. The low and high estimates reflect contrasting but not extreme underlying assumptions on the different driving factors having an impact on nuclear power development. These factors, and the ways they might evolve, vary from country to country. The latest (March, 1997) estimates indicate a total net installed capacity, by the year 2015, of between 370 and 510 gigawatts electric (GW(e), amounting to a modest increase.

The present market assessment is intended to cover only SMRs, which constitute an integral part of the overall nuclear power market together with large reactors. Most of the factors affecting the evolution of the overall nuclear market are equally relevant to any nuclear reactor whatever the size range. There are differences too, and these must be considered.

2. REACTOR SIZE RANGES

The choice of ranges is somewhat arbitrary but the usual practice is to take the upper limit of the SMR range as approximately half the power of the largest reactors in operation. Accordingly, reactors up to about 700 megawatts electric (MW(e)) are currently considered as SMRs. Other limits are defined by taking similar reductions. The ranges adopted are:

Very small reactors	<150 MW(e)
Small reactors	150-300 MW(e)
Medium reactors	300-700 MW(e)
Large reactors	>700 MW(e)

For heat-only or co-generation reactors, the range limits are applied to the electrical equivalencies of the thermal power . For example, for very small heat-only reactors, the upper limit is 500 megawatts thermal (MW(th)). It should be noted that all current heat-only reactor designs are in the very small reactor range.

Very small, small and medium are relative concepts, related to the power level of the largest reactors in operation. That is, at the time when the largest reactors in operation were about 200 MW(e), the corresponding upper limit of the SMR range was 100 MW(e); when 600 MW(e) units came into operation, the SMR range increased to 300 MW(e), and so on. Applying the current definition of the SMR range, a third of the operating nuclear power reactors qualify as SMRs. However, when most of these plants were designed and built, they were considered large reactors according to the prevailing definition of the term.

The above defined ranges for medium, small and very small reactors expressed in power levels (MW(e)), should be interpreted as approximate values. The variety of reactors with different characteristics included in each of these ranges, are intended to respond to different requirements, which should be considered to facilitate the assessment of the potential market.

Medium size reactors are power reactors whose objective is electricity generation. They can also be applied as co-generation plants supplying both electricity and heat, but the main product remains electricity. As such, they are base load plants intended for introduction into interconnected electric grid systems of suitable size. If operated in the co-generation mode, the heat supply would be up to about 20% of the energy produced. Economic competitiveness with equivalent fossil-fueled plants is expected under most conditions.

Small reactors are either power or co-generation reactors and may have a substantial share of heat supply. Due to size, they are not expected to be economically competitive with medium or large size nuclear power plants. They are therefore intended for special situations where the interconnected grid size does not permit larger (medium or large size) units and where alternative energy options are relatively expensive.

Very small reactors are not intended for base load electricity production under commercially competitive conditions, as units integrated into interconnected electrical systems. Clearly, very small reactors of current design are not scaled-down versions nor competitors of large, medium or even small power reactors. Very small reactors are to address specific objectives, such as the supply of heat and electricity or heat only (at either high or low temperature) for industrial processes, oil extraction, desalination, district heating, etc., propulsion of vessels or for energy supply of concentrated loads in remote locations. They may also serve as focal projects and stimulus for the development of nuclear infrastructures in countries starting a nuclear power programme.

Consideration of the specific objectives of the reactors in each power range has major relevance for the assessment of their respective markets.

3. BASIC ASSUMPTIONS, CRITERIA, SCOPE AND METHODS

3.1. Availability of SMRs

Market assessment is based on the assumption that suitable nuclear reactors are available both for domestic use and export, when required by interested buyers. Suitability is interpreted as meeting technical and economic conditions as defined by potential buyers, often called user requirements. The user requirements must be reasonable and not a wish-list with a collection of desirable goals impossible to achieve simultaneously. The nuclear reactors must be licensable; technical features must not require further research to prove viability and reliability; and costs must be within an acceptable range. Understanding costs and benefits in the wider sense instead of only in monetary terms, the buyers must find a favorable cost/benefit ratio.

Currently, seven countries have 15 SMRs under construction, 5 units in the small and 10 in the medium size ranges. The IAEA-TECDOC-881[1] contains descriptions of 29 SMR designs. Including additional concepts on which information is available, the number in different design stages is about 50 reactors. This shows considerable activity in the field of SMRs and can be interpreted as a positive sign for further development. The information and data provided by designers and vendors, as well as studies and plans of various countries regarding the launching of power reactor projects in the SMR range, support this assumption.

3.2. Governmental role and national policy

Possibly the most decisive factor promoting nuclear development is governmental commitment and active support of nuclear power as part of medium to long-term national energy development policy. In fact, this is considered a necessary condition for any country expecting to proceed with a nuclear programme or project. In the absence of active Governmental support, neither publicly owned utilities which directly respond to national policies, nor privately owned utilities which function in a regulated environment, can be expected to initiate new nuclear projects. Public acceptance is a factor affecting governmental policies and actions and its significance depends on the influence of public opinion on political power. Several countries have in force medium to long-term energy development and supply policies currently excluding the nuclear option, or which only provide passive or a reluctant acceptance of nuclear power as a last resort. However, governmental policies do not last forever and governments and policies may change in time.

3.3. Infrastructure availability

For any country, viability of a nuclear power programme depends on the availability of adequate infrastructures. These infrastructures are technological, manpower, industrial, economic, financial and institutional. In principle, any country can develop its infrastructures to an adequate level, but this requires substantial time and effort. Countries unable to invest the effort to develop their infrastructures in an appropriate time, or where such efforts are not justified by medium to long-term prospects of using nuclear power, are unlikely to start a nuclear power programme. Very small or small reactors offer an attractive option with which to start. Though these also need infrastructures, relatively lower and therefore more easily achievable development effort is required.

3.4. Programs with large units

Several countries with ongoing nuclear programs have interconnected electrical grid systems, which readily accept large size units. Unless there are compelling reasons which require or promote the use of SMRs, these countries are expected to add similar large size units when required to satisfy the electrical demand.

3.5. Economic and financial constraints

Countries with chronic economic problems, high indebtedness and scarce financial resources are not expected to invest in capital intensive projects, such as nuclear reactors.

3.6. Scope

The assessment includes all countries, and is not limited to those with ongoing nuclear power programs, or with expressed intentions of launching SMR projects. All countries are considered individually and all uses are included, electricity generation, heat only, and co-generation. Reactors on which construction has been started are not considered in the market assessment; it is only for new projects.

3.7. Time frames

The market assessment is for reactors coming on line up to the year 2015. Beyond a period of about 20 years, forecasts become very speculative. They are based more on postulated scenarios and general statistical analysis than on a country-by-country or project-by-project consideration, the approach adopted for the present assessment. For purposes of the market assessment, the average construction times assumed for medium, small and very small reactors are 6, 5 and 4 years respectively. Lead-times for preparation (planning, site qualification, feasibility studies, acquisition, infrastructure development or upgrading, institutional arrangements, etc.) vary with specific projects and conditions and situations prevailing in each country. They are therefore assessed on a case-by-case basis.

3.8. Method

A two-phase procedure is applied: in the first, individual countries are assessed applying the above- assumptions and criteria. The result is a short list of countries (Table I), assessed as having a potential demand for SMRs within the period considered, and which therefore deserve a more thorough consideration. Some countries not included in the short list might initiate and implement SMRs within the time frame; conversely, not all countries selected might fulfill expectations by implementing new projects. However, this should not substantially alter results of the market assessment. Neither exclusion from nor inclusion in the short list, should be interpreted as recommendations for individual countries or projects.

Countries selected for further consideration have been grouped according to their nuclear power development status, i.e., those which have already started implementation of their first nuclear power project, and those which have not yet done so.

TABLE I. LIST OF COUNTRIES FOR FURTHER CONSIDERATION

First nuclear power projects have been started	No nuclear power projects started
Argentina	Algeria
Canada	Belarus
China	Chile
Hungary	Croatia
India	Egypt
Iran, Islamic Republic of	Indonesia
Italy	Israel
Korea, Republic of	Libyan Arab Jamahiriya
Mexico	Malaysia
Pakistan	Morocco
Poland	Portugal
Russian Federation	Saudi Arabia
South Africa	Syrian Arab Republic
United States of America	Thailand
	Tunisia
	Turkey

In a second phase, the market for SMRs is assessed for each country selected, considering the plans or intentions of the individual countries, the previously mentioned criteria and a series of factors affecting the market, which are identified and discussed in the following section. The market is assessed separately for medium, small and very small reactors, as well as that for reactors expected to be imported or of domestic supply.

It has been attempted to be objective, practical and realistic. The high and low estimates obtained do not indicate a too optimistic theoretical maximum, nor an overly pessimistic minimum. They are rather the result of expectations under more or under less favorable conditions and scenarios, applied to both overall nuclear power development and to the role and market share of SMRs. However, both the high and the low estimates correspond to scenarios in which nuclear power remains a viable energy option in an environment graduallyevolving towards improved acceptance. Assuming more extreme scenarios apply, that is, where the attractiveness of nuclear power substantially improves worldwide on a short term, or where no noticeable improvement occurs, the corresponding high and low estimates would be respectively higher and lower than the results obtained in this market assessment.

4. FACTORS AFFECTING THE MARKET

Among the many factors affecting the market, either promoting or opposing nuclear power programs and SMRs in particular, the most important ones are identified and briefly discussed below, complementing the criteria previously established.

4.1. Energy resources and supply diversification

High dependence on imported fossil energy sources (oil, gas, coal) and little or no diversification in the pattern of energy supply tend to promote nuclear power development. Countries with these characteristics are more likely to adopt nuclear power then those with abundant and cheap conventional (fossil or hydraulic) energy resources.

4.2. Economic and financial resources

Nuclear power is capital-intensive and requires substantial investment. Countries with strong economies and access to financial resources are in a better position to launch nuclear projects than those with struggling economies, high indebtedness, and a general lack of capital. Privatization and deregulation often discourage nuclear projects because of high capital requirements and long-term return of investment. Within this negative context, SMRs are favored over large plants due to lower capital requirements, easier financing and shorter construction times.

4.3. Interconnected electrical systems

Due to the relatively large share of fixed costs in the energy production costs of nuclear power, base load operation is required to achieve favorable economic conditions. Therefore, nuclear power plants intended for electricity generation as the only or main product, must be integrated into the interconnected electrical grid systems. The total interconnected generating capacity limits the maximum unit size that can be added. The optimal unit size, determined through generation system expansion planning, however, is often smaller than the acceptable maximum unit size.

4.4. Growth rates

Countries characterized by sustained high GDP, large industrial production, and high growth in energy and electricity demand are more likely to adopt nuclear power programs than those with stagnant economies or in recession. High population growth unaccompanied by economic and industrial development are unfavorable to nuclear power.

4.5. Energy demand pattern

An increasing share of electricity in overall energy consumption, a high share of industrial demand in overall energy demand, and a high base load to peak load ratio are characteristics promoting nuclear power. Concentrated large demand for energy in the form of heat favors co-generation or heat-only reactors. Remote and isolated areas with relatively large energy (electricity and heat) demand and with lack of local energy resources are favorable conditions for very small reactors.

4.6. Electricity supply structure

Large utilities with solid economic and financial structures supported by a rentable tariff system are more likely to possess the investment capability and credit rating required for nuclear projects, than small, weak utilities and subsidized tariff systems. Experiences in power plant operation with high availability, reliable transmission and distribution systems, with low break down rate and low supply interruption rate, and especially, experience in nuclear power, provide a favorable background for new nuclear projects.

4.7. Industrial and technical development

If adopted as priority national development goals, they act in favor of nuclear programs. As shown by experience, nuclear projects promote quality improvements, transfer of technology, and general development of domestic capabilities. The side effects of nuclear power programs are recognized as important contributions, even though they are difficult to identify and measure.

4.8. Environmental and nuclear safety concerns

Worldwide concerns about climate change and environmental pollution from conventional energy sources are increasing and in principle, should promote nuclear power development. On the other hand, concerns with nuclear safety and radioactive waste disposal tend to discourage decision makers from this option. How these concerns balance and which will have the dominant role, influence national policies and therefore, affect the market. Concerns about nuclear safety do have a positive influence on the development and market potential of SMRs, which are perceived as offering improved safety features and safety levels.

5. MARKET ESTIMATES

According to the method adopted here, the market for SMRs is assessed for each country selected for further consideration, as listed in Table I. The results (high and low estimates) are presented in Table II, discriminated by geographical regions and by reactor size range. A summary is presented in Table III, which also contains an estimate of the market shares corresponding to domestic and foreign supply sources. The following are brief comments referring to the various countries with a potential market for SMRs.

Among the countries with ongoing nuclear power programs, China, India and the Russian Federation represent a substantial market for SMRs. In China, there is an ambitious nuclear power program firmly supported by the government.. In addition to some imported medium size units, a series of domestic design medium size, some small and also several very small units (including heat-only reactors) are expected to be put in place. There is continuing firm governmental support for the nuclear power program in India, and a large demand for

TABLE II. SMR MARKET ASSESSMENT BY GEOGRAPHIC AREAS

		HIGH ESTIMATE				LOW ESTIMATE			
Region	Size	2001-2005	2006-2010	2011-2015	Total (2001-15)	2001-2005	2006-2010	2011-2015	Total (2001-15)
North America	M	0	2	1	3	0	0	0	0
	S	0	0	0	0	0	0	0	0
	VS	0	0	0	0	0	0	0	0
South and Central America	M	0	0	4	4	0	0	2	2
	S	0	0	1	1	0	0	1	1
	VS	1	0	0	1	0	0	0	0
European Union	M	0	2	7	9	0	1	3	4
	S	0	0	0	0	0	0	0	0
	VS	0	0	0	0	0	0	0	0
Eastern Europe	M	1	4	7	12	0	2	6	8
	S	0	0	0	0	0	0	0	0
	VS	1	2	2	5	0	2	1	3
Africa	M	0	2	3	5	0	0	5	5
	S	0	0	3	3	0	0	0	0
	VS	1	2	1	4	0	0	1	1
Middle East and South & Middle Asia	M	1	5	10	16	1	3	5	9
	S	2	5	1	8	1	4	0	5
	VS	0	0	1	1	0	0	1	1
Southeast Asia and the Pacific	M	0	2	4	6	0	1	2	3
	S	0	0	0	0	0	0	0	0
	VS	0	0	1	1	0	0	0	0
Far East	M	5	4	2	11	3	4	4	11
	S	0	2	1	3	0	1	1	2
	VS	2	2	3	7	1	2	2	5
World Total	M	7	21	38	66	4	11	27	42
	S	2	7	6	15	1	5	2	8
	VS	5	6	8	19	1	4	5	10

Size definition M: 300-700 MW(e), S: 150-300 MW(e), VS:<150 MW(e) or equivalent

new capacity. The country is expected to proceed with its program based on domestic design SMRs. In the Russian Federation there is an ongoing nuclear power program based mainly on large size units, but limited by financial constraints. Several designs are under development, in particular in the medium and the very small reactor ranges. It is expected that a series of units in these ranges will be implemented. It is estimated that the market for SMRs in the above-three countries is of the order of 30 to 40 units, more than half of which correspond to medium size reactors.

Argentina, the Islamic Republic of Iran, the Republic of Korea and Pakistan have ongoing nuclear power programs including reactors under construction. In Argentina, follow-up nuclear power plants are expected to be in the medium size range; the development of a very small domestic design reactor has been pursued, and they intend building a first unit. In the Islamic Republic of Iran, the construction of two large power reactors has been started again, and they plan to acquire some small units. In Pakistan, a further small reactor is expected to be followed by a series of medium size units. Though large power reactors are the base for the ongoing nuclear program of the Republic of Korea, more units in the medium range are expected. Also, implementation of a domestic-design very small reactor is expected. The estimate for the four countries within the period considered is 10 to 15 units.

Canada may install some units to replace older plants; Hungary requires follow-up reactors to satisfy a growing electricity demand without unduly increasing its import dependence; Italy shut down all its nuclear power reactors following a political decision, but a change in attitude and in policy could lead to restarting the programme with advanced reactors; Mexico could follow-up its operating reactors with new projects; Poland canceled nuclear reactors under construction, but it could reconsider and implement new projects; South Africa is interested in implementing a series of very small reactors of modular design; and finally, the USA could end its de-facto nuclear moratorium and implement some advanced reactor projects it has been developing. None of these countries have nuclear reactors under construction, but they all possess adequate infrastructures to launch nuclear projects. It is possible that prevailing conditions will gradually change in favor of nuclear development and if so, the expected market for SMRs would be 5 to 15 units, most in the medium power range.

TABLE III. SMR MARKET ASSESSMENT SUMMARY

High estimate	2001-2005	2006-2010	2011-2015	TOTAL
Medium	7 (5+2)	21 (11+10)	38 (8+30)	66 (24+42)
Small	2 (0+2)	7 (6+1)	6 (1+5)	15 (7+8)
Very small	5 (4+1))	6 (4+2)	8 (6+2)	19 (14+5)
Total	14 (9+5)	34 (21+13)	52 (15+37)	100 (45+55)
Low estimate	**2001-2005**	**2006-2010**	**2011-2015**	**TOTAL**
Medium	4 (2+2)	11 (8+3)	27 (9+18)	42 (19+23)
Small	1 (0+1)	5 (3+2)	2 (1+1)	8 (4+4)
Very small	1 (1+0)	4 (4+0)	5 (4+1)	10 (9+1)
Total	6 (3+3)	20 (15+5)	34 (14+20)	60 (32+28)

Note: Numbers in brackets refer to units of domestic supply plus units of foreign supply.

Among countries not yet initiating nuclear power projects, Turkey and Indonesia are in the acquisition stage of their first units. Both have intended to go nuclear for a long time. Malaysia and Thailand performed studies indicating the convenience of the nuclear option. All four countries are potential markets for medium size reactors, and in addition, Indonesia might implement a very small unit at a remote site. The implementation of 5 to 10 SMRs is expected for this group of countries.

The North African countries: Algeria, Egypt, the Libyan Arab Jamahiriya, Morocco and Tunisia, show a high degree of interest in initiating nuclear power programs. All have performed studies and preparations, including, in some cases, attempts to acquire nuclear power reactors. It is expected that further attempts will finally succeed, leading to the implementation of 5 to 10 SMRs, including very small, small and medium size units.

Several countries not yet initiating nuclear power projects, have performed studies and indicated interest in launching nuclear programs. Belarus has persistent energy supply constraints and might acquire some medium size units. In Chile, nuclear power could contribute to energy supply diversification in a fast growing economy and corresponding energy and electricity demand. In Croatia, a follow-up unit to the 600 MW(e) plant built in Slovenia was planned; new attempts could lead to implementing a medium size unit. Israel has consistently indicated interest in nuclear power; it has a solid nuclear technology infrastructure and could implement a nuclear project, subject to the success of the Middle East peace process. This also applies to Syria, which intends to proceed with medium size units. Portugal was on the verge of launching a nuclear power programme in the past, but has since desisted; new attempts to implement medium size units could succeed. Saudi Arabia has very large oil and gas resources, but energy supply diversification seems advisable. A nuclear power program starting with a very small or small reactor might be launched. In addition, some other countries have indicated interest in nuclear power and in SMRs in particular, performing studies and building infrastructures:Peru, Uruguay, Bangladesh are examples. There are others, such as Cuba, Romania or the Philippines, where the construction of SMRs was suspended. In these countries, completing these projects would have priority over the initiation of new plants. The estimated market for SMRs in the above group of countries is 5 to 10 units altogether.

6. RESULTS

- **Overall market.** These results indicate a market with the rather wide range of 60 to 100 units to be implemented up to the year 2015. Probably not all countries will evolve according to either the high or to the low estimates. It seems reasonable to assume that there will be a certain compensatory effect. Also, it is recognized that forecasts, just like national development plans, tend to err on the optimistic side. Therefore, an overall market estimate of 70 to 80 units seems reasonable.

- **Evolution of the market.** There is a sustained, gradually increasing trend in the overall market. At first, countries which have already started nuclear projects have a dominant role with a share of about 70% of the market throughout the assessment. Initially, projects will primarily be supplied by domestic sources; only during the latter part are imports expected to attain major importance. During the entire period, domestic and foreign market shares are similar.

- **Market for medium size reactors.** About 70% of the SMR units anticipated are in the medium size range. An initially dominant position by domestic supplies is expected to gradually shift to a larger share for the foreign market. Three countries, China, India and the Russian Federation, together represent about 40% of the overall market for this reactor size.

- **Market for small and very small reactors.** Together, they represent about 30% of the overall SMR market, expressed in numbers of units. Very small reactors have a somewhat larger share of the market than small reactors. It is expected that they will be supplied predominantly by domestic sources, with China, the Russian Federation, India and the Republic of Korea accounting for about 80% of the units anticipated. For small reactors, domestic and foreign market shares appear similar.

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ECONOMIC AND FINANCIAL ASPECTS

(Session 2)

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FINANCING ASPECTS OF NUCLEAR POWER PROGRAMS

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Abstract

This paper considers the standards applied to investment appraisal by financiers. It looks at the spectrum of costs, benefits and risks, which the project sponsors must meet to satisfy prospective financiers. Most considerations are standard to most types of investment project, particularly in a country where the technology is new. These standards apply where external financing is sought. Clearly, governments investing in nuclear power with public funds may choose to do so for other than competitive economic reasons, although ultimately efficient investment requires that they apply similar criteria in allocating available resources among the many demands on the public fisc.

1. INTRODUCTION

Nuclear fuels have the potential to help meet the needs for electricity of many of the more advanced developing nations. These fuels are abundant and commercially available from a number of suppliers in a relatively open global market. There is a choice of nuclear power plant designs that are operating successfully. A number of large national and multinational companies have the capability, experience and ambition to supply components, manage construction and commissioning, support licensing, and train operators in plant operations and maintenance over the life of the plant. Investments in nuclear power provide a way to introduce large increments of electrical capacity, diversify fuel sources to reduce dependence on coal, oil and gas, and cut the impact of generating power from hydro potential and fossil fuels on the local or global environment. These are many reasons why a prospective host nation and other nations around the world may be attracted by nuclear power generation. In advancing this viewpoint, the specific problems for nuclear power of long-term waste disposal and high construction costs should not be overlooked.

2. FINANCIER'S PERSPECTIVE

From a financier's viewpoint, and by financiers it is generally meant providers of long-term debt financing, a nuclear investment project should not demand special treatment relative to other types of investments. Investments are subject to a common risk/reward standard since finance is globally fungible. Attractive investments are those in which all risks are secured, shared, assigned, compensated or allocated efficiently and where the returns over time appear commensurate with risk and at least comparable with returns from alternative investment opportunities that carry similar financial risk.

Ideally, financiers would neither favour nor penalise a nuclear project because it is nuclear, but examine the economic strength of the project and base a decision about their involvement on the expected returns in relation to the perceived risk. They would support only projects that conform to the relevant national and international regulations and conventions. In today's economic and political climate it is usually difficult for nuclear power investments to satisfy lenders on this score, but this is not a problem unique to nuclear power investments. However, financiers are in fact not always unbiased about nuclear power. Some lending institutions, particularly multi-laterals, have particular policy requirements about lending for nuclear power that reflect pressure from their shareholders, who in turn may react to popular attitudes towards nuclear power. Meanwhile some governments and government institutions may offer preferential terms, often for reasons other than strict financial ones. Again, nuclear power is not unique in these respects.

3. THE CHALLENGE FOR FINANCING NUCLEAR POWER PROJECTS

The challenge for financing nuclear power projects should not be regarded as one of finding "innovative financial arrangements" that somehow soften market-driven requirements. Instead, the challenge is to ensure that all risks are carried in the appropriate places and all sources of earnings and support for operations are secured over the life of the project. For this reason we have concentrated on underlying principles and have not attempted to look in any detail at particular examples; these can be found in the excellent IAEA Technical Report 353, "Financing Arrangements for Nuclear Power Projects in Developing Countries".

No financier readily invests in open-ended liabilities. Defining and securing risk is always a key factor in attracting investment, on a par with securing the project's revenue stream. Risks to be secured include completion, currency, market and financing risks, to name a crucial few. From a financial viewpoint, even an individual nuclear power project represents a much larger capital investment than alternative power projects - with the possible exception of the very largest hydroelectric schemes. Nuclear power and hydroelectric projects concentrate the financial risk in the projects themselves, whilst power plants fuelled by oil, gas or coal divide this risk by requiring substantial capital investment in upstream fuel supply facilities. The risk involved in such large investments, compared to the demand on an investor's resources, can be daunting. For this reason, to spread the risks and financial obligations, such projects are often financed by consortia of investors and banks.

A nuclear project also imposes special requirements on the physical, industrial and regulatory infrastructure of the host country. It has a planning, construction and licensing lead time and operating lifetime much longer than normal for industrial and power plant investments. Single plant programs face the additional challenges of carrying all the overhead costs and diseconomies of "prototype" investment even where a "standard" design is adopted. No wonder financing is seen as a major barrier for nuclear projects, and the challenge is to turn these projects into competitively attractive investments.

The paper approaches this task constructively by asking:

– What, from a financier's viewpoint, is "ideal"?
– How can such an ideal be approached in the real world?

The short answer is simple. The ideal is that the financier is confident that it has a complete picture of the project, it has accounted for every source of cost, risk and future earnings potential, and it is confident that the investment is competitive in the market into which the product will be traded, at least up to the time when the financier's interest in the project ceases. Frankly, this applies to every provider of funds, be it lenders, shareholders in companies involved in the project, governments, insurers and the customers for the product who do not wish to pay premium prices.

To apply these investment principles to nuclear power, investors must be reasonably secure that power generated will be priced to cover the costs of plant investment and operations. At the same time, they must be secure that power can be sold competitively in quantities sufficient to guarantee a financially viable revenue stream, even in more liberalised electricity markets. While the failure to price power adequately is not unique to nuclear power, the capital intensive nature of the nuclear plant tends to exacerbate this problem for investors.

The working assumption for this paper is that in today's energy market, nuclear power projects fall short of this ideal when examined in open competition with power projects fuelled by oil, gas or coal. Even small scale renewable systems, while arguably even more capital intensive than nuclear on a $/lifetime megawatt hour (MW(h)) basis, are easier to finance because of the dispersion of risk obtained from small cost increments and minimal infrastructure requirements. Moreover, especially in smaller economies and developing countries, there may be problems matching plant capacity with grid capacity and demand. Large single increments of power, such as those associated with nuclear power plants, can be disproportionate to transmission and load following capabilities in these countries.

There is the further assumption that financing of nuclear power by the host nation is generally not practical. Governments are increasingly incapable of simply underwriting investments without considering the quality and risk/return potential of such investments. Under these circumstances, host governments must ensure that they and sponsors of nuclear power projects meet a number of requirements – political, financial, market, regulatory, and commercial – to create the conditions for financing.

4. OPTIONS FOR THE REAL WORLD

The way ahead lies in three inter-related areas:

First, many requirements must be met for a nuclear project even to be considered for financing. These include steps to meet national political and regulatory requirements and to gain international approvals to minimise safety, regulatory and political risks to the project and long term operation of the plant. This includes assurance that future operators are capable of maintaining the plant in a fully licensable and operable state.

Second, doing everything to ensure that project costs are minimised and that risks to the costs and programme to complete the project are fully discharged by the constructors.

Third, doing everything to secure the income for the project's output. It is legitimate to provide the necessary guarantees so long as the measures taken have political and public support and will endure, are completely transparent, and do not remove the scope for competition in the power market. In general, the result must be the removal of both non-commercial volume and price risks in the supply market that arise from interference in the power market or from future changes in government or political priorities. The complexity of the management and financing arrangements for most large projects reflects the fact that those involved depend on each part of the arrangement functioning effectively. One failure, one uncovered risk that becomes material, and everyone can lose.

5. WHO LEADS?

The next key question is how are the responsibilities for securing the environment within which a nuclear project can be financed divided? We propose that any specific issue can be addressed from within a simple rule base.

Rule 1 - Financiers are not responsible for the success of the project! The financier's responsibilities are to uphold banking principles, notably that the expected returns are commensurate with the objectives of the bank and its attitude to risk.

Rule 2 - Project risks should always be carried by those who should be managing them at least cost, even if they must be paid to do so. For example, the completion risk to within cost and schedule of construction should be the sole responsibility of a general contractor under a competitively awarded turnkey contract.

Rule 3 - Project sponsors should engage those parties who consider themselves to be affected by a nuclear power project, whether inside or outside the country of the project, in a dialogue concerning the rationale (economic, safety) behind the proposed investment and the impact of the project on local communities.

Rule 4 - Every aspect of the project should be transparent – especially to the financiers.

6. REGULATORY REQUIREMENTS

While financing nuclear projects may exceed the capability of most governments, they bear responsibility for the context in which viable investments can be made with reasonable assurance of success. This includes providing a sound regulatory structure, and assurances against arbitrary changes in the regulations in a number of pertinent areas. Governments' vital regulatory responsibilities for financing nuclear power projects would thus include the following:

6.1. Market

Government is responsible for establishing an impartial regulatory framework for power purchases and pricing in the national power market, and applying consistent taxation and other policies. Government must make the rules clear, transparent and enduring and must keep the regulator of the power market as free as possible from political interference.

6.2. Safety and environment

Government is responsible for negotiating appropriate environmental compliance arrangements with project sponsors. They are also responsible for obtaining approvals and co-operation from the national community and international community and agencies. The safety regime should closely match that which is established in nations likely to provide designs, equipment, project and operational support. Government should require comprehensive safety-related infrastructure for its plants, access to relevant technology and research, training for regulatory staff and links to the international regulatory community to share experience and secure assistance. The safety regime should be clearly mandated, very powerful and independent of political influence, but accountable for the way in which it discharges its responsibilities.

6.3 Safeguards

If international finance and technology transfer is required, safeguards for non-proliferation are essential. This is non-negotiable. Government must fully accept commitments under international treaties and observe these requirements, and must impose the consequent duties on all involved under its jurisdiction.

6.4. Externalities impacting in the market

All externalities associated with the construction and operation of a nuclear power plant, deemed of sufficient national significance to affect power prices and market arrangements, are the responsibility of the host government. This includes environmental taxes or levies, tax incentives, and support for long term issues such as waste management. Other responsibilities of the government are features or concerns that are not externalities but are considered of national interest, such as linked deals for inward investment or technology transfer where the value extends beyond the particular project but represents an assured material benefit to the project and the country. In all cases the actions and the costs should be transparent, and be administered by regulators independent of short term changes in political or public mood. Contractors and financiers will seek guarantees that the regime negotiated and established for the project will have a known minimum lifetime.

6.5. Payment

In general, financiers wish to avoid reliance on payments from government budgets except where such payments are covered by a suitable bond or insurance.

7. CONCLUSION

Nuclear power can be and has been financed by world capital markets, so this is not the issue. The crucial question is whether host governments and interested utilities are willing to take the steps required to attract investment, and whether the nuclear industry is willing and able to become competitive in increasingly deregulated financial and energy markets.

PROJECTED COST COMPARISON OF NUCLEAR ELECTRICITY

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Abstract

Comparison of electricity generation costs has been done in the late years through a large co-operation between several organisations. The studies are aiming to provide reliable comparison of electricity generating costs of nuclear and conventional base load power plants. This paper includes the result of the joint IAEA/OECD study published in 1997.

1. INTRODUCTION

Since 1983 the IAEA has co-operated with the Nuclear Energy Agency (NEA) of OECD in a series of comparative studies on “Projected Costs of Generating Electricity”. The International Energy Agency (IEA) of OECD, the International Union of Producers and Distributors of Electrical Energy (UNIPEDE) and European Commission, have also joined in these studies. The fifth study (update 1997) has been implemented recently and the report of this study will be published shortly by the OECD/NEA.

The studies are aiming to provide reliable comparisons of electricity generating costs of nuclear and conventional base load power plants that can be expected to be commercialised on the horizon of 10-15 years. The 1997 study mainly includes advanced coal-fired, combined cycle gas-fired, and nuclear power (PWR, BWR and PHWR) plants. Five non-OECD countries, under the auspices of the IAEA, and fourteen OECD countries have participated in the latest study.

2. COST COMPARISON OF ELECTRICITY GENERATION

For the cost comparison of different types of base load plants, the constant money, levelized lifetime cost methodology is employed. The common assumptions for a reference case and sensitivity analyses are adopted by the expert group, as shown in Table I.

All costs are expressed in constant money terms and converted from the national currencies to US dollars by the exchange rates of the cost reference date, 1st July 1996. Since exchange rates do not necessarily reflect purchase power parities and might fluctuate over-time, it would be misleading to compare costs between countries. The cost comparisons between nuclear and fossil-fired power plants within each country are much more meaningful in the study.

For the reference case (currency in US $ of July 1, 1996 plant economic lifetime is 40 years and load factor 75%), the projected levelized electricity generation costs ranges, as shown in Table II, are considerably wide for nuclear, coal and gas fired power plants.

TABLE I. BASIC PARAMETERS FOR COST COMPARISON

Parameters	Values
Cost reference date	US dollar of 1st July 1996
Discount rate	5% and 10% p.a.
Date of commissioning	1st January 2005
Economic lifetime of plants	Reference 40 years Variants 30 and 25 years
Load factor	Reference 75% Variants 65% and 80%

The wide ranges of the cost variations are resulted from variations of plant design, plant size, multiple unit site, series production, labour costs and exchange rate volatility in different countries. At 5% and 10% p.a. discount rates the generation costs are shown in Figures 1 and 2. The study has shown that nuclear power is economically competitive with its alternatives in many countries and regions, in particular when 5% of discount rate is applied. The competitiveness of nuclear power is sensitive to the discount rate, fossil fuel price and policy decision concerning environmental standards and regulations in the countries.

At the low discount rate (5%), nuclear power is the preferred option in many countries that provide nuclear cost data for the study, with the exception of Finland and the United States, and the regions where cheap gas is available, like in Brazil and Turkey.

At the high discount rate (10%), nuclear power loses much of its competitive advantage in many countries, since nuclear power is highly capital intensive. The results show that nuclear power continues to be the cheapest base load electricity generation compared with coal and gas fired power plants, only in France, and in some compared types of plants in China, Japan and Russia. At the high discount rate, the gas fired plants (CCGT), which is least capital intensive among the three options, are the cheapest option against nuclear and coal fired plants in most countries. The significant technological development of gas fired power generation (e.g., high thermal efficiency) and recent low gas price have offered the economic advantage.

3. MAIN FACTORS INFLUENCING THE GENERATION COST

The sensitivity analysis of the electricity generation costs are carried out in the study to investigate the main factors influencing the generation cost.

3.1. Discount rate

The calculation of levelized electricity generation costs is very sensitive to the adopted economic parameters, e.g. discount rate. A lower discount rate is favourable to the more capital intensive options with long construction period, like nuclear power plant, while a higher discount rate favours low capital cost options, like gas fired plants. The high discount rate reflects both the scarcity of capital and the much larger profitability of new investment projects that compete for limited financial resources. The intensive capital costs of nuclear power make it less attractive to many developing countries which lack of investment capital.

TABLE II. RANGES OF PROJECTED GENERATION COSTS

		Nuclear		Coal		Gas	
Discount rate	%	5	10	5	10	5	10
Construction cost	US$/kW(e)	1020 - 2520		770 - 2560		400 - 1640	
Investment cost	US$/kW(e)	1400 - 2800	1700 - 3100	1000 - 2740	1100 - 2930	440 - 1700	470 - 1770
Levelized							
Investment cost	mills/kWh	12 - 25	26 - 48	9 - 24	16 - 45	4 - 15	7 - 27
O & M cost	mills/kWh	4.5 - 17	4.5 - 17	3 - 13	3 - 13	1 - 11	1 - 11
Fuel Cost	mills/kWh	2.3 - 16	2.3 - 15	9 - 40	9 - 38	18 - 56	17 - 50
Electricity generation cost	mills/kWh	25 - 57	39 - 80	25 - 56	35 - 76	27 - 79	27 - 84

Note: US $ of 1.7.1996

40 years economic lifetime, 75% load factor

most of coal plants equipped with FGD, a few with deNOx

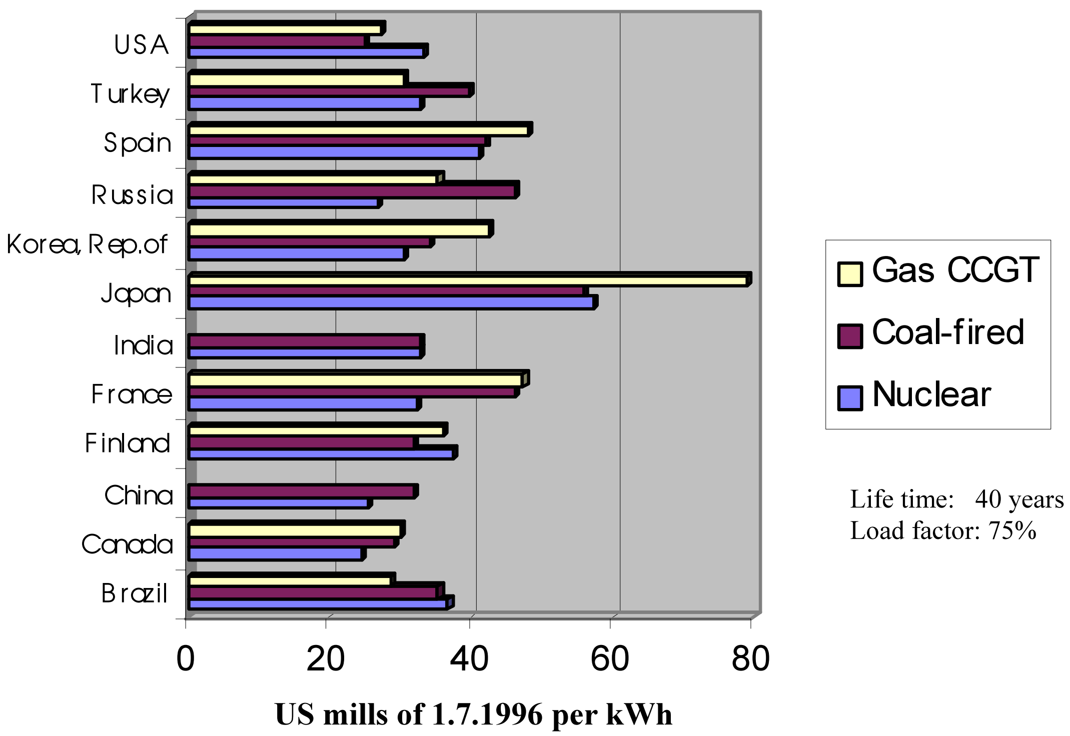

FIG. 1. Projected costs of generating electricity from nuclear and conventional power plants (Discount Rate 5%).

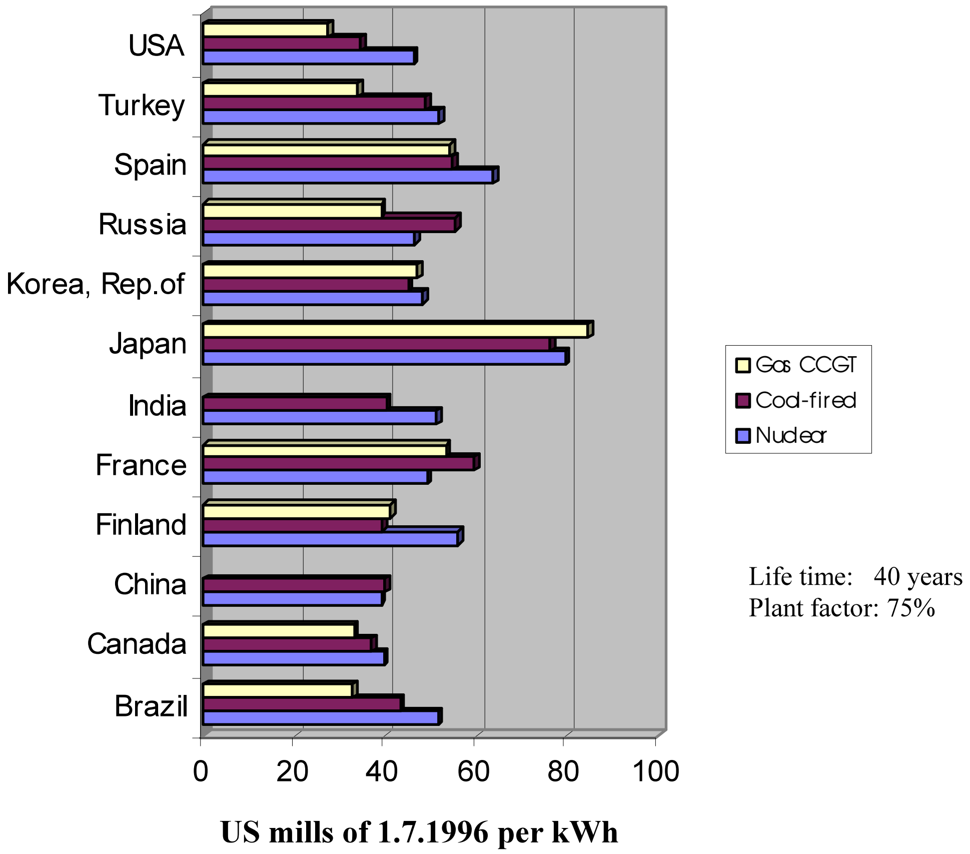

FIG. 2. Projected costs of generating electricity from nuclear and conventional power plants (Discount Rate 10%).

The discount rate may be set by Government policy concerning the national economic situation, financing resource and capital markets. It reflects the opportunity cost of money to a particular investor or in a particular country. In the view of project assessment, the choice of the discount rate is an important consideration by decision makers and policy analysts.

3.2. Plant economic lifetime

The plant economic lifetime is another sensitive economic parameter in the calculation for which period the cost levelization would be carried out. Based on technical performance and progress of nuclear and other base load power plants, the economic lifetime of 40 years has been agreed upon by the Expert Group of the study as a fundamental assumption for the levelized cost calculation. The sensitivity analysis was carried out for the case of lifetime of 25 and 30 years. Since nuclear power is characterised with capital intensive and low fuel cost, the longer economic lifetime is far more favourable, and, results in the decrease of levelized generation costs, as shown in Table III for the case of Finland, France and the Republic of Korea, as an example. In contrast, if longer lifetime requires extensive refurbishment costs or escalated fuel price in the long term, such as the case of gas fired power plants, increasing the economic lifetime has not much influence on levelized generation costs, as shown in this Table III.

TABLE III. EFFECT OF PLANT ECONOMIC LIFETIME ON GENERATION COSTS (mills/kWh) (DISCOUNT RATE 5%; LOAD FACTOR 75%)

Country	Type	Lifetime		Cost change
		25 years	40 years	
Finland	Nuclear	42.03	37.28	11.3%
	Coal	33.68	31.82	5.5%
	Gas	37.22	35.92	3.5%
France	Nuclear	36.33	32.24	11.3%
	Coal	49.37	46.38	6%
	Gas	49.16	47.42	3.5%
Korea	Nuclear	34.34	30.70	10.6%
	Coal	36.86	34.40	6.7%
	Gas	43.77	42.52	3%

3.3. Load factor

Improving plant performance by increasing plant load factor is an important means to reduce levelized generation costs, in particular, for capital intensive nuclear power plants. The results of the study show that when the load factor increases from 65% to 80%, the levelized generation costs could decrease by about 15% for nuclear, 10% for coal fired and 6% for gas fired plants, as shown in Table IV. The result suggest that nuclear generation with high availability is preferred as base load option and gas fired plants could offer the choice for peak load generation.

TABLE IV. EFFECT OF PLANT LOAD FACTOR ON GENERATION COSTS (mills/kWh) (DISCOUNT RATE 5%; LIFETIME 30 YEARS)

Country	Type	Load Factor		Cost change
		65%	80%	
Finland	Nuclear	44.59	37.88	15%
	Coal	35.53	31.71	10.7%
	Gas	39.20	35.57	9.3%
France	Nuclear	38.29	32.85	14.2%
	Coal	51.70	46.47	10%
	Gas	50.31	47.55	5.5%
Korea	Nuclear	36.81	30.95	16%
	Coal	38.78	34.47	11%
	Gas	44.63	42.61	4.5%

3.4. Fuel price

The cost comparison of electricity generation is heavily dependant on fuel prices and price escalation. It should be noted that electricity generation costs of fossil fired power plants are very sensitive to fossil fuel price escalation since the fuel costs account for 65-80% (for gas) or 50-65% (for coal) of total generation costs. The uncertainty and any fluctuations in gas price and availability should be taken into account for long term planning of electrical generating system expansion.

4. CONCLUSIONS

In view of comparison of electricity generation costs, the projected cost study has shown that nuclear power is economically competitive with other base load electricity generations in many countries and regions. The competitiveness of nuclear power, however, is very sensitive to local circumstances, such as technical, economic and environmental situations, as well as political policy. The economic comparisons of nuclear and fossil fired power plants differ from country to country, or even from region to region in a country. A number of economic parameters, such as discount rates and fossil fuel prices have a strong influence on the generation costs. The generation costs presented in this study do not include external costs which are raised from full fuel chain activities and other impacts on health, property, environment and climate. It is reported that nuclear industry in OECD countries has largely “internalised” such external costs through the adoption of strict emission and safety standards - the costs of which are reflected in its capital, fuel, operational costs and decommissioning costs. Concerning the global emission control, in particular $C0_2$ emission, carbon taxes have been variously applied or proposed in many countries. Such taxes would boost the costs of fossil fired electricity generation, making nuclear power an even more favourable option.

The economics of nuclear power is one of the most important factors for decision making to implement a nuclear power programme. A comprehensive comparative assessment, however, would be carried out to consider the technologies, economics, environmental and health impacts, and political and social issues. Among these aspects, projection of energy demand, resource availability, energy security, financing resource, industrial infrastructure and environment protection would be deliberated for national sustainable development. Nuclear power can be an important contributor to sustainable energy development in many parts of the world in the longer run.

IMPROVING THE ECONOMIC COMPETITIVENESS OF NUCLEAR POWER

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Abstract

This paper focuses on the new nuclear power plants in the economic competition framework, addressing the main issues to increase nuclear power competitiveness over other energy options.

1. BACKGROUND

There are more than 400 nuclear power plants in operation around the world. These can be divided into three broad categories:

a) Those whose capital cost was incurred some time ago, whose operating costs are in the normal range, and who do not anticipate major capital additions in the near future. Such plants can be economically competitive with any alternative.

b) Those built in countries and regions without access to pipeline natural gas. These can be competitive with alternatives other than pipeline gas.

c) Those not meeting the economic competition and will be shut down, or may be operated for strategic reasons.

While some of these existing plants are located in developing countries, it is not the intent of this paper to address the economics of these plants, but rather to focus on new plants.

Nuclear power will be important to developing countries mainly for the production of energy, and particularly electricity. Some plants may be built for desalination or as combined cycle units.

To put nuclear power in the context of global energy supply and demand, we note that, by the middle of the next century, global energy demand is expected to increase by at least a factor of two, and more likely by a factor of three. Most of this increase will be in developing countries. Developing countries are currently increasing their energy consumption by more than 5% per year. This trend will continue as long as these countries continue to expand their economies and improve the living standards of their citizens.

With current energy patterns in both the industrialized world and developing countries, most energy comes from fossil fuels. Thus, carbon dioxide emissions to the atmosphere follow the increase in energy consumption, and are also growing rapidly. Developing countries now account for one third of the global emissions. Nuclear power could fill some of the growing demand, while helping to limit carbon dioxide emissions.

However, the role of nuclear power in satisfying energy demand will depend strongly upon its economic competitiveness. To play a realistic part in global energy supply, nuclear power would need to achieve a significant market share; a reasonable target might be 30%.

This alone would by no means be adequate to meet the global carbon dioxide emission targets set in the Kyoto Protocol of 1997. It would still leave an enormous challenge for renewables to increase their commercial market share from the present insignificant level to more than 40% of global energy supply. Achieving a 30% market share for nuclear power is a formidable challenge. It would require the construction of several new plants every week for the next fifty years. While this is feasible industrially, it will not happen unless the new nuclear plants are economically competitive.

2. ECONOMIC COMPETITION

In most economic situations, new plants must compete with the most attractive alternatives. Developing countries cannot afford to pay a premium to use nuclear power. Economic competition varies regionally; in some areas it is cheap coal, in many areas with access to pipeline natural gas, the competition for electricity generation is from combined cycle gas turbines. Where pipeline gas is not available, liquified natural gas may be used, but at higher costs than pipeline gas.

Nuclear energy can be regarded as machine-made energy, and like other machine-made energy forms, it is capital intensive and relatively cheap to fuel and operate. Other examples are hydroelectric plants, solar systems and windmills. By contrast, systems using energy from the combustion of fossil fuels, are cheap to build, but very sensitive to fuel costs. Uranium prices could increase significantly before a severe economic penalty would occur in nuclear fueling cost. Thus, improving the economic competitiveness must focus primarily on reducing capital cost.

3. THE CHALLENGE: REDUCE NUCLEAR CAPITAL COST

The sheer magnitude of the nuclear capacity required to help the developing countries become energy-sufficient offers not only challenges, but also enormous opportunities for new approaches to competitiveness. First and foremost, a fresh focus is needed to introduce manufacturing technology into the design and manufacture of nuclear plants. Today, the nuclear industry is at a stage in its evolution comparable to the automobile industry at the time Henry Ford introduced manufacturing technology to that industry. Like the old automobile industry, today we have many models that work well, however, they have been built one or two at a time rather than manufactured. And they are not engineered for factory production.

Size is important. It is unlikely that developing countries will need plants greater than 1000 MW(e) for several decades. At the other end of the scale, numerous studies show that it is difficult to reduce costs sufficiently for plants to be economic in size ranges below 500 MW(e), using traditional construction methods. It seems likely then, that the focus will be on plants in the 500 to 1000 MW(e) class. This leads to a potential market of about 5000 plants of the 1000 MW(e) class, or 10,000 plants of the 500 MW(e) class by the middle of the next century. At this level there is enormous scope for capital cost-saving through mass production.

An enormous incentive remains to develop factory-manufactured smaller reactors, for example, of 100 MW(e) or less, that could compete by the sheer volume of production. A production rate of one or two units per day could meet the eventual target of 30%. Such a production rate is already being achieved globally in the commercial aircraft industry, which also produces large, high technology, capital intensive products. These plants must be virtually self regulating, with automatic startup, and hands-off operation, to reduce operating costs and to assure an appropriate level of safety. Studies of this approach are underway in American universities under an initiative of the American Nuclear Society.

4. STRATEGIES FOR DEPLOYMENT OF NEW POWER PLANTS

There are numerous possible avenues towards achieving a substantial market share for nuclear power. Outlined below is a series of factors that taken together could achieve a highly competitive situation in the shortest time. Practicalities, the availability of capital for launching the initiatives and concerns of national sovereignty over issues such as regulation may well stretch out the time-scale.

4.1. Standardize products

The benefits of mass production can be achieved only if there is sufficient volume. Thus, standardization on one or two designs is important; this could be achieved more easily if electricity producers of the developing countries define their requirements and produce a joint specification meeting all their collective needs. Based on this specification, international consortia of vendors could design competing units for global application. The consortia should have vendor companies from industrialized countries produce the engineering and high technology components, with companies from developing countries to manufacture most other components and assemble the plants.

Smaller units, if competitive, may have advantages in requiring less infrastructure for transmission facilities initially where the load centers are smaller. The move to larger sizes could be made as the load grows and infrastructure develops.

Consideration should be given to the pros and cons of adapting existing water-cooled reactor designs (PWR, BWR, CANDU), or branching out into new designs with greater long term promise, for example, high temperature gas-cooled reactors with integral gas turbines.

Special consideration should be given to barge mounted plants, factory-assembled and towed to the operating site. There they can be operated as floating plants offshore or towed into a prepared bay, sunk to the ocean floor, and back-filled to give a land-based plant.

Detailed analysis should evaluate the relative costs of manufacturing say, 70 plants per year at 1500 MW(e) each, versus more than 1000 plants per year at 100 MW(e) each.

Similarly, regulatory authorities of the world should agree on licensing criteria for the new nuclear units based on the electricity producers requirements. Using these criteria, the vendors consortia could apply for type-licenses for the new units in all developing countries.

4.2. Localize component manufacture

As in other global industries, such as automobile and aircraft manufacture, factories manufacturing components should be distributed as widely as practical, in light of the need to assemble plants at a few selected sites that can serve large geographic regions. This allows the development and growth of local industry, while achieving the standardization necessary for cost reduction.

The developing countries can benefit directly from the expansion of nuclear power facilities, by having a role in component manufacturing, thus contributing to their own projects and to their industrial development. The developing countries can then earn foreign currency producing the components for other countries as well as for their own.

4.3. Assemble plants regionally

A few strategically placed assembly plants could serve large areas such as the North Pacific, South Pacific, North Atlantic, etc.,. These would ideally be located with ocean access so special oceangoing transportation systems can transport large, factory-assembled modules to the plant sites, which insofar as possible, would also be readily accessible to the ocean.

5. OPERATIONAL FEATURES

Success in the use of nuclear power involves not only competitive capital costs, but cost-efficient operation and servicing. Major cost advantages can be achieved by focusing resources on servicing many plants from one or more centralized locations, which are set up to provide rapid refueling and service to many standardized plants.

- Regional Training Facilities Regional training facilities with simulators for the NPP models being built can serve a number of electricity producers, countries and regions. This can ensure uniformly high standards of training and refresher courses, and save costs relative to local training.
- Regional Refueling and Servicing Facilities Refueling for the plants can be designed for routine refueling on a two- to five-year cycle. The refueling service could be fulfilled through international companies equipped to provide it on a schedule for many different plants.
- Regional Fuel Fabrication Facilities Electricity producers or countries participating could invest in joint fuel fabrication facilities, as an alternative to buying fuel services.
- Regional Spent Fuel Facilities While of secondary importance to establishing nuclear generating stations, planning could be done for regional spent fuel facilities, to receive and store spent fuel until it is economic to reprocess and recycle plutonium, either in MOX fuel or in fast reactor fuel. In the meantime, regional spent fuel storage facilities can reduce costs, relieve local operators of the responsibility for managing spent fuel, and facilitate international safeguards. The storage could be owned by a consortium of the electricity producers generating the fuel, and be operated by the consortium, either directly or on contract to an organization to manage and store the spent fuel.

THE FRENCH EXPERIENCE IN NUCLEAR ENERGY: REASONS FOR SUCCESS

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Abstract

Nuclear energy for France represents a viable option in meeting energy demands in the near and medium terms due to few energy resources and dependency on imported oil. Basic decisions to launch the French nuclear program, successive series of PWRs installed and standardization due to technical progress are highlighted in this paper.

1. FRENCH NUCLEAR PROGRAM

After the oil crisis of 1973, French Authorities elected to adopt nuclear energy on a wide scale since France has few energy resources and was heavily dependent on imported energy, especially oil. But, to avoid escaping from one dependency only to fall into another, the authorities insisted on French control of all the aspects of development, from the entire fuel cycle, to the design, construction, and operation of nuclear power plants.

Basic decisions made to launch the French nuclear program were:

– To build a large number of plants employing a single technology. After experimenting with several types of reactor (gas graphite, heavy water, light water), Electricité de France (EDF) selected the PWR technology as the ideal model.
– To mobilize the necessary industrial capabilities and concentrate them in the hands of only a few participants: these participants were given long term objectives and assured of the continuity of the program. In response, they invested in human resources and industrial facilities necessary to ensure the success of the program.
– To establish a complete and consistent set of codes and standards to facilitate regulation.
– Finally, to develop the programme through series of identical units, to benefit from the standardization.
– A license agreement was signed between Framatome and Westinghouse for the Nuclear Steam Supply System (NSSS).

However, standardization does not mean frozen technology and a stepwise evolution was chosen, each step corresponding to an updated standard incorporating improvements due to technical progress and experience.

The successive series of PWRs installed in France were:

(i) The 900 MW(e) series (three loops);

– This series based on a twin-unit configuration was initiated by 2 units at Fessenheim and 4 units at Bugey contracted for in 1970 and 1971, before major expansion of the nuclear program.

- The first «program contract» (CP1) was signed in 1974 for 18 practically identical units, the only differences being due to the site conditions.
- The second multi-unit contract (CP2) was signed in 1976 for 10 units identical to the CP1 units except for the turbine hall, which is laid out axially instead of transversely, with respect to the reactor building.

(ii) The 1300 MW(e) series (four loops);

- The program continued with the signing of contracts in 1977 and 1979 for 20, more-powerful units of the 1300 MW(e) class including:
- 8 units of the P4 type
- 12 units of the P4 type, similar to the P4 but with a reduction in the size of the buildings, as a result of civil works optimization.

(iii) The 1450 MW(e) series (four loops);

- Four units of this N4 series have been ordered. They correspond to the latest development of French technology, with a completely French design and new types of steam generator, reactor coolant pump and turbine. The first two (Chooz B1 and B2) were connected to the grid in 1996 and 1997 respectively. Civaux 1 was connected at the end of 1997. Civaux is expected to come into operation by the end of 1998.
- During this period a complete and convenient nuclear fuel industry from uranium mining, conversion and enrichment to spent fuel retreatment was also developed.
- In brief, the French nuclear power program today is leading to gratifying results: 57 PWR units are in operation and 1 unit is under construction. About 75% of French electricity is produced by nuclear power with an availability factor above 80% and with a high degree of safety.
- Moreover, 9 units or nuclear islands, directly derived from the 900 MW(e) series have been exported by French nuclear industry, and are now in operation in Belgium, South Africa, Korea and China. Two other units of the same class were ordered by China at the beginning of 1996.
- Figure 1 shows the construction program with coupling dates of the French and exported nuclear units for the 27 last years.

2. ECONOMIC ACHIEVEMENT

2.1. Standardization

The key word for nuclear competition is "STANDARDIZATION". In fact, it is a series effect allowing such standardization and resulting from the continuity, extent and rhythm of the program and from multiple units siting.

A standardized design reduces engineering costs, licensing problems, equipment prices, construction time and site costs. The standardization of components avoids delays in procurement and on site installation and more generally, the risks and contingencies are significantly decreased with the number of identical units.

According to the French experience, practically all the benefits of standardization are obtained with series of about 10 units. Another factor of cost reduction is size of units. As mentioned, the successive series of PWRs built in France are in the range of 900 MW(e), then

1300 MW(e) and now 1450 MW(e). A few years ago, an EDF study showed that for the same total output, a series of 1450 MW(e) units would be about 15% cheaper than a larger series of 600 MW(e) units constructed in the same 10 year period.

The benefits of standardization are:

- Easier relationships with the Authorities;
- Minimized technical risks;
- Extensive research and development;
- Concentration of means and tools;
- Controlled backfitting of improvements;
- Reduction in design, manufacture, erection and commissioning durations and costs;
- Improvement of plant operation;
- Easier management and reduction of spare parts;
- Easier maintenance;
- Maximizing experience feedback.

The French nuclear program is schematically shown below:

- 600 reactor years of cumulative operating experience;
- 80% 0f the electricity generated in France;
- Availability factor above 80%;
- Full mastering of all engineering and manufacturing activities;
- Continuity Constant improvement through experience and modern technologies;
- 220 steam generators, 220 reactor coolant pumps, 70 reactor vessels, 10 000 fuel assemblies.

This lead to:

- good public acceptance;
- excellent safety results;
- economical competitivity;
- reliable long term partner for international cooperation.

2.2. Financing of French nuclear program

Financing for the PWR program amounted to about half of EDF's investments over the last 20 years. The resulting debt is judged normal for a large utility like EDF, which has replaced all of its power plants and dealt with a large increase in electricity demand during the same period.

Out of the total nuclear program amount (about 400 billion French francs excluding interest during construction), 50% was self-financed, 8% was directly financed by the State owner of EDF and the remaining 42% was financed through loans in France or on the international market. Such loans benefited of French Government guarantees.

In 1988, medium and long- term debts totaled 230 billion French francs. Now its debt is decreasing yearly and by the end of 1997, the EDF debt, essentially due to the nuclear program was 126 billion French francs, corresponding to 68% of its sales revenue and the debt interest of 3% of the sales revenue.

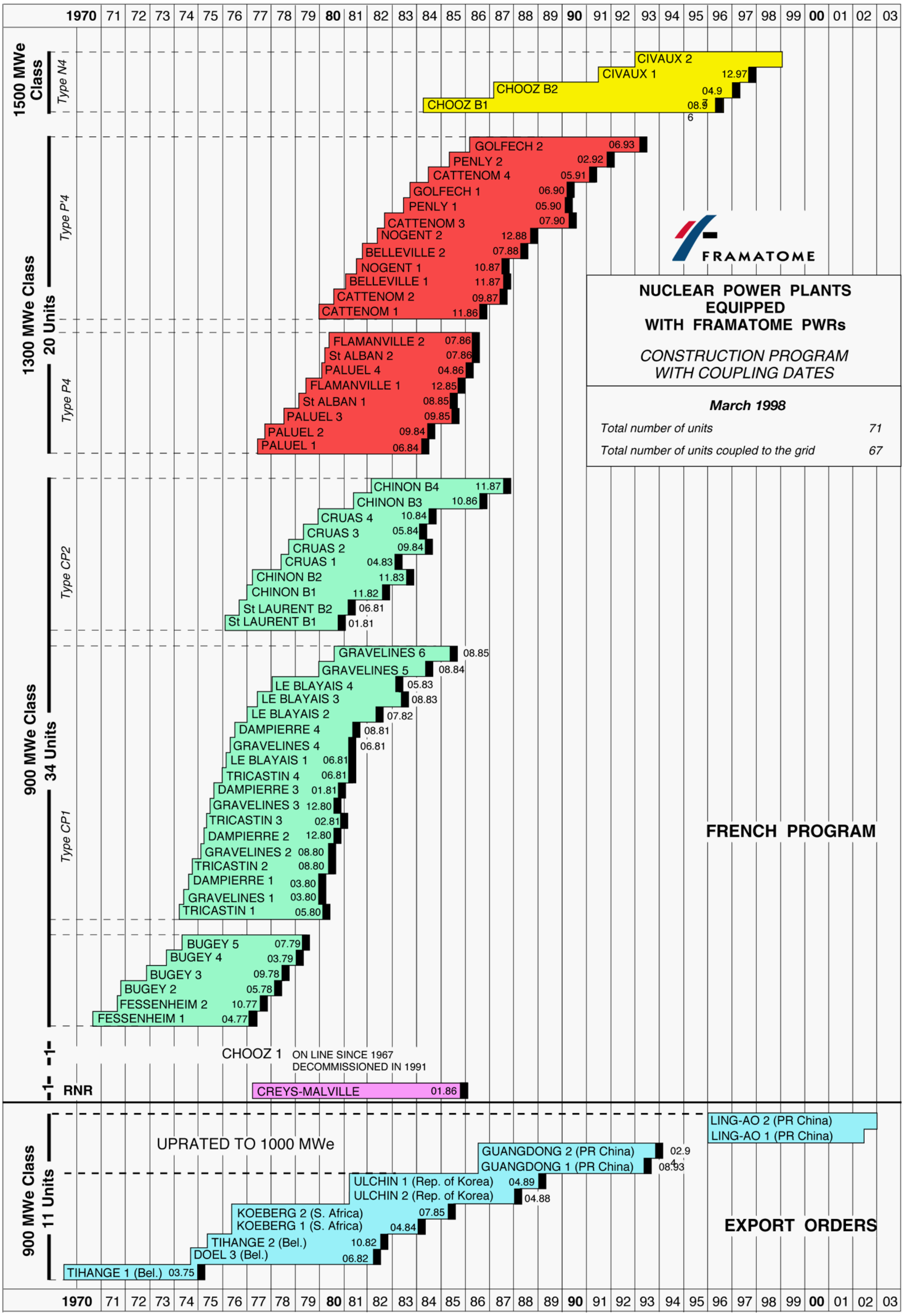

FIG. 1. Construction program with coupling dates of the French and exported nuclear units for the 27 last years.

TABLE I. BASE LOAD GENERATION COSTS IN FRANCE

	NUCLEAR	**GAS**	**COAL**
PLANT (MW)	2x1450	2x650	2x600
YEAR OF COD	2005	2005	2005
OVERNIGHT COST (FRF/KW)	8700	3950	7150
INVESTMENT COST (FRF/KW)	**11020**	**4370**	**8290**
LOAD FACTOR (%)	85	90	90
ECONOMIC LIFETIME (YEARS)	30	25	30
GENERATION COSTS (FRFcents/KWH)			
INVESTMENT	12.7	4.9	8.9
O & M	3.4	2.2	4.5
FUEL	4,3/4,8	12,0/21,1	8,8/12,9
TOTAL	**20,7/21,2**	**19,1/28,2**	**22,2/26,3**
FUEL ASSUMPTIONS	*20/25$/lbU3O8*	*2/3,9 $/M BTU*	*40/50 $/T CIF*
USD/FRF EXCHANGE RATE	*5/6,5*	*5/6,5*	*5/6,5*

3. WHAT FUTURE FOR NUCLEAR IN FRANCE?

Today, thanks to the amortization of most of the nuclear units into service, EDF can deliver low cost electricity to its customers; its goal is to maintain nuclear power plants in service as long as possible.

When the time comes to renew the park, nuclear power plants will compete with gas or coal-fired units. About every three years the French ministry of electricity issues a report giving the "reference costs" for units to be implemented in the future. The last report - DIGEC 97 - shows that, although coal and gas may challenge nuclear in some cases due to low fuel costs, nuclear energy remains a solid option (see Table I). It is up to all French nuclear actors to prepare now the nuclear units of the future to keep their costs (investment, O & M, fuel) as low as possible.

THE PROBLEMS OF FINANCING A NUCLEAR PROGRAMME IN DEVELOPING COUNTRIES

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Abstract

In the free market and deregulation framework financing of nuclear power in developing countries requires solutions different from those applied in the seventies and eighties. The paper presents the financial specificity of nuclear power, project finance concept and the market risk.

1. INTRODUCTION

Whenever the question of financing a nuclear power station is put to a banker nowadays, the banker inevitably replies that he is "not comfortable with nuclear issues".

The result is that financing a nuclear power station or, harder still, a development programme based on nuclear energy, is now considered an exercise that is doomed to failure.

What is the reality of the situation? What solutions can be envisaged for the real problems? These are the questions this note seeks to answer.

2. THE SPECIFIC NATURE OF NUCLEAR ENERGY IN FINANCIAL TERMS

First we will attempt to define what makes the nuclear industry as such into a special category.

The highly capital-intensive nature of the industry, for example, inconvenient as it may be for the financier, is not specific: certain major hydro-electric projects carry costs per kW installed of the same order of magnitude.

In fact, there are only two features truly specific to the industry:

– construction time;
– safety-related questions.

The length of construction time required (of the order of 5 to 7 years) is considered essentially as a source of extra costs due to the interim interest charges on investment capital, but this is only an extended version of a phenomenon which affects other major construction projects, e.g. (once again) large dams.

In fact, the lengthy duration is also a result of the complexity of construction, which involves a large number of participants, and creates a further problem as regards the quality of work executed in the light of one real specific issue for nuclear energy: safety.

For the financier, safety-related problems are examined solely in economic and regulatory terms - and not technical or political - and may be distilled into two types of question:

- does the host country have a clearly defined legal framework to deal with safety issues in terms of standard-setting (by an independent body) and in terms of responsibility (party to international agreements)?
- how will the new demands of safety authorities be incorporated into the economic structure of the project?

Clearly, the answers to these questions cannot be provided solely by the industrial players involved in the programme: the authorities of the country concerned must also be involved, in order to guarantee the existence and continuation of a reliable system to deal with all safety-related issues. At this stage, there is no question of any financial guarantee as such.

3. NUCLEAR ENERGY AND PROJECT FINANCE

If financing a nuclear power station seems difficult, recourse to project finance is considered impossible. Why should this be?

First let us review the concept underlying project finance.

3.1. The principles

As it has expanded and met with success in the field of power generation, so project finance has become more a method of analysing transactions than a simple financing technique.

In essence, the idea is very simple: instead of financing the company behind the project, it is the project itself that receives the financing. The result is that it is not the solvency of the company which concerns the lender, but the capacity of the project itself to generate sufficient revenue to service the debt incurred in its financing.

Then an appropriate structure is set up, in particular through the creation of a legal structure (trustee) dedicated to the project, in order to isolate it from the risks associated with the company's other, pre-existing operations. At this stage, the project is no more than a set of contracts between the JV thus created and the various commercial partners (equipment and fuel suppliers, or service providers and buyers of the end product). The investor bases his assessment - and hence the cost at which he is willing to lend - on the quality of these contracts which, from his standpoint, are assessed in terms of the security of cash flow into the JV.

The cornerstone of this analysis is an assessment of the risks and how they are distributed between the players concerned: each risk identified must be assumed by the partner best equipped to deal with it (in technical terms). Any risk whose consequences are not fully assumed by one of the partners thus becomes the responsibility of the JV.

It is then for the investor to decide whether or not he is prepared to accept the resulting risk.

If the response is positive, the result is "pure" project finance: under no circumstances will the JV partners be called upon to make good any default by the JV on repayments to its bankers (non-recourse financing).

Clearly, experience shows that certain residual risks are not accepted by the banks, who demand that these risks should be covered by the JV shareholders (known as limited-recourse financing).

These principles have proved particularly appropriate to the financing of power stations in that, where deregulation has led to the creation of IPPs, project finance has proved the best response to the needs of new legal entities created from nothing.

Are these principles equally applicable to the nuclear industry? Clearly, there is no reason why not. Yet certain minor modifications are required in particular areas, reflecting the specific nature of the industry:

– control of operating costs
– completion of work

3.2. Cost control

Operating and maintenance costs call for little comment, but particular attention must be paid to the cost of fuel.

What options have been chosen for the downstream element of the fuel cycle (storage/reprocessing)? What is the resulting charge, present and future, to be borne by the company? Analysis here is a delicate matter: the answers frequently lie outside the professional scope of the company concerned, and are governed more by the industrial policy of each state.

In any event, however, an option must be selected, the organisations capable of implementing it clearly identified, and the contractual framework clarified, in order to measure the resulting financial flows.

Cases exist where the industrial decision on the downstream element of the cycle is still in abeyance when the investment decision has to be made. In such cases, it is imperative that a system of provisions be put in place to ensure that the JV can meet its liabilities under any circumstances.

A similar problem is posed by the question of decommissioning. The regulatory requirements, and hence costs, are not clearly defined and, here again, sufficient provisions must be set aside.

As we have seen, since both these questions depend on public bodies unconnected to the JV, the approval of the appropriate public authorities is also required.

3.3. Completion of work

The stumbling block for any project finance scheme is the question of guarantees of completion of work and of quality (cost, deadline, performance). Investors seek to obtain the maximum possible guarantees of proper completion: these are also guarantees of the project's capacity to generate the projected revenue, and the method employed is to transfer as much as possible of the risk to a solid and responsible legal entity, i.e. to the constructor, by means of a turnkey contract.

In this respect, however, the construction of a nuclear power plant requires a complex organisation and specialists feel that it is not desirable - for industrial reasons which it is not for us to expand upon here - that such a project should be built under a turnkey contract.

However, the need to analyse the role and responsibility of all concerned still remains, and it is essential to implement a contractual structure between all parties concerned (sponsor, assistant project manager, construction firms, assembly firms, designers, etc.) which ensures that each party assumes the risk related to the execution of the work for which each is responsible.

The exercise is difficult, but not impossible.

Even so, the convenience of the turnkey contract incites investors to insist that a sound legal entity should take overall responsibility for the completion of works, in order to protect their interests in the event of any dispute between the various partners mentioned above. The only viable solution is the creation of a temporary trusteeship by the partners in construction.

Here again, the exercise is difficult but not impossible.

3.4. Partial conclusion

On the industrial front - as long as each partner, including the authorities on questions of safety, plays his part to the full - the construction and operation of a nuclear facility may be structured in such a way as to meet the classic requirements of project finance. Still to be analysed, however, is the most delicate question of all: that of revenue, current and future, and hence market risk.

4. REVENUE AND MARKET RISK

Still following the logic of project finance, we must consider the fact that revenue is very dependent on the organisation and regulatory framework of the host country's electricity system.

We assume that the nuclear facility to be financed is competitive when measured against alternative sources of energy: the method of measuring competitiveness (least cost option) is directly related to the sector's organisational model and particularly to the process of investment decision-making.

For the financier, irrespective of the organisation in place, it is important to analyse how competitiveness is dealt with in the operation of the electricity system, and what are the resulting risks.

From this standpoint, two extreme cases may be observed: total regulation under state control, or total deregulation. Diametrically opposed as they may seem, they may eventually lead to identical results.

4.1. Competitiveness and capital-intensiveness of the nuclear industry: Incidence on method of financing

To a certain extent, the capital-intensive nature of the nuclear industry is a handicap in measuring its competitiveness.

In reality, however, higher investment costs per kW than other forms of generation are - in economic terms - offset by a much longer lifetime (at least 40 years, without major supplementary investment spending).

However, in order to arrive at an acceptable cost per kWh over the *entire* period, the financing of such an investment must be set up in such a way that the costs are spread over its entire operating life.

It should be noted that the successful development of the gas combined cycle technique is due, at least in so far as investment and financing are concerned, to a high degree of compatibility between the "economic" lifetime of the facility, the duration of energy marketing contracts, and the period of loan terms generally accepted by the market.

From this standpoint, the nuclear industry closely resembles major hydro-electric schemes which are only completed thanks to an accompanying accommodation made by the market: acceptance of very long periods, particularly on the part of supranational bodies.

To a certain extent, the nuclear industry has now reached maturity in terms of quality assurance over long-term operation, and should therefore be able to attract longer-term financing, or even give rise to the emergence of a very long-term market, currently limited to a handful of sovereign loan issues.

An interesting development is gaining ground in the financing of independent power producers (IPPs) investing in conventional generating capacity: capital markets are showing a significant renewed interest in this type of investment, and thus offering interesting prospects:

- in terms of duration: longer terms than classic syndicated bank loans,
- in terms of repayment profile: in particular, bullet repayment is possible.

This second point is of great importance to the case which concerns us here. The structure of the bullet repayment system makes it possible to set up refinancing, so that debt servicing may be smoothed as much as possible over a period approaching that of the facility's life expectancy.

Taking our example of a 40-year life expectancy, the burden of debt could be optimised by introducing the following structure:

(1) for every 100 units borrowed, 25 are borrowed under the terms of a conventional loan repayable in 10 constant annual instalments, and 75 are repayable at term in 10 years' time. Over the first ten years, only the interest is paid on the 75 units, in addition to the annual instalments on the 25 units.

(2) After 10 years, the initial loan of 25 units is fully repaid, and the 75 units are refinanced by means of a further 25-unit loan repayable in 10 constant annual instalments and another 50-unit loan repayable at term in 10 years' time (i.e. in

year 20). This new debt generates a level of charges that is stable and slightly lower than in the first 10 years.

(3) In year 20, the 50 units are again refinanced in the same way, by a bullet loan of 25 units combined with a conventional loan for the same sum. All that remains between year 30 and year 40 is to repay the final conventional loan.

This represents a major step forward by the capital markets which, by accepting the refinancing risk, are demonstrating their belief in the economic viability of the facility over time. What has been done for the conventional IPPs, in terms of both technical quality and the market, should be possible for the nuclear industry.

It is by no means proven as yet, however, that the capital markets are sufficiently mature to accept the maturity of the nuclear industry.

Nevertheless, it may be noted that:

- firstly, the model described above is the one which, implicitly, allowed financing of the French nuclear industry. Lenders accepted the risk of the "nuclear energy/pricing regulation" complex in a context in which, in fact, the State played its role to the full.
- secondly, when it is a question of financing an integrated company, analysis and the conditions of the competitiveness are mutualised in all the activities, facilitating the acceptability of the risk relating to nuclear power by potential investors.

4.2. Nuclear power in a deregulated system/The capital market

In this kind of context, the real problem is the place that nuclear power is able to occupy in a diversified "mix" of production resources and the risk of competitiveness resulting therefrom in an open market.

4.2.1. The context

The seventies and the first part of the eighties were marked by a high price of fossil fuels, leading certain countries (particularly France) to develop a large-scale nuclear programme: since nuclear facilities produce most of the electricity in these countries, the price of the latter naturally reflected (in a logic of monopolistic regulation of the cost plus type) the development costs of these facilities.

The current situation is very different in that nuclear power no longer has the same comparative advantage and is in competition with facilities producing electricity from gas, including electricity supplied at base. More specifically, the cost of development of nuclear power at base could be higher or lower than that of a combined gas cycle (CCG), depending on which long-term gas price scenario is adopted.

In any event, if the price of electricity for a supply at base were adjusted in relation to the cost of facilities likely to be developed in order to satisfy this type of demand, the latter would no longer be systematically linked to the costs of nuclear power (unlike the situation which prevailed during the eighties). It would be equal to the cost of development of a gas facility, as soon as the latter appears to be the most profitable bearing in mind the initial price of the gas and its development prospects[1]. In a scenario of this type, the profitability of a nuclear facility would appear to be less than the average weighted cost of the capital reflecting the hoped-for profitability which one would be entitled to demand for this type of facility.[2]

Nuclear facilities which would be developed by project-companies in this context would lead to electricity sale contracts drawn up once and for all over the lifetime of the power station, and assumed to guarantee capital providers with appropriate remuneration. In practice, the temptation for the purchasing electricity company to seek to revise these contracts may be strong if it appears that facilities generating electricity on more favourable conditions could be developed. It may also be thought that investors who are conscious of this possibility will take account of this from the start, in terms of the profitability that they demand, and that this will help push up the sale price of the electricity generated by the power station.

The risk would be even more evident in a more deregulated system in which an electricity company created to operate a nuclear power station would have to sell its production directly to clients (on the basis of contracts of terms necessarily shorter than the lifetime of this power station). The need to align electricity prices with the cost of developing the least expensive technology would be seen each time a contract was renewed. From this standpoint, a system with a pool would probably be even more risky in the case of a nuclear investment, if it were to lead to a reduction in the term of the contracts between generators on the one hand, and industrial clients and electricity distributors on the other.

4.2.2. Analysis

However, one should also consider whether the risks described above are intrinsic to nuclear power or whether they could similarly affect a generator developing a combined gas cycle or a coal-fired power station (the latter is not unaffected by an increase in the price of gas or coal, giving back to nuclear power a net advantage in terms of competitiveness). There is, however, probably a certain dissymmetry between the case of nuclear power and that of other, thermal facilities, related firstly to the fact that the latter will, in current cost conditions, be called to the margin in relation to most of the monotonic, and also to the fact that construction deadlines in the case of nuclear power are significantly longer than those of other thermal facilities. For both these reasons, the development of more combined gas cycles in a context of falling gas prices would appear to be a less irreversible and less risky choice on the part of electricity generators than would be the development of more nuclear power in a context of rising gas prices[3].

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[1] In theory, comparison of the two development costs is possible only if there is a graph of the forward price of the gas over a period as long as the lifetime of a nuclear power station, which is unrealistic. In this comparison it is thus not possible to avoid the explanation of a medium-long term gas price development scenario.

[2] Conversely, in scenarios in which nuclear power is the most profitable development resource for the generation of electricity at base, the sale price of the electricity that would have to be applied should lead to capital remuneration greater than its average weighted cost.

[3] One should, notably, mention, irrespective of the construction time aspect, that such movements in relation to the price of gas would not affect, in the short term (i.e. with an unchanged set of power stations), the profitability of combined gas cycles, provided that the latter are marginal most of the time, since they would be passed on to the pool prices.

The fact that nuclear power stations constitute economically risky assets in a deregulated market in which electricity prices are a function of the costs of gas generation facilities is an essential factor to take into account when considering the best means to finance them. It is certainly true that, in order for investors to be interested by financing nuclear power, in a deregulated system, it would be necessary for them to have the conviction that in terms of mathematical expectation, and over the long term, the latter is, at base at least, less expensive than a combined cycle[4]: this is a necessary condition in that it appears both more risky, and has more irreversibility. But these investors should also be prepared to take the corresponding economic risks.

This has a major consequence: it will probably be difficult to finance nuclear power without using a sufficient equity funding. In particular, a financing structure based principally on indebtedness would probably be inappropriate. Creditors would then be tempted to protect themselves either by demanding high risk premiums – reflecting the fact that they assume de facto a part of the economic risk – or by imposing high financial charge coverage ratios, or a rapid repayment of the debt. In any event, this desire for protection by the creditors would be to the detriment of the competitiveness of nuclear power, at least during the first part of the lifetime of the power station.

Conversely, use of more equity, if it is possible, will tend to alleviate these competitiveness constraints. Remuneration of the equity has a less instantaneous effect on prices per kilowatt-hour generated by a power station than that of the debt. It is, notably, possible to reduce the rate of distribution of dividends during the first years of a power station, the additional remuneration of the shareholders then being achieved by means of a latent profit on their shares. Naturally, this is made easier if the corresponding shares may be exchanged with satisfactory liquidity and if this latent profit may thus be realised effectively.

The whole point is to ascertain whether there are sufficient numbers of equity investors prepared to invest in nuclear power in order to modify substantially the equity/debt ratio.

Without answering this question, it is possible to make two observations. In the first place, the economic risk of nuclear power (risk of loss of competitiveness) is notably linked, as has been seen, to the price of gas. It is thus a risk which is at least partially able to be covered by financial instruments. Secondly, the *economic* risk of nuclear power is a risk which is uncorrelated with other risks borne by investors: it may thus be imagined that for reasons of diversification investors would accept to finance such facilities without demanding excessively high risk premiums for their equity contributions.

The necessary weight of the equity should also no doubt be relativised: provided the volume of the latter exceeds a certain proportion, creditors should consider that the risk they are taking on is considerably reduced, and reduce their demands commensurately, particularly in terms of the debt repayment term, which would at the same time alleviate the competitiveness constraint hanging over the nuclear power station during the first part of its lifetime. In the same perspective, use of quasi-equity (for example, low-rate coupon bonds convertible into shares) would be financing solutions worth exploring.

One should also consider, in the case of nuclear power, the justification for funding on a station-by-station basis. Part of the difficulties mentioned above – those related in particular

[4] Even when one takes account of an irreversibility cost intrinsic to nuclear power.

to the debt repayment term – would be attenuated, albeit very gradually, if a set of power stations of different ages, all selling electricity at the same price for a given period of use, were financed. In such a scenario, the cash flows generated by the oldest power stations (which need not necessarily be nuclear ones) would help finance the newer ones. A solution of this type should thus be explored every time a country initiates a major nuclear power generation programme. It should be noted that the French nuclear programme relied on this principle of financing of a set of stations.

5. CONCLUSION

Financing of nuclear power in Developing countries and in the context of deregulation of the electricity market no doubt calls for solutions different from those imagined in the seventies and eighties in the Developed countries.

With current economic conditions (notably in relation to the price of gas), nuclear power may only occupy a part of electricity offer at base. Since, in countries developing it, it is unable to provide the guiding electricity price, it comes with a competitiveness risk combined with characteristics of irreversibility linked notably to its construction times.

However, since it appears that there is a place for nuclear facilities (once appropriate risk and irreversibility premiums are factored into the economic calculation), the question is no longer whether it is possible to finance these facilities but how to finance them. Use of a weight of financing by equity or by quasi-equity higher than for other types of facilities is an approach which seems favourable : it could allow capital remuneration to be better modified over time, and certain constraints imposed by creditors to be alleviated.

The whole question is, clearly, to know whether, bearing in mind the very capital-intensive nature of nuclear power, it will be possible to procure a sufficient volume of equity and quasi-equity on the market, even in the hypothesis of a curbed development, on a world level, of this type of generation resource.

Lastly, a financing solution for the entire industry is clearly preferable to the station-by-station financing solution according to the project financing model.

FINANCE STRUCTURE AND PUBLIC ENLIGHTENMENT PROGRAM OF THE FIRST TURKISH NUCLEAR POWER PLANT PROJECT (A CASE STUDY)

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Abstract

This paper deals with four closely related subjects. These are: the positioning of nuclear energy in energy planning of Turkey by presenting supply and demand figures of electricity, giving emphasis to resource availability, pointing out the necessity of diversification of resources; the on going situation for realization of Akkuyu Project with its updated milestones, alternative offers requested for Akkuyu Nuclear Power Plant and member companies of the consortiums who already have submitted the three bids; the financing of big-scale energy investment projects in developing countries by giving special emphasis to Akkuyu Nuclear Power Plant Project including the financing requirements in the Bid Specifications, OECD rules for financing, the requirements of financial agents, and financing means of domestic participation.; public enlightenment during establishment of nuclear power in Turkey.

1. NUCLEAR ENERGY IN MEDIUM AND LONG TERM ENERGY PLANNING OF TURKEY

Energy is a basic input for all socio-economic development activities. The consumption of electrical energy; with its easy use, possibility of convension into the other sorts of energy and wide spread availibility in daily life constitutes one of the most important indications of the development level of the countries. It is for this reason that Turkey's energy consumption has risen rapidly. For example, while installed capacity and energy generation were 2235 MW(e) and 8 billion 623 million kWh levels in 1970, they have reached 21901 MW(e) and 103.1 billion kWh by the end of 1997. Electricity generation has grown more than 10 times over the last twenty five years. The gross consumption of electricity per capita has become 1520 kWh by the end of 1996, from its level of 244 kWh in 1970.

Electrical energy demand of Turkey is growing rapidly with the rate of 8% increase in average since years. The studies on demand forecast for Turkey have shown that electrical energy demand will be 134.3 billion kWh in the year 2000, 290 billion kWh in 2010, 547 billion kWh in 2020 while in 1997 this was realized as 106.5 billion kWh. Depending on a realistic figure of 8% increase of demand per year for the coming 20 years, the demand studies for long and medium periods considering reliability of generation and reserve capacities have shown that the peak demand will reach to 21588 MW(e), 46219 MW(e), 88100 MW(e) in years 2000, 2010 and 2020 respectively, while this demand was realized as 16926 MW(e) in 1997. Linked to the increase in the installed capacity, the electricity generation will reach to 108.5 billion kWh, 158 billion kWh, 341 billion kWh, 620 billion kWh, in years 1998, 2000, 2010 and 2020 respectively. To meet the demand, the construction of new electricity generation facilities will be essential. Several reasons make nuclear power a viable and indispensable part of TEAS's energy future (Fig. 1).

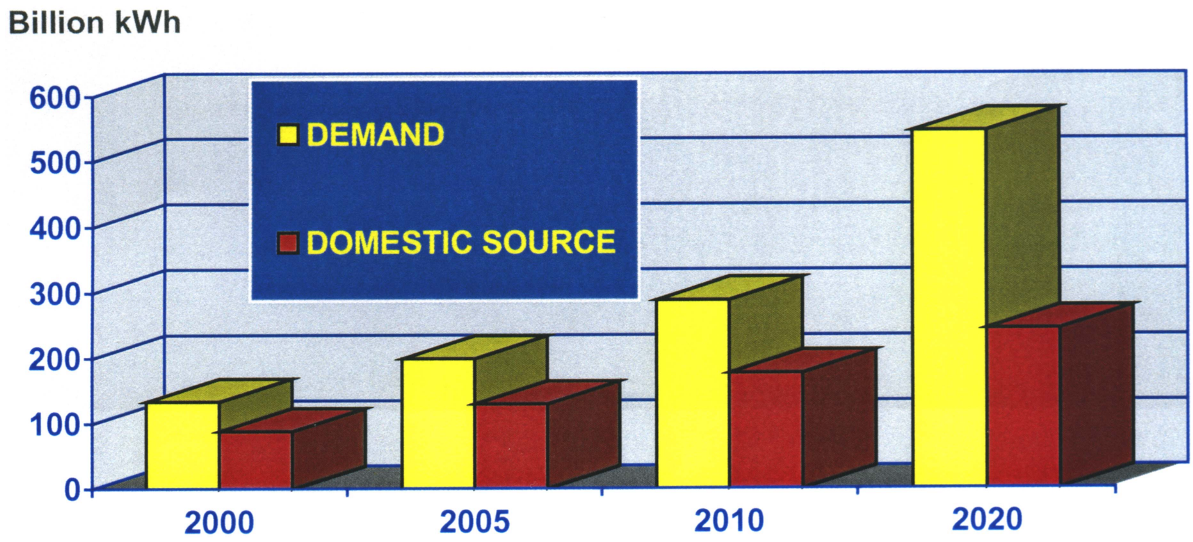

FIG. 1. 2000-2020 domestic source and demand.

Since electrical energy is generated via utilization of primary resources such as coal, oil, natural gas, nuclear and hydro, it is essential to make certain about the types of primary resources for expansion of electricity generation system; while analyzing the primary resources of Turkey very carefully.

The results of studies made on utilization of domestic primary resources for generation of electricity, have shown that, these domestic resources are mainly lignite and hydro.

Even all of the primary domestic resources of our country are brought into service, before reaching the year 2010, it won't be possible to meet the demand in full. Therefore to meet this demand, imported coal, imported natural gas and nuclear energy should be utilized in addition to these domestic resources (Table I).

TABLE I. UTILIZATION OF DOMESTIC RESOURCES

YEAR	LIGNITE + H.COAL (%)	HYDRAULIC (%)
End of 1997	26	29
End of F 2001	42	36
End of F 2010	64	70
End of 2020	100	82

At the end of 1997 the installed capacity of Turkey is 20.889 MW(e), of which 54% is thermal and 46% is hydro (Fig. 2).

To meet the energy demand reliably and with minimum cost, the planning studies considering the criteria such as the increase of utilization of domestic primary resources as long as they are economical, importation of these resources in an economical manner, going into diversification in country of origins and fuel types and environmental aspects, have shown that depending on the on-going plant constructions, in 1998 a deficit in electricity generation is going to occur and this deficit should be balanced by importation.

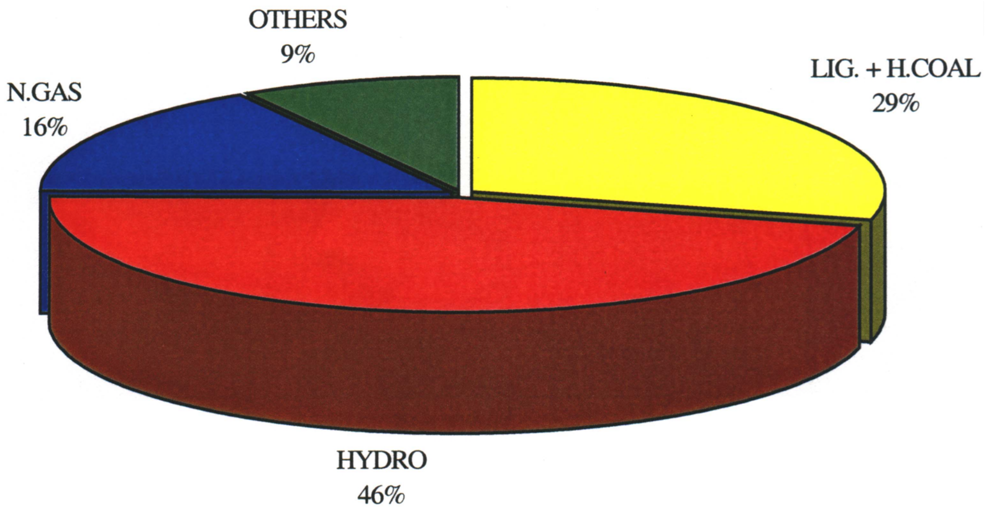

FIG. 2. Breakdown of installed capacity (1997).

For the subsequent years to compansate this deficit, it is necessary to add new plants of total capacities reaching 2000-4000 MW(e) in average per year to the Turkish grid until the year 2020.

Generation planning studies show that, the weight of thermal plants in the generation system will be more and more in years around 2000 as long as available potential is utilized economically, and from the aspect of primary resources, thermal plants shall utilize imported resources increasingly.

Imported resources on the other hand are mainly natural gas, coal of high calorific value and nuclear, since these resources cause less pollution of environment and consequently the environmental impact prevention measures cost less (Figs 3 and 4).

According to the available data of the above mentioned plannings, nuclear plants will have shares of 3% and 9% until the years of 2010 and 2020 respectively. The first nuclear unit is planned to be on the Turkish grid on 2006.

TEAS experience in similar big projects shows that the existing political and economical atmosphere prevailing in TURKEY inspire creditors and eximbanks to participate in this huge Power Plant Project and be a part of the Turkish Nuclear Program which will reach 10.000 MW(e) by the year 2020. As a result, the share of nuclear power in electricity generation will increase remarkably since 2006. In order to carry out this nation's nuclear power program without difficulties, it is necessary to promote better understanding concerning nuclear power with the general public and eventually gain public acceptance. Our aim is to convince ordinary people on the advantages of the nuclear energy and to use the arguments on the beneficial uses of nuclear energy whenever a debate arises.

2. THE ONGOING SITUATION OF AKKUYU NUCLEAR POWER PLANT PROJECT

For the first nuclear power plant of Turkey, Akkuyu site, near to Gülnar-Mersin has been selected. All site studies and infrastructure works for Akkuyu are complete. Site Permit was obtained from Turkish Atomic Energy Authority (TAEK) in June 1976.

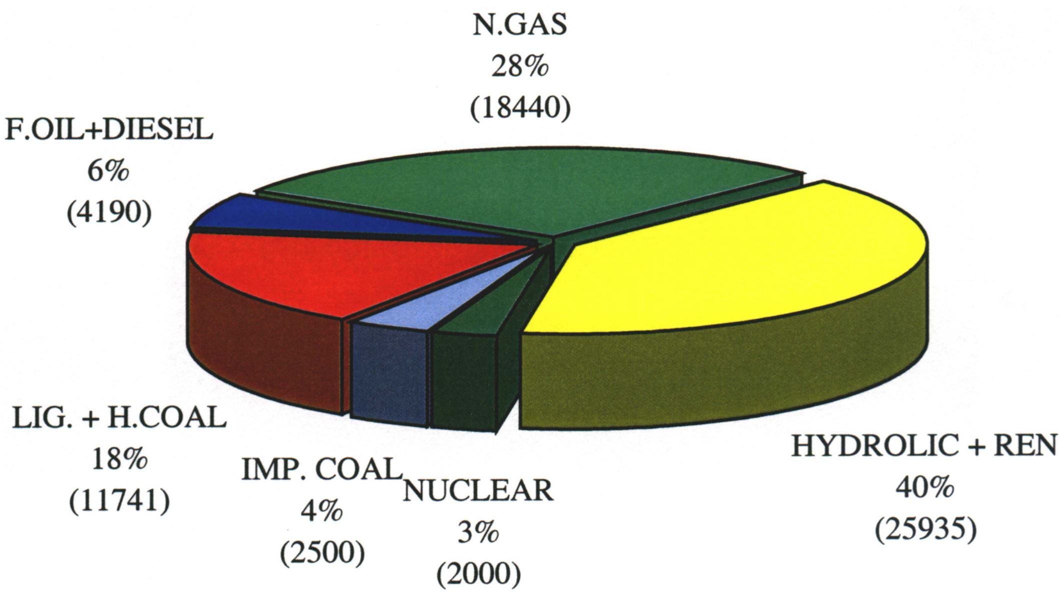

FIG. 3. Breakdown of installed capacity by fuel types for the year 2010 (MW(e)).

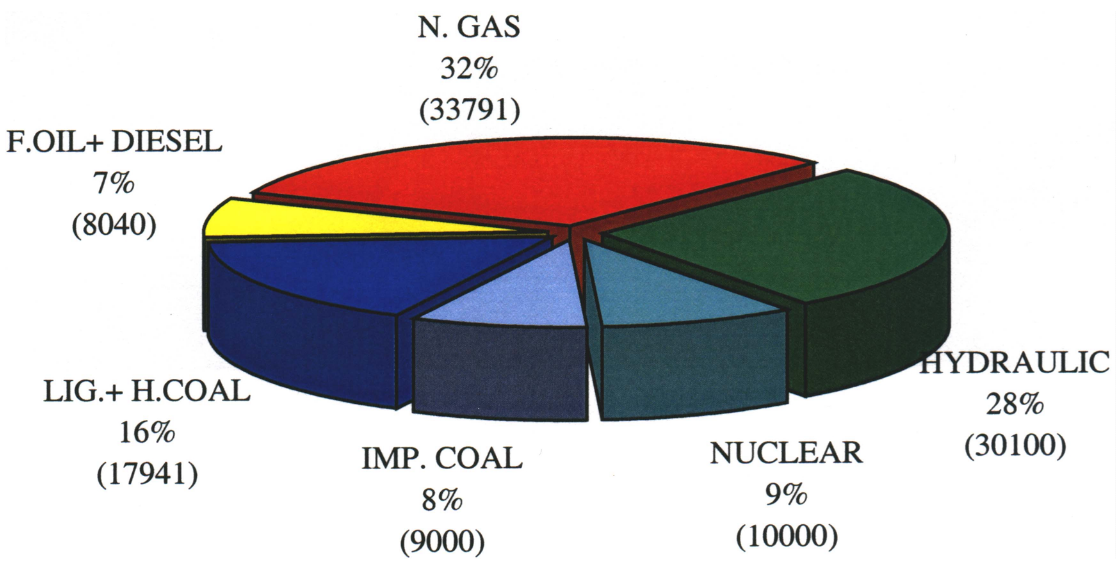

Fig. 4. Breakdown of installed capacity by fuel types for the year 2020 (MW(e)).

Considering its long construction period, to complete Akkuyu Nuclear Power Plant on time, this project was put into the Investment Program of 1993 and TEAS has restarted its nuclear program amounting to approximately 3000 MW(e) by announcing the bidding on 17th December 1996. Bids were received on 15th October 1997. Contract will be signed with the succesfull bidder after contract negotiations until the beginning of next year. The first unit of the NPP is scheduled to be commissioned in 2006.

Two alternative offers were requested for Akkuyu Nuclear Power Plant. These are:

1. Alternative Offer: A nuclear power plant of minimum net 800 MW(e) and net output not exceeding 1400 + 5% MW(e) having minimum one unit and unit size above and equal to 600 MW(e) net.
2. Alternative Offer (Optional): A nuclear power plant with net output not exceeding 2800 + 5% MW(e) having minimum two units and unit size above and equal to 600 MW(e) net. The bidding, in principle, is open to plants of PWR, BWR, and PHWR types commercially in operation.

Bidders are requested to bring 100% full financial loan for the I. Alternative Offer while for the optional unit(s) of the loan for the II. Alternative Offer is required from the Contractor in 1.5 years at most after signing of the Contract. Credits should be acceptable to the Treasure Undersecretariat of the Turkish Prime Ministery.

The bidders' consortium members and the size of plants they offered are shown in Table II.

TABLE II. BIDDERS AND SIZE OF POWER PLANTS OFFERED

Consortium	Members of Consortium	Bids	Net Output MW(e)
	Siemens	Alternative I (Main Bid)	1482
NPI	Framatom		(Single Unit)
	Gec Alsthom		
	Campenon Bernard		
	Garanti-Koza A.S. (Turkish)	AlternativeII	2964 (Two Units)
	TekfenA.S. (Turkish)		
	AECL	Alternative I (Main Bid)	1339
	Hitachi		(Two Units)
AECL	Gama (Turkish)		
	GüriS (Turkish)		
	Bayındır (Turkish)	Alternative II	2678 (Four Units)
	Mitsubishi Heavy Ind. Ltd.	Alternative I (Main Bid)	1218 (Single Unit)
	Westinghouse		
	Raytheon Eng.		
WESTING-	Duke Eng.		
HOUSE	Enka İnş. (Turkish)		
	Günal Const. (Turkish)	Alternative II	2436 (Two Units)

Note: All three consortia arranged 100% finance covering all bid items including local supply and advance payments for Alternative I.

3. FINANCING STRUCTURE OF AKKUYU NUCLEAR POWER PLANT PROJECT

For a nuclear project of this size, finance is the most important subject. In this paper finance of nuclear projects in general and specific to Akkuyu together with some innovative approaches shall be discussed.

3.1. Finance of nuclear projects in general

Nuclear Projects are capital intensive complex projects of long project time, realized with involvement of multinations. Finance of the nuclear projects are complex and large in size requiring many creditors and export-credit-agencies. Since delay of a nuclear project causes high cost increases, it is essential to make every effort to reduce the uncertanities in finance of the project and secure the smooth cash flow during construction phase.

Conventional options for financing power generation projects in developing countries, include utilities' own resources, national budgets, local commercial banks and foreign multilateral and biletaral sources which usually cover foreign exchange costs. The major problems which may occur in the developing country are:

- Scarcity of Capital
- Inability to mobilize their domestic capital markets for the finance of large complex projects.

The capability of utilities to finance a project of a nuclear power plant from their internal funds is greatly limited due to the lack of healty internal cash flow generation. Funds raised in the local money markets by Utilities is a methodology which can have success in certain countries with limitations.

Due to long construction time, high capital involvement and uncertainties of the nuclear projects; debt servicing by a developing country and the credibility is a great concern for the financing agents. Public acceptance, hesitance, changing political climate, public debate, frequent questioning of the nuclear program of a country bring extra costs, special arrangements, additional complementary mechanism which are to be induced by the financing agents.

The other major problem for the finance of nuclear projects is non-participating attitute of the multilateral financing resources for economic development. It should be pointed out here that World Bank, European Bank have not yet participated in the funding of any nuclear power project, up to day.

Another peculiar character of nuclear project finance is that no aid credits tends to favour nuclear projects which is the case for some conventional power plant projects.

Short grace periods of commercial credits creating a heavy cost burden on the long contstruction periods of nuclear projects is another problematic area to be solved by Utilities.

3.2. OECD rules for the finance of nuclear projects

Major sources of finance for the nuclear projects in a developing country are export credits of ECA's (Export-Credit-Agencies) usually covering 60-70% of the project cost.

The general features of export credits:

- Credits are either directly supplied by official financial institutions or commercial banks with the insurance of the special govermental entities,
- Credits are generally provided in the national currency of the exporting country,
- Interest during construction (IDC) is usually expected to be covered by the Utility from its own funds,
- Maturities are much longer than commercial credits' maturities,
- Grace period covers the construction period,
- Interest rates are lower than commercial credits' interest rates,
- The terms and conditions of the credits comply with OECD consensus for export credits.

OECD Guideline for the arrangement of the officially supported credits has the following major features:

- Advance Payment: 15% of the exported good and services which are not covered by the export credit and required purchasers to pay or arrange this cash payment.
- Officially supported credits for local cost and capitalisation of interest should not cover more than 15% of the export value. ECA's are reluctant to cover IDC.
- Export credits does not apply to items for which the buyer is usually responsible in particular, costs associated with land developement, roads, construction village, power lines, switchyard, water supply, as well as costs arising in the buyer's country from official approval procedures (ea; site permit, construction permit, fuel loading permit etc.)
- Maximum repayment term shall be 15 years (regular instalments, every six months)
- Repayment starts following the completion of plant and start-up (Grace period of about 7 years)
- Minimum interest rate is the "Special Commercial Interest Reference Rate" (SCIRR) which CIRRs (Commercial Interest Reference Rates) plus 75 basis points except Japanese Yen; which is CIRR plus 40 basis points. CIRR is calculated in general terms as base (primerate) plus 100 basis points.
- Tied aid credits, aid loans or grants more favorable than export credits shall not be provided. (inside the security fence of the power plant)
- In addition to direct credits, ECA's can also guarantee commercial bank loans.
- Official Credit Support for Nuclear Fuel:

  i) The initial core loading (maximum repayment terms of 4 years)
  ii) Two subsequent reloads (maximum repayment terms of two years)
  iii) Reprocessing and spent fuel arrangement shall not be covered by export credits
  iv) Free nuclear fuel or services shall not be provided.

The cost of officially supported credits, for nuclear power plants are 10% to 12% higher in comparison with conventional power plant projects but much less than commercial terms.

3.3. Finance problems specific to nuclear and Akkuyu project

The problems with nuclear project financing have a similar character as other big size projects. The commercial lending includes all loans from banks and institutions. The terms and conditions of the loans depend upon the functioning of the capital market, the standing of the borrower, the country risk.

Beside the above general rule for the finance of a power project, due to high risk and long construction and payback period of the nuclear projects, banks and financial agents are very keen for the borrowing conditions and long term outlook of the borrowing country. As indicated above, international banks such as World Bank, European Bank are not involved in nuclear projects. This is an important set-back to create the core of finance which would be backed up by ECA's and commercial banks in a comfortable financial atmosphere.

3.3.1. Finance requirements of Akkuyu project

Since Akkuyu Project is a turnkey project 100% finance is required from the bidders with following conditions.

- The financial package shall include all the items of the scope including foreign and local participation, infrastructure (the ones not yet finished), advance payments, credit insurance premiums,
- The credits arranged by the bidders are subject to the approval of Undersecretariat of Treasury of Turkey,
- Any loan offered to this project should be clear from previous allocations,
- For Alternative I (1400 MW(e)) firm credit letters; for optional part of Alternative II (1400 MW(e) + Optional 1400 MW(e)) a letter of intent received from Banks or respected financial agents are required.

The most critical part for the finance of Akkuyu Project is financing of local participation, advance payment and infrastructures which are beyond the coverage of ECA's.

3.4. Special requirements of financial agents specific to nuclear and Akkuyu project

Following points have to be fulfilled by TEAS being preconditions for credit agreements:

- Signed contract between Supplier and Owner (TEAS)
- Having necessary licences such as:
  - i) EIA approval (to be submitted to TEAS in 6 months after signing of the contract by the supplier)
  - ii) Preliminary safety analysis report (PSAR) (to be submitted to TEAS in 6 months after signing of the contract by the supplier)
    - a. Bilateral nuclear agreements to be signed between Turkey and nuclear material/equipment suppliers' countries (Canada: Signed, Germany: text is ready and initialled, France/USA: Text is reviewed)
  - iii) Third Party Nuclear Liability Law (prepared and submitted to Turkish Parliament for legislation)
- Proper construction and operation management organization, for Nuclear Power Plant.

4. PUBLIC ENLIGHTENMENT PROGRAM OF TEAS

4.1. Purpose

It is known by TEAS the nuclear power plant construction plan can be delayed if oppositions by local population, environmental groups abetted by international anti-nuclear groups, together with negative attitudes by the media and opinion leaders such as leading politicans become strong.

When a nation plans to implement a nuclear power program, oppositions by anti-nuclear voices immediately spring out as if they had been waiting for such a moment for a long time. These group are eager to abet the general public, particularly the local population living near the candidate site of a nuclear power plant, to oppose the nation's nuclear power program. A large portion of general public is apt to lean to the opposition line without recognizing the true facts and scientific data. Being aware of these facts, TEAS's nuclear program aims to inform the public about nuclear power, NPP, and nuclear program of Turkey, together with general energy policy of the country.

4.2. Program ın order to organize public ınformation program

The following points will undertake as the keys to such a program:

- Determining and answering the questions raised from public
- Determining the target groups
- Preparation of brochures
- Preparation of a video tape
- Organizing a mobile "enlightenment team" that will work at local area of Akkuyu NPP
- Developing a communication strategy.

4.3. Environmental ımpact assessment (EIA) - public participation meeting

Public enlightenment is also a part of EIA procedure. In this manner, a meeting is held by the owner to inform public and to get their opinions and suggestions following the first meeting of Inspection–Evaluation Commission after the EIA report is submitted to the Ministry of Environment.

The meeting place determined by the owner must be such that the local population that will be affected by the NPP can attend easily. Public opinions occuring in the meeting is notified to the Ministry by Its regional organisation.

People who want to inspect the EIA Report can do it within the Inspection–Evaluation Period in the Ministry or Its regional organisation and they can notify their opinions to the Ministry so that the Commission pays attention to that.

4.4. Questions from public and answers to them

The following answers can be given to some questions arise in the public media.

Question 1: Why nuclear power plant has choosen instead of our local resources? Isn't it possible to use renewable energy instead of nuclear?

Answer 1: Nuclear is a sound, tested, environmentally friendly option that produces large volumes of electricity economically. Renewable energy sources are appropriate for small-scale use, but are not expected to be economically viable for large-scale electricity production for several decades, and even then with significant penalties such as extensive land use.

Question 2: Why do we have a nuclear power plant built while the world abandons nuclear power?

Answer 2: The world is not abandoning nuclear power. While it is generally stagnant in most of Europe and North America after a prolonged period of growth, it continues to expand notably in Asia. Overall, the situation is stable: 17%of world electricity comes from nuclear year by year.

Question 3: Is the nuclear power plant being purchaised in order to make a bomb?

Answer 3: Bombs are not made from fuels or from nuclear power plants.

Question 4: Do nuclear power plants have negative environmental impacts?

Answer 4: In normal operations, no. Quite the reverse. However, spent fuel needs to be stored safely for long periods.

Question 5: Can an accident like Chernobyl occur?

Answer 5: Chernobyl was fortunately a very rare exception, both in terms of the unique reactor design (unlike those in the West) and in terms of the exceptional, experimental circumstances being tested immediately prior to the accident and which led to the reactor becoming unstable. Western reactors moreover must have containment domes that are designed to trap any radioactivity that might be released inside the plant itself.

Question 6: What are the advantages of nuclear energy?

Answer 6: Energy independence/security of supply, technological advance, no contribution to emissions of carbon dioxide or other toxic gases, etc.

Question 7: Are the wastes thrown into oceans?

Answer 7: Certainly not. They cool off in a storage pond at the site for a number of years before having to be disposed of. This may mean reprocessing (removal of re-usable plutonium and reduction in waste volume and toxicity) or deep geological burial.

Question 8: Are the uranium resources of the world enough to meet the demand of all nuclear power plants?

Answer 8: Absolutely. There are abundant supplies of uranium worldwide and the price is very moderate.

Question 9: How long can the radio isotopes that were released to the environment be remain there?

Answer 9: That depends on the radioisotopes. Iodine-131 has a half life of only one week. Other isotopes have half-lifes of hundreds or even thousands of years.

Question 10: Is there any research for final disposal of radioactive waste?

Answer 10: The development of radioactive waste management practice is of course an evolutionary process, but guiding principles first worked out decades ago remain the basis of current practice. As early as 1957, for example, it wasbeing suggested in international symposia that highly radioactive wastes, suitably conditioned, could be disposed of by emplacement in deep geological formations. Development of the technology to do so -should it be decided that this is a safe route for the final disposal of such wastes- is now well advanced. Effective management and disposal practices for wastes of lower activity already exist.

4.5. Target groups

The target groups that were determined are:

- Local population
- Employees of TEAS
- Nuclear-related industrial companies and the companies that need large amount of energy for production
- Business circles
- Political leaders and the major parties
- Media
- Local universities and local schools
- Students and teachers
- Labour unions
- Goverment officials, particularly of policy–making levels
- Religious leaders
- Medical professionals including nurses and radiation technicians
- Writers, artists, musicians and other artistic professionals
- Women’s associations
- Social groups
- Environmental groups with somewhat favorable concerns.

4.6. Legal approval of Akkuyu nuclear power plant project

In 1995 Environmental Protection Associations of İskenderun, Tarsus and Antakya made a claim in Adana 1st Administrative Court saying that the Akkuyu Nuclear Power Plant Project should be stopped since the project has been restarted without an EIA Report and therefore environment of Akkuyu is under the threat of this project if it is going to be realized.

After this claim has been rejected by Adana 1st Administrative Court, this time the above mentioned associations have appealed to the High Court of Appeal for the decision of Adana 1st Administrative Court to be overruled saying that the related decision was taken against laws and methods. Against this claim, the High Court of Appeal approved the former court rejection by stating the following points:

- As the first step, only the site permit for Akkuyu was granted by Turkish Atomic Energy Authoritiy (TAEK) after seismical, geological, geotechnical, hydrological, etc. investigations were completed and the related site report have been prepared.
- After the technology is selected and all laws and regulations are satisfied the Construction Licence is going to be granted by TAEK as the second step.
- EIA Report on the other hand, can be prepared according to Environmental Impact Regulations during the period of Construction Licence phase.
- After completion of construction, as the third step, the Operation Licence will be given by TAEK.

As the result of above mentioned statements, the High Court of Appeal concluded that the procedures followed by TEAS were in full conformity with the Turkish Laws, Regulations and methods from the aspects of environmental matters therefore Akkuyu Nuclear Power Plant Project should go on. As the result, the decision of Adana 1st Administrative Court was approved on 27th May 1997 by the High Court of Appeal which decision is final and can not be changed.

Finally, same associations have appealed to the same court with almost same claims in 1997. They also claimed that there were some reguired permissions according to other regulations such as the Regulation On Unhygienic Establishments. These claims have been rejected by the court again. The court judged that it was impossible to start EIA process before the Construction Licence Phase in technical and legal point of view.

4.7. Strategies

As the strategy of the program, TEAS decided to:

- Avoid any overkill and exaggeration
- Provide sincere honest and balanced (not biased) information
- Avoid to persuade but just provide correct information so that the public can judge independently
- Not make a high profile campain
- Try to adjust information to the changing situation
- Be open and transparent
- Stick to clear cut, single and understandable messages, good for comparison
- Not develop new arguments, unless forced to do so
- Repeat the messages in a timely manner.

5. CONCLUSION

To establish the strategy of public enlightenment program, it is necessary to understand anti-logics, so that it could be possible to develop counter-measures and a communication strategy. Anti-nuclear groups constantly insist on argumentation. In order to achieve their goal, they frequently use survival-related messages to threaten the public.

On the contrary, messages by nuclear industry have been traditionally focused on the non-survival matters, such as:

- Energy resources and nuclear power
- Basic principles of nuclear power
- Nuclear fuel cycle
- Economics of nuclear power
- Safety of nuclear power plant
- Radwaste magement
- Radiation and the use.

In this connection, it is quite necessary to develop most appropriate messages which can touch the ground feeling of the general public in compliance with the anti-nuclear arguments.

Nuclear Power Projects, as indicated before, are capital intensive multi-billion dollars projects.

To alleviate those adversities, developing countries which would like to start a nuclear program should reduce the project related uncertainties and risks, and should improve the overall climate for financing their projects.

Governments should take necessary and sufficient early steps and firm actions for putting into place the convenient legal and institutional arrangements required by the program, and they should open the way for consistent and fair dealings with lenders and investors.

Besides the state companies managing the nuclear projects should be equipped with authority means to reduce effectively the delays. If the delays of nuclear projects are not coped effectively, they may turn the project into an economical disaster (which you may know many examples over the world) both for the owner and for the supplier. Therefore if the state companies are managing the project, the decision making process and flexibility should be revised and improved to reach to timely decision making, and to encounter the delays and subsequent cost-overruns that may occur.

5.1. Unbalanced repayment program

Nuclear power project is generally financed up to 70-80% by export credits with favorable terms and conditions. If 100% finance is required in the bidding, 20-30% of the project cost is to financed by commercial banks with less favorable terms and conditions. So some components of the financing repayment may have to start during construction period necessitating further refinancing or repayments may cluster around first years of operation. Proper negotiations with the creditors should be conducted to ease this problem and the Utility should prepare himself for such a high pace of repayments.

5.2. Domestic financing for domestic participation

One of the major problems of the power projects in Turkey is the finance of domestic participation. As indicated above, at the moment domestic participation is financed with commercial credits with highly unfavorable conditions definetely increasing the project costs. On the other hand, turnkey contractors are reluctant to finance local participation of the power projects due to extra burden and responsibilities imposed on them.

To overcome this problem, a finance agent Inbank (so to say) may be established by the state to raise funds for large size power projects including nuclears.

Since privatization of electric sector will be highly accelerated in the coming years a financing agent such as above:

- Shall administer and manage the funds to be established to finance the electric sector,
- Arrange profitable investments of the money collected from funds,
- Finance the sector and investors,
- Manage the investment and credit insurances,
- Raise funds for domestic participation of the power projects.
- Administer and manage the state subsidies and budgetary contributions and allocations to the sector,
- Serve TEAS outstanding debts,

– Finance the future typical companies of the sector such as National Grid, Load Dispatching.

5.3. Leading bank

Last but not the least, for the finance of a nuclear project a highly capable bank having financing experience in large scale complex projects should be appointed for financial, commercial and legal advisory services. This will ease the management of multi-billion project financing process and give impact positively on the schedule of the project.

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CASE STUDY: THE ROMANIAN NUCLEAR PROGRAM — CERNAVODA NUCLEAR POWER PLANT

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Abstract

Cernavoda Nuclear Power Plant Project was and still is the largest investment in the electricity sector of Romania. History and status of the NPP project is presented in this paper.

1. INTRODUCTION

Romania started the construction of Cernavoda Nuclear Power Plant, with CANDU 600 megawatt electric (MWe), pressurized heavy water reactors (PHWR), in the 1980s. The first unit was connected to the grid by the middle of 1996 and in1997, Unit 1 produced 5.4 terawatt hours (TWhrs). RENEL now hopes to obtain financing to complete Unit 2 for a scheduled start up in 2002. Units 3 to 5 are on hold.

2. HISTORY OF THE PROJECT

For Romania, nuclear power is an important alternative. It represents the best solution for development of the power sector because it is a safe, economic and an ethical source of energy. That is why the Romanian Nuclear Power Program is an important component of the national power sector strategy. The focus of this program is the design and construction of the Cernavoda Nuclear Power Plant, consisting of five CANDU-6 units. Romania chose the CANDU reactor type because the design is a proven one, with an excellent operational record, offering a high a level of safety, public, environmental and seismic protection. It also satisfies all international standards, and has the potential to provide competitive power generation. Its ability to use natural uranium also suits Romania's interests in producing nuclear fuel and heavy water, along with other important components for plant operation.

2.1. Unit 1

In 1978 a contract was signed with Atomic Energy of Canada, Limited (AECL) for engineering and procurement services. Construction work started on Unit 1 in 1979. In the following years the activity on site was carried out as follows:

- 1981: Contract for Balance of Plant (BOP) was signed with ANSALDO and GENERAL ELECTRIC;
- 1985: First connection to the grid originally scheduled for December 1985;
- 1990-1991: Project managed by Romanian organizations employing traditional investment, project management, involvement of the central administration and a controlled budget;
- 1990: International Atomic Energy Agency (IAEA) Pre-OSART mission reviewed construction activities and made suggestions to enhance work quality and safety practices;

- 1991: Contract signed with AECL-ANSALDO Consortium for completion, commissioning and initial operation of Unit 1;
- 1996:
  - First criticality: April;
  - First connection to the grid: July;
  - Full Power: October;
  - Commercial operation: December.

Unit 1 was financed largely with public funds from the state budget, and with export credits from Canada and Italy, under a Romanian State sovereign guarantee. There was also a 1992 export credit of about $450 million to complete Unit 1 from 50% to 100%. The reimbursement of credits is scheduled until 2006.

Unit 1 is operating well, having recorded a gross capacity factor of 87% during the period January - December 1997 and producing more than 5.400TWhrs.

2.2. Unit 2

Preparatory works on Unit 2 began in 1980 and continued through 1995. In 1996, preparation began, but there was little progress because of lack of financing. Unit 2 is now about 35% complete, with major components now on site. We are now seeking financing to complete the Unit.

For breakdown of the capital cost of the Cernavoda Unit 2, Table 1 shows the amounts allocated to the civil works, reactor, balance of the nuclear island, conventional island, ancillary systems outside the power island, contingency, various expenses, fuel and heavy water.

The total capital cost to complete the project is about 750 million USD, with a 4 year schedule.

TABLE 1. THE BREAKDOWN OF THE CAPITAL COST FOR CERNAVODA UNIT 2

	Total	Realised	Balance
	[Mil USD]	[Mil USD]	[Mil USD]
Civil works	190	150	40
Reactor (calandria, pumps, fueling machine, boilers, pipes and all process within this area)	370	180	190
Balance of nuclear island (nuclear services building, heavy water recovery facilities, control room, laboratories, spent fuel handling and all processes within this area)	150	60	90
Conventional island (turbine, generator & auxiliary systems, electrical bays & cabling)	400	210	190
Ancillary systems outside power island (service water, transformers, diesel generators)	140	50	90
Fuel and heavy water	150	0	150
TOTAL	1400	650	750

Assumptions : The above figures include engineering, duties and contingency.

Unit 2 completion is based on the assumption that funds will come mainly from sources outside Romania, and the state budget, or RENEL's budget, will cover only the interest during construction. Adequate funding is a fundamental obstacle to completing the project according to schedule, to avoid additional costs. A multi-annual budget is an absolute necessity in any credit involved in the project.

A basic condition for developing and implementing a nuclear project is the political support of the Government, including legislation and financial actions. The 1997 revision of the least cost development study confirmed the need to complete Unit 2 of the Cernavoda NPP for commercial operation by the year 2002. The Government of Romania stated that completion of Unit 2 of the Cernavoda NPP is a national priority, declaring by the decree the strategic importance of this project for the development of the Romanian economy.

The Government believes that completion of Unit 2 will benefit from the experiences of the owner's staff during Unit 1 construction, testing and commissioning. Moreover, both units use the same western advanced technology and the same license.

The Romanian Government is ready to offer the necessary facilities to attract and enable the foreign financing. Even the Sovereign Guarantee of the Romanian Government is expected for the foreign loan, while competition for the Unit 2 project financing is underway. The project financing approach is an option accepted by the Romanian authorities.

To settle the main issues of the financing plan, an economic analyses was performed covering the life time of Unit 2. The main findings of the analyses show the project can reimburse loans only from the revenues from Unit 2 electricity sales. Project financing may therefore be difficult to obtain, at least in the short run. Electric power demand has been steadily declining (Figure 1) because of reduced activities in certain inefficient industrial sectors as well as upgrading the manufacturing technologies. However, forecasts predict a return to internal consumption levels equal to or greater than before 1990 by the year 2010. The completion milestones of the Cernavoda NPP Unit 2 are shown in Figure 2.

3. NUCLEAR INFRASTRUCTURE FOR CANDU PROJECTS

The infrastructure supporting this program is very strong. Today, the Romanian nuclear industry represents one of the most advanced sectors in engineering and technology and it has the capability to meet the requirements of the international codes and standards, with excellent quality assurance skills.

The Romanian infrastructure for the CANDU project consists of :

- a heavy water plant with an output of 100 tons/year, supplying the D_2O inventory of Unit 1;
- the CANDU type fuel bundles plant which was rehabilitated and qualified by the Canadian partners (ZIRCATEC and AECL) and which supplied some fuel bundles for the first load and reload of fuel for Unit 1 of the Cernavoda NPP;
- CITON - an engineering and design institute with nuclear objectives, ensuring nuclear documentation, waste management strategy and technical support;

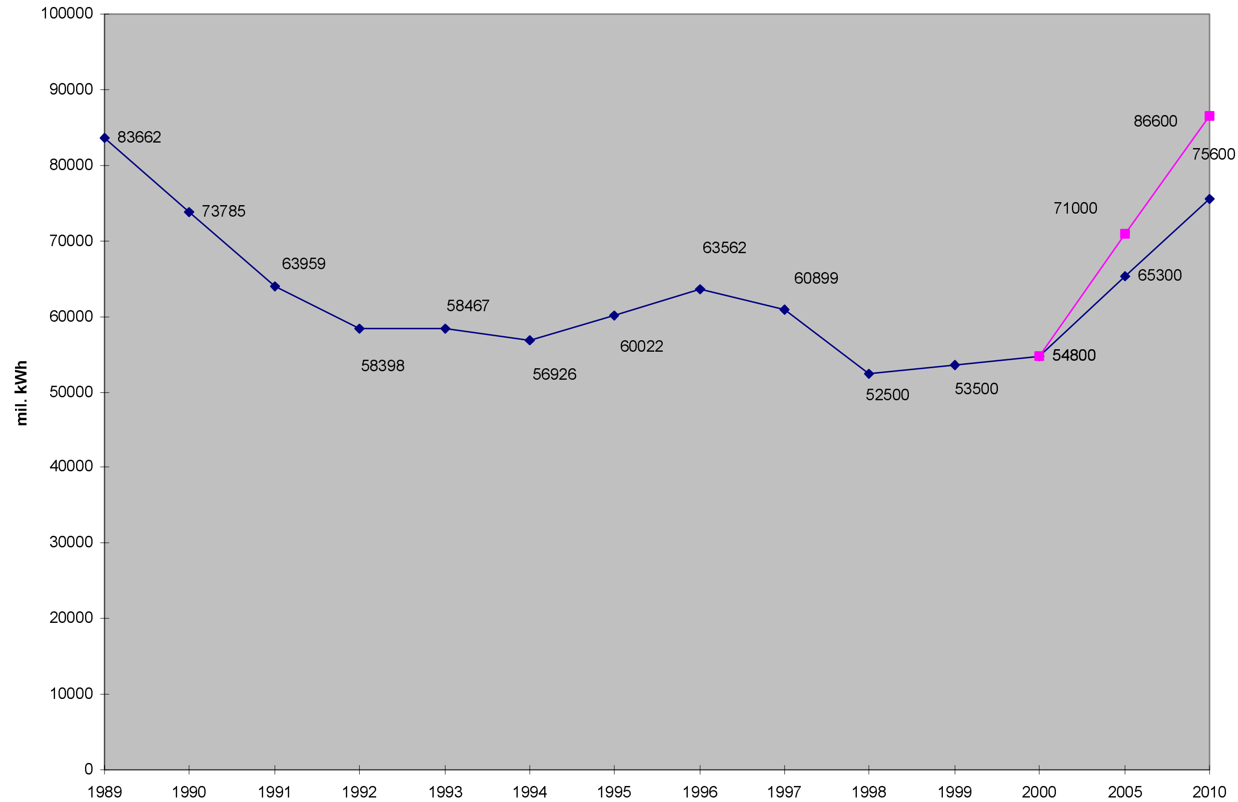

FIG. 1. The evolution of the internal consumption.

- ICN - a research institute in which the main directions are: non-destructive testing for in-service inspection, reactor physics, post-irradiation tests, fueling machine tests, waste management, nuclear electronics, etc.;
- Cernavoda training center - providing training on a full scale simulator - CANDU.

6. CONCLUSIONS

Benefits of the construction of Unit 1 include:

- the project is based on western advanced technology;
- the development of a national nuclear infrastructure (heavy water, fuel, heavy equipment, research, development, and engineering);
- the availability of trained staff.

Disadvantages in the Romanian nuclear programme include:

- total project size too large (5 units under construction at the same time);
- political pressure to accelerate work imposes unrealistic schedules;
- failure to follow procedures;
- non-motivated staff; and
- excessively ambitious Romanian industry participation.

For Romania, nuclear power based on PHWR technology is valid, safe, economical and ethical. Key issues are, to maintain the high level of expertise attained and increase international cooperation. We consider that Romania has good experience and capabilities to share with the members of the HWR community, but we also must have experience and expertise from other countries.

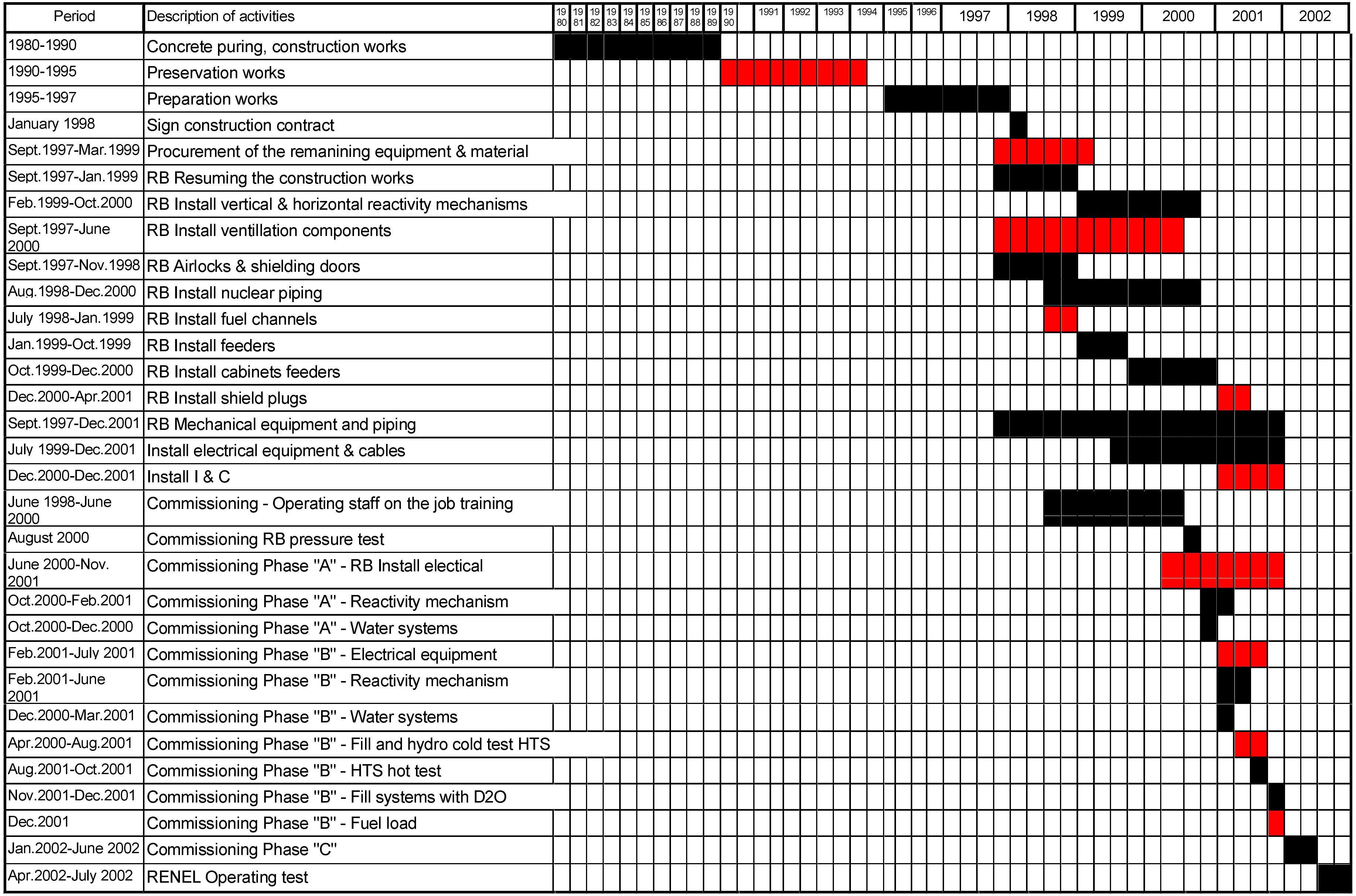

FIG. 2. Cernavoda NPP Unit 2. Complete millestones.

FINANCING FOR NUCLEAR POWER IN DEVELOPING COUNTRIES: CASE STUDY OF CHINA

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Abstract

This paper describes the Chinese experience in financing the construction of its nuclear power plants. The key issiue was utilization of a specific combination of export credit and commercial loans on both the international and domestic financial market.

1. INTRODUCTION

The development of nuclear power in developing countries meets many difficulties and an important one is financing. But, utilizing a combination of export credit from the supplier country and commercial loans in the international finance market, in addition to domestic bank loans or credit, may supply the necessary resources. In China, the financing framework for building Daya Bay NPP (2 × 900 MWe PWR) and Qinshan Phase 3 project (2 × 700 MWe CANDU) is based on that approach. This paper describes financing of Qinshan Phase 3 project as an example.

2. QUINSHAN PHASE 3

Qinshan phase 3 is a turn-key project. Atomic Energy of Canada, Limited (AECL) is the main contractor, who subcontracted the Balance of Plant (BOP) package and turbine generator sets to American Bechtel and Japanese Hitachi, and subcontracts civil works and installation works to Chinese construction companies.

In the commercial negotiation of Qinshan phase 3 project, AECL, Bechtel and Hitachi made commitments that their export credit agencies would provide credit. The State Development Bank of China (SDB), entrusted by the utility, negotiated financing with Export Development Corporation of Canada (EDC), Export-Import Bank of the US(US EXIM Bank), and the Export-Import Bank of Japan (JEXIM Bank) , and signed export credit agreements with them. Around 71% of total costs are offered by the three export credit agencies; about 70% comes from EDC, 16% from US EXIM Bank and 14 % from JEXIM Bank.

The main parameters of export credit are:

- Interest rate — under OECD guideline;
- Interest during construction — capitalized;
- Grace period of first repayment — six months after provisional acceptance of second unit;
- Period of repayment — 15 years, equal payable semi-annually.

Besides this, the State Development Bank of China (SDB) was entrusted by the utility to secure a commercial loan about 22% of total cost from the international finance market.

The framework of external financing is shown in Figure 1.

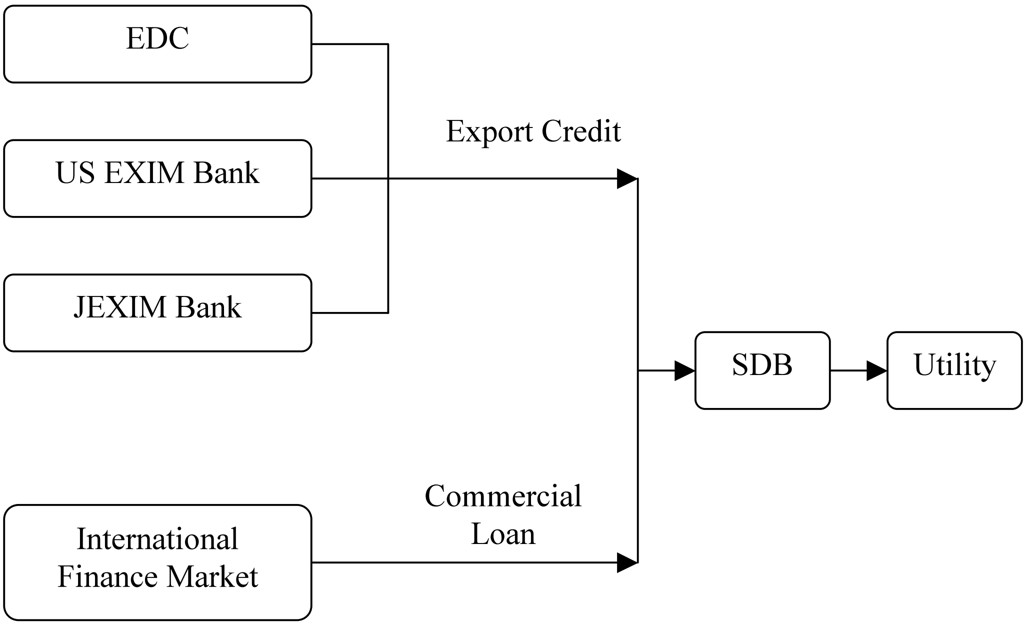

FIG. 1. Framework of external financing.

The remainder, about 7% of total cost will be funded internally by the utility itself as a domestic expenditure.

The framework of total financing is shown in Figure 2.

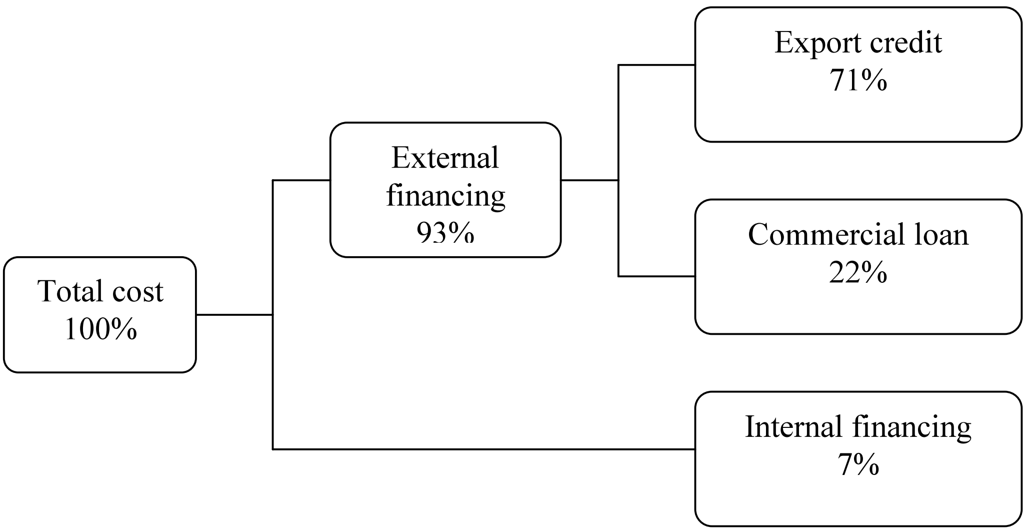

FIG. 2. Framework of total financing.

3. FINAL REMARKS

Finally, we would like to say, developing countries could adopt this diversified approach for financing the development of nuclear power. This paper is intended only as an example, for reference.

NUCLEAR TECHNOLOGY TRANSFER AND
NATIONAL PARTICIPATION

(Session 3)

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Key Issue Paper No. 3

TECHNOLOGY TRANSFER AND NATIONAL PARTICIPATION

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Abstract

Nuclear technology was developed in industrialized countries and largely remains in a few industrialized countries. Non-nuclear countries today find it necessary to import this technology. Some aspects of technology transfer: legal and institutional structure; different type of agreements; arrange74ments; and national participation are presented in this paper.

1. INTRODUCTION

While many countries are interested in acquiring nuclear power or expanding their nuclear base, the technology was developed and largely remains in a few industrialized countries. They possess and control most of the expertise. A few developing countries imported this technology and used it to develop self-reliance in at least some technological aspects of nuclear power plants and related fuel cycles. Non-nuclear countries today, whether developing or industrialized, find it necessary to import technology to pursue development.

Two definitions should be clear at the outset. First, technology is more than hardware and a bit of training. It includes management capabilities, an appropriate corporate culture, incentives for initiative, accountability, and for maintaining the assets, worker training and education, some necessary infrastructure and appropriate regulation. Second, technology transfer is not a gift or a magic trick or a substitute for foreign aid or for capital investment. It is a commercial, profit-making enterprise with mutual rights and responsibilities between the host and the investors, the vendors. The undertaking must benefit both the supplier and receiver of the technology. Technology transfer can be effected through any number of financing schemes and management arrangements, but to be successful these must have certain characteristics:

The arrangement must protect the property rights of the supplier. Technology is expensive to develop, and development costs are recovered through distribution and sale of the product. Licensing and patent arrangement are a way of doing this, and are a key to technology transfer.

The arrangement must be affordable in developing country markets and responsive to their needs.

Risks must be minimized and assigned efficiently, with the host government largely responsible for a stable framework for the venture.

The host must have a strong stake in the venture and committed to its success.

The forms of technology transfer that best fit these requirements are joint ventures and licensing schemes, as they convey with them both assurances for the investor and continued support and training for the hosts

2. TECHNOLOGY TRANSFER

2.1. General comments

Countries starting a nuclear power program are immediately involved in technology transfer with a range of institutions. Depending on existing capacity and capabilities, the utility may need to learn to manage, operate and maintain a nuclear plant, while engineering companies need to learn to construct nuclear plants, including specific local plant designs. The manufacturing industry must acquire the capability of manufacturing to nuclear standards, while the regulatory body must devise regulations and supervise their application. There is also a need for technology transfer to activities not purely nuclear such as standardizing and testing.

Technology transfer (TT) can benefit both supplier and receiver. For the supplier it can help achieve:

- A long term relationship with the receiving country and its industries, commercially positive to both;
- Development of a new market in nuclear and nuclear-related industries;
- An advancement in existing technology when TT is used on specific R&D projects.

For the receiving country TT permits:

- The acquisition of knowledge developed by others, in a shorter time and at lesser cost than if developed domestically;
- The acquisition of capabilities which can be spun off to other industries;
- Achievement of greater independence by internal control and management of the nuclear program as well as through increasing national participation in the project;
- An increase in the standards of technological education and training.

Finally, it is necessary to note that:

- TT is not simple but complex teaching, and can not produce instantaneous results;
- TT is a gradual process.

2.2. The legal and institutional structure of technology transfer

2.2.1. Intergovernmental agreements.

Where governments exercise control over the utility sector, and where international agreements are required for technology transfer, the role of government may be strong. Where energy and financial markets are being restructured and liberalized or privatized, government's role in technology transfer diminishes. In more centralized economies, comprehensive technology transfer can involve several organizations in both the supplier and receiver countries.

An intergovernmental agreement is a framework for working agreements to transfer the technology and provide the plants, equipment and services. Agreements between specific organizations need not be limited to companies in nuclear power but can include research and development organizations, government departments and educational institutions. A typical structure of bilateral agreements for nuclear technology transfer is shown in Figure 1.

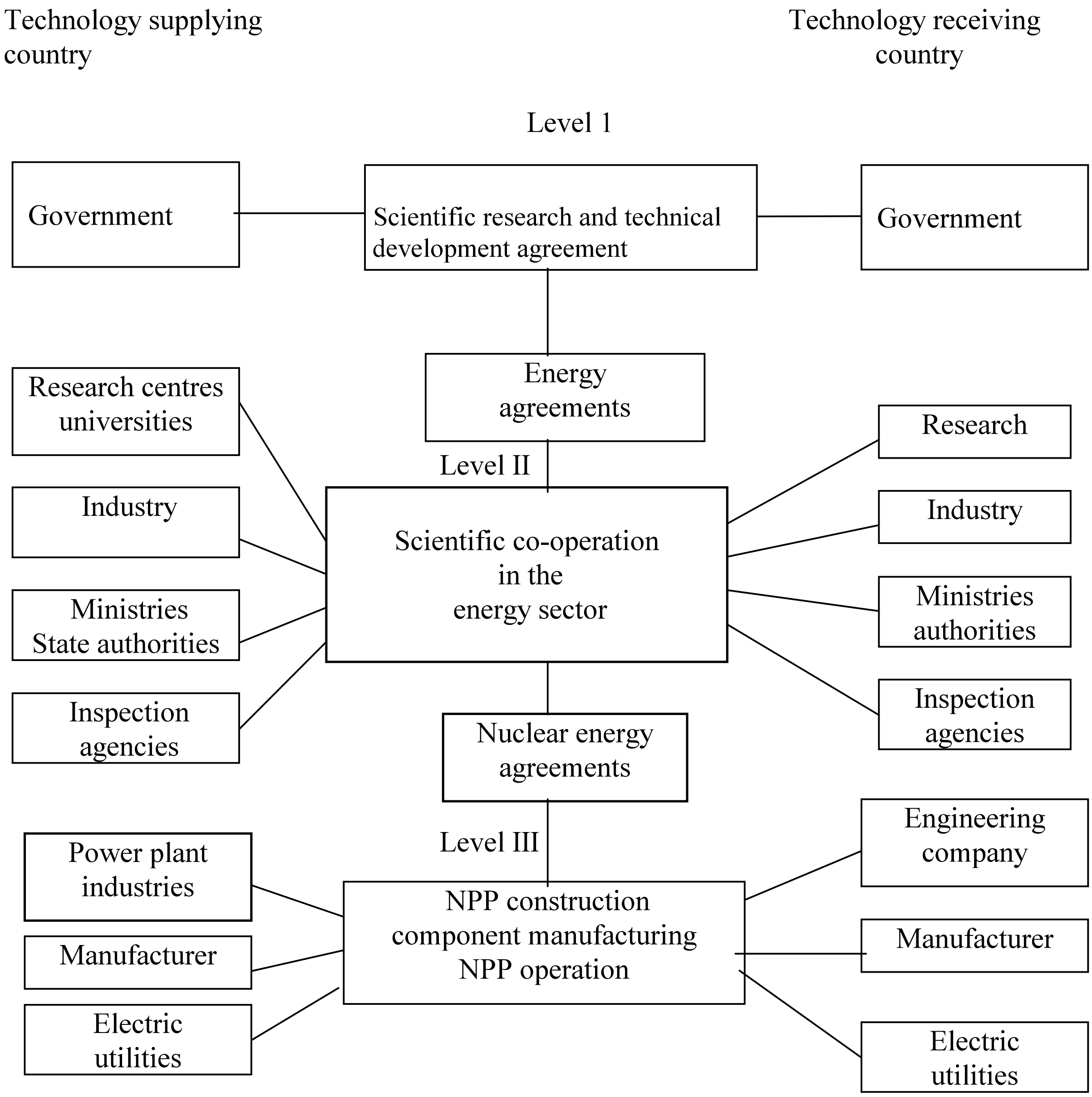

FIG. 1. Structure of an agreement for the nuclear technology transfer.

2.2.2. Agreements between companies

The agreements between companies and organizations involved in the technology transfer are important. They not only define the technology but the terms and conditions of the transfer, the rights, responsibilities and recourse of the parties, and the expected end result. There must also be a clear definition of how competence is to be established. Details might include the type and nature of documents, formal training, on-the-job training and the secondment of the supplier's personnel.

2.3. Characteristics of different type of agreements

There are a number of agreements under which technology can be transferred. The form is determined by the technical competence of the receiver and by the ways and means the supplier and receiver intend to use the technology after transfer.

2.3.1. The licensing agreement

Definition of the technology and technical services is important to a successful agreement. This includes clearly defining the scope of the technology, the scope and nature of technical services and assistance to be provided, the end product and the expertise involved. In practice, differences in expectations are a common problem in technology transfer and the perceptions of the receiver and the supplier may differ on many aspects of the technology to be transferred. Misunderstandings can be avoided by discussion and documentation.

A licensing agreement should provide rights to improvements in the technology. Clearly defining the technology ensures agreement about what an improvement is, although it may be difficult to distinguish between improvements and development. The licenser should guarantee:

- That the technology suits the products covered by the agreement;
- To whom the expertise belongs;
- That the technology can achieve the desired production;
- That the technology is complete;
- That documentation is completed within the scheduled time.

2.3.2. Technical co-operation agreements

The essence of these agreements is the same as for licensing. This means that, when the transfer is completed, each party continues to pursue its business independently. The word co-operation is used to recognize the close teamwork necessary for the period of the contract.

The agreement should specify arrangement of three aspects of the transfer process:

Setting up the agreement:	the supplier provides information on what may be transferred, on the scope and on the methods and administration. The recipient specifies his contribution, and his arrangements and obligations;
Implementing the transfer:	the supplier prepares documentation, provides consultant services and trains personnel; local participation and contribution are defined;
Licensing the technology transfer:	when the technology has been transferred, the supplier and receiver are licenser and licensee; the agreement must provide for continued use of the technology by both parties.

The amount of the down payment and royalty on use of the technology are resolved between the supplier and the receiver, and must be specified.

2.3.3. Joint venture

This is distinguished from licensing and co-operation by arrangements for conditions after technology transfer. In a joint venture, the supplier and receiver agree at the beginning that the association established for transferring the technology will be maintained, and will continue between the parties through the transfer into the exploitation phase. Joint venture implies a mutual interest in the outcome of the transfer and in the continuing association. This in turn implies that both parties will continue to commit resources to the venture after the initial transfer. The agreement should provide that the receiver will have access to improvements in the technology within a time-phase and under specified conditions.

2.3.4. Technical assistance

This is an agreement, usually for limited TT, in which the receiver performs work with the technical assistance of the supplier. This agreement is used chiefly in the manufacturing and construction sectors, where the supplier has a fairly dominant and leading role and in principle, the receiver follows the instructions of the supplier.

2.3.5. Consultancy

This agreement provides limited TT and the supplier plays a relatively passive role in contrast to that in the other agreements. In principle, the supplier advises but does not instruct the receiver, on how the work should be done or how a particular situation should be handled. This can be a good means for transferring software.

3. TECHNOLOGY TRANSFER ARRANGEMENTS

3.1. Protecting the technology

Building a technology transfer agreement is easier if the legal systems in the receiver country recognises the ownership of intellectual as well as physical property and gives technology transfer contracts the same legal protection as any lawful contract. There should be special provisions allowing the supplier to receive fair and reasonable compensation for technology transfer and protecting against unreasonable exploitation.

The function of a legal framework is to facilitate technology transfer by setting conditions which afford protection of the legitimate rights of the donor (supplier) and receiver. Host governments are responsible for assuring that such a framework is in place. Legislation must reflect a balance between the rights and interests of the supplier and those of the receiver. When this is achieved, responsible organizations can reach agreement within the legal framework.

3.2. The price of technology

The supplier develops the technology at some cost and risk over a period of time. Therefore, compensation is required when transferring technology because it is bought and sold like any commodity. In addition, considerable effort will probably be expended in executing the transfer. Establishment of a fair price is complicated because the receiver usually lacks experience in and appreciation of the complexity of the technology. Therefore, the receiver has difficulty appreciating or quantifying the costs.

For successful technology transfer, both parties must feel the agreement is profitable. To arrive at the price for transferring technology, factors to be considered are:

- The nature of the technology and the effort necessary to master it;
- Cost to the donor of developing the technology and of continuing development after transfer, since the receiver must update the original technology;
- The value of using a sales linked agreement (e.g., sale of the NPP);
- The possibility that the donor, in communicating knowledge of his technology is risking its unauthorised dissemination and consequent loss of competitiveness;
- The limitations on market, prices and materials incorporated in the agreements;
- An assessment of extra business in the new technology which will accrue to the receiver, including size of the domestic market, the cost of local labour, and trading relations with other countries;
- An assessment of the royalty and additional business accruing to the donor e.g., through access to new markets.

3.3. The effectiveness of technology transfer

The value of technology transfer is increased if its application is widespread: one-off investments are costly. In the case of nuclear power, a commitment to construct more then one unit within a specified time-frame greatly increases the attractiveness of investing significant money and resources. In most countries, procurement of the first NPP is essentially a turnkey job, with extensive supplier supervision and reduced technology transfer. A group of supplier-provided professionals with extensive industrial experience and previous exposure to basic nuclear physics and research reactor operations are essential to make technological choices and to establish the initial nuclear architect-engineer functions. The same engineering capability must be available domestically to perform as architect-engineers under supervision of the suppliers even if inadequate to act independently.

4. NATIONAL PARTICIPATION

4.1. Level of national participation

Clearly, the main objective of the authorities and/or utilities entering the nuclear field is to build a nuclear power plant within the required schedule which will produce electricity reliably and at as low a price as is consistent with safety and environmental measures. However, the nuclear power programs of most countries have been heavily influenced by clear preferences for the use of national resources. It is a common view that a nuclear power program is an opportunity to develop national capabilities, since it involves high demands on industry, technology, quality and technical personnel. Technology transfer through procurement as well as through training is thus often included in a transfer arrangement, with appropriate cost and quality control stipulations. There will always be an unavoidable minimum of domestic participation to fulfill host country obligations under the TT agreement.

In general, national participation should be defined in realistic terms considering existing industrial, technological, manpower and educational infrastructures and their possible future development. It should be co-ordinated with the nuclear power programme of the country and not simply oriented towards a particular project.

While there are examples of countries successfully increasing the proportion of national participation in each successive plant in an ongoing programme, opportunities are few for substantial local involvement in the first plant. The most significant opportunities in manufacturing are likely to occur first with non-nuclear, more conventional equipment and material. For the first nuclear plant, the extent of local participation depends on existing manufacturing capabilities, particularly those that can be readily upgraded to the required standards of quality. It is important to note that some countries beginning nuclear power programs have experienced considerable delay in the project resulting from local participation in areas where previous experience was non-existent.

The principal partners involved in national participation are the country's government, utilities, industry, research and development institutes and educational and training institutes. The typical distribution of responsibilities and functions among the principal partners is given in Table I and it is needless to say that co-operation among partners is essential for success.

To ensure the implementation of a national participation policy, the leading role belongs to the government. It is the government who will have to develop and apply a consistent set of procedures and methods establishing an adequate framework of conditions and incentives in which all partners of the national effort will effectively carry out their share of responsibilities and functions.

It is difficult to quantify an unavoidable minimum of local industrial support required for local participation since conditions vary in different countries. However, for meaningful local participation, the existence of a medium and heavy engineering industry experienced in the manufacture of cement, steel or chemicals and a well developed civil construction industry should be considered minimal. These should be in place before a nuclear power program can be conceived with a meaningful chance of success. It must be emphasized that there is a minimum necessary level of national participation in a nuclear programme and that means:

- A country must be able to accept the responsibility of achieving an acceptable and assured level of safety to make nuclear power a viable energy option;
- The regulatory authority must know its responsibilities and the future owner organisation must be "an informed buyer" and accept full responsibility for safety and reliable operation.

For minimum involvement even with the first plant, local engineering companies and industries might participate to a reasonable extent in the following activities:

- The detailed engineering of conventional civil and architectural work;
- The supply and manufacture of basic materials for civil, mechanical and electrical work;
- The completion of construction work in civil, mechanical and electrical work of conventional plant areas to the extent possible.

TABLE I. RESPONSIBILITIES AND FUNCTIONS FOR NATIONAL PARTICIPATION

Partners	Main responsibilities and function
Government	– Development of the nuclear power strategy and programme – Nuclear licensing and regulation – Establishment of bilateral or multilateral agreements, for the implementation of technology transfer, training, technical assistance, exchange of information – Definition of national participation policy – Legislation for nuclear power and for promoting national participation – Survey of the available national infrastructure and its capability – Study of the feasibility of national participation in general and in detail – Planning and co-ordination of the national effort – Elaboration of procedures and methods to implement and to increase national participation – Provision of financial assistance – Establishment of national policy for quality assurance
Utility/Owner	– Definition of overall and detailed supply requirements of the nuclear power projects – Completion of commercial arrangements for project implementation – Supporting advice and assistance to the Government in its tasks and functions – Development of manpower for utility/owner's requirements
National industry	– Analysis of supply requirements, market conditions and production possibilities, in particular regarding quality, schedule and cost – Development of supply proposals – Production and supply of goods and service – Specialised and on-the-job training in the respective fields of competence – Implementation of improvements and additions to existing capability – Supporting advice and assistance to the Government in its tasks and functions

TABLE I. (CONT.)

Partners	Main responsibilities and function
Research and development institutes	– Technical research and development in national participation areas – Technical and scientific assistance to the Government, utility and industry – Manpower development in basic and specialized fields – National information exchange centre – Supporting advice and assistance to the Government in its tasks and functions
Educational and training institutions	– Provision of basic and specialised academic education and training to professionals, technicians and craftsmen in fields of national interest – Planning and development of new national training capability according to the requirements – Supporting advice and assistance to the Government in its tasks and function
Foreign governments and suppliers; International organisations	– Conclude agreements and/or supply contracts with appropriate governmental or industrial organisations – Provision of technology transfer – Provision of information and technical assistance as established in bilateral or multilateral agreements – Provision of training opportunities – Active participation, joint ventures (possible) – Provision of financial assistance

The optimum level of national participation will evolve with time and experience as a function of the infrastructure. However, not infrequently, planners underestimate the time and effort necessary to obtain the required quality of national products. Too often the call for *maximum* participation is emphasized whereas the real objective should be *optimum* participation. National participation should in no case affect quality and on this there can be no compromise, even where national participation is subsidised. It is important to make a realistic assessment regarding adverse effects on the cost and time schedule of a project as a result of national participation. If, for strategic reasons and national policies, certain increases in cost and time schedule are consciously accepted in the initial stages, the long-term economics should be kept in view.

In selecting items for which domestic manufacture and supply is considered part of the optimum national participation, initial attention should concentrate on items which:

– Are currently manufactured in the country even if below the quality than needed and requiring a modest effort to upgrade;

- Already have an internal market in which planned expansion justifies the required investments in view of expected increased sales;
- Are not in the critical path of the plant construction.

4.2. Types of contract

One of the important activities and key decisions is the selection of the type of contract to be taken in realization of a nuclear power project. Basically, there are three main types of contract that have been used for nuclear power plants, namely:

- *Turnkey*. A single contractor or a consortium of contractors takes the overall responsibility for the whole work;
- *Split package*. The overall responsibility is divided between a relatively small number of contractors;
- *Multiple package*. The owner, by licensing or with the help of his architect-engineer (AE), assumes the overall responsibility for engineering the plant.

A common approach in the past has been that the first plants are ordered under turnkey contract and orderly progress is then made in subsequent plants towards split and multiple package contracts with each step placing increasing demands on the domestic infrastructures.

The turnkey type of contract refers to the supply of a complete power plant, ready for commercial operation, by one supplier, the so-called main contractor. A turnkey contract gives the main contractor comprehensive responsibility for completing all parts and all phases of the project to the satisfaction of the client, including the design, engineering, construction, erection, supply and installation, testing and commissioning of the plant, as well as the training of the owner's personnel. The main contractor will be in charge also of the overall project management. The main contractor might be a single company or group of contractors operating as a consortium, usually with one member acting as leader for the group. The main contractor has to guarantee both his own delivery and services, and the deliveries and services of all his subcontractors, foreign and local. Obtaining licenses from the national regulatory body should remain the responsibility of the buyer but the main contractor should guarantee the plant's licensability and prepare the safety analysis reports.

The essential advantage of this approach lies in the fact that one main contractor is held responsible by the buyer for all financial risks during construction. The turnkey approach seems especially advisable when there is little or no domestic experience with the management of very big projects. It has been used also in some countries where such qualifications existed, especially for the procurement of the first plants, but turnkey contracting generally has not been used by experienced organizations in recent years. It seems quite probable that the turnkey type of contract will again be used in industrialized countries if nuclear power programmes are revived, both because of the standardized plant designs now being offered and the additional security it offers to the plant owners.

In the split-package approach, the overall responsibility for design and construction of the plant is divided among a relatively small number of contractors, who manage, design, construct and/or manufacture large, functionally complete portions of the work, e.g., entire systems, buildings, etc. Each portion is called a package. Under the split-package approach the interface problems can lead to risks of delays and extra costs to the owner. To overcome this problem, one of the contractors is usually assigned the responsibility for overall system integration and functional design as well as project co-ordination and interfacing.

In the multiple-package approach, the owner, either within his own organization or through his architect-engineer, assumes the direct responsibility for the design and construction management of the project with a large number of contracts. The multiple-package may be adopted by a country, provided that proven capabilities in full-scope project management are available within the country. Bids are invited for the nuclear steam supply system (NSSS) and turbine-generator (TG) packages, the suppliers are selected and contracts are placed. The owner or his architect-engineer (AE) then designs the plant around this equipment, produces a very large part of the safety report and supervises construction, usually erecting the plant himself. This approach has been favoured as it offers the maximum opportunity to the buyer to select the plant that suits him best and to influence the design as he would wish, but it can result in a tailor-made plant, significantly different from a standardized design.

The main factors and considerations for evaluation and selection of the type of contractual approach are the following:

- Factors and conditions including existing management, engineering and construction capabilities, industrial infrastructure, national planning and implementation policy of the first project and subsequent projects in the long-term nuclear power programme;
- Experience in project management of similar projects, particularly of large fossil-fuelled power plants;
- Potential contractors and their capability, reliability and experience with different contractual approaches;
- Economic and competitiveness considerations;
- Foreign financing possibilities;
- Assurance of supply.

4.3. Considerations for national participation

It has been mentioned already that a number of countries entering a nuclear power programme wish to achieve highest levels of local participation. While there are examples of countries which have successfully increased the proportion of national participation in each successive plant in an ongoing nuclear power programme, opportunities for substantial local involvement in the first plant are few. The most significant opportunities in the manufacturing area are likely to occur first with the non-nuclear, more conventional items of equipment and material.

For the first nuclear power plant, the extent of local participation will depend on the country's existing manufacturing capabilities, particularly on those that can be readily upgraded to the required standards of quality. Even so, a significant level of local participation could be achieved in most countries.

It is probable that to achieve any degree of local participation in the manufacture of nuclear components an intensive programme of technology transfer will be required. The programme will require significant investment of both human and financial resources on a national scale. Training of the personnel required, at the professional, technical or skilled trades level will take a considerable time since the nation's total manpower development effort cannot and should not be solely directed toward the development of nuclear power. Similarly, the financial resources of the country must be assigned to meet the overall goals of the nation. It follows then that the development of the manufacturing sector, like other sectors of the nuclear industry, should take place in an orderly fashion and be phased in over a programme of several nuclear units. It is desirable that the initial entry into the manufacturing of components for nuclear plant should concentrate on less complex and less demanding equipment so that an appreciation can be gained of the standards of work and the quality assurance aspects required. Some studies and/or surveys have to be conducted in the country entering nuclear power development, before undertaking the necessary investments in manufacturing components and supplying material. The studies should be directed toward understanding

- How the present industrial capabilities can be used;
- To what products priority should be given;
- How quickly can the technology be assimilated and local production achieved;
- What is the disadvantage of local participation.

Some countries entering a nuclear power programme for the first time have found that considerable delays in the project can result from local participation in areas where previous experience did not exist. Therefore, scheduling is perhaps the greatest problem arising from the initial stage of local participation.

5. CONCLUDING REMARKS

There will clearly be stronger incentives for national participation to support a long-term nuclear power program consisting of several plants, than would exist for the construction of just a single plant. It is most important to give local suppliers confidence in achieving an adequate return on their investments. In this case national industry participation might proceed as follows:

Level 1. Local labor and some construction materials are used for on-site non-specialized purposes, especially for civil engineering work, as a minimal move toward established targets,

Level 2. Local construction industries take full or partial responsibility for civil work when possible, including design work,

Level 3. Locally manufactured components from existing factories are used for non-critical parts of the plant,

Level 4. Local manufacturers extend their normal product line to incorporate nuclear standards, possibly under licensing arrangements with foreign suppliers,

Level 5. Special factories are set up to manufacture heavy and specialized nuclear components. The economic viability of such undertakings should be assessed in view of future domestic markets and availability of such equipment internationally.

This type of plan has been followed in the Republic of Korea. In keeping with increasing participation by national industry, there was also a corresponding evolution in the contract form for each plant, from turnkey to split package and then to multiple package, with a corresponding expansion in the capabilities of the owner organization. A national organization is now responsible for new plant design and there is capability for plant export.

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KOREAN EXPERIENCE IN SELF-RELIANCE FOR NUCLEAR POWER TECHNOLOGY (A CASE STUDY IN THE REPUBLIC OF KOREA)

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Abstract

This paper describes the Korean experience in achieving self-reliance in nuclear power technology. The chronology of the nuclear program is presented introducing key factors and strategies for technological self-reliance. Experience in successful technology transfer of Nuclear Steam Supply System (NSSS) design, manufacture of NSSS and Turbine/Generator (T/G) equipment, nuclear fuel design and manufacture, and Architect/Engineering (A/E) is described. The nuclear plant standardization program is also described along with design and development approaches. Finally, experience in nuclear technology export is elaborated.

1. OVERVIEW

Domestic energy resources are scarce in the Republic of Korea, so stable energy supplies have been a principal consideration in formulating energy policy. As energy security is also of concern and nuclear power is considered semi-domestic because uranium is imported while other major sources of energy are domestic with self-reliance in design, manufacturing and construction, it was chosen as one of the main sources of electricity. Korea has put in place a highly successful nuclear self-reliance program employing technology transfer and standardization of nuclear power plants.

1.1. Chronology of the Korean Nuclear Power Program

The nuclear power program in Korea started with a feasibility study of plant introduction in the late 1960's. At the end of 1997, twelve units of nuclear power, 10 Pressurized Water Reactors (PWR) and 2 Pressurized Heavy Water Reactors (PHWR) are operating with an additional eight units under construction [1]. Nuclear power in Korea can be categorized in the following generations from the point of view of technology self-reliance:

1.1.1. The first generation: Total dependence and the imitation period

During the first generation, from the late 1960s to the early 1970s, three units, Kori - 1&2 and Wolsong - 1, were constructed through a turnkey contract, with the foreign vendor as prime contractor. This can be characterized as a period of total dependence and imitation of technologies. Due to lack of domestic experience in nuclear industries, Korea Electric Power Corporation (KEPCO) totally relied on foreign suppliers, granting them overall responsibility for project management from design and construction to start-up. Domestic industries were limited to civil and architectural work in service facilities, as subcontractors. Major goals for self-reliance in this period were to find items available to be localized and to imitate the technology (exactly as instructed) of the foreign suppliers.

1.1.2. The second generation: Self-reliance preparation period

During the second generation, from late 1970s to early 1980s six units, Kori - 3&4, YGN (Yonggwang) - 1&2 and UCN (Ulchin) - 1&2, were constructed through a component base contract with foreign prime contractors. In that time, KEPCO managed project construction assisted by a foreign Architect/Engineering (A/E) company. KEPCO procured the balance of plant equipment and Korean contractors managed site construction, while domestic industries expanded their engineering and equipment supply roles. During this period, domestic participation increased and various vehicles of technology self-reliance were opened as well.

1.1.3. The third generation: Self-reliance promotion period

In the third generation, from late 1980s to late 1990s, KEPCO led component base projects as before, but construction project management was internal. KEPCO assumed overall responsibility by awarding the prime contracts to Korean entities, while foreign suppliers served as subcontractors. In this period, YGN - 3&4, the first project of its kind, was started along with a technology transfer contract to increase self-reliance in parallel with plant construction. For the UCN - 3&4 project, Korean entities took responsibility for the entire project while foreign suppliers were mainly consultants.

1.2. Key factors for technology self-reliance

Korea has attained self-reliance in nuclear technology through a national policy for long-term self-reliance in fuel and plant design, manufacturing, construction and operation. To execute the policy, technology transfer and power plant standardization were chosen as major vehicles for self-reliance. The scope and responsibilities were defined and divided among the participating Korean entities as shown in Table I, and in conjunction with that, plant standardization was conducted. For effective transfer, joint design[1] with foreign partners was chosen as the mechanism for implementation [2].

1.3. Strategy [3]

The strategy to acquire self-reliance in nuclear power technology was supported by four major means; actual project execution, technology transfer, power plant standardization and gradual improvement through research and development(R&D).

YGN - 3&4 project was selected as the base for self-reliance. Since the nuclear market was a buyer's market when YGN-3&4 project was planned, the government included technology transfer as a condition of the contract. As a result, KEPCO engaged domestic main contractors while foreign subcontractors warranted the project. Well planned training and joint design were adopted as mechanism of implementation. The scope of technology transfer included the transfer of technical information, patents license, classroom training (CRT) and on-the-job training (OJT) and R&D participation and consultation.

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[1] All design activities are jointly carried out by engineers of the technology recipient and the technology supplier. The technology supplier takes all responsibilities and the warranties on the results of the joint design.

TABLE I. DIVISION OF RESPONSIBILITIES

ENTITY	RESPONSIBILITIES
KINS[a]	Licensing Support for the Government
KEPCO	Project Management, Operation
KOPEC[b]	Plant Design (A/E), Development of A/E Design Technology
KAERI[c f]	NSSS Design, Fuel Design, R&D
HANJUNG[d]	Component Design & Manufacturing, Development of Manufacturing Technology
KNFC[e]	Fuel Manufacturing, Development of Fuel Manufacturing Technology
Universities	Research & Tests of Key Technologies, Development of Key Technology

[a] Korea Institute of Nuclear Safety.
[b] Korea Power Engineering Co., Inc.
[c] Korea Atomic Energy Research Institute
[d] Korea Heavy Industries & Construction Co., Ltd.
[e] Korea Nuclear Fuel Co., Ltd.
[f] The division of responsibilities above was effective up to the end of December 1996. Currently, KOPEC is responsible for NSSS design and KNFC for fuel design.

Power plant standardization began with YGN - 3&4 as the reference plant. Korean-Standard Utility Requirements Document (K-SRED) and Korean-Standard Safety Analysis Report (K-SSAR) were the main outputs. The objectives of standardization were to develop the concept, identify items for design improvement, and improve the design over the reference.

Standardization means constructing plants to the same specifications in series for economic gains from repetitive works. But, new technology must be adapted to enhance safety and performance. In Korea, UCN - 3&4 is the first standardized plant and YGN - 5&6 and UCN - 5&6 replicate it, although gradual improvement through R&D was applied. Currently, Korea is developing the next generation reactor with a higher capacity, based on technology attained through self-reliance in 1000 MWe standard plant implementation.

2. TECHNOLOGY TRANSFER

2.1. YGN - 3&4 contract structure [4]

YGN - 3&4 was the first nuclear power project implemented on a component basis by local prime contractors. This was a turning point in Korean nuclear history because domestic involvement was markedly increased by technology transfer. KEPCO, the owner, designated KOPEC as the prime contractor for Architect/Engineering, HANJUNG for supply of the nuclear steam supply system and turbine/generator, KNFC for nuclear fuel manufacturing, and HECC for the construction. Procuring the balance of the plant was the responsibility of KEPCO as the owner. KAERI was designated as subcontractor to HANJUNG and KNFC for the design of NSSS and initial core, respectively. These entities subcontracted with foreign companies such as Sargent & Lundy (S&L), General Electric (GE) and Asea Brown Boveri-Combustion Engineering (ABB-CE) for engineering and equipment and related technology. The contract structure for the YGN - 3&4 project is shown in Figure 1.

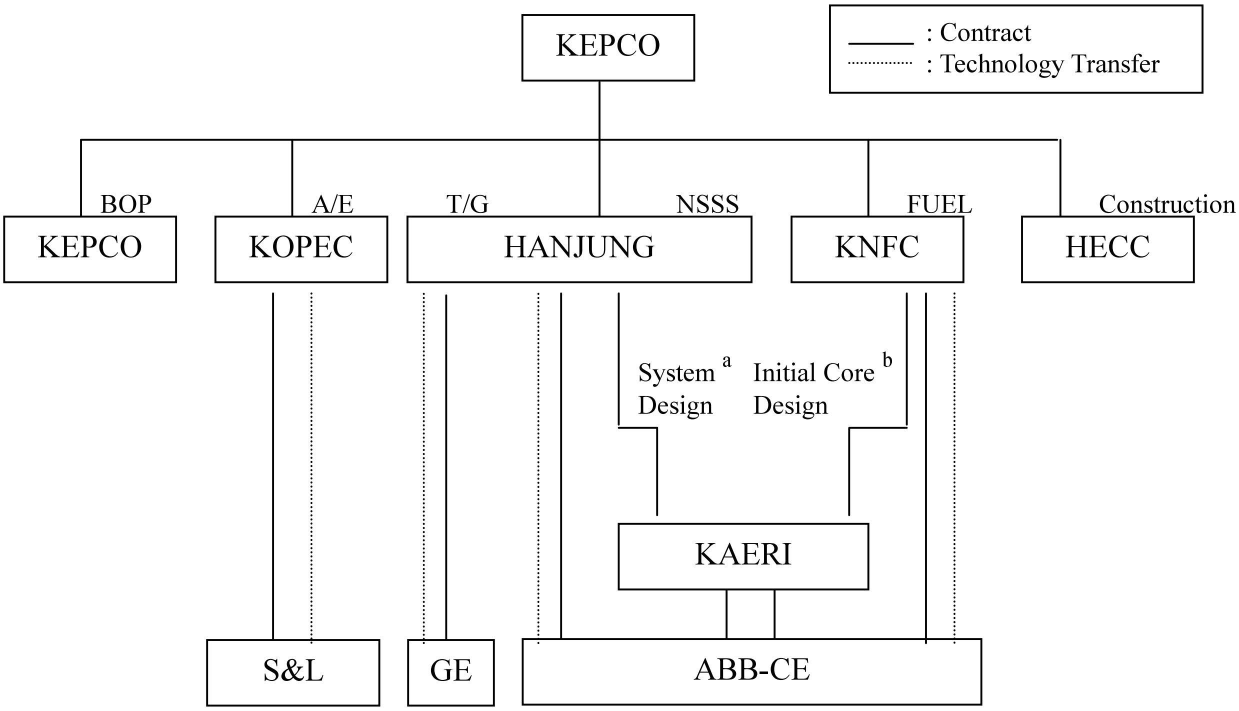

FIG. 1. YGN-3&4 contract structure.

2.2. Implementation method

Although there are various methods for transfer of technology, technical document, computer codes and patents licenses transfer are primary, in parallel with training and consultation. Korean entities added two more : joint design and research and development participation/joint research and development, to secure self-reliance.

Documents that were transferred were generic documents, including licensing related, quality assurance (QA) documents and procedures, and reference documents, including design documents, calculation notes, manuals, drawings, specifications, and procedures. Installation, verification and validation were major tasks in the transfer of computer codes, including source programs, manuals and QA verification documents. During the transfer, consultation was available when detail or additional works were needed.

The ten year technology transfer agreement made in 1987 was renewed and extended for another ten years in a technology cooperation agreement as of May 15, 1997.

2.3. NSSS design [4]

Technology transfer for NSSS design was implemented through four phases.

The first was the period of self-reliance for nuclear fuel technology. During this period, KAERI independently developed technology for PHWR fuel, and imported technology for PWR fuel from Siemens-KWU through technology transfer and joint design.

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[a] Currently, NSSS design by KOPEC.
[b] Currently, Fuel design by KNFC.

In the second phase, YGN - 3&4 was executed through technology transfer and joint design with ABB-CE. In this period, system design was supported through technical review, design repeat, mock-up design and joint R&D with ABB-CE.

In the third phase, KAERI performed its own NSSS design works with some technical consultation from ABB-CE. UCN - 3&4 was the first project of the period and became the reference plant for follow-on Korean Standard Nuclear Power Plants (KSNP). The standardization project was launched then and K-SRED and K-SSAR were the main outputs. R&D continued and improved design features were applied to the follow-on plants.

YGN - 5&6 and UCN - 5&6 projects are being executed independently by Korean entities with much less consultation from ABB-CE. Next generation reactor development has begun as well.

2.4. NSSS and T/G manufacturing [5]

Technology transfer for manufacturing NSSS and T/G equipment and components was accomplished in four phases: import, expansion, improvement and standardization and enhancement.

In phase I, partial domestic manufacturing was conducted under foreign supervision for the YGN - 1&2 and UCN - 1&2 projects, and this technology was expanded during phase II when components of YGN - 3&4 were manufactured under foreign supervision. A technology transfer agreement was made with the YGN-3&4 project contracts, and technical documents and computer programs were transferred from ABB-CE and GE. In keeping with the agreement, on-the-job training and on-the-job participation, consulting, mock-up tests for critical operation and facility improvement were performed.

Phase III was the period of technology improvement, UCN - 3&4 components were manufactured by Korean entities and technology previously transferred was utilized and improved.

In Phase IV, the period of standardization and technology enhancement, the YGN - 5&6 project was implemented and component manufacture expanded. Standardization and the development of advanced technology are the main targets in this period.

2.5. Nuclear fuel design & manufacturing [6]

To achieve self-reliance in nuclear fuel design and manufacturing, reload core was the first to be localized. KAERI imported design technology for reload core from Siemens-KWU and reload design was done jointly for eight Westinghouse type reactors.

For the initial core design, technology was transferred from ABB-CE along with the YGN - 3&4 project execution. According to the technology transfer agreement, technical data and computer codes were transferred and classroom training was delivered. During the execution of the YGN - 3&4 project, joint design with ABB-CE was fulfilled as a vehicle for technology transfer. Although preliminary design was done jointly with ABB-CE, final design was independently performed by KAERI and approved by ABB-CE. For the follow-on projects (UCN - 3&4 and YGN - 5&6) initial core designs were done by Korean engineers.

For fuel manufacturing, technology has been transferred from both Siemens-KWU and ABB-CE. Technical supervision has been provided for construction and operation of the factory.

2.6. Architect/engineering [7]

The technology self-reliance program for A/E was in three phases: import, localization and self-reliance consolidation.

During the first phase, related technology was imported from companies with previous experience in nuclear power projects. Bechtel provided engineering services for Kori - 3&4 and YGN - 1&2. French companies such as EdF, Framatome and Alsthom provided services for UCN - 1&2, and Canadian companies such as AECL and CANATOM provided services for Wolsong - 2,3&4. KOPEC participated as a subcontractor with foreign prime A/E contractors.

The YGN - 3&4 project was also the vehicle for self-reliance for KOPEC. KOPEC signed a technology transfer contract with S/L and technical information, including documents and computer programs were transferred. For the architect engineering of YGN - 3&4, S/L was responsible for initial design while KOPEC was responsible for final design. To add to technical abilities, KOPEC utilized consultation for technology transfer.

During Phase III, KOPEC attempted to consolidate self-reliance through utilization and improvement of the transferred technology. Projects for the Korean Standard Nuclear Power Plants such as UCN - 3&4, YGN - 5&6 and UCN - 5&6 were executed with gradual design improvement.

3. NPP STANDARDIZATION

3.1. Plan

The standardization of nuclear power plants in Korea was implemented in four phases beginning April 1983. The preliminary concept was formulated during the first phase from April 1983 to July 1985.

During phase II, from September 1985 to August 1987, standardization was developed by review of construction and operating experience, technology development, and identification of items for design improvement.

Since the YGN - 3&4 project was executed with technology transfer, it was used as the reference plant of the Korean Standard Nuclear Power Plant (KSNP). In this third phase, from February 1989 to April 1991, KSNP was developed referencing YGN - 3&4 and incorporating selected advanced design features.

Phase IV has been the period of constructing Korean Standard Nuclear Power Plants with UCN - 3&4 the leading plant. More units including YGN - 5&6 and UCN - 5&6 are under construction and will be completed by 2005. During Phase IV, gradual design improvements have been pursued.

3.2. Design approach [8]

To design the Korean Standard Nuclear Power Plant, four major factors are considered: enhanced safety, improved performance, use of proven technology, and severe accidents. Nuclear safety is a major concern and to secure it, advanced design features have been incorporated in the standard design. Improved performance is achieved through modularization of components and equipment and through standardized, gradually improved design and construction processes. Proven technology is required for licensing the standard plant, and for that, proven design and analysis methods, systems, components and structures are used.

Severe accidents are examined as a separate category for an additional safety margin beyond design basis accidents. To do so, post-Three Mile Island (TMI) action items, unresolved safety issues (USI) and generic safety issues (GSI) are selectively resolved and design features related to severe accident prevention and mitigation are incorporated.

3.3. Development approach [4]

Gradual improvement is key to the design of the Korean Standard Nuclear Power Plant. YGN - 3&4 (that is, a scaled down version of the System 80 plant of ABB-CE) was selected as the reference plant for the KSNP and improved with selected advanced design features. Electric Power Research Institute (EPRI) utility design requirements for Advanced Light Water Reactor (ALWR) and previous experience in construction and operation were considered in the development of the KSNP.

The first units of the Korean Standard Nuclear Power Plant are UCN - 3&4 and follow-on units such as YGN - 5&6 and UCN - 5&6 are under construction as a series of KSNP 1000 MWe class. Though the KSNP will be constructed repetitively, design will be gradually improved through R&D.

4. TECHNOLOGY EXPORT EXPERIENCE

4.1. Technical assistance and consultation

In 1993, KEPCO signed a three year technical assistance contract with Guangdong Nuclear Power Plant (PWR, 900MWe x 2units) in China. To implement this contract, engineers from KEPCO, KOPEC and the Korea Power Plant Service Co., Ltd. (KEPOS) were dispatched to Daya Bay Nuclear Power Plant to share experiences from operation and maintenance of the plants in Korea. In addition, Chinese staff were stationed at Ulchin Power Plant in Korea and trained in operation and maintenance [9].

In 1995, KAERI was awarded a consulting services contract from the Turkish Electricity Generation and Transmission Corporation (TEAS) to support the introduction of the first nuclear power plant to Turkey. KAERI's scope of work was as follows:

- Comparison of commercial reactor types and designs accepted internationally for applicability in Turkey, and recommendations for nuclear energy planning,
- Preparation of new Bid Specifications through revision and update, and
- Review of Bids, and support of TEAS in Bid evaluations and contract negotiations.

In 1996, KEPCO provided the Qinshan Nuclear Power Corporation with consulting services for the Qinshan Phase III project. KEPCO's was to review the draft contract for the supply of CANDU plant, to support the Qinshan Nuclear Power Company Ltd. in bid evaluation and contract negotiation, and to provide technical consultation based on experience from construction and operation of Wolsong - 1 Nuclear Power Plant.

4.2. Export of nuclear equipment

Experience from the Wolsong CANDU project allowed Korea's first export of nuclear equipment through a contract between AECL and HANJUNG in early 1997 for the supply of steam generators, pressurizers and heat exchangers for Qinshan Phase III project (PHWR, 700 MWe x 2 units) in China.[10] For the Qinshan Phase III project, HANJUNG is to supply 19 items of NSSS equipment, while 55 items are supplied by HANJUNG for Wolsong 3&4 project. [11]

5. CONCLUSIONS

Self-reliance in nuclear power technology in the Republic of Korea was achieved through well-developed policy and proper implementation. Considering the Korean experience, it may be concluded that the key factors are:

- Establishment of a long-term national plan to achieve self-reliance in nuclear power technology,
- Award of nuclear plant construction contracts with separate agreements stipulating specific avenues for technology transfer, and
- Establishment of a nuclear power plant standardization plan.

It is recommended that developing countries conduct joint work after, or in parallel with, training and transfer of technical information and computer codes through a separate technology transfer agreement.

As the technical capabilities of domestic industries grow through technology transfer and joint work, self-study (design repetition and mock-up design) and R&D should follow to implant and improve the transferred technology. Where a number of nuclear power plants are constructed in series within the framework of a long-term national power development plan, nuclear power plant standardization can definitely facilitate self-reliance in the technology.

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TECHNOLOGY TRANSFER OF NUCLEAR POWER DEVELOPMENT IN DEVELOPING COUNTRIES: CASE STUDY OF CHINA

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Abstract

This paper describes the specific experiences in the technology transfer of nuclear power in China, a country that both imported and developed indigenous nuclear technology. Based on this experience some recommendations are presented that should be considered particularly by the developing countries.

1. INTRODUCTION

The nuclear power industry is a modern one including research and development, design and engineering, equipment manufacture, project management, personnel training and operation and maintenance. It is a complex and comprehensive high technology, therefore, a certain infrastructure is absolutely necessary for development in any country. It is also the reason why nuclear power developed first in industrialized countries and then was introduced into some developing countries.

2. HISTORICAL REVIEW OF NUCLEAR POWER DEVELOPMENT IN CHINA

2.1. Nuclear power plants (NPPs) put into operation

In the early 1970's, the Chinese government decided to develop nuclear power. After investigating nuclear power development in the world and exploring the domestic capabilities for research and development (R&D), design and engineering, equipment vendors, fuel supply, manpower, and project management of utilities, experts proposed that nuclear power be initiated with a small (i.e. 300 MWe) pressurized water reactor (PWR). The Chinese government adopted this proposal and decided to build the first NPP with a 300 MWe PWR unit at Qinshan, Haiyan County, Zhejiang Province. Through construction and operation of the Qinshan NPP Phase 1 we have mastered key technologies, accumulated valuable experience, trained personnel in operation and maintenance, and set up the necessary infrastructure for development of nuclear power. The capability to design, construct and operate medium and large PWR NPP has been also fostered.

During construction of Qinshan NPP, Phase 1, more than 100 institutes, universities and factories engaged in more than 400 R & D programs on subjects such as reactor physics, thermo-hydraulics, radiation shielding, material research, stress analysis, earthquake-resistant design and safety analysis. Fuel assemblies and related components, reactor internals, control rod drive mechanisms, steam generators, pressurizers, turbine-generators, instrumentation and control(I & C), and so on, were domestically manufactured for the unit. In addition, we carried out the necessary technology transfer. For example, we exchanged information and personnel with foreign institutes, asked foreign AE companies and vendors to consult on the layout and control room design, as well as the design of the steam generator and turbine-generator of the plant. We have purchased software for design, analysis and some manufacturing technology, and dispatched Chinese engineers to visit foreign NPPs and education centers for training in operation and maintenance of NPPs. Through a combination of unremitting domestic efforts and the above-mentioned technology transfer, the construction of Qinshan NPP Phase 1 was completed by the end of 1991 and put into full power operation in July, 1992. Since then Qinshan NPP Phase 1 has had a good operating record; Figure 1 shows the annual load factor. Now we have independently mastered design, construction and operation of a 300 MW PWR NPP.

In addition, a 300 MWe, PWR NPP is being constructed by the China National Nuclear Corporation (CNNC) in Pakistan including some technology transfer and personnel training. CNNC takes turn-key responsibility for this project and subcontracts some auxiliary building to Pakistani companies. According to the project schedule, this NPP will be completed in 1999.

Daya Bay NPP with 2×900 MW PWR is the second NPP on the mainland of China. To meet the demand for electricity in Guangdong Province and Hong Kong, in the middle of 1980's, the Chinese government approved construction of this large NPP through a joint venture with a Hong Kong utility. The design and equipment supply of the nuclear island of the NPP was provided by French Framatome Company. The British and French GEC ALSTHOM Company provided the design and equipment of the conventional island of the NPP. The Balance of Plant (BOP) equipment was purchased in the international market and Chinese companies were responsible for construction and installation. The French EDF company was asked to provide project services including technical responsibility for the project (coordinating interfacing of suppliers, assisting the owner with design review and procurement of BOP), training personnel in operation and maintenance and taking commissioning of the first unit, as well as to assist with project management. The framework of contracts is illustrated in Figure 2. The operating record of the NPP after commercial operation in 1992 is quite good; Figure 3 shows the annual load factors.

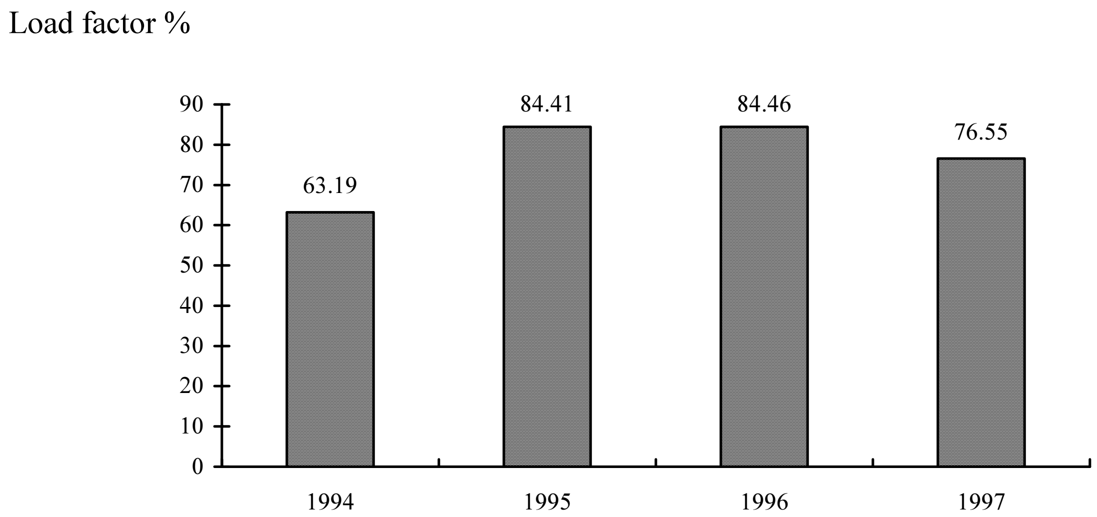

FIG. 1. Annual load factor of Qinshan NPP, Phase 1.

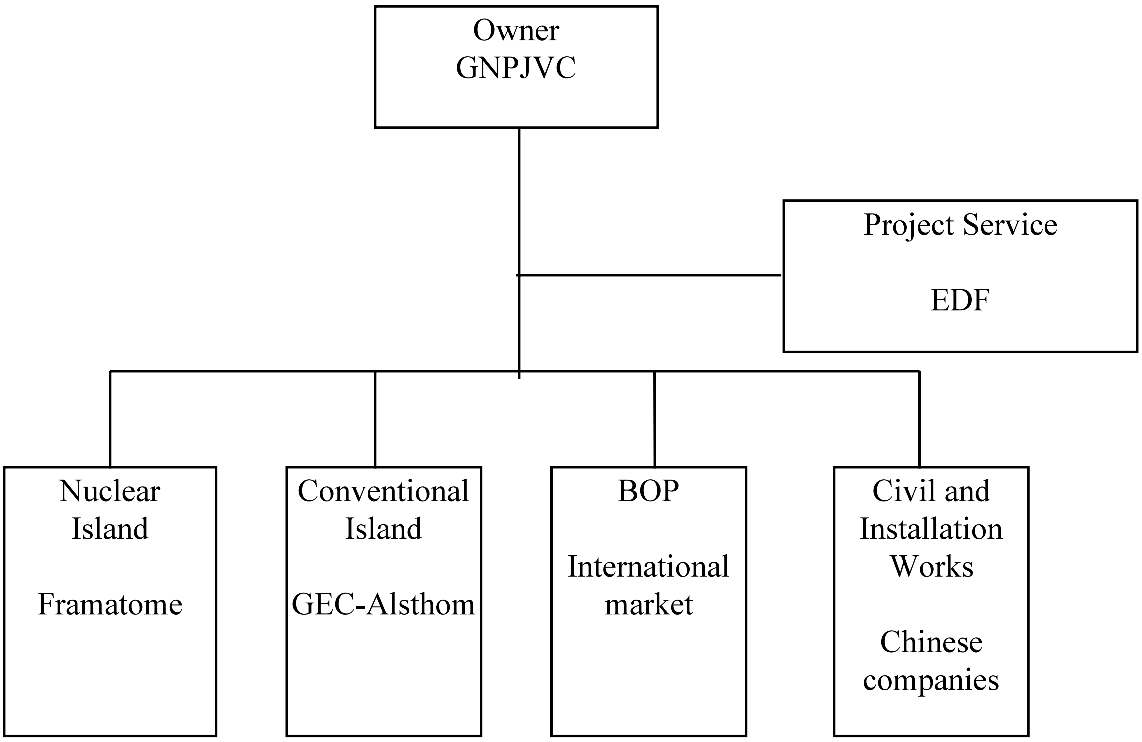

FIG. 2. Framework of Daya Bay contracts.

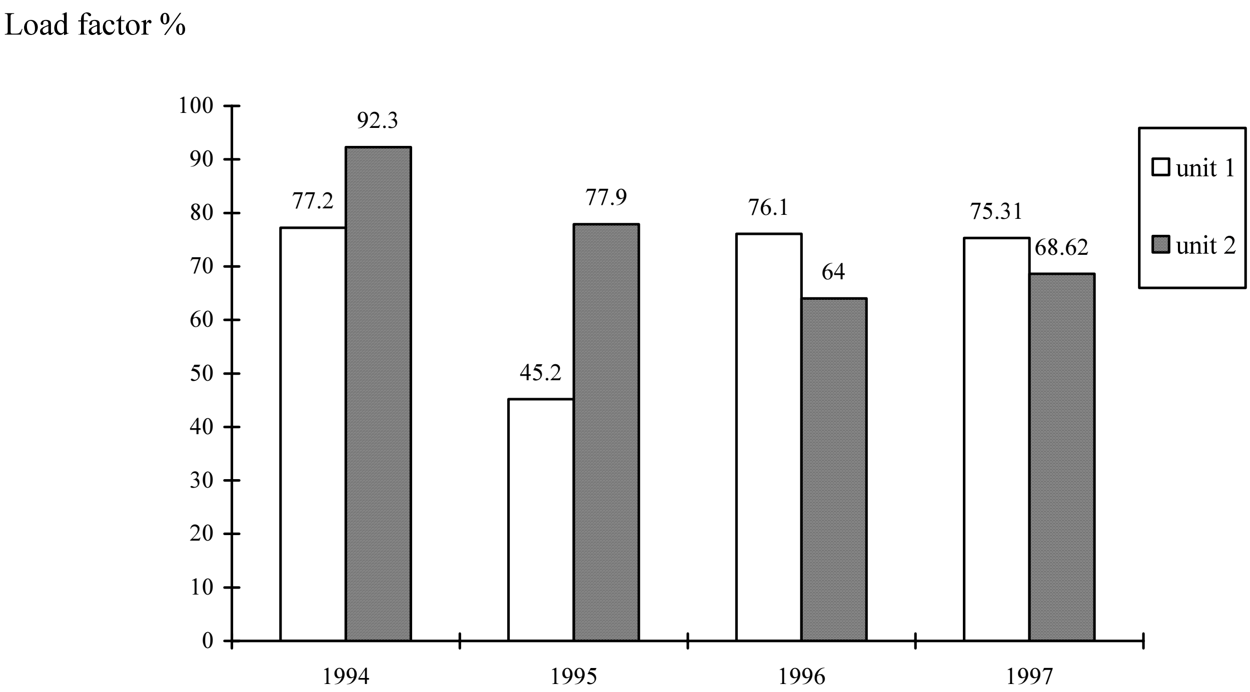

FIG. 3. Annual load factor of Daya Bay.

2.2. NPP under construction

The successful operating record of the self-designed and self-constructed Qinshan NPP Phase 1, as well as the imported Daya Bay NPP excited Chinese government and utilities of some provinces and encouraged them to further develop nuclear power. It is also very helpful for consolidating public acceptance for nuclear power in China. At present there are 4 NPPs with 8 units under construction as follows:

(1) Qinshan NPP Phase 2, with 2×600 MW PWR

This is the second self-designed and self-constructed NPP with 2 PWR units of medium scale. To provide design and engineering testing data for localization of equipment, some R & D facilities have been newly set up or extended operations. Moreover, based on technology transfer for Qinshan Phase 1, we have imported a full set of design drawing of the reference plant and the related codes and standards. We have purchased more than 100 design and analysis software programs for system, equipment and fuel assembly from French Framatome, EDF and Fagema companies. These firms have been asked to consult and review a part of the plant design. The construction of Qinshan NPP Phase 2 started with the first pouring of concrete in June 1996. According to the project schedule It is expected to be connected into the grid in the year 2002. We believe that through corresponding training from the technology transfer, especially construction of Qinshan NPP Phase 2, the best practice of this kind of technology transfer, we are independently capable of design, construction and operation of 600 MW PWR NPP.

(2) Lingao NPP, with 2×900 MW PWR

Lingao NPP is actually a duplicate of Daya Bay with some improvements, and will be the second largest commercial nuclear plant in mainland China. For this project, Framatome and GEC ALSTHOM remain responsible for equipment supply of the nuclear island and conventional island, respectively. But EDF was invited to provide project consulting instead of project services for the Daya Bay project. Chinese companies will take part in design and part of the equipment supply. The percentage of local procurement of BOP equipment will be increased. Chinese companies are in charge of construction and installation of the NPP. Chinese engineering institutes have been asked to be responsible for overall design, BOP design and technical coordination with consultation from foreign suppliers. The first concrete was poured in May 1997. The 1st unit is scheduled to be put into operation in the year 2003.

(3) Qinshan NPP Phase 3, with 2×720 MW CANDU 6 units

Taking into account that we lack infrastructure for pressurized hot water reactors (PHWR) and are not familiar with the technology, the Qinshan Phase 3 will be implemented as a turn-key project. That means that Atomic Energy of Canada, Limited (AECL), as the main contractor, will be in charge of project management, overall design, design and equipment supply of the nuclear steam plant (NSP) and technical coordination. The consortium from Japanese Hitachi and American Bechtel, as the subcontractor of AECL, is responsible for the design and equipment supply of BOP. Construction and installation of the project are still born by Chinese companies. The frame of contracts is illustrated in Figure 4. According to the project schedule, the first concrete will be poured in June 1998 and the first unit will be put into commercial operation in 2003.

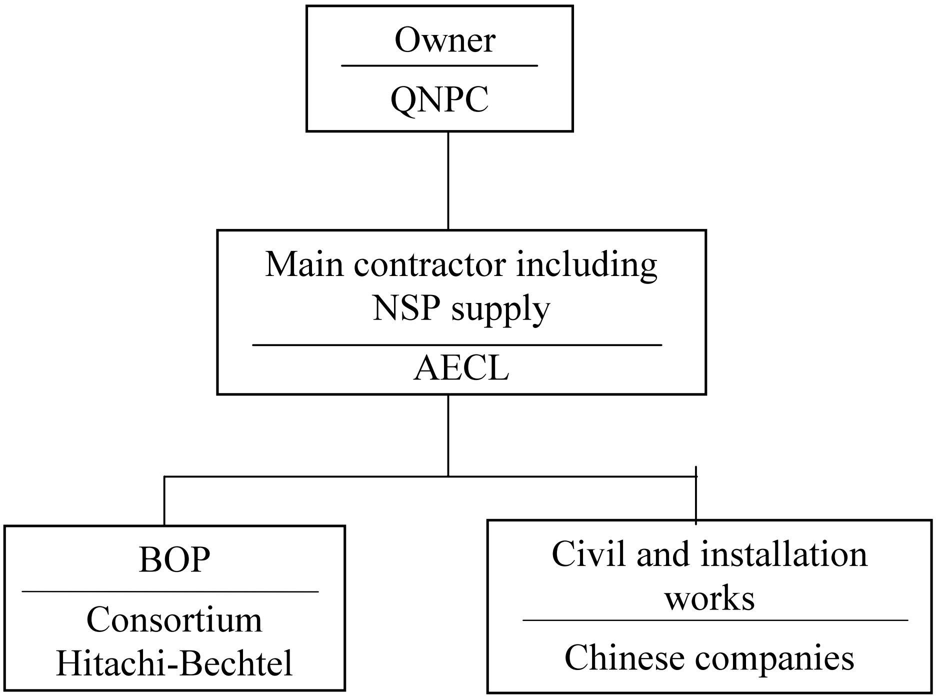

FIG. 4. Framework of contracts for Qinshan NPP, Phase 3.

(4) Lianyungang NPP with 2 × 1000 MW VVER units

This large commercial NPP is the result of co-operation between China and Russia. The design shall be the responsibility of Russian institutes, but Chinese institutes shall also take part in it. Russia shall provide all equipment, except I & C design and equipment will be provided from a third country. As in all of the nuclear power projects in China, Chinese companies are responsible for construction and installation of Lianyungang NPP. The General Contract was signed in December 1997and it is expected to go into operation in the year 2004.

The following electricity development policy is being implemented currently in China: To optimize the structure of fossil power development , to develop hydropower extensively and to develop nuclear power appropriately, according to the local situation . We can expect nuclear power to play a more important role in China in the next century.

3. TECHNOLOGY TRANSFER FOR NUCLEAR POWER DEVELOPMENT IN CHINA

According to local conditions, each country has a way to get nuclear power through technology transfer. Besides political, diplomatic and economic factors, from the technical point of view, factors such as the national nuclear power development plan, reactor type and size, capability of R & D, the level of industrialization and manpower resources, must be carefully investigated. It is our understanding that through technology transfer, the recipient country can use the transferred technology to realize localization. For example, after design technology has been transferred, the recipient party will have ability to design NPP through its own efforts. The recipient party can utilize the transferred manufacturing technology to enhance its manufacturing ability and to extend the local equipment supply. The recipient party will be able to operate the nuclear power plant independently after having received technology transfer on operation.

Therefore, we are aiming at the ultimate purpose, i.e. realizing localized design, manufacture, construction, project management and operation of NPP, carried out through different ways of technology transfer for different nuclear power projects.

As above mentioned, during the implementation of Qinshan NPP Phase 1 project the objectives of technology transfer were focused on the following:

- To establish R/D facilities;
- To train personnel in design, engineering, manufacture, construction, operation and maintenance;
- To accumulate the experiences of project management;
- To establish QA systems.

For Daya Bay NPP project, the objectives of technology transfer were focused on:

- To train personnel in large scale project management matched with international practice, including investment control, quality control and schedule control;
- To gain experiences in constructing large scale nuclear power through cooperation with foreign vendors;
- To be able to operate and maintain imported nuclear power units independently.

For Qinshan NPP Phase 2 project, the objectives of technology transfer were focused on the following:

- To enhance the domestic capabilities of project engineering and equipment manufacture through documents, information and computer codes of the reference plant as well as consultation of foreign vendors;
- To be able to issue technical specifications for procurement of equipment and components in the international markets;
- To increase the domestic capabilities for building large scale nuclear power units including engineering, construction and supply of equipment and components.

The manner of technology transfer in China can be summarized as follows:

- Purchasing the documents, drawings and corresponding software, then studying and mastering them;
- Asking experienced foreign companies to work with us as consultants;
- Dispatching our engineers in various disciplines to get on the job training abroad and inviting foreign experts to conduct lectures and seminars in China.

Additionally, in development of nuclear power, we got very useful assistance from the International Atomic Energy Agency (IAEA), which covers:

- research and development;
- design and engineering;
- project management; and
- training of operation and maintenance personnel.

According to statistics, from 1985 to 1996 1342 man-hours of training were provided to Chinese engineers abroad and 582 man-hours of technical services were provided by foreign experts dispatched to China under arrangements by the IAEA. It must be especially noted that over a hundred operators of Qinshan phase 1 NPP were trained abroad through IAEA channels.

4. SOME ISSUES OF TECHNOLOGY TRANSFER FOR NUCLEAR POWER DEVELOPMENT IN DEVELOPING COUNTRIES

The scope of technology transfer for nuclear power development involves many factors. It is important for a developing country to carefully investigate its own situation and then establish its technology transfer policy and scope. The following issues should be considered particularly:

(1) First, the government should establish a long-term plan for nuclear power development. This plan determines the total scale of development of nuclear power in the country, the technical line including reactor type, unit size, compatibility with the electricity grid etc. according to the infrastructure of the country.

(2) Attention must be paid to the technology which will be transferred; it must be proven and advanced. Proven technology means it has been successfully applied in existing NPPs; advanced technology means it will show its potential in the next century.

(3) If a developing country has an ambitious nuclear power development plan and wants to build a series of nuclear power plants, it should examine its infrastructure in the field of R & D, equipment manufacture, and so on, to determine its suitability for substantial development. Technology transfer should be implemented in all related areas, not only design and manufacturing technology, but also operation and maintenance of NPP. The ultimate purpose of technology transfer is to increase the capability of self-reliance, to foster standardization and localization, and to increase the competitiveness of nuclear power by decreasing generating costs.

(4) If a developing country only wants to meet electricity demands and increase its generating capability by building a few nuclear power stations, it is not necessary to conduct an overall technology transfer. However, technology transfer on operation and maintenance must be done to be able to operate NPP safely and effectively.

Finally, we deem that for developing countries, the ultimate purpose of technology transfer is to increase domestic capabilities in R&D, engineering, manufacturing, construction, operation, maintenance and project management, and only in this way, reduce the investment and operating costs of NPP in their countries.

Therefore, to establish policies for technology transfer, developing countries should determine the scope, objectives and nature of the technology transfer based on their capabilities and make the transfer more economic and effective.

TECHNOLOGY TRANSFER AND LOCALIZATION: A FRAMATOME PERSPECTIVE

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Abstract

Localization and technology transfer have been important factors influencing the decision-making process in countries embarking on a nuclear power programme. It seems natural that relationships between donors and recipients of technology, beginning with sub-contracting, should evolve towards technology transfers and cooperation on an equal footing. France was both a receiver and a donor of technology transfer in the area of nuclear power. This paper describes the French experience in technology transfer and the lesson learned therefor.

1. INTRODUCTION

Despite its attractiveness as a key energy source, nuclear power has its constraints. Its wastes, although lower in quantity than those from fossil fueled plants, must be responsibly managed. Public safety must be guaranteed under all conceivable operational mishaps and concerns of non-proliferation and third party nuclear liability fall within a rigid legal framework. There is also a comparatively high initial investment, although balanced by relatively low operating expenses, and a need for specifically trained engineers to support safe and efficient operations.

These boundary conditions and their political implications give the nuclear investment a truly strategic dimension. It is therefore understandable that countries wishing to start a nuclear program usually wish to acquire the technology and capability to design, build, operate and maintain nuclear plants with limited outside help. While that entails fairly high front end investments for industrial infrastructures and engineering capabilities by the recipient, it can pay off over the longer term, through a substantial nuclear program.

2. FRAMETOME'S EXPERIENCE AS A TECHNOLOGY RECEIVER

At Framatome, we have been able to look at technology transfer from the vantage point of the receiver as well as that of the transferor : almost forty years ago, we began construction of our first Pressurized Water Reactors (PWR) and our specific nuclear industrial infrastructure as a licensee of the vendor, Westinghouse. We know, apart from financial compensations, the effort we expended to fully assimilate the technology, so we could develop and license new models on our own. This paid off nicely because the series of nuclear plants built in France allow the country today to produce one of the cheapest kilowatt hours (kWh) in the European Union.

3. TECHNOLOGICAL SCOPE

Before discussing Frametome's experience as a transferor of technology, it is important to understand the actual breadth and depth of its technology, since a company can only transfer the know-how it actually implements. In areas where Framatome uses subcontrators, transferring technology entails organizing the transfer of the subcontractor’s technology, which is quite feasible but not as straightforward as transferring a technology actually owned and mastered.

Framatome's in-house technology is broad and deep, since it designs the nuclear island and designs and fabricates key components of the nuclear steam supply system. This includes reactor vessel and internals, steam generators and pressurizer, primary coolant pump and motor, control rod drive mechanisms, in-core instrumentation, fuel handling equipment and so on. It also designs and fabricates fuel assemblies, including sub-components such as pellets, grids and cladding. Further, it has qualified subcontractors that can be encouraged and assisted in their own technology transfers and localization schemes. Lastly, Framatome is capable of nuclear power plant backfitting, inspection and maintenance, to apply to utilities specific requirements. This base ensures a highly consistent technology transfer.

4. THE KOREAN EXPERIENCE

Our first comprehensive experience in transferring technology and localizing equipment fabrication was eighteen years ago at the construction of Uljin 1 & 2 units (2 × 950 MW), in Korea. When we signed the contract in 1980, KHIC, was designated by KEPCO (the Korean national utility), as our main partner for fabrication of the heavy nuclear components although it was a new company with little nuclear experience. It had had a number of organizational changes in its limited life, and we worried about the firm performing successfully and meeting contractual schedules. Although we provided more technical assistance than anticipated, in the end the quality appeared and schedules were met.

Some of the most challenging achievements were the final assembly of the reactor pressure vessels from machined shells and bottom heads delivered by Framatome. KHIC performed the circular welds and the strip stainless steel cladding of the inside surface, as well as the incore tube welding. For the steam generators, KHIC manufactured the dryer section and assembled the steam drum, with the lower assembly provided by Framatome. The pressurizers, accumulators and boron injection tanks were also assembled by KHIC from semi-finished products supplied by Framatome. The lighter pressure vessels and heat exchangers as well as the polar crane and a number of miscellaneous components were also manufactured in KHIC workshops from our drawings and technical specifications. All this was made possible by the highly concentrated industrial investment in the Changwon plant.

Technical assistance by Framatome focused on quality assurance and quality control, welding processes and welders qualification, planning and scheduling. Since at that time, the KHIC workshop in Changwon, had only limited experience with nuclear fabrications and no experience with the French nuclear code RCCM, we insisted on informal "preliminary fabrication tests" before starting formal qualification. This allowed us to test procedures and confirm the feasibility of the manufacturing operations, thus avoiding time and money consuming road blocks on the critical path of plant construction.

Other fabrication was localized with varying degrees of technical assistance through seven different Korean companies. They included emergency diesel generators from Hyundai Electrical Machinery Co., low voltage switchboards and transformers from Hyosung, medium voltage switchboards from Goldstar, electrical cables from Taehan Cables, lifting equipment, silencers, waste treatment components, etc., from a number of other Korean companies.

Fabrication follow-up was conducted from an advanced echelon in Seoul, Korea, under the supervision and general coordination of the Framatome headquarters in France. The consistently good performance of Uljin 1 & 2 can certainly be credited to KEPCO, the plant operator, but also to cooperation between Framatome and its subcontractors and the Korean industry during construction.

5. THE CHINESE EXPERIENCE

5.1. Daya Bay and QinShan Phase 2

In China, Framatome received its first contract for Daya Bay 1 & 2 (2 × 950 MW) in GuangDong province in 1986, a second large contract for LingAo 1 & 2 (also 2 × 950 MW) in 1995 and smaller contracts to support the construction of QinShan Phase 2 (2 × 600 MW).

The first large scale technology transfer was initiated in 1991 in fuel assembly design and fabrication. Manufacturing technology was transferred to the Yibin fuel fabrication plant of the CNNC (China National Nuclear Corporation) in the south Sichuan region, and design technology to the Nuclear Power Institute of China (NPIC). The first full reload fabricated in Yibin was loaded in the Daya Bay Unit 2 in 1995 after its first operating cycle. Since that time no less than 350 fuel assemblies were produced with the transferred technology and delivered to both units at Daya Bay, where they perform to the satisfaction of the operator.

Erection and startup testing of the Daya Bay units was conducted in cooperation with the 23rd Company of the CNNC and was an opportunity to transfer the related technologies. Also, refueling outages initially performed by Framatome on a more or less turnkey basis, have been gradually become the responsibility of the client with personnel trained on the job by Framatome. The quality of maintenance has been demonstrated by the smooth operation of the units, which produced more than12 billions kWh in 1997.

In engineering, a comprehensive technology transfer agreement, involving Framatome, and the French national utility EDF, was signed in 1992 with the CNNC. It allowed the implementation of French design technology by two institutes as "nominated users", the Beijing Institute of Nuclear Engineering (BINE) and the above-mentioned NPIC, for design of the Qinshan Phase 2 units (2 x 600 MW), now under construction in Zhejiang province.

The way Framatome transfers design technology and helps in its assimilation by the receiving entities is also illustrated by two 1996 agreements with NPIC, the first, to perform plant modifications and improvements on Daya Bay units 1 & 2, the other, to enlarge the cooperation started in 1991 in the area of fuel design, management and services.

5.2. LingAo

With the LingAo contract, currently underway, technology transfer and localization have increased dramatically. Framatome cooperates with no less than fifteen different factories in many Chinese provinces. Many key components or parts are fabricated under cooperative arrangements with companies benefiting from Framatome technology transfer. To name a few : reactor internals are fabricated by the Shanghai Machine Tool Work N°1 (SMTW N°1) factory of the Shanghai Electric Corp. (SEC); the steam generators, pressurizers, accumulators, boron injection tanks by DongFang Boiler Works in the SiChuan province ; heavy components supports by the ErZhong factory in that same province; fuel handling equipment by the Xi'an 524 factory in the Shaanxi province ; control rod drive mechanisms by the XianFeng factory and boilerworks by SPEC, both subsidiaries of SEC in Shanghai ; primary coolant pumps by the ShenYang Pump factory in the Liaoning province ; cable trays in the Zhejiang and Jiangsu provinces, and so on.

Partners were selected after a number of technical audits involving quality assurance (QA) organization and procedures, adequacy of the equipment, technical capability for fabrication and control operations, willingness of management to meet stringent nuclear standards and invest in training and factory improvement. A number of problems had to be overcome, and new ones will certainly arise as the tasks are ambitious and demanding. However, we can now say that, with a commitment from all parties, delivery schedules can be met, and quality maintained. Technology transfers are important steps toward the self reliance of Chinese industry in nuclear plant design, construction, operation and maintenance that Framatome and its partners have endeavored to support with all technological resources.

6. LESSONS LEARNED

We can now summarize what these Korean and Chinese experiences have taught us so far.

We have learned repeatedly that technology is not only transferred through the physical transmission of documents, drawings, specifications, and computer codes, it takes cooperation and communication between people, often of different cultures. It requires resolution of practical problems together under the pressure of tight project schedules and demanding project managers who do not accept as an excuse for being late that a component, or design package, is being implemented for the first time by a facility.

Technology transfer is likely to be more successful if it is well planned. Some benefit can be derived from piecemeal transfers of technological packages, but it may be hard for a recipient country aiming to become fully self-reliant, to put the pieces back together and produce an organization capable of taking full responsibility. The scope of the main recipient entity does not need to be as comprehensive as Framatome's, but the more comprehensive it is, the more likely a full-fledged vendor will emerge from the transfer.

Another important lesson is that, although there may be orders of magnitude difference in labor costs between the transferor's country and the recipient, it does not mean that, initially, when all costs are calculated, localized equipment will necessarily be cheaper than those manufactured by experienced suppliers.

The first reason is that there is no compromise in nuclear quality standards. The transferor must provide training and technical assistance necessary to assure that the quality of the components meets those stringent standards, regardless of nuclear experience. This technical assistance is usually provided by senior expatriate engineers.

Further, only a limited number of typical tasks are performed by the technology receivers for the first project localized, so as not to jeopardize the overall project schedule. Therefore, cheaper labor costs in the receivers' country do not generally compensate for the impact of localization.

Another reason is that productivity in the factory in the original country and the recipient is at vastly different positions on the learning curve, at least initially.

A last reason is more complex procurement, since fabrications are often shared between transferor's factories and recipient factories. This adds facilities to be supervised at a greater distance from headquarters and requires setting up decentralized procurement offices, and the management of many additional interfaces.

The remarks made above also apply when engineering studies are performed by two separate groups, in two different countries with different positions on the learning curve.

It is easy to understand that localization and technology transfer require dedication and motivation by transferor and by the receiver. This motivation can most easily be raised when the program provides some degree of assurance that the initial investment in training, organization and facility improvement can be amortized, and the initial costs can be reversed to take full advantage of the cheaper labor of the recipient ; that is, when technical assistance is no longer necessary and productivity has risen to the level of the transferor's facilities.

7. CONCLUSIONS

Localization and technology transfer have had an important impact on our philosophy. We view them not as an impoverishment, but as an opportunity to enlarge the technological base of Framatome by cooperation with our licensees. Technology cannot survive in file cabinets; if it is to progress, it must be employed wherever applications can be found. It seems natural that relationships beginning with sub-contracting should evolve towards technology transfers and cooperation on an equal footing. This last phase can best be developed when parties solidify their relationship with jointly owned entities.

TRANSFER OF NUCLEAR TECHNOLOGY: A DESIGNER-CONTRACTOR'S PERSPECTIVE

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Abstract

The paper presents the successful Canadian experience in developing a nuclear power technology - CANDU - and exporting it. Consideration is paid to technology that has to be transferred, receiver country objectives and mechanisms and organizational framework.

1. INTRODUCTION

The flow of technology between trading partners is a significant feature of contemporary international trade. This occurs within the industrialized world and, more importantly, between developed and developing nations. Nuclear power projects are by their nature technology intensive and embody the latest developments in engineering, construction, materials, manufacturing and information. With few exceptions, such as the United Kingdom’s Sizewell B project, nuclear projects are being implemented in newly industrialized and developing countries by or with the assistance of developed countries.

It is not surprising, therefore, that the implementation of nuclear power programs often includes transfer of related technologies. While the primary purpose of a nuclear power project is the generation of electricity, the benefits of a carefully planned program can extend beyond supplying reliable and inexpensive power and can have a significant positive impact on the economy. Typically, the economic sectors affected are not only related to engineering, manufacturing and constructing the plant but extend to research and development programs, with spin-off into commercial and industrial sectors only marginally linked to nuclear energy. New skills and methods learned in the nuclear program can be applied to other sectors and provide benefits to the social and economic fabric of the nation.

Over the decades, Canada developed an autonomous nuclear industry even without an established large-scale industrial base at the beginning of its program. The end product, the CANDU reactor system, has an impressive record of performance and is competitive with the best power reactors of the world's industrial giants. There are now many developed countries with indigenous nuclear power systems, therefore, it is ineffective use of resources for countries considering a nuclear power program to expend the same effort to develop nuclear power on their own. Technology transfer provides a sound basis for creating an indigenous nuclear industry. The experience in establishing its own nuclear industry puts Canada in a favorable position to understand and develop the scope and processes of technology transfer essential to a successful nuclear program and, as shown later in this paper, facilitates absorption of this technology by host nations.

The available technology includes the complete fuel cycle from uranium exploration through fuel fabrication to eventual disposal; engineering design and development; heavy water production; construction, commissioning and operation of nuclear plants; project and construction management techniques; supporting research and development and, of course, the manufacture of CANDU components and systems.

In this paper we make observations on the technology, particularly CANDU technology, look at experiences in Romania, Korea and Argentina and consider appropriate measures for a developing country.

2. NUCLEAR TECHNOLOGY

CANDU nuclear power plants have performed extremely well and are consistently ranked among the world's best in terms of both annual and lifetime performance. Such an achievement does not occur by chance; it is the result of a system design reflecting ease of component manufacture, simple operation and maintenance and careful attention to detail and quality in all phases of the design, construction and operation of the plants.

Nuclear technology in Canada goes beyond the power plant itself. It encompasses the total infrastructure appropriate to the CANDU heavy water moderated, natural uranium fuelled reactor system. Thus, these essential components are well established in Canada:

- the complete CANDU fuel cycle from uranium exploration, mining and refining, through fuel fabrication to eventual disposal,
- plant siting, engineering design and development,
- component design and manufacture,
- heavy water production,
- project and construction management techniques,
- construction, commissioning and operation of the nuclear power plant,
- supporting research and development, and
- licensing and regulation.

Some of these components, particularly those required by conventional power industries, are already well established in some form in developing host countries. Nevertheless, it may be worth looking further at four particular aspects.

2.1. Fuel cycle

Technology for the complete natural uranium fuel cycle is available in Canada, one of the few countries which, by itself, can cover the total fuel cycle. As one of the world's principal uranium producers, Canada has developed exploration techniques and the methods required in mining and refining. Two independent Canadian commercial fuel fabricators provide fuel for CANDU nuclear power plants both in Canada and abroad. Storage techniques for spent CANDU fuel are simple and well established and, as related later, the technology for safe disposal of spent fuel or reprocessing wastes is well in hand.

2.2. CANDU manufacturing

CANDU manufacturing technology is very adaptable. It is possible, as was the case in Canada, to introduce the manufacture of CANDU components to existing industries, taking advantage of and enhancing existing manufacturing skills. In Canada today, more than one hundred individual companies are involved in the manufacture of CANDU components and, for most, the nuclear business represents less than 20 percent of their total output. These companies are from diverse segments of industry: automotive parts, shipbuilding, general machining, aerospace and electronics, and others. Thus, new technology and employment opportunities have benefited and continue to benefit a large segment of the industrial economy.

2.3. Research and development

A major factor in the continuing success of the CANDU system is the strong research and development component (R&D) existing within the Canadian nuclear industry. The nuclear R&D laboratories of Atomic Energy of Canada Limited (AECL) actively participated both in the initial and ongoing development and responded quickly and effectively to problems which arose in the operation of the CANDU plants. Such response capability is invaluable, for unforeseen problems arise even with the best systems. Further, an established R&D program ensures continued development and advancement of CANDU nuclear technology.

2.4. Operation and maintenance support

A principal reason for the outstanding performance of CANDU plants is the emphasis placed on operation and maintenance. Special attention is given to simplifying the man-machine interface, to operator training and retraining and to providing readily accessible maintenance through the design of the plant. Expertise in operation and maintenance technology, developed in partnership with Canadian utilities and the system designer, is transferred to other utilities which have chosen the CANDU system. This on-going expertise is available to operators of all CANDU power plants.

More recently, as the CANDU system was adopted by several utilities, AECL R&D related to maintenance and operation has been supported and complemented through an association termed the CANDU Owner's Group (COG). This group not only shares information related to operation and maintenance similarly to INPO in the US, it funds R&D to eliminate potential problem areas and improve performance.

3. THE CASE FOR TECHNOLOGY TRANSFER

The driving force behind successful transfer of technology are the benefits, whether short or long-term, which accrue to the participants. For the source nation or industry, the transfer enhances market opportunities and permits a return on its investment in research and development, whether directly through licensing or indirectly through some joint enterprise. The nation also gains stature through the recognition and acceptance of its technology.

A nuclear power project is a complex undertaking, especially for a country building its first plant. From the perspective of AECL, technology transfer associated with the project can be split into two broad categories; viz.:

- the technology which must be assimilated for plant licensing, operation and maintenance;
- those technologies which further the objectives of the receiver country, which are not well known or defined at the time of negotiations or bidding for the project.

While the first category, the 'basic technology', is essential for plant owners to realize returns from their investment, the second category, the 'enabling technology' is the focus of this paper. The constituents of the two broad technology categories are shown in Figure 1.

Figure 1 summarises the basic technologies involved in the design, construction and operation of a CANDU nuclear power plant. It also illustrates the interests of national governments, the utility and the local industries. The government has an overall interest in all facets of the technology, and in most cases, determines the expected degree of transfer and its timing. The utility, on the other hand, needs no other technology than that required to successfully maintain and operate the plant, i.e. the upper half of Figure 1. Local industry, whether engineering design companies, constructors or component manufacturers, is usually only concerned with technology to do the job and in the results of R&D, but not the R&D itself.

It is not self-evident that transfer of enabling technology is beneficial to the receiver country as measured, for example by growth in economic productivity or by return on the investment. By reviewing historical patterns of technology transfer in industrialized countries (for example Canada, Japan, the United Kingdom) and developing countries (such as India, Korea) in science and industry in general and in nuclear power in particular, we can identify factors contributing to the overall benefit of technology transfer.

Reviews of the flow of technology to and from Canada and other industrialized countries show that technology transfer occurs constantly amongst trading partners through such mechanisms as foreign manufacturing plants, licensing and joint ventures. The driving force for transfers between developed countries is almost always entry into foreign markets or, more recently, to exploit favorable cost contributors such as materials, labor, productivity or entry into third markets. In these industrialized countries, national policy on science and technology, if it exists, does not play a key role. In developing countries, the driver is often national policy as typified by India, China and Korea. From this casual examination of historical cases, it is reasonable to conclude that to derive a measurable benefit to the receiver country, technology transfer should be driven by market forces and/or by national policy.

The degree to which there is real benefit from transfer of technology depends on a number of factors which are not always separable. Studies by the United Nations University have termed these the "Five Ms". If we examine the "Five Ms" of enabling technology in the context of nuclear power, we can assign the following areas to each:

(1) Materials to be used for production
   - zirconium alloys, refined/enriched uranium, high grade steels and alloys

(2) Machines to process the materials
   - uranium refineries, facilities for manufacturing reactor components, nuclear grade and quality pumps, heat exchangers, steam generators, valves and other components

(3) Manpower which combines materials and machines in production
   – education, training, design skills, manufacturing skills, analytical skills, plant operations

(4) Management which combines production and marketing
   – plant management, public acceptance program, infrastructure program

(5) Markets for the products
   – on-going nuclear programs featuring construction of a number of generating plants over medium to long term and/or an export market for products and services.

4. RECEIVER COUNTRY OBJECTIVES

As demonstrated below, transfer of technology requires recipient organizations or, at the beginning, personnel to form the core of such organizations. There is therefore an implicit cost for the receiver country as an initial investment. Benefits from this investment are maximized when there is a continued demand for the products and services resulting from this technology. In this environment, localized R&D and manufacturing can contribute towards further development of the technology to benefit both the source and receiver countries.

It is thus of utmost importance that the receiver country have a technology policy addressing the needs of the future as well as today's nuclear power program. To realize a return on its investment, and to stimulate further development of acquired technology, there should be an active nuclear program, providing a steady productive output and incremental improvements. Thus, the fifth M must exist, i.e. there must be a market for the local products and services, domestic or export, as exemplified by Korean companies which assimilated CANDU technology. Some of the objectives of receiver countries are discussed in the context of CANDU technology.

4.1. Technology/Energy independence

For the receiving nation or industry, the technology transferred helps establish a domestic capability to provide goods and services previously imported and, moreover, an opportunity to export these same goods and services. The technological base and stature of the nation will clearly be enhanced and employment opportunities will be created. A degree of technological independence from foreign sources is also secured through this domestic core of competence. The additional benefit is that, with training of its people and assimilation of the complete nuclear technology, the receiver country can establish a major self-sufficient energy source.

4.2. Localization of supply

The experience in Korea demonstrates the extent to which CANDU technology can be successfully localized. The first CANDU 6 unit (Wolsong 1) was supplied on a turnkey basis. The contract included a significant amount of localized procurement and technology transfer, including training of designers and operations staff.

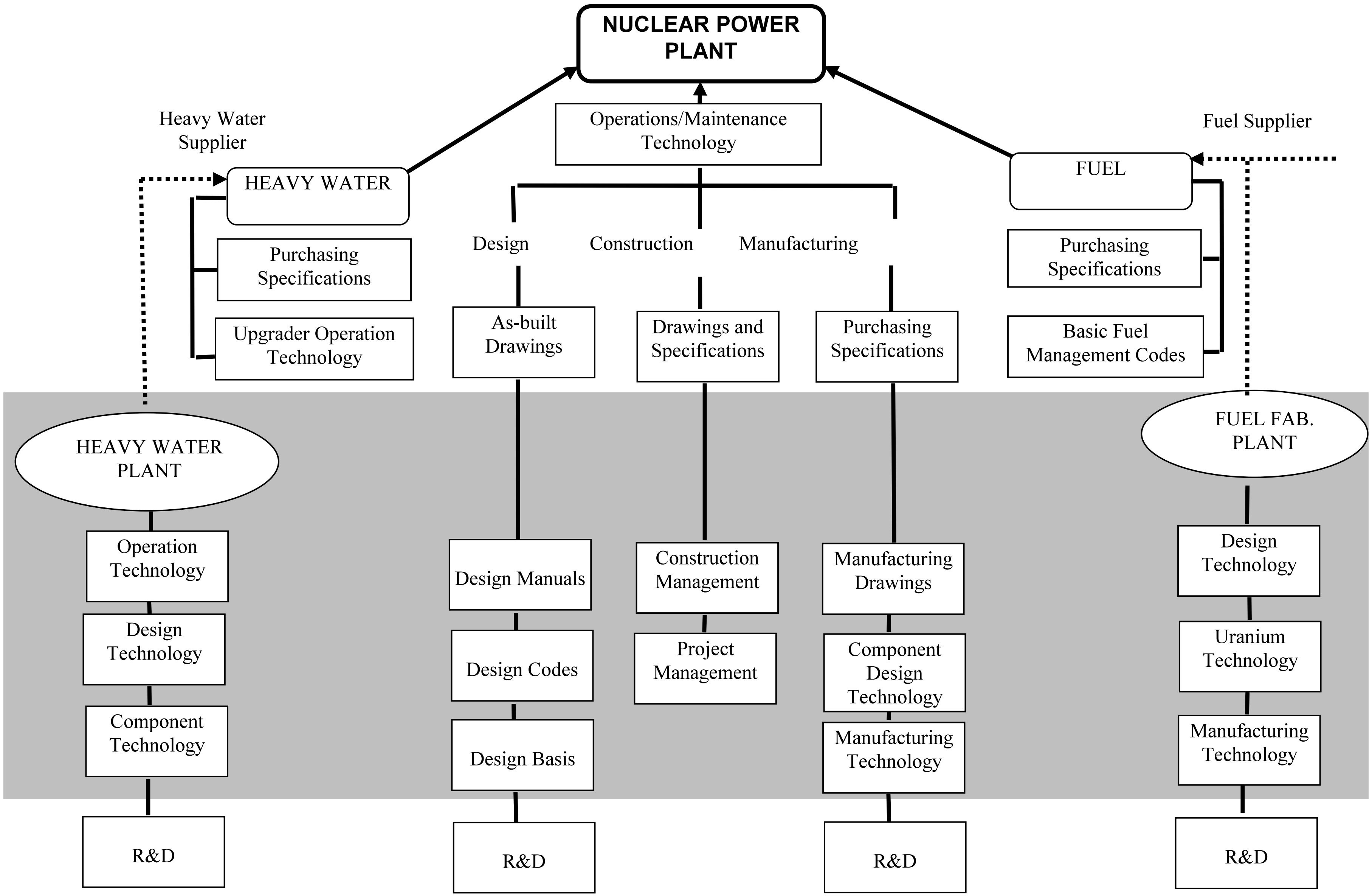

FIG. 1. Basic technologies involved in the design, construction and operation of a CANDU nuclear power plant.

Successful performance of the Wolsong 1 plant led to the purchase of three more CANDU 6 reactors. Recently the Wolsong 2 and 3 reactors entered service and construction is nearing completion on Wolsong unit 4. As a result of technology transfer, the localization rates for these subsequent units have increased substantially. For Wolsong 1, the local content for Korean firms was approximately 14% for equipment supply and 16% for design and engineering, while for later plants the overall localization increased to 75% as shown in the Figure 2. Included in this is the fabrication of major reactor components including the calandria/shield tank assembly and the steam generators.

The ease of transfer of CANDU technology is evident from the experience in Korea. In the Korean CANDU program, technology was transferred to the utility, Korea Electric Power Company (KEPCO), to the Korea Heavy Industry Company (KHIC - now HANJUNG) and to other Korean firms. Fuel manufacturing technology had been transferred to Korea Nuclear Fuel Company (KNFC) and localized with the first CANDU 6 unit along with construction technology. This contrasts with the experience in Korea's PWR program where fuel manufacture was not localized until eight PWR units were constructed.

5. MECHANISMS AND ORGANIZATIONAL FRAMEWORK

It is useful to review the form in which technology exists and the institutions in which it resides. In Canada, the distribution of nuclear technology rests with the designers, regulators, manufacturers and the utilities with nuclear power plants. As the result of technology transferred to receiver countries beginning in the late 60s up to the present time, CANDU technology has been assimilated by many more countries where it is being developed as shown in the Table I.

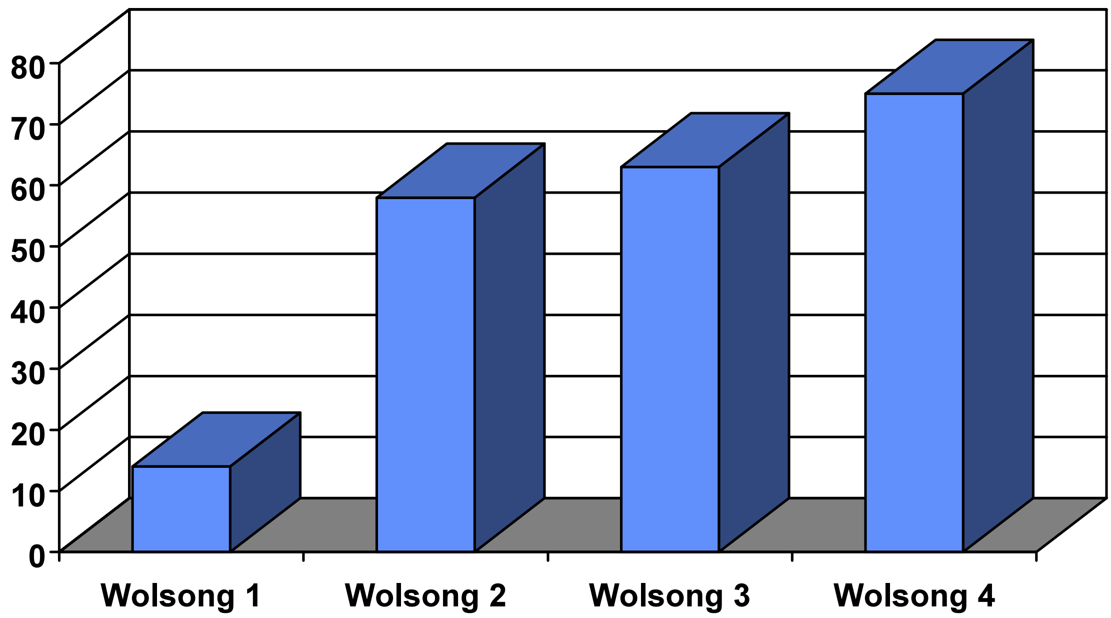

FIG. 2. Wolsong localization rates.

TABLE I. EXISTING AND DEVELOPED CANDU TECHNOLOGY IN THE WORLD

Reactor, Plant and System Design	AECL, Ontario Hydro A/E firms in Canada, Korea, Argentina, Romania
Component and Equipment Mfr, specific to CANDU	Industry in Canada, Korea, Romania AECL
Component and Equipment Mfr, nuclear and conventional	Industrialized countries, e.g. Canada, UK, USA, Japan, etc.
Research and Development	AECL, Ontario Hydro R&D organizations in Argentina, Korea
Regulatory, Safety and Licensing	AECL, AECB, NB Power, Hydro Quebec, Ontario Hydro; Regulators and utilities in Argentina, Korea, Romania
Plant Operations	AECL, NB Power, Hydro Quebec, Ontario Hydro Utilities in Argentina, Korea, Romania

5.1. Documents

These include designs, analyses, drawings, specifications, reports, and procedures covering areas related to nuclear power programs such as R&D, design, manufacturing, construction, commissioning and operations.

5.2. Computer programs and databases

These include items such as analytical models, programs, CAE/CAD models and databases, equipment and materials databases.

5.3. Personnel

The knowledge and skills of staff should be viewed as a repository of technology. This is especially important in the design and R&D functions where individual expertise complements documents and data. While the latter are necessary in technology transfer, individual know-how and the ability to manage and use the technology must be assimilated to achieve independence.

It is evident that transfer of technology is best achieved on an institutional-organizational and a personnel-individual level. For the technology to be absorbed and assimilated, the receiver country must have personnel who will be educated in the technology and either the organizations in place or the objective of establishing those organizations. This allows the receiver to establish a framework for effecting the transfer.

Typically, this begins with an agreement, or commercial contract. The form of the framework depends mostly on the stage which the receiver country has attained with its nuclear power program. At the outset, technology cooperation agreements are common. These are generally high level agreements between organizations, which allow documents, computer codes and data to be delivered, and exchange of personnel and training. As the receiver country's nuclear program advances, the framework under which technology is transferred becomes more formal and contractual in nature, particularly if it is under the umbrella of a nuclear power plant construction project. The means for effecting technology transfer can include the following:

5.3.1. Formal training programs

This is usually for the utility staff who will operate, maintain and provide technical support for the plant. The receiver country's regulator and other organizations, such as those charged with waste management, also receive training in the technology.

5.3.2. Business enterprises

These include direct investments by foreign corporations in production facilities, joint ventures with local partners and licensing agreements. Typically, they pertain to equipment, components and materials aspects of a nuclear power program. Korea, Romania and Argentina have examples of agreements between investor owned or investor-state owned enterprises resulting in local manufactured components for the domestic power program. In particular, fabrication of fuel for CANDU reactors has been localized in these countries. In Korea, this is extended to where Korean manufactured components such as heat exchangers, steam generators and the calandria are manufactured locally for the domestic program and are also exported to third markets.

5.3.3. Research and development agreements

On-going agreements with Korea's research organizations provide for joint research and development programs covering such topics as fuel and fuel cycles, thermohydraulics and system chemistry. In recent years, KAERI and AECL have cooperated on the design of Korea's HANARO, a research reactor using the Canadian MAPLE research reactor concept as a base.

In Argentina, a technical transfer agreement provides Argentina with the technology to design and construct its own CANDU 6 units. The scope of the agreement includes transfer of detailed design data and documents appropriate to the CANDU 6, generic scientific and engineering information including computer codes, and fuel testing in Canadian research reactors. This is a comprehensive program and spanned a 14-year period.

6. PROGRAMS FOR NEW CANDU COUNTRIES

Many lessons were and are still being learned from AECL's experiences in technology transfer. Perhaps some of the more pertinent ones to ensure a successful program are the importance of people, the need for flexibility and, above all, an enduring commitment by all participants. Canada's experiences provide insight into some factors contributing to the success of technology transfer. These "lessons learned" are incorporated in our overall approach. Some of the factors are:

6.1. Applicability of the technology

The technology must fit the needs of the recipient and be compatible with existing or planned development of other local technologies.

6.2. Importance of people and training

While the physical form of a technology resides in documentation, e.g. drawings, manuals, computer codes, etc. people are the principal vehicle for technology transfer. Without trained personnel to interpret the documentation and implement the technology, it is worthless.

Training is a necessary ingredient, especially since not all the technology is documented and much of it, especially that related to application, can only be transferred through personal communication.

On-the-job experience is most effective in transferring technology and is a cornerstone of our programs. However, if the technology transferred is not put into practice but shelved to be addressed later, the expertise quickly dissipates and must be relearned.

6.3. Recognition of potential conflicts

It is likely that more than one objective exists, for example, use of local suppliers of equipment and services may sometimes appear to conflict with project schedules and overall costs. It is essential that both parties recognize the many possible objectives and reach an understanding of the priorities to be accorded to each.

6.4. Environmental differences

Design changes are clearly needed to accommodate different site characteristics, however, broader socio-economic-technological differences influencing the ways in which people behave, and work is achieved, must be recognized. Such differences change with each country but they are relative rather than absolute since, in the end, technology transfer has one common denominator - people communicating with people.

6.5. Clear definition of scope

Despite the best intentions of both parties, there may be misconceptions or misinterpretation about what is involved or expected of technology transfer. These may stem from a lack of appreciation of the completeness of documentation and sometimes belief that documentation can substitute for training. There may be a lack of understanding of the scope of technology to be supplied, of communication facilities available or of the "correctness" of information channels.

A precise definition of the scope of technology to be supplied and the processes to be followed can minimize these misconceptions or misinterpretations. There would be fewer disappointments for the recipient in what he receives and for the supplier in the costs associated with the transfer. However, our experience strongly suggests that there should be a mechanism to adjust both scope and processes throughout the period of exchange or agreement. The technology associated with nuclear plants is dynamic and the transfer of technology should be also.

6.6. A flexible approach needed

Each country and client has unique needs and priorities and technology transfer must meet these needs to be compatible with industrial development. Even within one country priorities may differ. For example, plant owners are primarily interested in the supply of generating plants in as short a time and at as low a cost as is consistent with safe, economic and reliable operation. In this respect, the goals of the owner and the supplier are the same, however, national goals may have different priorities.

National governments, especially in developing countries, view technology transfer as a means of industrial and economic development and, eventually, a means of assuring a high degree of autonomy and security in a major energy source. The industrial sector seeks additional business opportunities, is concerned with the return on its investment and the potential market for its new products both domestic and foreign.

Canada is flexible in transferring nuclear technology. Each program has been different and has reflected the needs of the client and the same approach will be taken in the future.

6.7. Long-term commitment essential

In transferring nuclear technology, an agreement between governments normally sets the framework within which all other transactions and arrangements are accomplished. Subsequent agreements may provide for staff exchange, licensing arrangements, the formation of joint ventures and so on. However, there is one overriding factor, the success of the transfer of technology and its assimilation depends on the will of the parties involved and their commitment to the success of the project.

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OPTIMAL ELECTRICITY GENERATION SYSTEM EXPANSION AND NUCLEAR POWER OPTION IN BELARUS

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Abstract

After having declared the independence the Republic of Belarus forced to import 90% of fuel consumed and 25% of electricity. The deficit of peak electric capacity reached 40%. The imported fuel covers last years because of the drop in the production the energy consumption reduced in the Republic but the needs of the energy sector. Annual payments for imported fuel and electricity are equal the sum of an annual state budget of Belarus (about 1.5 billion USD) and current debts were not lower 300 million. Comparative analysis of the different scenarios of the electricity generation system expansion showed that an optimum way for electricity generation is installation of the combine cycle units and construction nuclear power plants. The results of the study also showed that the option based on replacement of deficit of the electricity generation by the way of the construction combine cycle units with capacities 450 MW turned to be the best solution among non nuclear option.

1. REVIEW OF THE MAIN FUELS TO BE USED IN THE BELARUS

The Belarus takes one of the last places as to the supply of fuel and energy resources even among the countries of Central and Eastern Europe. In 1990 it supplied a little bit more than 10% of all energy needs of the Republic. The cost of fuel and electric energy annually purchased (mainly from Russia) according to nowadays prices at the CIS market is about 1.5 billion USD, what exceeds the sum of a total state budget of the Republic. In going to world prices, which we inevitably reach at the nearest years, the cost will still increase by 1 billion USD, and at the recovering the energy consumption level of 1990 it reaches 3.5 billion USD per year. But even now one can see chronic debts of the Republic of Belarus to Russia for fuel and electric energy supplied; in the first half of 1998 it was not lower the level of 200-250 million USD.

Domestic energy resources in the Belarus in 1990 constituted 13% of the total primary energy consumption. Development of the energy sector is mainly based of the imported fuel (natural gas, oil and coal) and at a little extent on the domestic resources (oil, peat, woods, and wood waste). Table I includes general historical energy balance data for Belarus.

Crude oil resources estimated as 363 million t, are most significant. Reserves being explored are of high quality (0.3% sulfur contents) and not over developed (with respect to the number of development wells drilled and the production rates). Crude oil production declined from 2.55 million t in 1980 to about 2 million t per year in 1985, and has remained steady at that level since.

Four to five millions tons of peat as a fuel were produced annually during the last ten year, most of which was harvested at located near 37 peat briquetting plants. The production on a dry basis amounted to about one million tons in 1993. Most of the peat harvested is used

TABLE I. PRIMARY ENERGY CONSUMPTION

	1990	1991	1992	1993	1994	1995	1996
Fuel natural gas, million m^3	15479	13463	18286	16978	14662	13840	14548
Coal, thousand tons	2547	2198	1860	1608	1199	1125	1116
Gasoline, thousand tons	2361	2592	2235	1558	1094	1269	1322
Diesel, thousand tons	3318	3333	2893	3039	1966	1805	1898
Fuel oil, thousand tons	13327	13401	9027	7063	6135	5178	4711
Peat, thousand CE	971	883	717	639	513	692	750
Fuel briquettes, thousand CE	2076	1978	1726	1525	1600	1339	1268
Firewood, thousand m^3	2294	2161	2107	2011	1882	2098	2245
Wood waste, thousand m^3	328	299	263	271	259	211	228

in briquette production, sometimes to about mixed with imported coal (some briquette plants also use the peat as an energy source). It is estimated that 20% of total peat resources have been extracted already. The Government, in order to protect lands wetlands, has decided to restrict peat production to already harvested deposits. Therefore, only about 11% percent of total peat reserves can be considered as energy resources.

The total annual harvest of wood, 10-12 million m^3 in the 1993, has recently declined to 9 million m^3. In 1990, energy application amounted to 2.2 million m^3 (approximately 1.5 million t of wood or about 4.1 million Gcal). Approximately 0.3 million m^3 of fuel wood used to be sold to household by wood processing plants. Of the 6,7 million m^3 industrial round wood harvested in 1990, 40% represented waste, out of which 1-1.5 million m^3 were burned in boilers.

The potential reserves of slates are estimated in 11 billion t and for industrial using can be used resources of 3 billion t. One million tons of such slates are approximately equivalent to 220000 toe. The heating value of brown coal constitutes 1000-1510 Gcal/kg; ash content - 75%, output of resins - 6-9.2%, sulfur content - 2.6%. As to their quantitative indices Belarus slates are not effective fuel because of their high ash content and low heating value. The reserves of brown coal are estimated in 151.6 million t. Coals are available for heat generation in rural area.

2. ELECTRICITY GENERATION SYSTEM

Electricity generation facilities in Belarus include very old units. Oldest of them had been produced in 1927. If this equipment is operated in accordance with the existing rules for operation, 2005-2009 will retire about 60% of it. Most of the electric power units either have exhausted their operating life (300,000 hours operating life for a turbine) or will reach it by

2005. Changes in the installed capacity of the Belarus electricity generating system including retired is shown in Figure 1. Here the forecast of peak demand is from the World Bank Report. The retirement schedule assumes that units are taken out of operation 300000 hours after their startup.

3. AVAILABLE TECHNOLOGIES FOR ELECTRICITY AND GENERATION

Economic and political independence of the Belarus cannot be without energy supply independence. There are two more or less reasonable options to overcome electricity supply problem in nearest future. Electricity generation system can be based on utilization of the renewable energy resources or conventional technologies. To evaluate possibilities of utilization of solar and wind energy resources for electricity generation relevant capacities factors has been calculated for territory of Belarus. Capacity factor for wind and solar energy can be defined as:

$$CP_W = \int_0^T (U/U_{max})^3 \, dt \qquad CP_S = \int_0^T (E/E_{max}) \, dt \, .$$

where:

CP_w Capacity factor of wind energy;
CP_s Capacity factor of solar energy;
U Wind velocity hourly data;
U_{max} Maximal value of the wind velocity during a year;
E Direct and diffused solar radiation;
E_{max} Maximum value of the solar radiation;
T Period to be considered (one year).

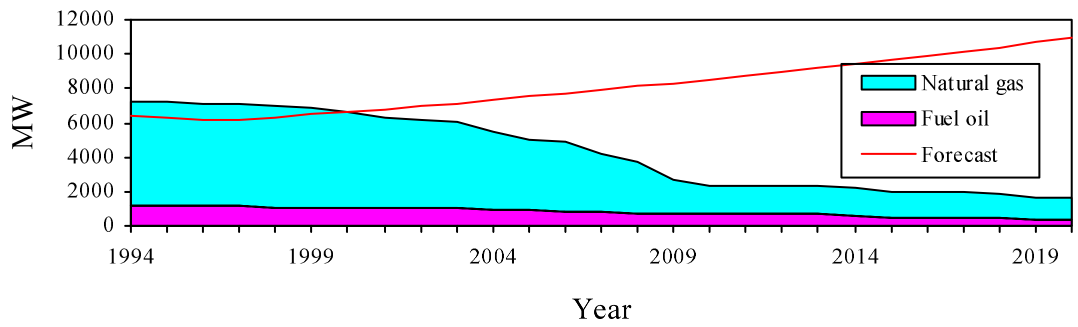

FIG. 1. Installed capacities of the Belarus electricity generation system.

Calculation of the capacity factors was based on the measured hourly data of wind velocity and solar energy flux. The result shows that capacity factor for any wind unit cannot be more than approximately 9.5-10 %. To calculate capacity factor for solar unit the hourly data on direct and diffused solar radiation during period since July 1989 to June 1990 has been used. This period is considered to have been relatively warm. Even for this case capacity factor for any solar unit cannot be more than 11-12 %.

Then, the value of the internal rate of return as a function of capital cost and electricity price had been evaluated. The results are shown on Table II and Table III.

Thus, utilization solar and wind units on the territory of Belarus can be compatible with conventional technologies only if capital cost of the units will not be more than 200-250 US$/kW.

That is why the scenarios for the electricity system expansion plan included only conventional technologies. Using WASP III Plus computer code [1-2] the optimal expansion plan of the electricity generation system based on installation new combine cycle units and nuclear power plants has been developed. Optimal least cost expansion plan has been chosen as a result of comparative analysis of the three scenarios. Every scenario included available technologies for electricity generation and fuel mix. Technology and fuel types considered for each case is summarized in Table IV.

Technical and economical parameters of the expansion candidates used for the WASP analyses are summarized in Tables V and VI, respectively. These parameters are typical for technologies that are expected to be available during the planning period.

TABLE II. INTERNAL RATE OF RETURN FOR WIND UNITS

Capital cost	Electricity price, $/kWh	
$/kW	0.05	0.1
100	36%	78%
150	22%	50%
200	14%	36%

TABLE III. INTERNAL RATE OF RETURN FOR SOLAR UNITS

Capital cost	Electricity price, $/kWh	
$/W	0.05	0.1
0.25	14%	36%
0.5	-1%	14%
1		-1%

TABLE IV. TECHNOLOGY AND FUEL TYPES

Characteristic	Scenario 1	Scenario 2	Scenario 3
Technology	Steam turbine, Combined cycle, Gas turbine	Steam turbine, Combined cycle, Gas turbine	Steam turbine, Combined cycle, Gas turbine
Fuel type	Natural gas	Natural gas, Coal	Natural gas, Nuclear

TABLE V. TECHNICAL PARAMETERS OF THE CANDIDATE UNITS [3]

Unit type	Capacity single unit MW	Fuel type	Heat rate, kcal/kWh		FOR	Sched. Maint.	O&M Costs	
			base	INCR	%	days	fixed $/kWm	variable $/MWh
Gas turbine	120	Gas	4518.77	1936.62	10.7	22	0.233	1.68
Combine cycle	150	Gas	2154.04	1566.84	7.3	53	0.514	3.7
Combine cycle	320	Gas	2048.23	1515.50	10.1	64	0.442	3.18
Combine cycle	450	Gas	2145.74	1560.79	8.8	71	0.494	3.56
Steam turbine	250	Gas	2642.10	1782.32	7.8	66	0.667	4.8
Steam turbine	450	Gas	2450.61	1653.12	8.3	69	0.567	4.08
Coal fired PP	500	Coal	2277.19	1567.48	8.5	73	0.609	4.39
Nuclear PP	640	Nuclear	2570.00	2570.00	11	50	5.000	1

TABLE VI. ECONOMICAL PARAMETERS OF THE CANDIDATES FOR EXPANSION OF THE BELARUS ELECTRICITY SYSTEM [4–6]

Plant name	Capital cost Inclusive IDC (Depreciable part)		IDC	Construction time	Plant Life
	Domestic	Foreign	%	Years	Year
Gas turbine	24.2	656	8.08	2	20
Combine cycle	100.5	724.7	10.02	2.5	25
Combine cycle	142.2	639.1	11.92	3	25
Combine cycle	86.9	652.2	11.92	3	25
Steam turbine	252	1140	11.92	3	25
Steam turbine	215.6	966.7	13.79	3.5	25
Coal fired PP	282	1552	15.63	4	25
Nuclear PP	0	1880	29.22	8	30

Presently, the works connected with the preparedness for NPP construction in the Republic site survey for NPP are being carried out. The first stage of siting process according to the IAEA classification has been completed. It was based on a set of criteria answered to A Safety Guide of the IAEA "Site Survey for Nuclear Power Plants" and requirements to be accepted in Russia for NPP placement sites. The result of the preliminary studies had shown that there are at least three sites for construction of the NPP. It allows including nuclear power option in the list of possible technologies for electricity generation.

TABLE VII. FUEL PRICE FORECAST, $/GCAL [7–11]

Year	Coal	Fuel oil	Nuclear	Natural gas
1998	11.6	8.8	2.33	10.6
2000	12.3	9.6	2.33	11.7
2005	13.3	10.7	2.38	13.8
2010	14.4	11.9	2.44	15.3
2015	15.6	13.3	2.51	16.8
2020	16.8	14.8	2.57	19.1

4. FUEL PRICE FORECAST

The Government in the Republic of Belarus regulates prices for energy resources to a considerable extent. With the aim of social protection of the population prices for natural gas, electric energy and heat are overestimated sufficiently for industry and underestimated for the population. In comparison with 1994 prices in the terms of USD for natural gas constituted 75 $/1000 m^3 in 1995, for fuel oil - 107 $/t, and for fuel oil - 72 $/t. To some extent, these prices are considered to be corresponded to the balance between demand and supply.

A considerable growth of natural gas cost within 1998-2010 is connected, first of all, with the forecasted lowering of its mining. The reason of this is, first of all, the exhaustion of the deposits and the necessity to master the new and more almost inaccessible ones. It is also necessary to take into account of the possibility to introduce a tax for incineration of organic fuels in world practice aimed at diminishing the danger of global warming. For Belarus the forecast of prices for natural gas supplied from Russia, which up to the present moment and probably in the nearest future, is the main and even the only supplier of natural gas to Belarus is of the more important significance. Fuel prices for analysis are summarized the Table VII.

5. ANALYSIS

Using WASP III plus computer code optimal electricity generation system expansion plan for each scenario had been found. Calculations had been carried out for discount rate equaled 8 %. Electricity generation cost for scenarios is shown in Table VIII.

The results of calculation are shown that electricity system expansion plan based on utilization of coal as a fuel has highest generation cost. Otherwise, implementation on nuclear power will allow decreasing generation cost up to 3.26 cents/kWh. In accordance with calculation optimal solution includes construction four nuclear units and first unit has to start up in 2010 year.

The comparative analysis of the different scenarios is presented on Figure 2. For Scenario 3 based on natural gas and nuclear fuel mix is expected to be least total electricity generation cost and it is most economically attractive option. Realization of the Scenario 3 first of all allow decreasing of the annual natural gas purchasing and save up to 259 million dollars per year.

TABLE VIII. ELECTRICITY GENERATION COST FOR DIFFERENT SCENARIOS

Scenario 1	3.60 cents/kWh
Scenario 2	3.62 cents/kWh
Scenario 3	3.26 cents/kWh

Capital cash flow for different scenarios is shown on Figure 3. For all scenarios annual capital cost is not very different. It means that irrespective of scenario to be chosen money requirement for electricity system expansion is approximately the same. Thus, there is no reason to turn down nuclear option on the bases of high cost of the nuclear power plant construction.

Optimal structure of the electricity generation system by technology type use to depend on the historical hourly load and available fuel resources. Two peaks characterize the hourly load curve. The morning peak is at 10 am and the afternoon peak is at 6 p.m. Both peaks are close to each other, the morning peak is slightly higher. To cover peak load demand only 15-20% of the installed capacities use to be needed. Most of the units Belarus electricity generation system works in a base load regime. Therefore, the optimal structure of the technologies for electricity generation includes units which traditionally are considered as a most attractive for covering base load.

In accordance with results of the WASP runs only 4-5% of the total capacity can meet of the gas turbines. Optimal structure of the Belarus electricity generation system is shown on Figure 4. Optimal share of nuclear energy doesn't exceed 22% and approximately equals the share steam turbines. As it is presented on Figure 4 combine cycle technology can provide about 55% of capacity to be required.

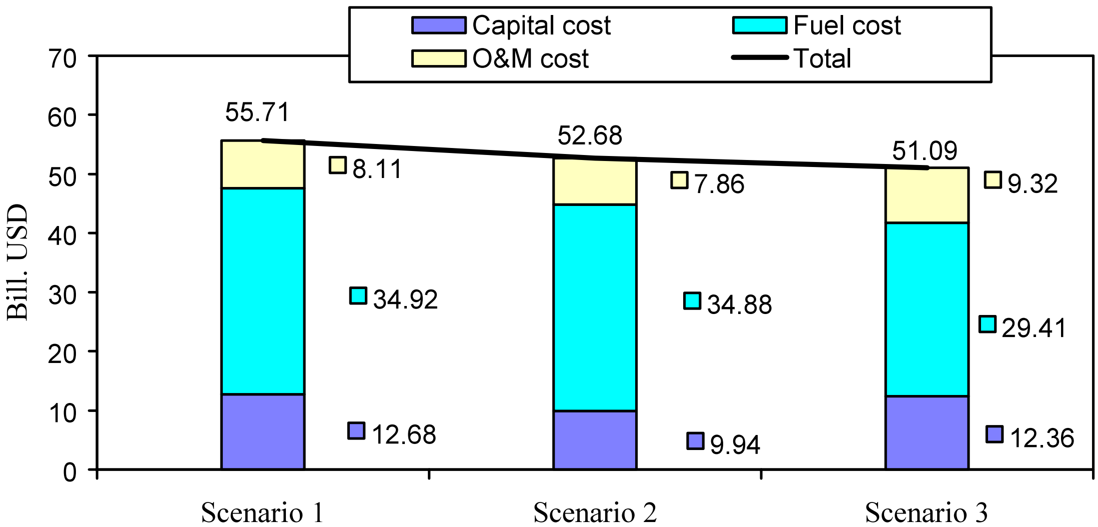

FIG. 2. Total cost of electricity generation during 25 years.

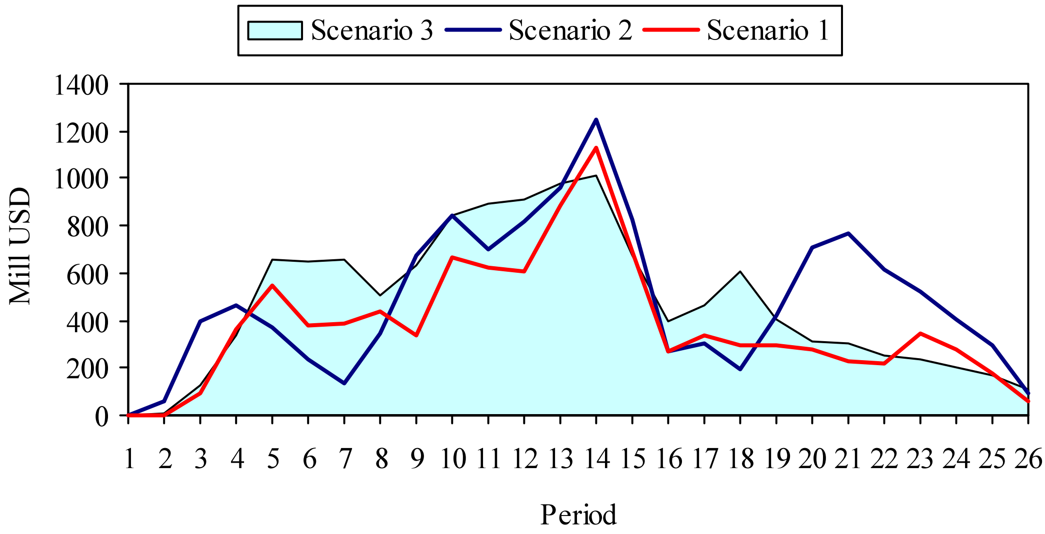

FIG. 3. Capital cash flow for different scenarios.

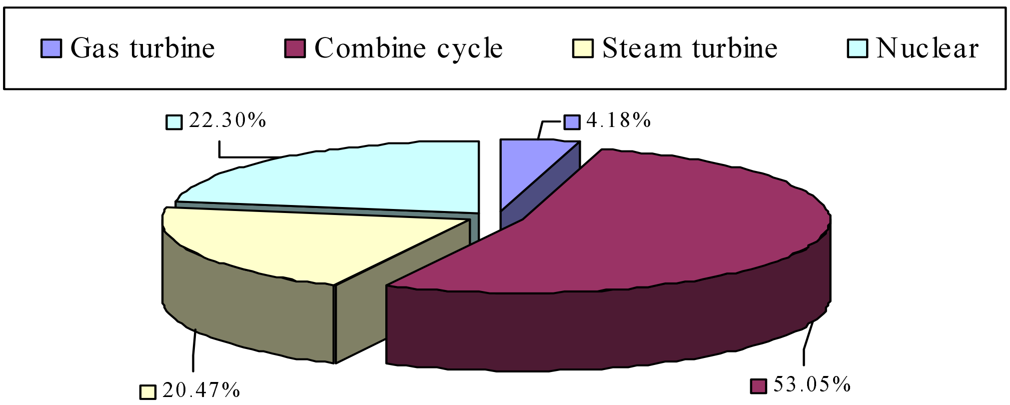

FIG. 4. Optimal structure of the Belarus electricity generation system by technologies type.

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THE ELECTRICITY SUPPLY OPTIONS IN CUBA AND THE POTENTIAL ROLE OF NUCLEAR ENERGY

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Abstract

Cuba is poor in primary energy resources. After economic crisis initiated in 1990, a recuperation process began in 1994, but in electric sector we could not reach the 1989 generation level. A comparative assessment of different options to cover electricity demand until 2015 performed using DECADES tools shows that the most important options are: Hydro, nuclear, biomass, combined cycle and combustion turbines. The nuclear power option in the evaluated electric system expansion cases can play an important economic and environment role. The introduction of one nuclear power plant will save 330 million dollars in the expansion of the national electricity system. Environment emissions calculations during the study period, taking into consideration only the generation step, show that only the introduction of one NPP until 2015 will produce significant environment benefits. With the assumption that in generation step Hydro, nuclear an biomass plants do not produce emissions, if the amount of electricity generated by these plants during study period would be generated in conventional Oil Steam Boilers with typical emission factors for Cuban conditions, the CO_2 emissions would increase in 26 millions tonnes, 576 thousand tonnes of SOx and 102 thousand tonnes of NO_x. The NPP cover 80% of these reductions.

1. INTRODUCTION

There is a deep scarcity of primary energy resources in Cuba. There are not coal deposits and the production of oil is very limited. Domestic Crude Oil has high viscosity and high sulfur content. Companion oil gas reserve is also restricted. Due to the narrow and long shape of the Island there are not big and copious rivers that would otherwise allow a substantial increment in the utilization of hydraulic energy for electricity production [1].

The sugar cane biomass (bagasse and sugar cane crop residues) are important renewable fuels. The traditional sugar mill has a very low-level efficiency in energy terms. When bagasse is burnt in efficient boilers, important amount of surplus electric power can be obtained in the sugar mill and it can be sold to public grid or to other users at a rate as high as 100 kWh per tone of cane crushed [2]. This energy potential of sugar cane is important not only in terms of environment due to its contribution to reduce the green house effect (CO_2 emission at the generation step are compensated in full energy chain by CO_2 absorption during photosynthesis process) when used in substitution of fossil fuels, but also as a source of benefits for sugar industry if a good selling price of the electricity can be agreed with the buyer. The co-generation in sugar industry can play an important role taking into consideration that the bagasse is a natural energy source (byproduct of sugar cane production).

After the crisis initiated in 1990, the Cuban economy started a recuperation process in 1994. During this period the electric sector experimented a serious depression, deficit of electricity and blackouts were a constant practice. To mitigate this situation a decision was taken in order to burn directly domestic crude oil, without previous preparation of the power plants designed to use fuel oil [3]. These practices created different difficulties in the operation of the power plants, reduced the efficiency and increased the SO_x emissions per kWh. Nevertheless total SO_x emissions were less than before crisis, because the generation in this period was reduced [4].

The lack of energy resources, the advantages of nuclear energy and the perspective broad application of nuclear techniques in different fields were taken into consideration to decide the construction of NPP in our country in the decade of eighties, but the economical crisis stopped the project 1992. Nowadays the negotiation process is in progress to try to restart the construction of Juragua NPP.

The objective of this paper is to present the supply options in the electric sector and to show the potential role that nuclear energy can play in the expansion of Cuban electric system.

2. CHARACTERISTICS OF CUBAN ELECTRIC SYSTEM

Since 1994 the electricity supply increased, but we could not reach the 1989 level. The structure of generation at the end of 1997 is presented in Table I. These data do not include the installed capacity in the sugar and industrial sectors (827 MW and 94 MW respectively), because both of them consume more than what they produce. The installed capacity in different cays and isolated places (70 MW) is not included in these figures because it is not connected to the National Electrical System [3].

The existing and firmly committed power plants are shown in Table II.

A program of maintenance and modernization of 100 MW, 125 MW and 250 MW units is in progress from 1997 to 2001, some of the power plants were adapted to burn a mixture of domestic crude and imported heavy fuel oil. Recently was introduced a demand side management program to reduce electricity consumption, including the application of a differentiated tariff program that reduce the nigh peak demand, introduction of measures to reduce the consumption, etc.

3. ELECTRICITY SUPPLY OPTIONS

A comparative assessment of different options to cover electricity demand until 2015 was performed using DECADES tools [5, 6]. A large number of expansion candidates were analyzed outside DECADES. From them, taking into consideration the annual production costs, national conditions and limitations, we selected the most economical options. They were nuclear, oil and imported coal steam boilers, combustion turbines, combined cycle, diesel motors, combustion biomass system and hydroenergy. Screening curves of the main selected candidates are presented in Fig. 1. We excluded combustion turbines and diesel motor, because the peak load candidates have another range of values and would hardly fit in the same figure.

TABLE I. INSTALLED CAPACITY AND GENERATION IN CUBAN ELECTRIC SYSTEM

Technology	Capacity, MW	%	Generation, GW.h
Conventional Oil Steam Boilers (OSB)	3 090	96	12 634
Gas Turbines (GT)	80	3	13
Hydroelectric Power Plant	43	1	73
Total	3 213	100	12 720

TABLE II. EXISTING AND FIRMLY COMMITTED POWER PLANTS

Power Plant	# Units	Capacity, MW	Type	Fuel
AG	1	330	OSB Conventional	Mix (Fuel + Crude Oil)
F	1	250	OSB Conventional	Mix (Fuel + Crude Oil)
CCEn	1	184	GTCC[a]	Oil Companion Gas
CMC	2	158	OSB Conventional	Fuel Oil
DO	3	125	OSB Conventional	Fuel Oil
H, M, AM	11	100	OSB Conventional	Mix (Fuel + Crude Oil)
DO, T, R	4	64	OSB Conventional	Fuel Oil
T	1	60	OSB Conventional	Fuel Oil
M, AM	6	50	OSB Conventional	Mix (Fuel + Crude Oil)
R	1	40	OSB Conventional	Fuel Oil
JM	1	35	OSB Conventional	Mix (Fuel + Crude Oil)
En	4	35	GT	Oil Companion Gas
CMC,HP	2	30	OSB Conventional	Fuel Oil
FP	2	20	OSB Conventional	Fuel Oil
PP	5	20	GT	Diesel
RM	1	16	OSB Conventional	Crude Oil
FHyd	1	43	Annual regulation	Water
Duaba	1	25	Daily regulation	Water

[a] Gas Turbine Combined Cycle

TABLE III. CHARACTERISTICS OF EXPANSION CANDIDATES

Plant Code	Capacity, MW	Technology	Net Overnight Cost, US$/kWe	Fuel
NPP	417	PWR	1847	U235 3.4%
OSB	350	Conventional OSB	900	Fuel Oil
C+FGD	300	Conventional CSB [b]	1450	Imported Coal
CT100	100	Combustion Turbine	350	Companion Gas
CC250	250	Combined Cycle	550	Diesel
CC125	125	Combined Cycle	650	Diesel
DM50	50	Diesel Motor	1420	Diesel
BIO	20	Comb. Bio System [c]	1172	Bagasse
Hydro1	37	Daily Reg. Reservoir	1500	Water
Hydro2	26	Daily Reg. Reservoir	1500	Water
Hydro3	20	Daily Reg. Reservoir	1500	Water

[b] Conventional Coal Steam Boiler.

[c] Conventional Combustion Biomass System.

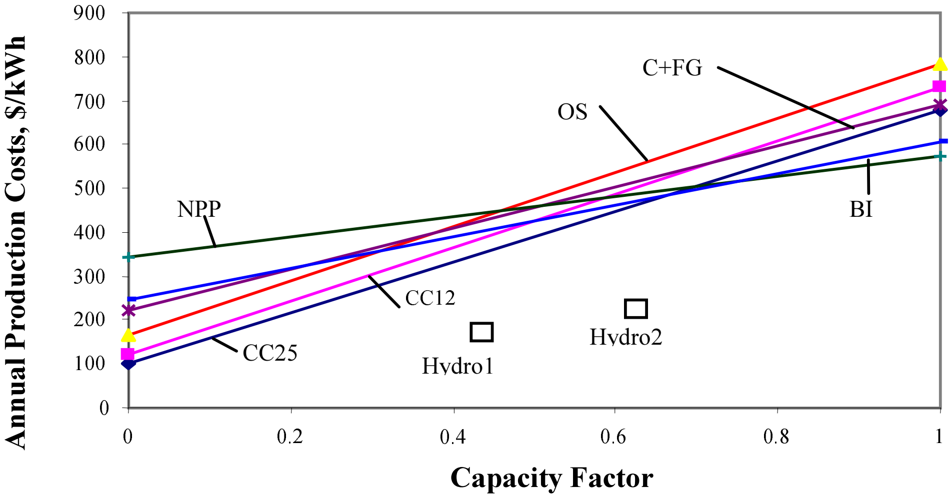

FIG. 1. Screening curves of expansion candidates.

As shown in Fig. 1 for high capacity factor the most competitive options are nuclear and biomass. The biomass systems in this case work 120 days per year, which is the sugar cane crop period. To reach higher utilization of sugar cane biomass system it is necessary to find alternative fuel for the inter-crop months. This can be the sugar cane crop residues or fossil fuel. Nowadays the economic and environment feasibility of utilization sugar cane crop residues during intercrop period is under study [7].

For medium capacity factor the combined cycle technologies are the best options and to cover peak load the best choices seem to be gas turbines. Although the hydroelectric projects are small (between 25 and 37 MW each one), they constitute the best expansion alternative. Due to geographical and environmental limitations only 4 hydro projects were evaluated.

4. POTENTIAL ROLE OF NUCLEAR POWER IN THE ELECTRICITY EXPANSION POLICIES

Electricity expansion study was carried out for the period from 1997 to 2015 for the reference scenario. Demand forecast was taken from the projection of development electricity consumption until 2010. Demand forecast will increase at the beginning of study period at a rate of 5% and later will decrease to 2.9% at the end of study period. The reliability criterion for the expansion of the system was considered loss of load probability (LOLP) of 0.5%, that means 44 h/y without electricity and energy not served (ENS) cost of 1.9 $/kWh. Two hydrological condition were examined: wet and dry (0.75% and 0.25% probability each one). A retirement program of some units in 2005 and 2010 was taking into consideration. The discount rate for evaluation was 12%. Reserve margin of the system was assumed to be between 15% and 45%.

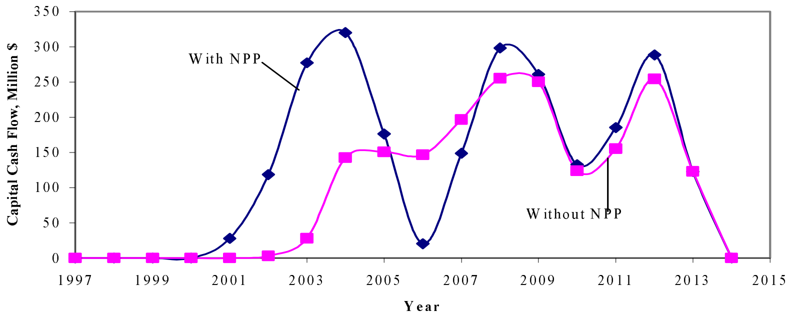

FIG. 2. Capital cost of the case of expansion of electric system with and without NPP.

Assessment of the potential role of nuclear energy was performed through evaluation of electricity system expansion cases: one including a NPP as expansion candidate and second case excluding NPP from candidates. In both cases conditions and limitations were maintained invariable. Complementary cases were also evaluated.

Study results show that in the expansion case without NPP an optimal solution will be to include one more 350 MW Conventional OSB. Also will be certain increase in generation from other power plants to cover demand.

As shown in Figs 2 and 3 the investment cost of the option with NPP is higher than the one without NPP, but total operation costs of the electric system (operation and maintenance, ENS and fuel cost) of the option without NPP are higher. In this evaluated case the introduction of only one NPP in 2006 will create, from economic point of view, a saving of 330 million dollars in the expansion of the electricity system in the study period.

The results of environment emissions calculations during study period, taking into consideration only the generation step (not the full energy chain that is out of scope of this paper) are shown in Figs. 4-7. As it can be seen, the introduction of one NPP until 2015 will produce significant environment benefits. The particles, SO_x, NO_x and CO_2 emissions will be substantially reduced.

During study period in Hydro power plants will be generated 5 632 GW.h, in NPP 27 300 GW.h and co-generated in combustion bagasse systems 984 GW.h. The rest of generation will be in other plants. In generation step we can consider that hydro, nuclear and biomass

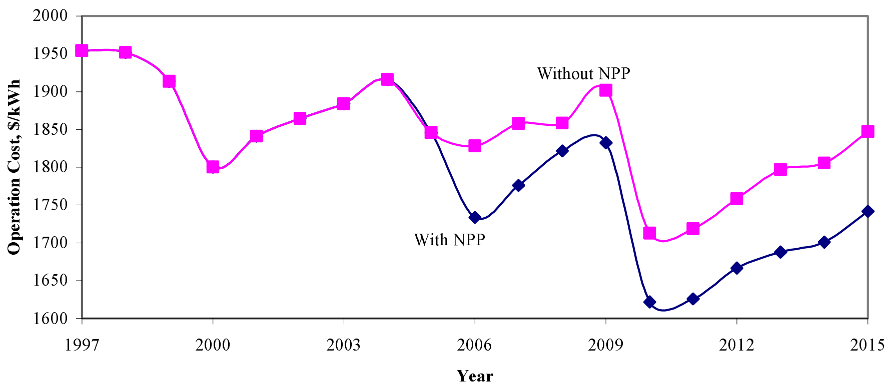

FIG. 3. Operation costs of the case of expansion of electric system with and without NPP.

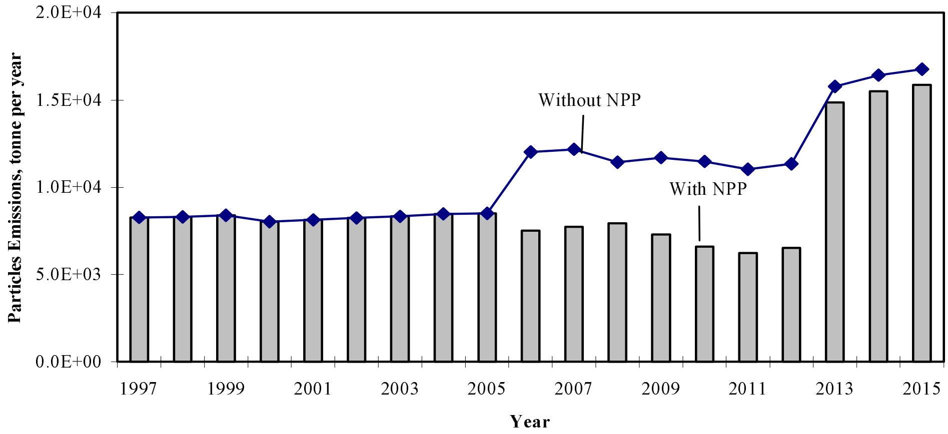

FIG. 4. Particles emissions of the expansion case of electric system with and without NPP.

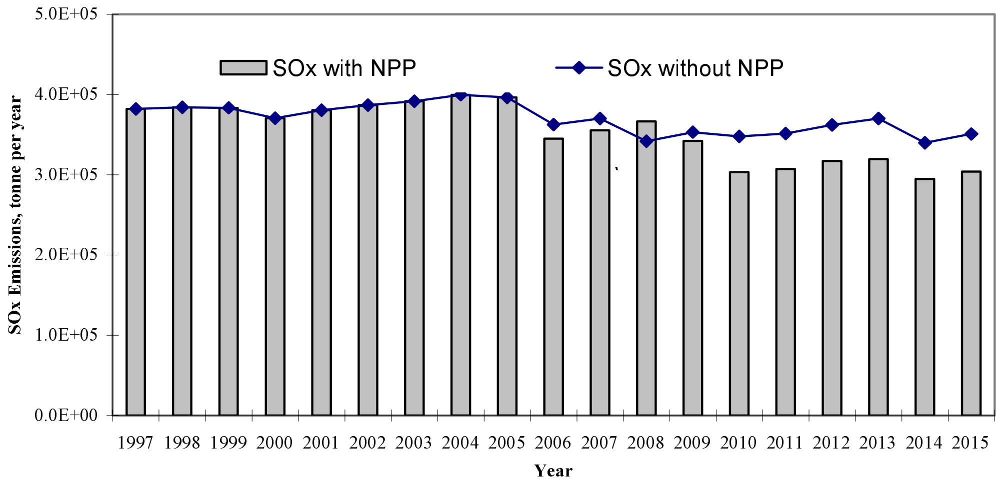

FIG. 5. SO_x Emissions of the expansion case of electric system with and without NPP.

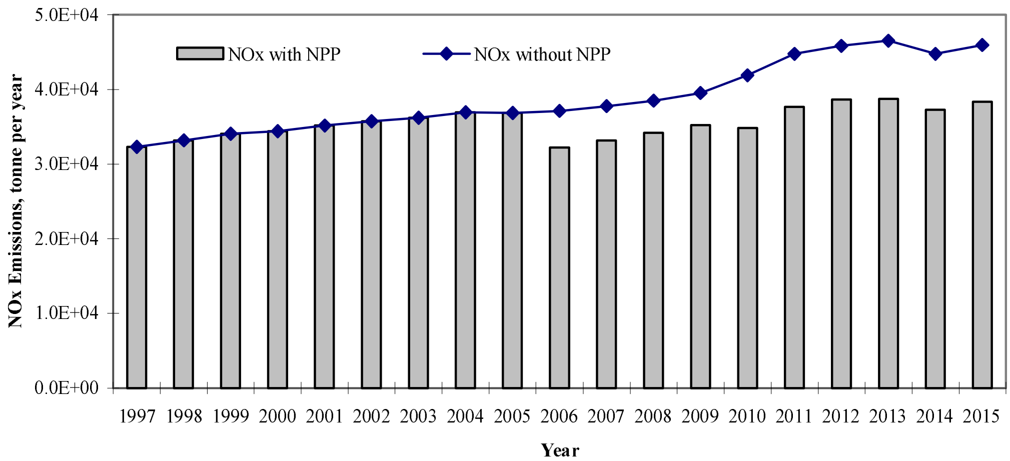

FIG. 6. NO_x Emissions of the expansion case of electric system with and without NPP.

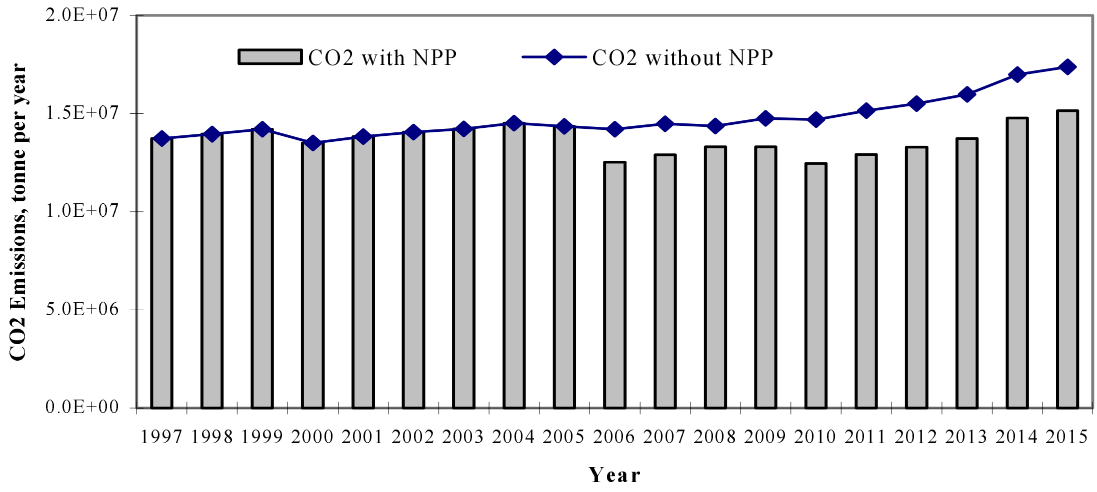

FIG. 7. CO_2 Emissions of the expansion case of electric system with and without NPP.

plants do not generate emissions. If the above mentioned amount of electricity would be generated in conventional 350 MW OSB with typical (average) emission factors for Cuban conditions (760 g/k/kW.h for CO_2, 17 g/kW.h for SO_x and 3 g/kW.h for NO_x) the emissions would increase in 26 millions tons of CO_2, 576 thousand tons of SO_x and 102 thousand tons of NO_x. The case with one NPP reduces these emissions in 80%.

5. CONCLUSION AND RECOMMENDATIONS

The most attractive electricity supply options for expansion of Cuban electric system as results of this evaluation are: Hydro, nuclear, biomass, combined cycle and gas turbines power plants.

In the evaluated electric system expansion the nuclear power option can play an important economic role. The introduction of one nuclear power plant in this evaluated case would create a saving of 330 million dollars in the expansion of the national electric system. Other studied cases show savings of 500 and 900 million dollars for different expansion conditions.

In other hand environment emissions calculations during study period, taking into consideration only the effect in generation step show that introduction of only one NPP will reduce annually 2 million tonnes CO_2. It represents around 15% of today CO_2 emissions in Cuban electric sector. Reduction in SOx and NO_x emissions will be also significant.

It is recommended to evaluate other expansion cases as: considering alternative fuel for intercrop period for combustion biomass systems, additional cost related to creation of necessary infractucture for imported coal transportation and evaluation of full chain emission assessment.

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GHANA AND THE NUCLEAR POWER OPTION

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Abstract

For every country, dependable and continuous supply of electricity is a prerequisite for ensuring sustainable development. In Ghana, Ghanaians have currently known the consequences of disrupted and inadequate supply of electricity. Globally too the call of ''Agenda 21'' of the Rio de Janeiro Conference (Earth Summit) to engage in the development and supply of electricity in a sustainable manner imposes on us certain limitations in our choice of energy option to utilise. Taking into account the high economic and population growths with the subsequent increase in demand for electricity in the 21st century, the fact that Ghana has no coal and imports oil which will be in dwindling supply in the 21st century and that the total hydro supply in Ghana will not be sufficient for our electricity demand in the next century, this paper proposes that Ghana starts now to plan for the introduction of the nuclear option so that in the long term, we may have in place environmentally friendly, dependable and reliable supply of energy. The paper also highlights the economic competitiveness of nuclear power over the other energy options in Ghana and addresses the apprehension and misunderstanding surrounding the nuclear power option.

1. INTRODUCTION

One of the major challenges facing most countries up to next century and beyond is the production and consumption of energy in a sustainable manner. Energy is indeed essential for economic and social development and improved quality of life in every country. Ghana is currently experiencing electricity crisis due to the low water level of the hydro-electric dam which serves as the main source of electricity in the country. This has caused rationing of electric power supply to consumers and has seriously affected the life of the people in the country. The main cause of this crisis is the poor rainfall in the catchment area of the dam. In addition to the poor rainfall, the high demand for electricity has played a significant role in precipitating Ghana's present predicament. The severity of the present crisis despite the complementation of the hydro system with a 200MW(e) thermal plant and importation of power from the Ivory Coast proves this fact. The high demand for electricity is not in Ghana alone but world-wide. Since 1970, the world's generation of electricity has more than doubled, growing from 5000 Terawatthour (TW·h) to 11,000 TW·h in 1989 [1]. The growth is faster in the developing countries (8.2% per annum on the average) than in the industrialised countries (3.5% per annum on the average). The reasons for the faster growth in the developing countries has been found to include; faster economic growth, rural electrification, ownership of household appliances, development of electric-intensive industries, rapid increase in construction of modern commercial buildings and inefficient use of electricity. Indeed, the building of our commercial, industrial, transportation and other infrastructures requires large quantities of energy-intensive materials and huge peak and base load supply of electricity.

The recent electricity crisis has called for the deployment of alternate energy sources for electricity generation instead of relying on hydro power which is rainfall dependent. Generation of electricity from alternate energy sources has been on government plan as far as the early sixties. Ghana in the sixties was aspiring to develop hydro power, solar energy and nuclear energy for electricity generation, but only the hydro electricity materialised in 1966. In 1961 "The Ghana Nuclear Reactor Project" was launched.

The objectives were:

(1) To introduce nuclear science and technology into the country and exploit nuclear energy in its peaceful applications to aid national development.
(2) To use the reactor facility to develop the manpower and plan for the introduction of nuclear energy for electricity in the country.

The Ghana Atomic Energy Commission (GAEC) was established in 1963 to realise part of the above objectives. The generation of electricity from alternative sources has now become a national concern. Where as Ghanaians generally accept the development of hydro power, oil and gas, biomass/biogas and solar energy for electric power generation, some have misgivings about nuclear energy. Some Ghanaians however hold the view that the nuclear power option should be seriously considered for the future while in the short term we utilise the options that offer us better opportunities to develop the country. The above view is held by the Energy Research Group (ERG). The Draft Science and Technology Policy also addresses the issue of research and development in nuclear energy for electricity and other applications. This paper supports the view that nuclear energy for electricity should be Ghana's future option. Its role in future development of the nation will be crucial and unavoidable and the way forward is to start planning for it now, since it takes about 10 to 15 years to plan and introduce nuclear power into a country.

2. GHANA'S ENERGY SITUATION

2.1. Ghana's electricity generation system

Ghana relies heavily on hydro power for electricity generation. Hydro power constitutes about 98% of power generation system which is being operated by the Volta River Authority (VRA). The hydro power system is produced from dams constructed across the river Volta at Akosombo and Kpong. The total installed hydro capacity is 1072 MW(e); 912 MW(e) from the Akosombo dam which was completed in early 1966 and 160 MW(e) from the Kpong dam which was completed in 1982. In addition, a 30 MW(e) plant at Tema has been rehabilitated and is currently in operation. The Ghana power system is connected to the systems in neighbouring countries, Togo, Benin and the Ivory Coast (la Cote D'Ivoire). These interconnections enable power exchanges up to 100 MW(e) between the systems. This therefore allows energy to be imported to meet short term power shortages. Of the total power generated, 45% is consumed by a single industry, the Tema aluminium smelting company. Other industrial consumers, residential and commercial consumers account for 48% with the remaining 7% being exported to neighbouring states.

2.2. Short and medium term expansion plan

Since March this year, Ghana has been experiencing shortages in electric power supply due to the low level of the Volta lake. The main course is the poor rainfall in the catchment area of the lake. This is the third occurrence of such crisis. The first and the second crises occurred in 1984 and 1994 respectively. After the second crisis, the VRA considered the expansion of the generation capacity to meet short and medium term demand through construction of a 300 MW(e) thermal plant at Takoradi. The thermal plant which is a gas/steam combined cycle is partially completed and is currently generating 200 MW(e) power. It is expected to be fully completed by the end of this year. Due to the current crisis efforts are underway by the VRA and the Ghana National Petroleum Company (GNPC) to build additional thermal plants. The total capacity of the thermal plants to be added to the existing hydro power system is about 1000MW(e). The existing thermal plant in Takoradi runs on light crude oil. Efforts are being made to import liquefied petroleum gas (LPG) from Nigeria through the connection of a pipeline from Ghana to Nigeria through the neighbouring Togo and Benin. The VRA is considering the possibility of generating power from other hydro resources. The most economic hydro potential is at Bui on the Black Volta with a capacity of about 300 MW(e). In addition to increasing the capacity of power supply system, the government has embarked on energy conservation programme for the efficient use of electricity.

3. ENERGY RESOURCE AVAILABILITY

3.1. Resource availability world-wide

In the utilisation of any energy source, a critical look has to be taken on its availability. There are proven reserves of coal world-wide that are sufficient to last for more than 200 years at current level of use. Oil and gas are expected to take 40 and 60 years respectively to last at the current level of use.[2, 3] There are efforts under way to increase the resource base of oil and gas through improved recovery techniques and the reprocessing of oil-shale and sand-shale. This is expected to double the resource base but the economic viability of these techniques is a matter of concern. In addition to the limited resource base, about 65% of oil reserves are found at the troubled spots of the world i.e. the Middle East. These factors threaten the security of oil supply especially in the next century. Renewable energy sources will be available as long as the planet Earth exists but they generally require large land area to capture substantial amount of energy.

Known uranium reserves from which uranium-235 isotope, a nuclear fuel, is produced are expected to last for 50 years without reprocessing the spent fuel. There is however the possibility of recycling plutonium-239, a nuclear fuel, from the reprocessing of spent fuel and also, the use of fast breeder reactors to convert the non-fissionable uranium-238 to plutonium-239. These techniques can increase the energy potential of today's known uranium reserves up to 70 times, enough to last for more than 3000 years at today's level of use. Additionally, thorium which like uranium has no significant use other than as a nuclear fuel contains the thorium-232 isotope which can be converted to uranium-233 nuclear fuel in breeder reactors [2].

3.2. Resource availability in Ghana

On the local scene, Ghana has no coal deposits. There are reports that river Tano basin contains oil and gas deposits. Generally, the deposits are in tight formations and hence difficult and expensive to extract. The Ghana National Petroleum Company (GNPC) is currently developing gas reserves in North and South Tano basin for power generation. The reserves have been estimated to produce about 130 MW(e) power for 15 years. Work conducted in the early 70's indicated that there are uranium deposits in Ghana but follow up work to establish the commercial viability of these deposits is yet to be conducted [4].

Like any developing country, Ghana relies heavily on biomass for her energy needs. Biomass is the greatest source of energy in the country accounting for about 71% of the total energy consumed. It is used mainly as fuel wood for cooking other domestic use. Biomass is not expected to play any significant role in electricity generation due to the high cost involved, the deforestation problem associated with its extensive use. In addition, the high population growth will cause a heavy dependence on biomass for cooking and domestic use. The potential of producing biogas from waste in large quantities for power generation is being assessed. Early projections indicated that as in the case of other renewables biogas will not play any significant role in base load electricity generation in the country. With the location of Ghana being well within the tropical zone (between latitudes 5-12 degrees North) solar energy is abundant. The mean solar radiation levels are between 5-5.5 kW·h /m^2 in the northern part of the country and 4 - 4.9 kW·h /m^2 in the southern part of the country. Notwithstanding these favourable solar energy levels, solar energy has not played any significant role in electricity generation due to the high generation cost. Except for few isolated coastal areas, wind energy resources are quite low with velocities generally considered insufficient for electricity generation from current wind turbine technologies. Ghana has hydro resources mostly located in the Northern and Western parts of the country. The total undeveloped hydro resource potential is estimated to be about 1000 MW(e).

4. GHANA'S ELECTRICITY DEMAND

4.1. Growth rate in electricity demand

Ghana's electricity demand has increased dramatically over the years. Before 1985, the average annual generation growth rate was 2% but this has increased in excess of 10% per annum in the years beyond. More significantly the average annual growth rate in electricity since 1991 is 15% [5]. The striking issue also is that the present high demand for electricity has been attained with about only 35% the population drawing power from the grid. This means that if the rest of the population is to draw power from the grid proportionately, Ghana has to generate about 2.8 times the present capacity. With the present demand estimated to be in excess of 1000MW(e), Ghana has to generate some 3000 MW(e) of electricity to meet the demand of the entire present population. This amount does not only exceed the installed hydro capacity of 1072 MW(e), but the total installed and potential hydro capacities, which is estimated to be about 2000 MW(e).

4.2. Ghana's electricity demand and "Vision-2020"

Two major factors influencing energy demand are population growth and economic growth. In addition, technological advancement plays a significant role in electricity demand. Modern technology is highly dependent on electricity. In 1995, the Ghana government launched the "Co-ordinated Programme of Economic and Social Development Policies". This programme has come to be known as "Ghana - Vision 2020" and it is the Ghana Governments medium to long-term development plan for the country. The main goals of the Vision are:

(1) *Human Development* which involves the reduction of population growth to 2% per annum by the year 2020 so as to reduce poverty and increase income levels for better living conditions.

(2) *Rural Development* which involves the reduction of disparities between incomes and standard of living of urban dwellers and rural dwellers which form more than two-thirds of Ghana population.

(3) *Economic Growth*. Economic growth of 8% per annum targeted to transform the nation to a middle income nation by the year 2020 with a targeted average income per head of US $1700.

(4) *Urban Development*. Development of small and medium size town and cities to adequately fulfil their role in national development.

(5) *Enabling Environment.* Creation of an enabling environment for all sections of the society to contribute to the sustained and accelerated rate of social and economic development.

For the above objectives to be realised, high-energy utilisation especially electrical energy is required. If the 15% annual growth rate of electricity demand is maintained, Ghana will need about 16 times the generation capacity of the Akosombo dam or 16000MW by the year 2020. Analyses done on the relationship between energy growth and GDP, and energy consumption per capita of typical middle income countries whose living standards conform to the that set by the vision 2020 indicate that Ghana will need about 10 times the generation capacity of the Akosombo dam.

Considering the limited availability of the other energy options, the envisaged high electricity demand cannot be met without the use of nuclear energy. The total potential capacity of hydro is about 1000MW(e) thus making hydro unable to meet the future energy demand. Non-hydroelectric renewable cannot play any significant role in meeting high capacity base load demand due to their high generation cost. International bodies like the World Energy Council (WEC) and International Energy Agency (IEA) have predicted that non-hydroelectric renewables will not be economically competitive for large scale production in the foreseeable future and that they will play no more than a limited role in the decades to come. According to WEC, even with adequate support and subsidies, the share of renewables could reach only 5% - 8% of primary energy supply by the year 2020 [2]. For high capacity power supply therefore the choice is between oil and nuclear. The worldwide limited availability of oil and gas for energy requirements of the next century doesn't make them suitable for long term use. The reliance on Nigeria for liquefied petroleum gas is also subject to political influences. There is also the high possibility that with increasing world energy demand vis-à-vis the expected shortage, Nigeria may in the course of time use her gas for her domestic needs alone thus cutting export. (Nigeria has about 1.6% of the total world oil reserves).

There is also the high emission of environmentally unfriendly gases like CO_2, SO_2 etc. in the use of oil and gas which cause global warming, acid rains, respiratory problems etc. According to the world health organisation (WHO), suspended particulate matter alone from energy generation and use, is responsible for about half a million premature deaths per year from urban air pollution. It has been estimated that the amount of CO_2 emitted from fossil fuel plants ranges from about 460g to about 1300g per kW·h [2]. This means that 300MW gas fired plant like the Takoradi plant operating at 75% capacity factor with low emission level will emit about 910,000 tonnes of CO_2 a year. It follows that if the nation is to add only thermal plants to the available hydro sources to meet the electricity demand for the Vision

2020, some 24 million tonnes of CO_2 will be emitted every year. The environmental degradation associated with the use of fossil fuel has caused a global concern on the heavy reliance on oil for energy supply. The Earth Summit held in Rio de Janerio adopted the Agenda 21 calling for global collaboration that would ‘’...halt and reverse the negative impact of human behaviour on the physical environment and promote environmentally sustainable economic development in all countries.’’ This call was made because though “energy is essential to economic and social development and improved quality of life, much of the world’s energy is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially.’’ The Intergovernmental Panel on Climate Change (IPCC) maintains that there is a potential vital role for nuclear power, particularly in the electricity sphere. Its (IPCC) technical paper 1, in examining options to reduce greenhouse emissions by switching to non-fossil fuel sources, states; ‘’nuclear energy could replace base load fossil fuel electricity in many parts of the world if generally acceptable responses can be found to concerns such as reactor safety, radioactive waste transport and disposal, and nuclear proliferation.’’

4.3 Cost competitiveness of nuclear power in Ghana

Studies have shown that nuclear energy is more cost competitive than other base load electricity generation alternatives in most countries. According to studies conducted jointly by the IAEA and international organisations like the International Energy Council (IEA) and the Nuclear Energy Agency (NEA), the overnight construction cost of evolutionary advanced nuclear power plants which could commence operation around the year 2000 or shortly thereafter are projected to range from US $1100 to US $2500 per kW(e) in most countries [6]. The lower end of the cost range favours countries with low labour cost. If contingencies, interest during construction and discounted cost for decommissioning and refurbishment are added this leads to a capital investment cost of about $1500 to $3000 per kW(e) at 5% interest/discount rate and $1700 to $3500 per kW(e) at 10% discount/interest rate. In a developing country like Ghana where the labour cost is low and discount rate is high, the investment cost is therefore expected to be about US $1700 to US $2500 per kW. The corresponding generation costs are 3 US cents to 5.4 US cents per kW·h at 5% interest/discount rate and 4 US cents to 7.7 US cents per kW·h at 10% interest/discount rate. Using the aforementioned argument for the capital cost, the generation cost is expected to be about 4 US cents to 5.9 US cents in Ghana. The 300 MW(e) Takoradi thermal plant costs about US $400 million (excluding the cost of the gas pipeline from Nigeria) thus costing about US $1300 per kW. The current total generation cost in Ghana involving the combination of the Volta hydro power and the thermal complementation is about 4.9 cents per kW·h. The generation cost of some base load power generation options in Ghana are as follows;

Bui Hydro (300 MW)	6.9 US cents/kW·h
Juale Hydro (90 MW)	8.1 US cents/kW·h
Tema Diesel (including fuel tax, 20MW)	13.0 US cents/kW·h
Takoradi Thermal (Combined Cycle, 300MW)	5.0- 5.5 US cents/kW·h

It must be noted that the economic competitiveness of nuclear power could increase significantly if externality costs generally not included in energy generation from fossil fuel like waste management, decommissioning and pollution abatement costs are taken into account. These costs are already included in the generation cost of nuclear power. If stringent environmental policies are put in place the cost of generating power from fossil fuels would increase significantly thus making nuclear power more cost competitive over fossil fuels. The expected shortage of oil and gas reserves in the middle of the next century will also seriously affect their costs. These will make nuclear power very competitive over fossil fuel in the long term.

5. CONCERNS ABOUT NUCLEAR POWER

5.1. Concerns about nuclear safety and radioactive waste

Though nuclear power is obviously a favourable option for Ghana's electricity generation, some Ghanaians have some misgivings about nuclear power. Interaction with those with such misgivings has shown that these misgivings are due to misconception about nuclear power operation due to lack of education. Two main issues of concern are nuclear safety and radioactive waste management. In the case of nuclear safety, the Chernobyl accident is cited as an example. Some Ghanaians also base their argument on the ''culture of maintenance'' in Ghana which according to them is poor and could affect nuclear power plant operation if such a technology is introduced into the country. The fact however is that when safety is at stake attitude to maintenance is different. This is proved by the fact that Ghanaians have performed creditably in other safety related areas like the mining sector and in the airline industry, like Ghana Airways, all of which have very good safety record. In the case of the power sector, Ghanaians generally are comfortable with thermal systems where there could be severe accidents like explosions and fires and hydro power systems where there could be dam breaks and over-toppings. Thermal and hydro systems have higher short term fatality cases than nuclear power which has 31 short term fatalities and about 3500 persons being projected to die from cancer later in their life from the Chernobyl accident (Table I)[2]. Ghanaians have operated a hydro power plant for 32 years with outstanding safety record.

TABLE I. SHORT TERM FATALITIES OF ENERGY RELATED ACCIDENTS (1970-1992)

Energy Source	Number of Events	Fatalities per Event	Total Fatalities	Average Fatalities per GW(e)
Coal	133	5 - 434	6418	0.32
Oil	295	5 - 500	10273	0.36
Natural gas	88	5 - 450	1200	0.09
L.P.G	77	5 - 100	2292	3.1
Hydro	13	10 - 2500	4015	0.8
Nuclear	1	31	31	0.01

Though severe accident cases of nuclear is lower than the other power generation systems and the severity of the Chernobyl accident could have been avoided with the construction of containment building over the reactor assembly, there are even the evolution of nuclear power plants with better safety systems. It must be noted that the IAEA and other international and national organisations have produced technical documents on the design and development of small and medium reactors {20-700 MW(e)} [7]. These have passive safety systems in which the cooling system depends on natural convection instead on pumps etc. thus requiring no human intervention. On radioactive waste management there is the fear in certain circles that there is no proper radioactive disposal method in the world. There are proper disposal methods but some waste management organisations rather by pass the laid down regulations and dispose radioactive waste improperly causing environmental problems and concerns.

5.2. Unfounded fears

There are also unfounded fears on the operation of nuclear power plants. Some fears are being entertained that nuclear power plants can explode like atomic bombs. This type of explosion has been found to be impossible in nuclear power plants since the fuel is diluted with non-fissionable materials like uranium-238. Another unfounded fear is the release of high level radioactive radiation in the normal operation of such plants. The fact is that the amount of radiation received from the natural background far exceeds that emitted from the nuclear industries. Radiation is a natural component of the air we breathe, of the earth we walk on, of the homes we live in, of the human tissue and bones. We are continuously exposed to cosmic radiation, particularly at high altitudes during air travel. Studies have shown that an hour long flight gives four times the amount of radiation which the average person receives from the nuclear industry in a year [8]. On the global average all the routine nuclear power related activities account for a minimal 0.006% of the amount of radiation an individual receives annually [2].

6. CONCLUSION

The facts mentioned above indicate that Ghana’s reliance on nuclear energy for her future electric power requirement for sustainable socio-economic development is inevitable. It is therefore necessary for the nuclear option to be included in Ghana’s energy mix. Ghana has already acquired a research reactor and the government has to support GAEC to plan and execute its program for the reactor utilisation. Since it takes a long time (more than 10 years) to plan and introduce a nuclear power plant it is imperative to plan now with the other energy options being utilised in the short term. In line with the issues and concerns associated with nuclear power utilisation the following strategies are being suggested:-

(1) The objectives for our national energy policy and nuclear power policy should be specified to serve as basis upon which feasible strategic action plans for improved energy independence to be developed.

(2) The government should declare its intention to plan for the nuclear option and openly request the IAEA to assist with planning through expert advice, training etc. This will assure the local public and international community on issues about non- proliferation, illicit trafficking, waste management, financial issues, siting etc. on the nuclear option.

(3) Educating the public on nuclear power safety to enhance public acceptance.

(4) Establishment of nuclear power regulatory body to paticipate in the planning, construction and later the operation of power plants to ensure nuclear safety

(5) A regional policy which will address the various issues involving the nuclear option in such a way as to ensure peace, stability and co-operation should be developed

(6) The member states of the African Regional Co-operative Agreement (AFRA) should be encouraged by the Organisation of African Unity (OAU) to study this option and produce a generic guideline for choosing the option and type of reactor and financing.

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THE NEED FOR NUCLEAR POWER IN INDONESIA

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Abstract

Nuclear power generation is a well-proven technology for electricity production. World-wide, in both developed and developing countries, by the mid of May 1997, 443 Nuclear Power Plants (NPPs) have been in operation contributing around 18% to the world electricity supply with a total generating capacity of 351 GWe in 32 countries. There are 35 NPPs now under construction in 14 countries. Now, most of us have come to realize that an increasing demand and supply of energy is a reality and a necessity to support socio-economic development. This is especially true in developing countries where most of the population have a low consumption of energy and a low standard of living, and the need for a lot of energy to fuel the development and to improve the quality of life is imminent. In regard to electricity supply, this situation can be translated into the need for a large base load power generation. The electricity demand in Indonesia is very high due to the National Economic Development Plan based on industrialization and supported by a strong agriculture base. This situation calls for development and deployment of all energy technologies including nuclear, fossil and renewables to supply the energy needed. The need of nuclear power in Indonesia is in line with national energy policy, which stresses diversification and conservation, economic competitiveness, and environmentally clean. The prepared Nuclear Science and Technology Base and its potential to support the high-tech industry development will lead Indonesia to a sustainable national development.

1. INTRODUCTION

We all have come to realize that an increasing demand and supply of energy is a reality and a necessity to support socio-economic development. Developing countries, like Indonesia and other Southeast Asian countries, have low standard of living and low consumption of energy. In their endeavors to reach a high quality of life, they need a lot of energy and electricity to fuel their socio-economic development. As a consequence the annual electricity growth rate is very high, around 15% per annum. This situation calls for development and deployment of all energy technologies including nuclear, fossil and renewables to supply the energy need. The driving forces as important factors for the implementation of a new energy technology in a country are as follows:

(1) A national energy policy which is conducive to sustainable development.
(2) Whether there is high demand for energy/electricity.
(3) The technology should be well proven by industrial operation standards.
(4) It should be safe and environmentally clean.
(5) It should be economically competitive.
(6) There should be a science and technology base to support the program.
(7) There should already be an independent regulatory body.
(8) A good financing scheme should be developed to realize it.

Nuclear power has all the above driving forces, so it is a very prospective and potential energy source for Indonesia. We will discuss further those above driving forces in later chapters.

2. WHAT INEVITABLE FACTORS ARE LEADING INDONESIA TO NUCLEAR POWER

2.1. National energy policy

In order to successfully support the national development program in the second long-term development programme (LTDP-II), and considering to the changes of global environmental strategy, an integrated and solid energy policy has been set up.

Principally, there are five main energy policy measures:

(1) *Diversification*: To maximize and economize the supply of energy, to curb the rate of excessive use of hydrocarbon resources. To reduce the dependence on a single type of fuel (i.e. petroleum), and later to replace it with other available fuels. In 1995 oil's share was around 60%, and at the end of LTDP-II (2020) is projected to be around 40%;

(2) *Intensification:* To increase and expand the exploration of the available energy sources; aiming at secure sufficient supply of energy;

(3) *Conservation:* To economize energy production and utilization;

(4) *Energy Price:* To formulate energy price based on economic value and by taking into consideration its environmental cost;

(5) *Clean Energy Technologies:* To support environmental program and toward a sustainable development.

The implementation of the energy policy covers several aspects such as issuance of regulations, standards, energy pricing incentives and disincentives, and the application of appropriate technologies.

The technologies that would be considered are identified as follows:

(1) The technology to produce substitutes for oil, as oil is non-renewable and limited resources.

(2) The technology to support a more sustainable energy supplies.

(3) The technology for clean and efficient energy to support environmental programs and toward a sustainable development.

The nuclear energy option unquestionably is capable of meeting the objectives of reducing the dependence on oil and gas. They could be used for export and feedstock to support the take-off era towards the LTDP-II, as a secured long term energy supply as well as to support the reduction of the potential impact of air pollution.

Parallel with energy diversification policy, exploratory study for inventarizing resources of radioactive mineral has been conducted throughout the feasible region of Indonesia. Currently, intensive survey has been focussed to only two (2) regions.

2.2. Electricity demand

As for the Java-Bali interconnected system, which represents 80% of the Indonesia's total electricity consumption. The projected installed capacity for the year 2003/2004 is 31.8 GW, which is far greater than the previous projection that account for 25.5 GW even for the year 2010/2011.

In view of this the government has decided to conduct feasibility studies of the nuclear option, in the goal to fulfill the deficit or gap in supply where other options are likely to reach their limitations.

In September 1989, the Indonesian government through the National Energy Co-ordination Board (BAKOREN) decided to perform the NPP feasibility study including comprehensive investigations of the Muria Peninsula as a candidate site for NPPs. The study itself had to be carried out by the National Atomic Energy Agency (BATAN), under the directives of the Energy Technical Committee (PTE) of the department of mines and energy, including other institutions as well.

In May 1996, the feasibility study for the first NPP in Indonesia was completed. The result of the feasibility study, especially on the electrical system analysis using the WASP-III of the ENPEP program shows that the introduction of nuclear power plants in the early 2000s to the Java-Bali electric system represents an optimal solution. A preferred site had also been selected through detail external and environmental events assessment conducted under the auspicious of IAEA.

2.3. A well proven technology

The nuclear technology is a proven technology, which has already made important contribution toward electricity supply, where 18% of total worldwide electricity consumption comes from nuclear.

In May 1997, 443 NPPs with a total generating capacity of 351 GWe were in operation in 32 countries in the world. And another 35 units with a generating capacity of close to 28 GWe were under construction. There are 35 nuclear power plants now under construction, only 3 are in Western Europe (France), 15 in Eastern Europe (Czech Republic: 2; Romania: 1; Russia: 4; Slovak: 4;Ukraine: 4), 2 in Latin America and 15 in south East Asia. The total accumulated operating experience of nuclear power plants by the middle of May 1997 amounted to over 9000 reactor years, corresponding to an average operating period per plant of more than 18 years.

A rigorous study to assess existing NPP design for their appropriateness with Indonesian situation has been conducted in most of BATAN research facilities.

2.4. Safe and environmentally clean

2.4.1. Safety of nuclear power plants

Safety has always been our prime concern especially when it comes to nuclear power plants. The plants we are planning to have shall be designed, built and operated under a series of strictly enforced regulations and to well-established codes and standards. These regulations, codes and standards, at least in the “western” world, have continually evolved to take into account the experiences gained in the building and operating of many nuclear power plants. An independent national regulatory authority shall ensure that all activities from the designing until decommissioning are performed safely.

The approach to safety followed in all commercial NPPs is *defense-in-depth*, which covers accident prevention, accident protection and mitigation, and accident accommodation, compensates for potential human and mechanical failures.

In the endeavor to master nuclear technology, Indonesia, from the very beginning, the aspect of safety has always and will be of the highest priority and concern.

2.4.2. Environmentally clean

The nuclear energy contributes significantly in reducing atmospheric pollutants generated by fossil plants that can cause respiratory diseases, acid rains and global warming.

New requirements in air pollution controls on coal plants will increase the cost and regulatory uncertainties of electricity generation by coal plants. Increased concerns on long term effects of greenhouse gas emissions calls for greater priority in utilizing electricity generations that produce less greenhouse gas.

Above considerations show the viability and environmentally friendly of nuclear power plants in curbing pollutants coming from coal plants.

Compared to coal, nuclear offers the following advantages:

(1) Nuclear energy is more environmentally friendly since it does not emit dangerous elements like heavy metals (Cd., Pb., As, Hg, V), VHC, SO_2, NO_x, and CO_2.
(2) Nuclear wastes have smaller volumes compared to those produced by other energy sources; therefore, they can easily be isolated and stored for the protection of human health and of the environment.
(3) The electricity cost of a nuclear source is more competitive to that of coal that utilizes environmental protection equipment.
(4) Uranium, used as nuclear fuel, has more energy content than any other sources of energy (hydro, gas, oil, geothermal, and coal).

2.5. Economically competitive

The result of the feasibility study for the generation cost shows that the generation cost of the conventional scheme for the 600-900 MWe class Nuclear Power Plant units is competitive to the generation cost of a similar capacity of Coal Fired Plants using $deSO_x$ and $deNO_x$. The generation cost of these NPPs varies from 48 mills/kWh to 61 mills/kWh.

The attractiveness of nuclear energy lies, among others, on the low cost of fuel, which results in the insensitiveness of the total generating cost to the fuel cost. The fuel constitutes only a few percent of the total generating cost, and that any severe fluctuation of fuel cost would never affect the total cost.

2.6. The presence of science and technology bases to support the program

Improvements in the performance, safety and environmental impacts of power generating plants are always in demand due to ever increasing quality requirements from the public and government. Therefore, it is absolutely necessary to undertake research and development in energy technology to achieve these desired improvements. This policy for improvements has been especially imposed for power generating plants in the 90's and beyond. Research and development also are absolutely necessary for the operation, maintenance, improvement of and development of human resources for NPPs. Indonesia has made outstanding progress in the establishment and operation of Nuclear Science and Technology Bases (STB) during the last 35 years. The latest one is the BATAN Nuclear Research Complex at PUSPIPTEK, Serpong, about 30 km from the capital city of Jakarta.

2.7. Regulatory body

In recognition of the need to develop an effective nuclear regulatory infrastructure in order to proceed with the development of nuclear power, Indonesia has issued a new Act on Nuclear Energy (Act No.10 of 1997) dated April 10, 1997 to replace the Act No. 31 of 1964. In the new Act, the promotional function (in the application of nuclear energy) is separated from the control functions. The responsibility to promote the applications of nuclear energy is vested in the promotional body, which is BATAN, and the responsibility to regulate and control of nuclear energy is vested in the Indonesian Nuclear Regulatory Agency. The new Act also includes the provision for third party liability in the case of nuclear damage. It regulates the limitation of liability in terms of the amount of compensation and time.

2.8. Financing schemes

Financing for NPPs in developing countries, due to high investment capital cost, is a major hurdle. That is why, at the present, we have been studying various schemes to finance the construction of NPPs in Indonesia. The financing schemes should achieve two objectives: minimal costs to the government and affordable electricity price. Four schemes have been pursued, they are conventional export-credit approach, build-operate-own (BOO) approach, modified BOO or joint venture approach, and the possibilities of a barter approach.

3. CONCLUDING REMARKS

It can be concluded that for Indonesia’s future, the nuclear option is inevitable. Indonesia can only afford to give the best and careful preparations as well as the highest priority to the safety in the introduction of NPP.

In line with this conclusion, a series of rigorous preparatory study for NPP adoption in Indonesia has been conducted in BATAN research facilities. Currently, most of infrastructures required for NPP development have been prepared, including Independent Regulatory Body, Appropriate Financing Scheme, Economic Feasibility, Environment and Safety Analysis, Well Selected Site, Public Acceptance Program, and others.

We welcome other countries' cooperation in our endeavor to introduce and develop nuclear power in Indonesia.

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THE MODERN TRENDS IN ENERGY AND NUCLEAR INDUSTRY OF KAZAKHSTAN*

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Abstract

Kazakhstan has the potentials to be self-sufficient in energy resources in perspective and also to export such resources to other countries. This article describes the energy sector of the Kazakhstan, the perspectives of the development the energy and nuclear industry and shows the problems and methods of its solutions. The energy sector of the Kazakhstan has the diversified sources of energy resources. The open market of electricity will generate the investments and direct them on the development on more efficiency use of these resources. Rehabilitation of old power stations and its modernisation will allow to cover the future needs of the Kazakhstan. The nuclear industry of Kazakhstan has the infrastructure, high-qualified staff, enterprises, reactors and investments for the development. The energy police of the Republic of Kazakhstan are directed to find the balance between different sources of energy to decrease the emissions of greenhouse gas.

1. INTRODUCTION

Kazakhstan has the considerable resources in uranium approximately 1.17 billion tonnes. The Republic of Kazakhstan has the developed industrial infrastructure by the exploration, extraction and exploitation the uranium mining and production the thermonuclear elements for the nuclear stations. Kazakhstan has the scientific staff and potential for the development the nuclear industry.

Kazakhstan is a member of MEGATE and the national joint-stock company “Kazakhstanatomenergoprom” - is a member of the London uranium institute.

Kazakhstan’s uranium and production are sold in 14 countries of the world including USA, Canada, France, Germany, Great Britain, Japan, Russia and others.

The necessity of development of nuclear industry is based on next reasons:

(1) Lack or shortage of other energy resources;
(2) Strategic need of the nuclear potential by using in applied and military aims;
(3) Including the nuclear industry in energy sector can stabilise this sector and decrease the emissions and influence on environment.
(4) The Kazakhstan nuclear industry can enter to the world market with the commercial product.

The economic base of the nuclear industry is:

(1) The own resources of uranium;
(2) The developed industry by working up the resources, its enrichment and production the commercial product;

* Work performed within framework of the Concept of the Development of Energy Sector of Kazakhstan for the Government of the Republic of Kazakhstan.

(3) Machine-building industry, which can produce the equipment and materials for the nuclear reactors;
(4) Scientific staff and management which can provide the production management, control and safety.

Kazakhstan has the enterprises and scientific staff that were the part of the former Soviet Union system of nuclear production.

2. THE ENERGY SECTOR OF THE REPUBLIC OF KAZAKHSTAN

The energy sector of the Kazakhstan is more capitalised part of the economy that is why it is more important to estimate foresee the new possible progressive directions of the development of its components and to adopt the modern instruments for its realisation. It is more important for the Republic of Kazakhstan to realise the long-term strategy of the development because of the important role of energy sector in the economy of the Republic of Kazakhstan.

The real provision of the energy resources is more significant for the new independent countries like Kazakhstan. The development and modernisation of internal system of energy provision of electricity on the base of local energy resources and export/import exchange with other countries are necessary.

The universal principles are that the main projects by the development the energy base can continue further quantitative growth and qualitative improvement of the energy sector of the Republic of Kazakhstan are defined.

The task of the energy sector is reliable and safety (in ecology and technical aspects) provision the population, communal services and industry of the Republic of Kazakhstan with fuel, coal, electricity, heating and etc. The task also includes the improvement of the structure of energy complex, liquidation the gaps and deficits, improvement of environment, solution social and political purposes in the Republic of Kazakhstan.

Four main items of the energy policy of the world which realise by the energy policy of the Republic of Kazakhstan are:

- material security of the energy complex for the sustainable economic growth;
- social security of human needs in energy services by cheaper prices;
- support the reliable work of energy system which can guarantee the energy security;
- safety of environment and climate change.

3. ENERGY RESOURCES

Kazakhstan has the all kinds of the energy resources. The main resource of the energy sector is the coal. The coal is mainly produced in the Ekibastuz region (west north of Kazakhstan).

The huge investments have been directed in the coal industry and coal power electricity stations and defined the main aspects of its development.

The coal fields mainly are situated in North and Central of Kazakhstan, where also situated mineral and fossil fuel deposits. They are the main industry potential of Kazakhstan. The main sources of the electricity also are situated in North and Central Kazakhstan. These regions have enough energy resources and have the surplus of them.

The region of South Kazakhstan has not enough the energy resources. The main part of existing resources is hydro resources. The development of hydro resources is very difficult in this region because of infrastructure. The local and foreign investors are going to build two large hydro stations. On the river Charyn is Mainak hydro station and on the river Ili is Kerbulak hydro station. Local authorities are going to build about 50 small hydro stations.

The expected scale of the exploitation the energy resources can not cover future demand on the energy resources. The energy sector of South Kazakhstan is based on the import of coal and natural gas from other regions. The region also produces the black product as the waste of refinery. Yet the main part of the demand on electricity is covered by the import.

The region of Western Kazakhstan – is the main fossil fuel region of Kazakhstan. Historically, the electricity provision of Akjubinsk and Uralsk regions is provided from the electricity station, which are situated in Russia. Yet Kazakhstan has the possibility fully provide the needs of the electricity by the development of existing energy resources in short time and provide the additional import resources.

4. THE CONSUMPTION OF ENERGY RESOURCES

The structure of energy resources defines the structure of the generation of electricity. This structure is characterised by the next indicators (% of the volume of generation of electricity):

– Combined heat and power system - 75-81%

– Gas-fired combustion turbines - 12-13%

– Hydro stations - 6-11%

– Nuclear power plant in Aktau - 0,7%

The whole length of power lines the is 464133 km. including:

i) 1421 km of lines with a voltage of 1150 kV

ii) 5455 km of lines with a voltage of 500 kV

iii) 20241 km of lines with a voltage of 220 kV

iv) 44475 km of lines with a voltage of 110 kV

v) 62088 km of lines with a voltage of 35 kV

vi) 203938 km of lines with a voltage of 6-10 kV

vii) 122058 km of lines with a voltage of 0,4 kV

5. COMMON CHARACTERISTICS OF KAZAKHSTAN

	1990	1995	1997
Population (million)	16,79	16,6	15,86
Electricity consumption GW(h)	104,7	74,38	57,12
Electricity consumption per man kW(h)	6236	4480	3600
GDP (billion $)	37,55	22,08	22,4
GDP per capital ($)	2236	1330	1412
Rated capacity of power stations GW	17,57	18,42	17,927
Electricity generation GW(h)	87,4	66,98	52,17
Export of electricity GW(h):	11,01	4,89	3,44
Russia	10,78	2,01	3,37
Central Asia	0,23	2,88	0,08
Import of electricity GW(h) :	28,34	12,28	8,39
Russia	18,37	6,2	6,4
Central Asia:	9,97	5,22	1,99
Uzbekistan	7,83	0,43	0,02
Kyrgyzstan	1,92	0,78	0,79
Tadjikistan	-	0,31	-
Turkmenistan	-	1,68	1,18
Net import	17,34	7,4	4,95

6. THE ELECTRICITY GENERATION

The huge generation of electricity in Kazakhstan was in 1989 and consisted of 88,9 GW(h) per year. The installed capacity of power station is 1682 GW(h) with number of used hours 5285. The modern installed capacity of power station allows reach the potential of electricity generation to 95 GW(h) per year with the intensive of used hour as in 1989.

The Ekibastuz energy complex is intensively developed in North Kazakhstan. It provides the electricity supply for consumers of Kazakhstan, Western Siberia (Russia) and Central part of the Russia. The development of Ekibastuz allows Kazakhstan to be energy independent and make the export of electricity. The unique overhead lines with voltage 1150 kV and 500 kV including the transmission line Siberia – Kazakhstan – Ural can provide the large transportation of electricity. These transmission lines are the main element of the infrastructure of modern economy of Kazakhstan. They allow solve the main part of the economic problems by the supply the electricity for a long-term period.

The levels of the development the energy sector are mainly influence on the development of the economy of the Republic of Kazakhstan. The independent energy provision and energy security are the conditions of the stable energy supply in the economy. This can provide the base for the economic security of the Kazakhstan.

In 1990 the power stations of Kazakhstan generated 87,4 GW(h). In further time the combined heat and power plant, in Ekibastuz GRES-2, combined heat and power plant in Karaganda TEC-3, the gas-fired combustion turbine in Aktubinsk (Akturbo) and Shulbinsk hydro station were built on the territory of Kazakhstan. The full installed capacity of them is more 7 GW(h).

As a result of this potential the generated capacity is more than 95 GW(h). This level of consumption is expected to the period after 2015.

By the different problems the generation of electricity on the power stations decrease significantly after the decrease of the demand on electricity. In 1997 the generation of electricity was 52,2 GW(h), the level of consumption was 57,1 GW(h).

The main problem before the economy of Kazakhstan is a recovery of the generation of electricity on the power stations and it is not important who is the owner of them.

The rehabilitation of power station is the wide world experience. This way may allow generate the electricity with low expenses and in short time. This is more important for the society. The old power stations have the building, infrastructure, means of communications, heat grid lines for the heat capacity, high-qualified staff, and solved as a rule social problems.

The energy equipment on the power stations and electricity grid lines have not repaired since 1990th and had not maintenance. The equipment exhausts all its resources and need the modernisation and installation of the new equipment and technology.

The recovery of power station is one of the significant problems of the energy sector. The South and West zones of Kazakhstan have not enough capacity for the generation of electricity. These zones have the deficit in electricity.

Under the conditions of recovery and maintenance the energy sector the forecast growth of demand on electricity can not cover without building the new capacity of generation the electricity. The new power station can keep the balance in the system when the old power station will be modernised and will be excluded from the system. Ones of the main current problems are building the new power stations and increasing the capacity of the existing power stations which have the necessary infrastructure and high-qualified staff.

The main problems of the development the energy sector:

i) The recovery of generation on existing power stations by the rehabilitation and reconstruction as more cheaper and quick solution;

ii) Keeping the capacity on power stations on the installed level and to put into the new equipment and new technology on them;

iii) To increase capacity on the existing power station, building the power stations to cover the internal needs of Kazakhstan and create potential for export. To improve the structure of generated capacities and to create the reserves of peak capacity;

iv) Wider use of natural gas and casing head gas or dissolved natural gas;

v) Development economical competitive renewable energy resources;

vi) Further development of the national electricity grid lines and building the new transmission lines, reconstruction and rehabilitation of them for the improvement the structure of energy sector and development the internal and external markets.

The main tool of energy policy and solution the problems of its development is market. In 1995 the "the law of electricity energy" of the Republic of Kazakhstan was approved. This law became the base of the reform in energy sector. All main power stations were privatised and became the participants of energy market. The company KEGOC is operator of the wholesale energy market and organises the management under the interregional and interstate transmission electricity lines. The company KEGOC is not buyer or seller of the electricity and capacity. This company is responsible only for the transportation of electricity.

At this moment the wholesale market of electricity is formed. The company KEGOC together with Ministry of Energy, Industry and Trade work out the legislation by the further improvement of the energy market. The Government of the Republic of Kazakhstan realises the policy of step-by-step privatisation of local distribution companies to create the open retail market. The process of privatisation in the internal energy market will be continued till creation open competitive energy market.

Among the possible variants of further development of energy sector on long-term perspective is the variant of building the nuclear power plant with capacity 3×640 MW (or 13,5 GW(h)). The capacity of nuclear power plant will be increased according the growth of demand on electricity. The government will accept the decision after public consideration of feasibility study of this station. According the international standards, methods and after international expertise this station will be built.

7. THE PERSPECTIVES OF THE DEVELOPMENT THE NUCLEAR INDUSTRY IN KAZAKHSTAN

The nuclear-power complex of Kazakhstan was formed as an integral part of the nuclear industry of the former Soviet Union and in many aspects it is closely connected with enterprises and scientific centres in Russia and Ukraine.

The nuclear industry consists of 7 mines by the extraction of uranium, 2 factories producing uranium oxide (in Aktau and Stepnogorsk), 1 factory processes UF_6 and VO_2 and produces thermonuclear elements for the reactors.

Kazakhstan State Corporation of nuclear power industry and enterprises coordinates the activity of nuclear complex. The corporation includes Caspian metallurgical and Tselinograd mine-chemistry plants, Ulbinsky metallurgic plant. Their main activity was processing and enrichment of the products of uranium mining companies. Today they are mainly produced the rare-landed elements, noble metals, mineral fertilisers and consumer goods.

Only one nuclear power plant in Kazakhstan has operated since 1972 as a part of Mangyshlak energy plant on the basis of the fast neutrons nuclear reactor BN-350, which exhaust all its resources. It is suggested to replace the existing reactor in Aktau by small capacity reactors as BMN-170 which also is a fast neutrons nuclear reactor. This reactor is produced as mono-block, equipped with shut down and after cooling functions that keep the work of the reactor in safe mode, independently from the support and maintenance systems and activities of technical staff. The existing nuclear power plant generates 125 MW and also produces the fresh water (10,000 t per day) and some steam which is used for technical purposes.

Mangyshlak power plant supplies Aktau and other inhabited places near Caspian Sea with energy and fresh water.

The research and production association “Luch” which is located in Semipalatinsk has the special technical equipment and high-qualified scientific and technical staff. On the territory of the Republic of Kazakhstan four scientific reactors are situated. Three of them are situated in Semipalatinsk. These reactors are used for the testing of nuclear missile engines, researches in nuclear materials of reactor and testing safe operation on the nuclear power stations.

The nature is disposed so that Kazakhstan has almost half of all the proven uranium resources in CIS. Uranium is produced in Kazakhstan but there are no consumers of the uranium inside the Kazakhstan. The Kazakhstan's uranium also can not find the consumers in CIS. Kazakhstan should offer the uranium to the world market in compliance with MAGATE regulations and to the countries which signed the convention of non-distribution the nuclear weapons.

The orientation on the construction of nuclear power plant can lead to the problem of radioactive waste utilisation. In Soviet time the wastes from the nuclear enterprises and nuclear plants were utilised on the territory of Russia and Kyrgyzstan. Now it is necessary to create the own system of utilisation. This problem can be solved with low expenses for Kazakhstan. The radioactive waste can be utilised on the territory of Semipalatinsk nuclear test polygon or saline mines of Azgirsky nuclear test polygon.

8. THE REAL ACTIVITIES FOR THE REDUCTION OF CO_2 EMISSION

The growth of concentration the CO_2 in atmosphere can be the main factor which can restrict the using fossil-fuel and coal in the future because of increase the temperature of the land surface as a greenhouse effect.

According the development the energy sector the economic analysis show that it is necessary to make the reconstruction and modernisation combined heat and power plants. The part of combined heat and power plants in the economy of the Kazakhstan is 48% in 1990 from all volume of generated electricity.

The main effective directions to decrease fuel expenditures by electricity generation of the large coal central steam plants are:

(i) Further development and improvement of combined heat and power plants;

(ii) Improvement the heat scheme of large coal central steam plant, creation combined cycle plant, building the new power plants and to transform turbo-generator power plant into compressed air storage power station.

The significant factor for the reduction CO_2 emission is the activities by the effective using of the fuel or energy efficiency. The potential of the energy efficiency in Kazakhstan is very high. The government Republic of Kazakhstan together with USAID worked out and approved by decree the National Program of Energy Efficiency.

The realisation of the short-term and middle-term programs of this national program will allow decrease the expenditures on the fuel on 25% and by the long-term program on 40%.

The specialists of Kazakhstan considers the natural energy resources of Kazakhstan, technical and scientific development and the results of expertise and they choose the next activities of the reduction of CO_2 emissions in energy sector:

(1) The modernisation of large coal central steam plants;

(2) Construction the new hydro stations, wind station;

(3) Consideration the project by the construction the nuclear plant;

(4) Using the other renewable source of energy.

To decrease the restrictions which connect with concentration of the CO_2 emission in atmosphere we can make the conclusion that to develop the energy sector have to consider the balance of generation heat and power between different sources of energy and try to safe the environment.

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THE ROLE OF THE NUCLEAR PROGRAMME IN THE DEVELOPMENT OF THE ROMANIAN POWER SYSTEM

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Abstract

The power system, major component of the Romanian development is strictly related to the social-economic and technological policy and to the external factors influencing this development. Taking into consideration the future evolution of the electricity demand in Romania over the period 2000-2020 it is necessary to devise an optimized strategy for electricity generation in order to ensure the economic development of the country and to achieve a high standard of living. For these reasons is presented the role of the nuclear programme for different patterns of electricity consumption evolution, taking into account the present situation of Romanian power system, the evolution of the domestic primary energy resources, the fuel prices evolution, the technologies of the electric and thermal power generation and the environmental requirements. The analysis is achieved in the context of the new political and economic trends facing European countries, related to Joint Agreement with European Community and to the requirements of the single energy market.

1. INTRODUCTION

Romania is a country in transition from a centrally planned economy to a market economy. In these conditions a sound energy policy is a key importance for successful development of the economy and the nation as a whole.

For this reason it is very important to adopt proper strategies for the reorganization and development of the energy sector, aiming at efficient production and use of energy resources. Such strategies cannot be adopted without use of analysis methods that permit a better appraisal of the economic and the environmental aspects of alternatives.

The evolution of the power system is related to the social-economic and technological policy and to the external factors and is established on the base of the studies for optimal utilization of the primary energy resources, reduction of energy intensity and specific energy consumption, increasing of the energy efficiency, pollution mitigation etc.

One important characteristic of the Romanian power system is its over capacity because in 1997 total installed capacity exceeded 22,000 MW and the electricity consumption decreased with about 35% during the period 1989–1997 due to the restructuring of the economy.

The total available capacity of the Romanian generation system at the end of 1997 was 15,481 MW, of which 8,974 MW were in thermal power plants (TPP), 630 MW were in nuclear power plant (NPP) and 5,877 MW were in hydropower plants (HPP). The available capacity was significantly lower than the installed capacity due to various problems and difficulties with equipment reliability, operation and maintenance of power plants. This available capacity will decrease in the period 1998 – 2020 from 15,481 MW in 1997 to 9,569 MW in 2020, mainly as the result of the generation units retiring at the end of their economic lifetimes. Because of this, after 2002 the extant generation system will not be able to satisfy the electricity demand without new additional capacities.

An important characteristic of the Romanian power system is a large number of cogeneration plants that supply heat to both residential and industrial consumers amounted to 260 PJ in 1997. In these conditions it is very important to establish the evolution of Romanian power system considering both electric and thermal power demand.

It is important to emphasize that in 1997 there were under construction a total of 4,300 MW in new generation capacities. From these 2,800 MW belongs to nuclear power plant (NPP) Cernavoda, designed with five units of 700 MW each, provided with CANDU reactor. Unit 1 was put in to operation in 1996 and operates at designed parameters. Unit 2 of Cernavoda NPP is performed about 46% and the others between 17% and 6%. So the projects under construction are considered as expansion candidates and in planning activity it is important to establish the necessity for the finalizing of some HPPs and of four units of Cernavoda NPP.

Romania has multiple primary energy resources (coal, crude oil, natural gas, uranium, hydropower as well as geothermal, solar and biomass energy sources) which are, however, limited. The quantities of energy resources in Romania were not large enough to cover the increasing of the energy demand. So in 1997 were imported about 26% of the total primary energy consumption. The quantities of crude oil and oil products accounted 60% of total energy imports and the quantity of natural gas about 25%. Taking in to consideration the demand and production forecasts it is expected that fuel imports will still increase. Under these conditions, it is very important to make comprehensive comparative assessments of different energy chains for electricity generation in the planning and decision making process.

2. DESCRIPTION OF ALTERNATIVES ANALYSED

The establishment of the scenarios considered in the comparative analyses of alternative strategies for development of electricity generation capacities is based on Romania’s present situation.

The main factors, which have particular importantce in the electricity supply study, are electricity demand projection, energy supply options, modernization and rehabilitation of the extant units and fuel price projections.

Electricity demand projections are evaluated for three variants of economic growth: medium economic growth (reference scenario), low economic growth and high economic growth (Table I). [1]

TABLE I. THE EVOLUTION OF ELECTRICITY DEMAND (TWh)

Scenario	1990	1995	2000	2010	2020
(a) Low			45.1	56.7	68.6
(b) Medium	60.216	46.463	45.1	62.0	79.0
(c) High			47.0	70.7	99.5

Under the impact of economic growth, electricity demand would continue to rise up to 2020, despite of the significant decline of the energy intensities. In 2020, energy demand would be in the range 68.6 TWh (Low scenario) to 99.5 TWh (High scenario). This is an increasing of aproximately 22-53 TWh. It is important to emphasize that due of restructuring and modernization of the Romanian economy and of the energy efficiency increasing, is projected to save 61-81 TWh acording to scenarios (Low to High).

Related to energy supply options, taking into consideration that Romanian will be a net energy importer , the following possible energy policies regarding the availability and diversification of energy imports are considered in the creation of different scenarios:

i) The imported quantity of natural gas is assumed to increase from approximately 7 billion m^3 in 1995 to 13-14 billion m^3 per year in 2005 from one exporter. Also the imported quantities of oil and coal will be considered available throught the study period to provide additional energy, if domestic energy resources cannot adequately meet energy demand.
ii) After 2005 additional quantity of gas will be available from import and the imported quantities of oil and coal will be unconstrained.
iii) Expanded nuclear programme is considered for the decreasing of Romania dependency on fossil fuel imports.

Related to the modernization and rehabilitation of the extant electricity generation capacities on hard coal, lignite, fuel oil and natural gas will be considered the following scenarios:

i) Extant condensing units (higher than 200 MW) and cogeneration units will be candidates for rehabilitation.
ii) Only cogeneration units will be rehabilitated, while the condensing units will be retired from operation at the end of their economic lifetimes.

The World Bank projection of fuel prices on the international market are used (Table II) [2].

For sensitive analysis the International Energy Agency (IEA) projection of fuel prices are used (Table III).

Taking in to consideration these main assumptions were created and analyzed a reference case and six alternatives, presented in Table IV.

TABLE II. THE WORLD BANK PROJECTION OF FUEL PRICES [2] (CONSTANT 1995 DOLLARS)

Fuel	Unit	Actual 1995	Short – Term Projection			Long – Term Projection		
			1996	1997	1998	2000	2005	2020[a]
Petroleum	$/bbl	17.18	15.97	15.14	15.22	14.94	14.94	14.94
Coal	$/tone	39.18	38.72	38.79	38.75	38.66	38.55	38.55
Natural gas,Eur.	$/Mbtu	2.73	2.61	2.56	2.49	2.37	2.28	2.28

[a] *Since World Bank projection ends in 2005, it was assumed that prices would remain constant thereafter.*

To cover the electricity demand in next period the following options have been assumed:

- works completion to the power plants under different construction stages and not included into the programme up to the year 2000 (that mean-935 MW in hydropower plants, 2800 MW in the nuclear power plant Cernavoda, 570 MW in thermal power plants of which 440 MW in cogeneration plants);
- rehabilitation of power plants;
- construction of new power plants.

The types of new power plants used as candidates in the optimization analyses are as follows:

- conventional thermal power plants with condensing units of 330 MW and 500 MW running on domestic lignite or imported hard coal;
- new nuclear units with CANDU reactors;
- 660 MW combined cycle units on natural gas.

TABLE III. IEA PRIMARY ENERGY PRICE PROJECTION [3] (CONSTANT 1995 DOLLARS)

Fuel	Unit	1993	2000	2005	2010	2020[b]
Crude Oil[a]	\$/bbl	17.75	24.90	30.32	30.32	30.32
Coal-import Europe	\$/tone	46.7	58.14	61.79	61.79	61.79
Natural Gas-import Europe	$\$/10^3m^3$	98.13	128.11	155.08	155.08	155.08

[a] *The average CIF price of crude oil imported into IEA countries.*
[b] *Since the IEA projection ends in 2010, it was assumed that prices would remain constant thereafter.*

TABLE IV. THE MAIN CHARACTERISTICS OF THE ALTERNATIVES

	CODE OF ALTERNATIVE						
	V1 Reference case	V2 Low economic growth	V3 High economic growth	V4 Energy diversification 1	V5 Energy diversification 2	V6 Expanded Nuclear program	V7 No rehabilitation
Economic growth	Medium	Low	High	Medium	Medium	Medium	Medium
Energy supply scenarios	Type a	Type a	Type a	Type b	Type b	Type c	Type a
Scenarios of sector modernization and rehabilitation	Type a	Type a	Type a	Type a	Type a	Type a	Type b
Fuel price projections	World Bank	World Bank	World Bank	World Bank	IEA	World Bank	World Bank

3. DEVELOPMENT OF GENERATION CAPACITIES

The criteria used in the economic evaluation of different expansion alternatives are:

- a single discount rate of 10% is applied to both domestic and foreign capital investment and operation costs;
- cost excalation has been applied to fuel prices according to the assumption for projection of energy prices on the international market;
- the sinkinig fund depreciation method was applied to calculate salvage value of the plants committed during the study period;
- economic loading order was used for the simulation of generation system operation;
- for free optimization the lower and upper limits of the reserve margin were specified very widely, exceeding the peak demand from 15 to 50%;
- the cost of unserved energy was estimated at US $/1/kWh;
- the upper limit of the loss of load probability (LOLP) was specified as 0.274% (1 day per year).

The results of analyses of different alternatives show that in the period 1997-2020 will be added to the power system the new installed capacities of 13,600 MW in alternative V2 (Low economic growth) and 20,800 MW in alternative V3 (High economic growth). The installed capacity in new units will represent 62-65% of total installed capacity of the power system. In the alternative V7 (without rehabilitation of extant units) the share of the new installed capacity will reach 80% of total installed capacity.

The rehabilitation of the existing units will play an important role up to 2008-2010.

The results of the optimization of the long-term development of the power system show that 660 MW gas-fired combined cycle units are preferable candidates for system expansion in all alternatives considered and in both alternatives for fuel price projections.

For the alternative V1, V4, V5, V6, V7 result the following remarks (see Table V):

- up to 2010, 75-80% of the added capacities are rehabilitated units;
- the new units added up to 2008 were under construction in 1997;
- the share of new HPP is 3-5% of the total added capacity for 1995-2020;
- the share of new NPP is between 5% in alternative V4 and 60% in alternative 6 of total capacity added for 1995-2020;
- unit 2 of Cernavoda NPP is part of the least cost solution in all alternatives and new nuclear units are required after 2010, except alternative V6 (expanded nuclear programme);
- for IEA fuel price projections all units of Cernavoda NPP are required in the least cost solution.

Regarding to the structure of the available generation capacity, must be highlighted the following features (Table VI):

- the share of HPP in total available generation capcity is significant and will decrease up to 2020 in all alternatives to 29.8-30.7% against 40.8% in 1995;
- the share of NPP in total available generation capacity in 2010 will be about 8% in all alternative, except the alternative V6 in which will be about 16%;

– the share of TPP in total available generation capcity will be between 50-60% during the study period in all alternatives, except the alternative V6 (extended nuclear program) in which will be 43% in 2020.

In Table VII is presented the contribution of the HPP, NPP and TPP to the total electricity generation. It can observe that HPP share in total electricity generation will increase up to 2000 due to the reduction of the electricity demand against 1995 and will decrease from 32.8% to 18.9-19.6% between 2000 and 2020. The share of NPP in total electricity generation will reach 8.6% in 2000 and 12.5% in 2010, in all alternatives, except the alternative V6 in wich will be 25.6%.

TABLE V. INSTALLED CAPACITY IN THE ALTERNATIVES (MW)

Code of alternative	Capacity added	1995-2000	2001-2010	2011-202
V1	Total	3324	4230	8388
	of which in:			
	HPP	130	-	358
	NPP	-	700	700
	TPP	3194	3530	7330
	TPP on coal	2655	2040	7330
V4	Total	3324	4150	7670
	of which in:			
	HPP	130	-	-
	NPP	-	700	-
	TPP	3194	3450	7670
	TPP on coal	2655	1485	870
V5	Total	3324	4160	7966
	of which in:			
	HPP	130	-	186
	NPP	-	700	2100
	TPP	3194	3460	5680
	TPP on coal	2655	1695	1320
V6	Total	3324	4240	8906
	of which in:			
	HPP	130	-	186
	NPP	-	2100	7000
	TPP	3194	2140	1720
	TPP on coal	2655	1485	1320
V7	Total	3324	4730	9263
	of which in:			
	HPP	130	-	380
	NPP	-	700	2100
	TPP	3194	4030	6783
	TPP on coal	2655	645	6500

In 2020 the share of TPP in the total electricity generation is posible to reach the highest value at 71.1% in the alternative V4 and the least value in alternative V6 (in expanded nuclear program).

The increasing of the fuel prices according to AIE prognoses will determine in 2020 a reduction of TPP share in the total electricity generation to 45%, the increasing of NPP share up to 25.5% and a slightly increasing of HPP share.

The fossil fuel requirement for electricity generation up to 2020 is presented in Table VIII. Due to the reduction of the electricity generation and the operation of the unit 1 of Cernavoda NPP, the fossil fuel requirement in 2000 is with about 28% lower than the achievement of 1995. On remark a reduction with 20% of the coal consumption in the alternatives with low fuel price escalation and only with 5% in alternative V6 with high fuel price escalation.

In the period 2001-2010 the fossil fuel requirement will reach the highest value (11 mill toe) in the alternative V1 and the lowest value (9.1 mill toe) in the alternative V6. The coal requirement will reach the highest value (6.8 mill toe) in the alternative V5 with high fuel price escalation.

TABLE VI. THE SHARE OF HPP, NPP AND TPP IN TOTAL AVAILABLE GENERATION CAPACITY (%)

Code of alternative	Available generation capacity	1995	2000	2010	2020
V1	Total	100	100	100	100
	of which in:				
	HPP	40.80	37.7	37.2	30.70
	NPP	-	3.9	7.9	9.3
	TPP	59.20	58.4	54.9	60.0
V4	Total	100	100	100	100
	of which in:				
	HPP	40.80	37.5	37.1	29.90
	NPP	-	3.9	7.9	6.4
	TPP	59.20	58.6	55.0	63.7
V5	Total	100	100	100	100
	of which in:				
	HPP	40.80	37.7	36.6	30.6
	NPP	-	3.9	7.8	15.9
	TPP	59.20	58.4	55.6	53.5
V6	Total	100	100	100	100
	of which in:				
	HPP	40.80	37.7	37.1	29.8
	NPP	-	3.9	15.9	43.0
	TPP	59.20	58.4	47.0	27.2
V7	Total	100	100	100	100
	of which in:				
	HPP	40.80	37.4	36.2	30.5
	NPP	-	3.9	7.7	15.3
	TPP	59.20	58.7	56.1	54.2

In the period 2011-2020 the fossil fuel requirement for electricity generation presents big differences regarding the total and the structure from one alternative to other. The bigest value at 12.2-12.6 mill toe for 2020 is for alternatives V1 and V4 and presents an increasing of 18% against 1995.

The development of the power system only by adding of new units with high efficiency and new cogeneration units will determine the reduction of the fossil fuel requirement for electricity generation in 2020 at 9.9 mill toe (alternative V7).

The increasing of the fuel price excalation will determine the development of the Cernavoda NPP to the maximum capacity up to 2020 and the reduction of the fossil fuel requirement from 12.2 mill toe to 10.7 mill toe, that mean 12.3%.

The expantion of the nuclear program will determine in 2020 the reducion of the natural gas import with 9.4 mill toe.

These fossil fuel requirements explain the evolution of air emissions by alternatives (Table IX). Analizing these informations it results that particules and SO_x quantities will be

TABLE VII. THE SHARE OF HPP, NPP AND TPP IN TOTAL ELECTRICITY GENERATION (%)

Code of alternative	Electricity generation	1995	2000	2010	2020
V1	Total	100	100	100	100
	of which in:				
	HPP	31.3	32.8	23.9	19.3
	NPP	-	8.6	12.5	15.1
	TPP	68.7	58.6	63.6	65.6
V4	Total	100	100	100	100
	of which in:				
	HPP	31.3	32.8	23.9	18.9
	NPP	-	8.6	12.5	10.0
	TPP	68.7	58.6	63.6	71.1
V5	Total	100	100	100	100
	of which in:				
	HPP	31.3	32.8	23.9	19.5
	NPP	-	8.6	12.5	25.5
	TPP	68.7	58.6	63.6	45.0
V6	Total	100	100	100	100
	of which in:				
	HPP	31.3	32.8	23.9	18.9
	NPP	-	8.6	25.6	64.0
	TPP	68.7	58.6	50.5	17.1
V7	Total	100	100	100	100
	of which in:				
	HPP	31.3	32.8	23.9	19.6
	NPP	-	8.6	12.5	25.5
	TPP	68.7	58.6	63.6	54.9

decreased in time throughout all alternatives due to the substitution of extant coal fired units with performant units equipped with more efficient environmental protection installations.

The alternatives, which content important added capacity of NPP, prove the lowest values for all air pollutant emissions (alternative 6).

4. CONCLUSIONS

The least cost solution for electricty generation in Romania is based on the combined cycle units on natural gas. Investments costs for electricty generation capacities with this type of units reach about 9.8 bill US $ for the period 1997-2020 with an average value of 600-710 mill US $/year for the period 2005-2020. The imported quantity of natural gas only for electricty generation will reach 12.2 bill m^3 in 2020. This will represent about 79% of the total electricity system requirement for fossil fuels. About 35% of the total imported quantity of natural gas in 2020 will be used for electricity generation.

TABLE VIII. FOSSIL FUEL REQUIREMENT FOR ELECTRICITY GENERATION (mill toe)

Code of alternative	Fossil Fuel	1995	2000	2010	2020
V1	Total	10.7	7.7	11.0	12.6
	of which:				
	coal	5.8	4.6	6.5	11.1
	fuel oil	1.3	1.3	2.9	0.7
	natural gas	3.6	1.8	1.6	0.8
V4	Total	10.7	7.7	10.3	12.2
	of which:				
	coal	5.8	4.6	4.5	1.0
	fuel oil	1.3	1.3	2.9	0.7
	natural gas	3.6	1.8	2.9	10.5
V5	Total	10.7	7.9	10.8	10.7
	of which:				
	coal	5.8	5.5	6.8	4.1
	fuel oil	1.3	1.1	2.4	0.7
	natural gas	3.6	1.3	1.6	5.9
V6	Total	10.7	7.7	9.1	2.8
	of which:				
	coal	5.8	4.6	4.5	1.0
	fuel oil	1.3	1.3	2.9	0.7
	natural gas	3.6	1.8	1.7	1.1
V7					
	Total	10.7	7.7	10.3	9.9
	of which:				
	coal	5.8	4.6	6.4	8.1
	fuel oil	1.3	1.3	2.0	0.5
	natural gas	3.6	1.8	1.9	1.3

If Romania will not diversify the imported natural gas sources to increase the quantities and to made it available for electricity generation an alternative solution will be imported hard coal. In this alternative, total investment costs for electricity generation capacities will reach about 15.2 bill US $ up to 2020 with an average yearly value of 900-1,170 mil US $ between 2005-2020. The imported hard coal quantity will amount to about 9.8 mill toe in 2020, which will represent about 72% of the total electricity system requirement for fossil fuels. This solution has a negative impact on the environment So the CO_2 emissions will increase in 2020 against the solution with combined cycle units on natural gas with about 72%.

The extended nuclear program can be an alternative for reduction of both the fossil fuel import and greenhouse gas emission. Total investment costs for electricity generation

TABLE IX. AIR EMISSIONS BY ALTERNATIVES ([10^6tonne)

Cod of alternative	Emission/ Year	1995	2000	2005	2010	2015	2020
V1	Particulates	0.02	0.01	0.02	0.03	0.02	0.02
	SO_x	0.44	0.36	0.52	0.63	0.27	0.17
	NO_x	0.10	0.07	0.09	0.12	0.09	0.09
	CO_2	34.26	26.23	33.39	43.24	41.67	49.12
V2	Particulates	0.02	0.01	0.02	0.02	0.02	0.02
	SO_x	0.44	0.36	0.48	0.47	0.24	0.21
	NO_x	0.10	0.07	0.08	0.10	0.08	0.08
	CO_2	34.26	26.23	30.24	36.01	35.67	39.61
V3	Particulates	0.02	0.02	0.02	0.03	0.02	0.02
	SO_x	0.44	0.41	0.60	0.57	0.18	0.13
	NO_x	0.10	0.08	0.10	0.12	0.09	0.11
	CO_2	34.26	28.98	38.73	46.68	47.86	61.56
V4	Particulates	0.02	0.01	0.02	0.02	0.01	0.00
	SO_x	0.44	0.36	0.45	0.42	0.09	0.03
	NO_x	0.10	0.07	0.08	0.10	0.06	0.06
	CO_2	34.26	26.23	30.69	35.91	27.57	28.51
V5	Particulates	0.02	0.01	0.02	0.02	0.01	0.00
	SO_x	0.44	0.36	0.54	0.44	0.11	0.09
	NO_x	0.10	0.07	0.09	0.10	0.06	0.06
	CO_2	34.26	26.23	34.05	36.57	22.41	24.98
V6	Particulates	0.02	0.01	0.02	0.02	0.01	0.00
	SO_x	0.44	0.36	0.52	0.42	0.13	0.08
	NO_x	0.10	0.07	0.09	0.09	0.04	0.02
	CO_2	34.26	26.23	33.71	32.06	13.66	7.76
V7	Particulates	0.02	0.01	0.02	0.02	0.01	0.01
	SO_x	0.44	0.36	0.51	0.43	0.09	0.06
	NO_x	0.10	0.07	0.09	0.09	0.07	0.07
	CO_2	34.26	26.24	32.40	38.75	37.94	39.20

over the period 1997-2020 will reach about 24.8 bill US $ with an average yearly value of 1,600-1,800 bill US $/year , that mean over two time higher than in the alternative based on the combined cycle on natural gas. In this case the fossil fuels requirements for electricity generation will decrease to about 2.8 mil toe in 2020.

The role of nuclear power plants in Romania electric power system consist in the reduction of both imported fossil fuels and greenhouse gas emissions. This benefit is reduced by highest investment costs and consequently by highest cost of electricity generated.

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CURRENT STATUS AND PERSPECTIVES OF ATOMIC ENERGY DEVELOPMENT IN UKRAINE

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Abstract

The share of the power produced by the NPPs during the last years is increasing constantly and had reached by the year of 1997 44,9%. During the last 15 years the only nuclear power plants in Ukraine that had been put into operation. Comparing to the awful conditions of the traditional power industries caused by the lack of the organic fuels (gas, black oil, coal), physical and moral deterioration of power plants and power transmission equipment the nuclear power industry functioning is rather stable.

1. INTRODUCTION

The power energy is one of the most important components of the power industries of Ukraine. It plays an outstanding role in its economy.

NPPs are the most modern power sources, therefore during the last 15 years the only nuclear power plants in Ukraine that had been put into operation. Comparing to the awful conditions of the traditional power industries caused by the lack of the organic fuels (gas, black oil, coal), physical and moral deterioration of power plants and power transmission equipment the nuclear power industry functioning is rather stable.

The share of the electricity produced by the NPPs during these last years is increasing constantly and had reached by the year of 1997 44,9%. That exceeds the 40% expected by the National Energetic Programme of Ukraine. In 1993 the NPPs share in the total electricity output was as much as 32,7%. On the one hand such trends show stability of the NPPs functioning, on the other hand its may worry because of a number of reasons. One of the reason is that all Ukrainian NPPs had been designed for the basic functioning mode. Using them for the power regulation badly influences their safety and security for the number of loading and unloading cycles which is strictly limited for the basic equipment as well as for the nuclear fuel. The increase of the NPPs power production share will emphasize this problem for Ukraine.

The deficiency of powers needed for maintaining the current frequency in the power system forced us to involve into this process the thriftiest thermal power plant units of a big capacity. That accelerates deterioration of their equipment and causes an increase of consumption of the scarce organic fuel.

A considerable NPPs power production amount (while their share in the set up output of all the power plants is equal to 25%) is not an achievement of the nuclear energy but a demonstration of poor availability of the energy in general.

For the first time in recent years it is the first time in recent years that the Coefficient of the Utilization of the Setup Capacity of the NPPs has achieved the designed index (70%)

and even exceeded it by 1,3%. On the other hand there was a shortfall of the utilization of all five NPPs setup capacity which was equal to 28,7%.

2. SAFETY AND MODERNIZATION

The nuclear energy development in Ukraine is realized in accordance with the «State Nuclear Energy of Ukraine Development Programme Until the Year 2010» adopted by the Control Authorities of Ukraine.

The operating units safety is a basic condition for the present and future of nuclear energy. Any accident, even not as tragic in consequences as the Chernobyl one will be the final verdict to the nuclear power engineering.

In 1997 there were 64 incidents taken into consideration by the international scale INES, that is 18 less than in 1996.

The fact is surely positive but it is too early to affirm that the safety level has improved.

The design decisions of the safety systems carried out at the Ukrainian NPPs met the requirements of the normative documents which were in force at the moment of their construction. Taking into consideration the operation experience and the analysis of the causes and consequences of the accidents at the «Three Mile Island» and Chernobyl NPPs the safety requirements have changed to become more strong.

New rules coming to force in Ukraine since 1991 defined design and operational failures of the fuel assemblies, probabilities of the core damage under BDBA -10^{-5} and accident releases -10^{-7} reactor/years. These are the magnitudes to aim at.

These rules are also obligatory for the all operating NPPs which were designed before the rules was started to act.

Now the Ukrainian NPPs turned out to be falling short of the rules and requirements that are in force in the country and to be operating out of the legal field. Bringing them to such conformity is either impossible or requires much redesigning, additional calculations, reconstruction and modernization works have to be done. This requires tens and hundreds million gryvnas expenses.

According to the approved plans the NPP safety increasing the priorities are:

(i) fundamental reconstruction of Automatic Systems of Technological Processes Control for the essential safety increase taking into account the operator support systems, inner diagnostics etc;
(ii) complex of NPP processes diagnostic systems;
(iii) implementation of additional safety systems working on the passive principle basis;
(iv) complex of works for improving of operation safety (replacement of thermal-insulation of the primary by the removable one, steam generators replacement, providing of hydrogen burning systems etc);
(v) providing measures on nuclear and radiation safety, fire protection labor safeguard.

After well-known events at Chernobyl and some western NPPs all the countries have launched the operating NPPs design reassessment to increase their safety. The considerable revisions were added to the designes. In particular, many measures were carried out first of all for the Chernobyl NPP units and for operating or being commissioned PWR units.

For the safety NPPs operation there are the following proposals:

i) in the real economic conditions in Ukraine the provision of designed (current) NPPs safety should be considered as the main objective. The "safety increasing" term should be changed to "safety providing";

ii) the former rules and requirements according to which all the operating power units were designed and built should be readopted;

iii) define necessity and time of bringing the operating and being built units to conformity with the new rules;

iv) the needed amendments should be inserted into the laws and deeds in force;

v) all the new legislative deeds and their adoptation should meet the economical situation.

3. CURRENT STATUS AND PERSPECTIVES OF DEVELOPMENT OF NUCLEAR LEGISLATION

The Conception of State Nuclear Safety Regulation and Control was the first step toward creation of nuclear legislation. It became a basis for working out the new nuclear legislation and determined preliminarily its structure. The next step was the Law "About Nuclear Energy Use and Radiation Safety". On the 30 of June 1995 the Law "About the Radioactive Waste Management". Later on for the new nuclear legislation worked out in 1998 there are only direct laws that are to be adopted:

i) the 1995 new wording of the Law "About Nuclear Energy Use and Radiation Safety" due to the ratification of the Nuclear Safety Convention;

ii) the Law "About Nuclear Insurance";

iii) the Law " the « State Nuclear Energy of Ukraine Development Programme Until the Year 2010".

Further the Legislation of Ukraine to conformity with the standards of laws concerning the nuclear power use is envisaged.

4. THE PRESENT STATE OF PUBLIC OPINION AND PUBLIC CONSULTATION PROGRAMS

Before the Chernobyl accident the perspectives of development of Nuclear Energy were discussed and resolved by limited circles of specialists and representatives of the state organizations responsible for realization of the power engineering programs. At that time it was hard to imagine that questions of design, construction and operating of NPPs could be resolved depending on the public opinion. The hard consequences of the Chernobyl accident have formed a strong public opposition to the projects of nuclear energy development in short time.

Due to the actual economical, social and political circumstances without taking into account the public opinion, an active dialogue with the people who are against NPPs construction and operating and scientifically based propaganda in favor of advantages of the nuclear energy its subsequent development seems to be problematic.

After the different factors ranking according to the degree of their importance the most significant one is the NPP staff reliability, the second one is trust to the administration institutions and the third one is trust to the medicine and guarantee of impossibility of a new Chernobyl accident repetition. Those are the factors that should be focused mostly in practical work.

The public attitude to the further NPPs operation and new units constructions associated with its attitude to the living conditions in general. Most of people living near the NPPs think that the regions around the NPPs should get a particular status increasing their social security and providing advantages in medical care, salary rise etc. as a compensation.

5. THE «SHELTER» OBJECT

The shelter object is the destroyed Chernobyl NPP unit 4 where the essential measures for decreasing the accident consequences are carried out and nuclear and radioactive safety control of it current status is realized. The «SHELTER» object was erected in 1986 within 6 months duration. At these very hard radioactive conditions more than 300 000 m^3 of concrete and 10 000 tons of reinforced concrete were laid. The building and assembly of the construction rates exceeded those of the European consortium at the La Manche tunnel construction. The main factor determining the radiological and nuclear safety of the «SHELTER» object is 200 tons of burnt-out nuclear fuel disposed in it. Buildings destruction as a result of tornadoes, fires seismic influences with a partial radioactivity spreading by air and water are under consideration as hypothetical accidents. This proves once more that the «SHELTER» object should be transformed into an ecologically safety system. This work is expected to be accomplished in four phases:

(1) existing object stabilization, decrease the probability of potentially dangerous events including putting the object into regulation state;

(2) construction of a new protective shell which would meet the set up safety rules and standards while processing and extraction of the fuel containing masses and radioactive materials from the object;

(3) the fuel containing and radioactive materials processing with subsequent extraction and burial of those in the radioactive waste storage;

(4) ecologically safety systems reconstruction for some object for their subsequent use or liquidation may be provided.

6. THE BRANCH MANAGEMENT AND QUALITY GUARANTEE

For the last 6 years the branch management has been in the state of reorganization. Future will show to which extent it was efficient.

At market economy conditions the structure reorganization of branches is determined first of all by the economic efficiency factors: complete competition allowing the lowest industrial expenses, free price formation and investment stimulus.

The nuclear power engineering is one of those spheres of economy that can't work under conditions of complete competition during the transition period.

Preservation of regulation elements is imposed by the need:

i) to ensure carrying out the principles of the Vienna Convention for Nuclear Detriment Compensation;

ii) to create a systems spent nuclear fuel and radioactive waste;
iii) for fundamental reconstruction of the operating power units in order to increase their safety;
iv) to create a system of scientific and design support.

For the subsequent reorganization it is necessary as a minimum carry out a management audit with participation of independent experts and to take into account economic and technical aspects and human resources.

7. PERSPECTIVES OF NUCLEAR ENERGY DEVELOPMENT

The scientific and technical development of the nuclear energy in Ukraine until the year of 2005 will be based on the carrying out of the «National Nuclear Energy Programme of Ukraine until 2005» and the «State Nuclear Energy of Ukraine Development Programme Until the Year 2010» adopted by the Control Authorities of Ukraine State.

Nuclear energy plays an outstanding role in the total energy of Ukraine. The share of power produced by the NPPs for the last 5 years has been increasing constantly. The programs for development of the nuclear energy until 2005 consider keeping the share of the electricity output by NPPs at the reached level 40-50%. For a safety NPPs operation within alternating schedules of power production measures for operation system modernization, scientific and design support, creation a new nuclear fuel etc should be ensured.

The scientific and technical development of the nuclear energy complex until 2005 will be realized on a such directions as:

- increase of electricity output by NPPs in 2005 up to 77.5 mlrd. KWt/h;
- management, operation, maintenance repair, safety increasing measures, the operating NPPs modernization and reconstruction support;
- completion of the KhNPP2 (1999) and RoNPP4 (2000);
- creation of own nuclear fuel cycle will be ensured by 5 programs:
    i) Program 1. Uranium ore extraction and processing.
    ii) Program 2. Zirconium alloy production.
    iii) Program 3. Zirconium rolling production .
    iv) Program 4. Production of fuel assemblies.
    v) Program 5. Scientific and design technological support of the nuclear fuel cycle. Developing new and exploitation of operating uranium deposits, creation of capacities for nuclear pure zirconium production and its rolling, organization of a new Ukrainian-Russian-Kazakh joint venture for production of a new 4-year fuel for the PWR 1000 reactor NPPs of Ukraine;
- providing of the NPPs operating safety and reliability by realization of measures for preventing the spent nuclear fuel accumulation in the exposure basins exceeding the admitted limits as for the spent nuclear fuel management;
- the ChNPP decommissioning which will start in 2000;
- transformation of the «SHELTER» object into ecologically safety system:
    i) 1 phase - stabilization of the object current status;
    ii) 2 phase- engineering preparation for the fuel containing masses from the «Shelter» object removal;
    iii) 3 phase- the fuel containing masses removal from the «Shelter» object. Improvement of legislation and normative basis on radioactive waste (RW)

management, elaboration of equipment and RW utilization technology, working out and production of unified transportation containers, working out and creation of domestically produced decontamination and protection means, working out and construction of RW storages and underground storages in the geological formations.

- scientific and engineering support of the NPPs and new units operating.

CONSIDERATIONS ON TECHNOLOGY TRANSFER PROCESS IN NUCLEAR POWER INDUSTRY FOR DEVELOPING COUNTRIES

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Abstract

Nuclear know-how cannot possibly be developed globally in developing countries, so technology transfer is the only conceivable way to make nuclear power accessible to these countries. Technology transfer process accounts for three mayor steps, namely *acquisition*, *assimilation* and *diffusion*, so a serious nuclear power program should comprise all of them. Substantial national efforts should be made by developing countries in financial, industrial, scientific, organizational and many other aspects in order to succeed a profitable technology transfer, but developing countries cannot make it by themselves. Finance is the biggest problem for developing world nuclear power projects. Human resource qualification is other important aspect of the nuclear power technology transfer, where technology receptor countries should prepare thousands of professionals in domestic and foreign schools. Challenge for nuclear power deployment is economical, but also social and political. Developed countries should be opened to cooperate with developing countries in meeting their needs for nuclear power deployment that should be stimulated and coordinated by an international body which should serve as mediator for nuclear power technology transfer. This process must be carried out on the basis of mutual benefits, in which developed world can exploit the fast growing market of energy in developing world, but with the necessary condition of the previous preparation of our countries for this technology transfer.

1. INTRODUCTION

Nuclear power is the only viable non-fossil alternative, which is a proven and mature technology that can meet the growing demand for electricity in the developing world, in keeping with the objectives of energy security and environmental congeniality. As an advanced technology, nuclear know-how cannot possibly be developed globally in developing countries, so technology transfer is the only conceivable way to have the nuclear power promoted there [1].

Technology transfer process accounts for three major steps, namely *acquisition*, *assimilation* and *diffusion*, so a serious nuclear power program should comprise all of them with specific activities for each one:

- Acquisition involves technology selection (PWR, BWR, HWR, LMPR, etc.), feasibility study considering cash flow, contractual agreement discussion, etc. One country is in better conditions to choose the nuclear power technology more adequate to its political, economical, social, cultural and environmental characteristics if it counts with an experienced scientific staff capable to make selections and recommendations from an integral point of view about some technology, which means that human resource preparation and qualification should be scheduled as an initial stage in the indigenous nuclear power program.
- Assimilation deals with technology adaptation to specific conditions of the receptor country, technical, economical, organizational, social and environmental valuation of

its functioning, technology development and improvement based on the acquired experience during its exploitation, etc. In this respect, nuclear power technology assimilation is possible only if the country has reached a certain level of industrial development, in addition to the manpower requirements needed for above step. Below a critical level, only *Build, Operate and Transfer* (BOT) channels may make the introduction of nuclear power (or other adequate ways in which the required national involvement is very low).

– Diffusion consists in the technology generalization and deployment to the different economy and services branches. Great technology autonomy is reached with this step, in which countries become nuclear technology suppliers also. Backward engineering techniques and technology transfer centers play an important role in meeting this purpose. Leading technologies such as material related, microelectronic, high precision mechanic among many others, much reach its maturity.

Substantial national efforts should be made by developing countries in financial, industrial, scientific, organizational and many other aspects in order to succeed a profitable technology transfer, but developing countries cannot make it by themselves.

An international consensus should be get involving developed world in a special way, which is the only possible source for founds, technology and personnel training needed to fulfil developing countries nuclear power programs and decrease the amounts of fossil fuel usage for electricity generation, resulting in a smaller dependency of developing countries on energy imports, less degradation of local and regional environment and a diminishment of greenhouse gases emissions.

2. ACTUAL SITUATION AND THE NUCLEAR POWER DEPLOYMENT

Finance is the biggest problem for developing world nuclear power projects [2]. Some of them have been canceled and others have been stopped during construction for this reason.

Because of the rigorous safety standards needed for construction, operation and decommissioning of nuclear power plants, spent fuel management and nuclear wastes disposal, as well as the leading technologies involved in these process, nuclear power projects become extremely expensive. Developed countries, as technology suppliers, should adequate the actual nuclear power technology standards to the necessities, and even more to the possibilities of developing countries as technology receptors, by developing prototypes based on modular design, intrinsic safety, low and medium power, etc., with the purpose of turn nuclear projects competitive with respect to fossil projects. They should, in addition, adopt flexible positions in terms of payment agreements.

As nuclear power is both an energy source and a development mean for the socio-economic status of the country, a great infrastructure is required to carry out nuclear power programs, opening spaces for science and technology activities under the government responsibilities having R&D centers and technology transfer centers in subordination [3]. Technical universities should be created and updated to respond the necessity of new professionals in new technology.

Human resource qualification is other important aspect of the nuclear power technology transfer, where technology receptor countries should prepare thousands of professionals in domestic and foreign schools, beginning in many cases by creating their domestic school. Technical and scientific staff preparation should be scheduled as one of the initial steps in the indigenous nuclear power program as well as specialist preparation in quality assurance, management of technology capabilities, etc. Developed countries should play an important role in meeting the qualification personnel needs of developing world, including this aspect in the technology package, opening a plan of scholarships, fellowships, master degree courses, doctor degree courses and training courses for developing countries in all required branches, promoting inter-governmental agreements for developing countries universities and technical institutes creation and updating, etc.

Rudimentary or none activities in the field of energy, electricity and nuclear power planning are carried out in developing countries, so electricity expansion plans are made in general on empirical bases and no optimization strategies are followed. In this respect DECADES project [4] should play an important role in the comparative assessment of different energy sources for electricity generation, as a modern and accessible tool for developing countries.

Spent fuel management and waste handling and storage is other important aspect tailing nuclear power use. With the deployment of the nuclear power in developing countries a big amount of nuclear wastes will be generated, and temporary storage facilities and final repositories will be needed in a long term future.

Finally, nuclear power technology transfer should not be conditioned to economical, social, or political concessions or adjustments in developing countries. It must not be taken as a domination mechanism of some developed countries over developed world.

3. CONCLUDING REMARKS

There are many aspects to be considered for achieving nuclear power deployment in developing countries as stated in the previous topic, but only joined efforts can propitiate the adequate international climate to solve them in order to perform a satisfactory evolution of the nuclear power programs.

Nuclear power deployment should be stimulated and coordinated by an international body which should serve as mediator for nuclear power technology transfer under stated conditions. In addition, regional cooperation blocks should play an important role in exchanging experience and serving as mutual support in negotiations. Maturity and expertise reached by IAEA in these fields should not be neglected.

Then, challenge for nuclear power deployment is economical, but also social and political [5]. Developed countries should be opened to accept this reality and to cooperate with developing countries in meeting their needs for nuclear power deployment, and to play an active role in the international body mentioned above. This process must be carried out on the basis of mutual benefits, in which developed world can exploit the fast growing market of energy in developing world, but with the necessary condition of the previous preparation of our countries for this technology transfer. On the contrary, developing world will find a no way out situation in which the attempts to satisfy its energy needs will be done by choosing “cheaper” technologies based on fossil fuel firing [6], with the resultant increasing of their dependency on energy imports, basing their energy security on the uncertainties of fossil fuel prices and increasing the global emissions of greenhouse gases, etc.

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NUCLEAR ENERGY IN LITHUANIA: ITS ROLE, EFFICIENCY AND SAFETY ISSUES

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Abstract

Paper describes present status of the Lithuanian economy and the power sector as well as problems related to further operation of the Ignalina Nuclear Power Plant (Ignalina NPP). It plays a crucial role in the Lithuanian energy sector. Recent studies have validated that it is economic to keep the Ignalina NPP in operation as long as this is possible and the necessary licenses can be obtained. However, its safe operation remains a very important issue determining its lifetime. Development of an infrastructure and activities necessary for safe and reliable operation of the plant is also very important.

1. INTRODUCTION

Lithuania is the largest of the three Baltic states, sharing a 610 km long border with the Republic of Latvia, a 724 km border with the Republic of Belarus, a 110 km border with the Republic of Poland and a 303 km border with the Kaliningrad region of the Republic of Russian Federation. With a 99 km coastline and a total area of 65.3 thousand square kilometers, it supports at the beginning of 1998 a population of 3.7 mln. For half a century, Lithuania was fully integrated into the Former Soviet Union (FSU) and had to live under the centrally planned economy of a huge country. The policy for reforms in all sectors of economy has been stated by the Lithuanian Parliament and Government since the first days of regained independence in 1990. At the collapse of the FSU Lithuania is facing many difficulties. Transition to a free market economy is much longer and harder than it was expected by majority of population at the beginning of 90s. Economic slump in Lithuania was larger than in other Central and East European countries because of the high degree of integration within the network of exchange of raw materials, energy resources and goods in the FSU. At the end of 1994 the Lithuanian Gross Domestic Product (GDP) dropped to 56% of the 1990 value. In 1995 GDP increased by 3.3%, in 1996 by 4.7% and finally in 1997 by 5.7 % (Fig. 1).

Lithuania has a comparatively modern energy sector. However its institutional and technical structure inherited from the past does not meet requirements of a small country. Capacity of the energy sector considerably exceeds requirements of the country because the principal energy enterprises were planned within the borders of the larger FSU North-Western region. In addition the construction of many energy enterprises was planned in relation with a very optimistic rate of the economic development. Existing overcapacities are potentially advantageous for restructuring of the national economy, but their effective use in transition is a very complicated problem. Decline in the energy consumption in Lithuania and in other

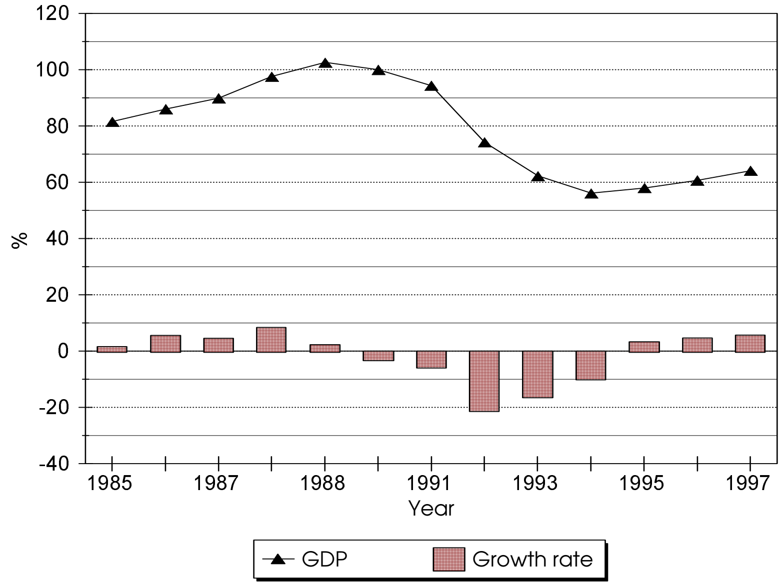

FIG. 1. Annual changes of GDP.

countries of the former Eastern Block and absence of an interconnection with Poland does not allow to get tangible benefit from the electricity export.

On the other hand a very important problem for the national economy is energy efficiency. All sectors of economy in Lithuania as well as in other countries of the former Eastern Block were formed with an excessive end-use of energy caused by: the past existence of very low energy prices; inadequate on non-existent metering and control of energy production and consumption; lack of incentives for energy efficiency, etc. Reduction of energy intensity is very attractive issue, but large financial resources are required for implementation of new technologies, improvement of thermal performance of buildings and modernization of the energy sector.

2. EXISTING POWER PLANTS

Before Lithuania re-established its independence, its power system was an integrated part of the North-Western United System of FSU. The largest power plants, the Lithuanian Thermal Power Plant (TPP), the Ignalina NPP and the Kruonis Hydro Pumped Storage Plant, were designed to satisfy regional rather than just domestic needs for electricity. The total installed capacity of the Lithuanian power plants is 6526 MW. The characteristics of the Lithuanian power plants as of July 1998 are given in Table I.

Until 1991, significant amounts of electricity generated in Lithuania were exported to Belarus, Latvia and Kaliningrad region (the Russian Federation). As a consequence of deep economic crisis, electricity demand within the country decreased sharply in 1992. Economic recession in neighbouring countries and problems with payments reduced demand for electricity export. Electricity export to Belarus was even stopped when debts for electricity supply remained unpaid. Kaliningrad region was supplied from Russia through the Lithuanian power grid. These changes of electricity production and consumption within the country are shown in Fig. 2.

TABLE I. CHARACTERISTICS OF THE LITHUANIAN POWER PLANTS

Power plant	Fuel	Capacity, MW	
		installed	available
Lithuanian Thermal Power Plant	Heavy fuel oil, natural gas	1800	1800
Vilnius Combined Heat and Power	Heavy fuel oil, natural gas	384	364
Kaunas Combined Heat and Power	Heavy fuel oil, natural gas	178	178
Mazeikiai Combined Heat and Power	Heavy fuel oil	194	99
Klaipeda Combined Heat and Power	Heavy fuel oil, natural gas	11	11
Hydro power plants		108	108
Kruonis Hydro Pumped Storage Plant		800	760
Ignalina Nuclear Power Plant	Nuclear energy	3000	2600
Other power plants	Heavy fuel oil, natural gas	51	51
Total		6526	5971

The Ignalina NPP plays especially important role in the Lithuanian power sector. Although its share in the balance of available capacities is only 43.5%, share of electricity produced by this power plant is increasing since the beginning of its operation and lately it produces more than 85% (Fig. 3). At the same time the share electricity generated at the Lithuanian TPP decreased from 55.2% in 1994 to 4.1% in 1995.

There are two units at the Ignalina NPP; one was commissioned in December 1983 and the other in August 1987. The power station was built in Lithuania but with the purpose of meeting regional electricity demand. The designed capacity was 6,000 MW - 4 units of 1,500 MW each. These units are the most powerful in the world and have been included in the Guinness Book of Records. Construction of a third unit started in 1984, but it was stopped in 1989 because of political pressure. This is the most advanced version of the RBMK reactor design series (actually only two units of this type were built). Compared to the Chernobyl NPP units of the Ignalina NPP are more powerful. Ignalina NPP is provided also with an improved accident confinement system. In most other respects this plant is quite similar to its predecessors. The reactors have two parallel cooling loops, a direct cycle, fuel clusters loaded into individual channels, and the neutron spectrum is thermalized by the massive blocks of graphite. The plant uses slightly enriched nuclear fuel. After the accident at Chernobyl the capacity of the Ignalina NPP was derated to 2600 MW for safety reasons. Detailed overview of design and operational indicators of the Ignalina NPP is presented in [1].

3. DEVELOPMENT OF INSTITUTIONAL AND LEGAL FRAMEWORK

Before the collapse of the FSU supervision of all nuclear power plants was carried out by a single regulatory authority. Since 1991 the Lithuanian Government is responsible for safe operation of the Ignalina NPP. However at this time Lithuania did not have much of an infrastructure necessary for operation of nuclear power plant. All know-how connected to the design of this plant was concentrated in Russia. The Ignalina NPP was only operational organization and had no full responsibility for the safe operation of the plant. Lithuanian Nuclear Power Safety Inspectorate (VATESI), as a state regulatory body for supervision of the Ignalina NPP, was established in November 1991. Majority of technical, operating,

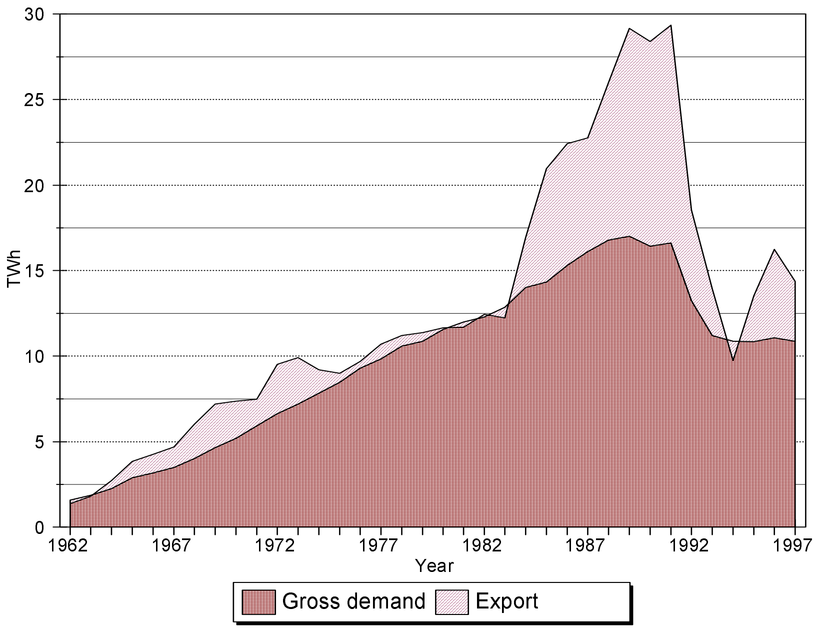

FIG. 2. Changes of electricity production and consumption.

administrating staff of the Ignalina NPP has decided to continue their job in Lithuania. However our country had limited resources in many respects. It was necessary to make many efforts in order to develop necessary infrastructure. To reinforce VATESI and other structures with skilled staff the Nuclear and Radiation Safety Advisory Committee (NRSAC) and technical supporting organizations were established. The NRSAC consists of well known experts from Germany, Great Britain, Finland, Japan, Lithuania, Russia, Sweden and Ukraine.

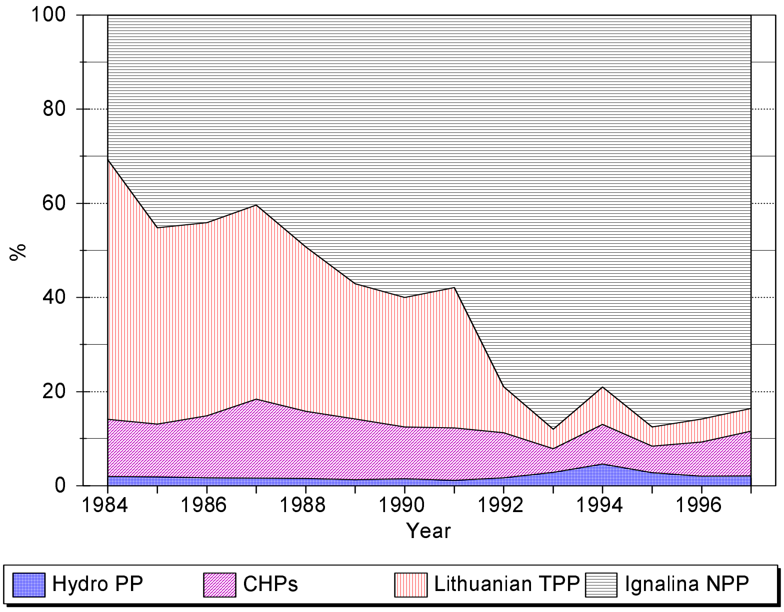

FIG. 3. Structure of electricity production.

Cooperation with experts from other countries especially from Sweden and foreign support was very important factors stimulating process for strengthening of intellectual potential working in the nuclear energy field. Coordination of activities of all experts (regulating authority VATESI, its supporting organizations, operating staff of Ignalina NPP, the Lithuanian Government being the owner of the Ignalina NPP) in Lithuania was very efficient and allowed to solve various problems related to reliable and safe operation of the Ignalina NPP. In July 1997, the NRSAC was reorganized into the Nuclear Safety Advisory Committee. At present several ministries are responsible for regulation of the nuclear energy use: the Ministry of Economy, the Ministry of Health, the Ministry of Environmental protection and the Ministry of Foreign Affairs. Since 1997 newly established Ministry of Economy has assumed all obligations and duties of nuclear energy management, including development of the legal framework of the Ignalina NPP.

Creation of legal framework in the energy sector was very important problem since the first days of regained independence in 1990. Activities in this field were concentrated to preparation of the Energy Law that is the main law regulating activities in the energy sector. It was passed by the Parliament in 1995. It sets down broad principles only and gives the general legal framework for the energy sector development. The Law explains the aims of the National Energy Strategy, its structure, its timing (the strategy was developed for a 20 year period, but should be revised every five year period), and its role in the energy sector development. It defines also the main objectives of the Lithuanian energy policy. To ensure nuclear safety and the use of nuclear energy for satisfaction of peaceful needs only the Nuclear Energy Law was prepared and passed by the Parliament at the end of 1996. It regulates public relations arising out of the use of nuclear power for generation of electricity and heat. The Law provides a legal basis for natural and legal persons to operate within the sphere of nuclear energy production.

Other important task of the Lithuanian Government was to sign international treaties and conventions related to nuclear energy. In 1991 Lithuania signed Treaty on the Non-Proliferation of Nuclear Weapons with the International Atomic Energy Agency (IAEA) and joined the IAEA in 1993. The Law on the Control of Import, Export and Transport of Goods and Technology was passed in 1995. It aims to regulate activities that will ensure the implementation of measures prohibiting such proliferation. In 1994 the Convention of the Physical Protection of Nuclear Material has come into force, and its basic principles were adopted by the Governmental resolution on the same year. As regards of the nuclear third part liability, Lithuania acceded to the Vienna Convention (ratified in 1992) and to its Joint Protocol. The Law on Nuclear Energy, adopted on 1996, establishes principles contained in the convention and it's protocols. The Convention on Nuclear Safety was ratified on 1996. The basic assumptions of the Law on Nuclear Energy reinforce obligations of Lithuania under this convention. The Joint Convention on the Safety of Spent Fuel Management and Safety Radioactive Waste Management was signed on 1997. The Law on Nuclear Energy does not completely reflect the specific features of spent fuel management and Lithuanian obligations laid in convention. Therefore the Law on Radioactive Waste Management is currently under preparation. Other conventions: Convention on Early Notification of a Nuclear Accident has come into force in 1994, Convention on Assistance in Case of Nuclear Accident or Radiological Emergency will be signed in the nearest future.

4. NUCLEAR SAFETY IMPROVEMENT PROGRAMMES

The accident at the Chernobyl NPP was an important event showing that development of the nuclear power is a matter of international concern. At this time it was reorganized that the safety level of reactors in the FSU was lower than standards of reactors operating in the West. Many Western countries at the end of 80s and at the beginning of 90s were against the further operation of the Ignalina NPP. Thus, a very important objective of the Lithuanian Government is to ensure that the Ignalina NPP satisfies international nuclear safety standards.

A significant programme of safety improvements was established by the plant immediately after commissioning of the units. After the Chernobyl accident additional measures were implemented. Efforts to upgrade the Ignalina NPP safety were accelerated since 1991. The first Safety Improvement Programme has been prepared by the plant with the assistance of Western experts. It was approved by the VATESI in 1993. To realize this programme a Grant Agreement was signed in 1994 between the Lithuanian Government, the Ignalina NPP and the European Bank for Reconstruction and Development (EBRD) of behalf of the Nuclear Safety Account. The grant of 33 million ECU was used for short-term safety upgrades. This programme is practically implemented.

During the last years an in-depth safety assessment of the Ignalina NPP has been carried out, and a Safety Analysis Report (SAR) has been prepared. The safety assessment of the Ignalina NPP was the first attempt to perform Western style analysis for any nuclear power plant of Soviet design. This report was reviewed at the end of 1996 by experts from Western and Eastern technical support organizations, including the Lithuanian Energy Institute, and an independent Review of Safety Report was prepared. In addition, the Ignalina Safety Panel (ISP) consisting of senior international nuclear experts was established. The main tasks of the ISP were to monitor and supervise process of safety assessment as well as to review the SAR and to prepare recommendations to the Lithuanian Government, the Ignalina NPP and VATESI.

The SAR and its independent review were performed in parallel providing interactive feedback and ensuring an objective in-debt assessment. As a result many recommendations on necessary safety improvements in design, operation and safety culture were prepared. The IPS recommended that all necessary safety measures should be implemented as soon as practically possible. The most important safety issues are following:

- the Ignalina NPP should introduce an appropriate management structure to ensure safe operation of the plant, efficient implementation of necessary safety improvements and adequate support of the licensing process;
- the safety case for the reactor control and protection system should be completed by the Ignalina NPP;
- the safety case for the accident localization system should be provided by the Ignalina NPP;
- the safety case for the structural integrity of the reactor cooling circuit should be provided by the Ignalina NPP;
- a fire hazard analysis for all safety systems should be carried out by the Ignalina NPP;
- the Ignalina NPP should develop and implement emergency operating procedures and the limits and conditions of safe operation.

All the most important measures provided in the second Safety Improvement Programme will be performed within a time period about 3 years and total planned cost is about USD 170 million. After implementation of all these improvements the probability of having a nuclear accident at the Ignalina NPP will be as low as for many Western reactors of the same vintage.

5. ACTIVITIES OF THE LITHUANIAN ENERGY INSTITUTE

An important component in the total structure of Lithuanian nuclear safety is the Ignalina Safety Analysis Group established at the Lithuanian Energy Institute in 1992. This group is concentrating its activity on the following topics:

- analysis of safety-related operational transients and loss-of-coolant accidents,
- development of the Ignalina NPP analyzer,
- assessment of structural response of the accident confinement system and other plant buildings,
- strength analysis of pipelines and other elements of the main circulation circuit,
- evaluation of graphite and fuel channels aging and safety-related concerns,
- development of the RBMK-1500 neutron dynamics models,
- probabilistic safety assessment of the Ignalina NPP.

Thus, the main objectives of this group are: to model and to analyze consequences of possible accidents; to collect, systematize and verify design and operational indicators; to assess the safety level of the Ignalina NPP and to determine priorities for safety improvement; to provide the Lithuanian Government, the Ignalina NPP, the VATESI and international organizations by scientific and technical advice, etc.

Other important issue related to operation of the Ignalina NPP is work on safety assessment and management of radioactive waste. Group of experts at the Lithuanian Energy Institute undertakes the following activities:

- safety assessment of interim storage facilities for spent nuclear fuel,
- long term safety assessment of radioactive waste storage facilities,
- analysis of decommissioning of nuclear power plants,
- strategy of management of radioactive waste,
- creation of legal and regulatory base for radioactive waste management.

Management of radioactive waste in the FSU was organized in centralized manner. It was planned to transport the spent fuel from the Ignalina NPP to Russia for further processing. At present safe handling and storage of the spent fuel is an important factor of the nuclear safety and it is fully dependent on the Lithuanian authorities. All spent fuel is stored in special water polls, located in the same buildings as the reactors. However, the volume of these pools is limited and for unit 1 the pool is almost fully loaded. To further operate the Ignalina NPP it is necessary to construct new storage. When a fuel assembly is taken out from the reactor, it still radiates heat. Therefore it has to be cooled in water for about three years. Later the spent fuel can be further cooled in gas environment. To solve this problem in 1992 the Ignalina NPP together with the Ministry of Energy announced an international tender for the storage of spent nuclear fuel. After evaluation of proposals presented by six companies from Canada, USA, Germany and France, the contract was awarded to GNB from Germany. According to contract that was signed in April 1994 company supplied the first 10 steel casks of the CASTOR type. In January 1996 another contract was signed for supply of further 10 casks. These containers are used for dry storage of the spent fuel that has been stored in water pools for at least 5 years. The baskets with spent fuel are transferred to the containers under the water. After the container tops are sealed water is pumped out, and vacuum is filled up with the helium. It is expected that helium will perform three functions: improve the heat exchange, protect the containers from corrosion, and control their sealing. Containers will be stored in a special site within the premises of the Ignalina NPP. Steel containers of this type are considered the most reliable and safe. They can be used not only for storage of the spent fuel but also for transportation to the site of final disposal of radioactive waste.

Experts of the Lithuanian Energy Institute take active part in examination of this technology of dry storage. They performed detailed calculations of the thermal behaviour of the containers in normal operation and in emergencies by the ALGOR computer programme prepared in USA. Expert evaluations of sealing system, transportation of the containers, examinations of radiation protection system were performed as well.

The third group of experts is concentrating its activity on analysis of efficiency of the Ignalina NPP in the general context of the energy sector development. The most important objectives of research in this field are following:

- to prepare least-cost power sector development programme, including rehabilitation of the existing power plants, in the context of various scenarios for decommissioning of the Ignalina NPP,
- to assess the consequences of these decommissioning scenarios,
- to determine corresponding investment programmes showing financial requirements for demand side management, rehabilitation and expansion of power plants.

In accordance with the Grant Agreement with the EBRD mentioned above a detailed least-cost programme for power sector development was prepared in 1996 [2]. Analysis of possible scenarios of the Ignalina NPP decommissioning was based on the optimization model EFOM-ENV. This model allowed selection from a given set of alternative technologies the most efficient structure of electricity generation, transportation and end-use options for each scenario. The most important conclusion to be drawn from the model results is that it is economic to keep both units in operation as long as this is possible, and if the necessary licenses can be obtained [3, 4]. These results are validated in the study of implementation of the IAEA's planning tools (MAED and WASP-III Plus) in Lithuania. The most recent study is conducted under the technical cooperation programme of the IAEA using methodology widely accept in the study could be valued an important contribution for justification of recommendations in the renewed National Energy Strategy.

6. ROLE OF THE IGNALINA NPP FOR THE POWER SECTOR DEVELOPMENT

It is expected that in 1999 unit 1 of the Ignalina NPP will receive a license for continued operation, which will be in line with the international requirements. However, until this work is not finished and research work of fuel channels and graphite is not carried out (to be completed in 1999) it is impossible to make the final decision about the real dates of closure the Ignalina NPP. It was stipulated in the Nuclear Safety Account Grant Agreement that fuel channels will not be replaced after the end of their life time. However, this pre-condition was made on the ground of limited information about the Ignalina NPP safety available in 1993.

In the last years after deep safety ensuring analysis, and large number of important safety improvement measures being introduced this situation has changed radically [5], and further investments into safety improvements satisfy the criterion of least cost power sector development [6]. Available preliminary information about the state of fuel channels enables to make predictions, that in the unit 1 they can serve till 2005 and in the unit 2 - up to 2010. Possible inaccuracy might reach one or two years, which has no essential influence on the development of the power sector.

Therefore for the purpose of the National Energy Strategy two scenarios have been chosen for the evaluation of the Ignalina NPP: 1)unit 1 of the Ignalina NPP will be shut down in 2005, unit 2 - 2010, i.e., at the end of allowable lifetime of the fuel channels. At those date a half of the designed technical lifetime of the Ignalina NPP will have elapsed; 2)fuel channels will be replaced by new fuel channels according to the design criteria for this type of RBMK reactors. In this case the Ignalina NPP will be kept in operation during whole period analyzed in the National Energy Strategy.

Because the Ignalina NPP produces electricity considerably cheaper in comparison with other available power plants in Lithuania or probable new power plants, Lithuania will suffer huge losses without re-channeling. The preliminary studies [7,8] have indicated that these losses would amount to USD 1.2-2.2 billion in energy sector and to USD 3.3-3.9 billion in the whole economy for the 2005-2025 year period. These losses are calculated without evaluation of the profit that would be received from the export of all surplus energy. Longer operation would help to accumulate means necessary for the Ignalina NPP closure, nuclear waste management, and spent nuclear fuel final disposal. These costs may reach USD 2.5-2.8 billion [9]. In the case of re-channeling undesirable social problems related to finding of new work places for the discharged workers will not appear. Premature closure also will require early capital investments into whole energy sector development. It will be a heavy burden for the country's economy that just begins to recover.

If the Ignalina NPP is closed and electricity is mainly generated by the thermal power plants, total emissions of harmful substances and CO_2 into the atmosphere in the year 2015 would reach the 1990 level, with nearly twice-lower electricity production [2].

In the future Programme of Action of the National Energy Strategy all measures necessary to prepare for the premature closure of the Ignalina NPP must be defined:

- a detailed plan of decommissioning and dismantling, including cost evaluation;
- a plan for nuclear waste and spent fuel management and interim storage;
- a programme for handling social problems related with premature closure;
- a detailed programme for the power sector development in the case of premature closure.
- In order to prepare for the probable re-channeling it is necessary:
- to prepare for the fulfillment of the new safety analysis report;
- to carry out the detailed economic analysis of the power sector using the least cost method, to evaluate future prices of nuclear fuel, costs of spent fuel storage, its processing and final disposal and changes in fossil fuel market;
- to prepare the development of infrastructure (administrative, supervision, scientific-technical support, staff training) necessary for the long term safe and economic operation of the Ignalina NPP.

6.1. The capacity balance

If the Ignalina NPP operated only a half of its lifetime, the existing capacities would satisfy national demand till 2010 in all cases of demand growth. With upgrading of the Lithuanian TPP by transferring it into combined cycle, the capacity balance over the period concerned (till 2020) would satisfy internal demand only in the case of slow economic growth. If the Ignalina NPP operated till the end of its lifetime and the Lithuanian TPP was upgraded the excess capacity of the Lithuanian power sector would exceed 1,4 GW even without introduction of any new capacities and even in the case of fast economic growth (Fig. 4).

6.2. Future power plants

Should new capacities be needed, CHP modules with a diesel engine or gas turbines or new combined cycle gas turbine (CCGT) would be the most attractive source of electricity from the economical point of view (Table II). The competitiveness of the eventual chain of hydro power plants built on the Neris river and the middle of the Nemunas river becomes obvious. However, the total capacity of these hydro power plants is only 172 MW. Thus, they do not influence the power balance much.

The CHP modules become very attractive for the conditions of Lithuania by implementing them instead of common boiler houses in available district heating systems. The best way to increase efficiency of heat supply systems is to replace large boiler houses by the low capacity thermal power plants. This is prevailing tendency in the power sectors of Western countries. A further economically efficient source of power production (after the combined cycle power plants and CHP modules) could be the refurbished Lithuanian TPP at

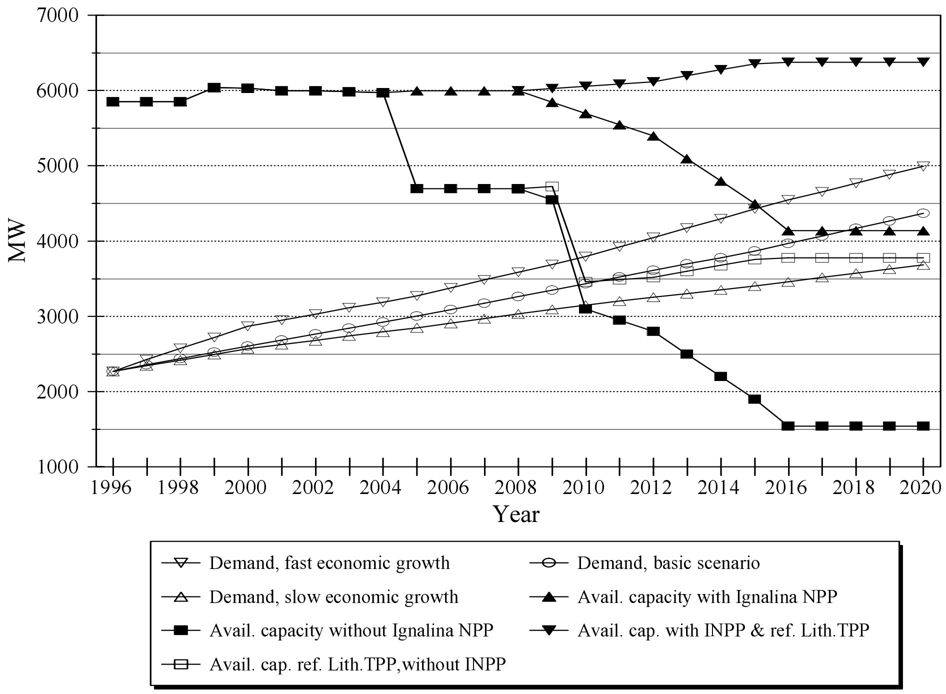

FIG. 4. The balance of capacities of the Lithuanian power sector.

Elektrenai. If the price level of fossil fuel remains the same as today, its refurbishment will be a more attractive option than the construction of a new CCGT. This alternative comparing with new CCGT requires fewer investments (for 300 MW units - 150 USD/kW, for 150 MW units - about 190 USD/kW), but operational costs due to lower efficiency factor are higher. However this power plant is designed to burn various kinds of fuel (gas, HFO and orimulsion), and it does not depend on any single source. The presented analysis is carried out for the case study when the flue gas desulphurization equipment is not installed. Lithuanian TPP should be preserved as a source of reserve capacity.

TABLE. II. FORECASTS OF ELECTRICITY PRODUCTION COSTS BY THE POWER PLANTS IN 2010 (ct96/kWh)

Power plant	Maximum time of capacity utilization, h					
	3000	5000	7000	3000	5000	7000
	With 10% discount rate			With 5% discount rate		
Lithuanian TPP, 300 MW	14.8	12.7	11.9	14.4	12.5	11.7
CCGT	16.6-20.0	12.5-14.6	10.8-12.2	12.8-14.9	10.3-11.5	9.1-10.0
Probable HPP on Neris and Nemunas	21.7-29.8	13.0-17.9	9.3- 12.8	10.5-14.2	6.3- 8.5	4.5- 6.1
Modules	13.3	9.4	7.7	9.7	7.2	6.1
New NPP	34.1	21.5	21.5	24.1	15.5	11.8
Ignalina NPP*	10.8	8.7	7.6	11.1	8.9	7.8

* - Average in the planning period.

In the Strategy of Radioactive Waste Management that was prepared by experts of the Lithuanian Energy Institute and the Ministry of Economy a legal basis for activities in this field is presented. The main directions of management strategy of nuclear waste of low and medium radioactivity:

- safety assessment of the existing storage facilities of radioactive waste and the licensing of their operation;
- safety assessment of treatment technologies of radioactive waste and their licensing;
- assessment of the safety of the long-term storage facilities of radioactive waste and their licensing for the disposal of accumulated and new waste;
- the selection of the site for the surface type disposal of waste of low and medium radioactivity and its installation, giving priority to the site located by the Ignalina NPP;
- the removal and appropriate treatment of existing radioactive waste accumulated in storage facilities for long-term storage and/or disposal if such waste does not meet the criteria for its burial in the present state.

Main directions of the spent nuclear fuel (SNF) management are following:

- storage of SNF, removed from the reactor, in the pools for 5 years;
- storage of SNF in the Dry Spent Fuel storage facilities for 50-100 years;
- research works in order to explore the possibilities for disposal of SNF in the territory of Lithuania.

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THE DECOMMISSIONING CONCEPT FOR NUCLEAR FACILITIES IN UKRAINE

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Abstract

The basic task of the conception is a formulating of the basic directions and priorities, terms of schedules and plans, calculation of costs of works on endurance, preservations, dismantle of nuclear facilities and returning of territories in the unlimited usage. Without dependence from rates of development of nuclear energy in Ukraine this problem has to be solved already today.

1. INTRODUCTION

Ukraine ranks among the first ten countries in the world concerning the number of operating nuclear units (15). The total capacity of 5 nuclear power plants units is 12, 8 mln KWt, which is 24% of the installed capacity of all Ukrainian power plants. NPPs specific position in the overall electricity generation underwent a rise from 25% in 1990 to 44,9% in 1997. Nuclear power plants generated 79472 mln KWt/h in 1997.

The Soviet Union, being a nuclear state, didn't have a single law, regulating the rights and responsibilities while utilising nuclear energy, during several ten-years. Only regulatory acts and normative documents were in force - radioactive safety standards and sanitary inspection rules, which didn't provide lawful protection of the subjects, operating in the field of nuclear energy utilisation.

After becoming independent in 1991, nuclear legislation has been founded in Ukraine and is still developing. The Constitution of Ukraine consolidated responsibility of the state for environmental safety ensuring, environmental equilibrium maintenance and overcoming of the Chernobyl accident results. The main law in the field of nuclear energy utilization is the Law of Ukraine "Concerning nuclear energy utilization and radioactive safety", passed in 1995.

Nuclear energy utilization department, being a part of the Ministry of Energy of Ukraine, exercises the role of a state management body in the field of nuclear energy utilization.

State policy's realization in the field of nuclear energy utilization is being implemented by carrying out the National energy program and the Program of radioactive waste management, approved in 1996.

All nuclear facilities in Ukraine must be decommissioned after the end of operation for dismantling and return of the site for unlimited use.

2. DECOMMISSIONING CONCEPT DEVELOPMENT: MAIN TASKS

The main task of the developing conception of nuclear facilities decommissioning is:

- formulation of the main purposes and priorities;

- definition of entering terms and volumes of radioactive wastes, appeared while decommissioning;
- definition of the radioactive waste volumes, accumulated during operation;
- definition of the disposals or repositories construction terms for all types of radioactive wastes and spent fuel;
- cost definition for each stage of decommissioning;
- development of the actions for reducing the negative social consequences etc.

A list of units, related by the national legislation to the nuclear facilities, is given in the Table I.

3. SOME PECULIARITIES IN UKRAINE

Prior to describing the main provisions of the conception of nuclear facilities decommissioning it is necessary to note some peculiarities.

First of all it concerns “Shelter” facility, which is often called “Sarcophagus”.

“Shelter” facility is unit #4 of Chernobylskaya NPP, destroyed in a not projected accident. In the process of its construction in 1986 it was not possible to ensure the proper level of quality, corresponding the requirements for nuclear energy facilities. The amount of fuel containing masses, their concentration, location, destruction processes etc. do not allow to guarantee the nuclear safety of the facility. That is why to make it environmentally safe, it is necessary to extract all radioactive wastes, contained in it (first of all those which contain fission materials) with further disposal of them in the suitable facility. “Shelter” facility’s transformation into environmentally safe system is foreseen to be conducted in three stages:

(1) stabilization of existing facility’s construction;
(2) building of “Shelter-2” facility;
(3) dismantling of the unit, extraction and disposal of radioactive materials.

TABLE I. NUCLEAR FACILITIES LIST

Name	Type	Year of commissioning	Year of decommissioning
Chernobylskaya NPP			
unit #1	RBMK-1000	1977	closed out 1997
unit #2	RBMK-1000	1978	2000
unit #3	RBMK-1000	1981	2000
“Shelter” facility		1986	
Zaporozhskaya NPP			
unit #1	WWER-1000	1984	2014
unit#2	WWER-1000	1985	2015
unit #3	WWER-1000	1986	2016
unit #4	WWER-1000	1987	2017
unit #5	WWER-1000	1989	2019
unit #6	WWER-1000	1995	2025
Yuzhno-Ukrainskaya NPP			
unit #1	WWER-1000	1982	2012
unit #2	WWER-1000	1985	2015
unit #3	WWER-1000	1989	2018

TABLE I. (CONT.)

Name	Type	Year of commissioning	Year of decommissioning
Rovenskaya NPP			
unit #1	WWER-440	1980	2010
unit #2	WWER-440	1981	2011
unit #3	WWER-1000	1989	2019
unit #4	WWER-1000	under construction	
Khmelnitskaya NPP			
unit #1	WWER-1000	1987	2017
unit #2	WWER-1000	under construction	
Nuclear research institute, Kyiv	VVR-M	1960	not defined
Nuclear energy and industry institute, Sevastopol	RR-200	1966	not defined
ChNPP, disposal NWD #1			not defined

Certainly at each stage of work development of a set of measures to evaluate and forecast probable dangerous events and their consequences is foreseen.

The second peculiarity is the fact, that a decision about ahead of time decommissioning of Chernobylskaya NPP is a political one, which didn't let to prepare and conduct all set of necessary measures in proper time.

According to Memorandum of understanding between the Governments of G-7 countries, European Bank for Reconstruction and Development and the Government of Ukraine our country took a commitment to shut down Chernobylskaya NPP in 2000.

At present the works in the frames of international technical assistance in Chernobylskaya NPP decommissioning for construction of a repository #2 for spent nuclear fuel, plants for liquid and solid radioactive wastes processing, heating boiler and many other facilities have been started and are under way.

Following the decision of the government, unit #1 of Chernobylskaya NPP was finally shut down in 1997 and works, connected with preparation of it's decommissioning are in process.

Operating units of other NPPs will be shut down when their designed life cycle is over-from 2010 to 2025. Operating period for some of the units can be extended after agreement with design institute and regulatory body.

4. PROVISIONS OF DECOMMISSIONING CONCEPT

Conception of Ukrainian nuclear plants decommissioning foresees an integrated solution of the problem:

i) management of all Ukrainian radioactive waste, Chernobylskaya NPP alienation zone, "Shelter" facility and those appearing in the process of decommissioning;

ii) management of spent nuclear fuel of RBMK and WWER reactors;
iii) selection of the best option for a long term storage and disposal of LLW, MAW and HLW, including those, containing long living radionuclides;
iv) radioactive contamination of territories, reservoirs, including a cooling pond of Chernobylskaya NPP;
v) social protection and creation of new working positions for the staff of nuclear plants, being decommissioned and for population of the towns Slavutich, Energodar, Kuznetsovsk, Neteshin, Yuzhno-Ukrainsk, where the families of NPP staff live.

The only organization operating nuclear power plants was established by the government and is the National nuclear energy generating company "Energoatom", which consolidates all NPPs of Ukraine.

5. STAGES OF DECOMMISSIONING

Main stages of nuclear plants decommissioning are stated in the national normative document "General provisions for safety insurance while decommissioning nuclear power plants and in nuclear reactors research", which are in force since February, 1998 and are the following:

(1) Shutdown:

– nuclear fuel discharge;
– removal working materials from the loop;
– removal of potentially dangerous substances;
– decontamination of systems and elements of the plant;
– removal of accumulated LRW and SRW;
– outage of certain systems and elements of the plant, etc.

(2) Closure:

– dismantling of outside reactor systems and elements, which have no influence on safety;
– conservation and strengthening of barriers, preventing dissemination of radioactive substances;
– composing of a list and levels of contamination of radioactively contaminated systems and elements of the plant etc.

(3) Moth-balling:

– reliable moth-balling of the parts of plant, which can't be dismantled;
– making conditions for temporal controlled storage of radioactive substances at the plant;
– collection and conditioning of radioactive wastes, appeared at this stage and transfer of them to disposal etc.

(4) Maintenance

– operation of systems and elements providing a safe storage of radioactive substances, located in a moth-balled plant;
– maintenance and periodic inspection of a moth-balled plant etc.

(5) Dismantling:

- dismantling and extraction of all systems and elements of the plant;
- collection and conditioning of all radioactive wastes and transfer of them to disposal;
- radiation inspection of not dismantling part of the plant, controlled zone and sanitary-protective zone.

6. CONCLUDING REMARKS

Decommissioning is considered to be finally completed after limitations for territory utilization are revoked.

Decommissioning works are being fulfilled with obligatory agreement of radiation protection programs, radioactive waste management and quality ensuring.

To provide all these works, an operating organization-SJSEC "Energoatom" must have the necessary financial sources. A special decommissioning fund was formed, where funds are accumulated due to deductions from NPPs generated electricity.

Low-level and medium-active wastes, containing short living substances (semi-fission period not more than 30 years) are to be disposed at "Vector" facility, which is being constructed in the alienation zone.

It is planned to store high level wastes and wastes, containing long living radionuclides in near surface repositories. Their final disposal, according to the national legislation, is allowed in deep geological formations. At present a program of creating repositories of this type is being developed.

Spent nuclear fuel from reactors RBMK (Chernobylskaya NPP) is not a subject to processing. That is why it is planned to construct repository#2 for all fuel from Chernobylskaya NPP. Repository #1 will be dismantled in future.

Spent nuclear fuel from reactors WWER is sent to Russia for processing. Glazed high-level wastes after being processed are returned to Ukraine for disposal.

DEALING WITH LOCAL AND INTERNATIONAL MEDIA — EXPERIENCE OF LITHUANIA

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Abstract

Public acceptance is one of most serious conditions for nuclear power introduction or successful operation of nuclear power plants. After restoring it's independence Lithuania has inherited large nuclear power plant with RBMK type reactors widely known as Chernobyl type reactors. Several small case studies of dealing with media on nuclear matters are presented and efforts to adopt an active attitude on different levels are described.

1. INTRODUCTION

Though the first Soviet design nuclear reactor of RBMK type was successfully built and put into operation in Leningradskaya Nuclear Power Plant, after ill-fame accident of 1986 all reactors of this type, including two RBMK-1500 reactors of more modern design operated by Ignalina Nuclear Power Plant in Lithuania (hereinafter - INPP or Ignalina NPP), are referred to as Chernobyl type reactors. It is only one of examples of clichés that are consistently used by international media.

After restoration of independence of the Republic of Lithuania in 1991 when INPP went to the ownership of Lithuanian state not only its benefits, like relatively inexpensive electricity, were inherited, but also its problems, like spent fuel and nuclear waste management, nuclear safety and radiation protection issues, and especially correction of negative post - Chernobyl image of nuclear power in general and RBMK type reactors in particular. Though said reactors were built at a time when nobody felt a need or obligation to listen to the opinion of general population on nuclear issues, its operation in different conditions of independent Lithuania has also raised a lot of issues of dealing with media, population, local and foreign organizations. We do not have any finished recipes, but analysis of several small case studies could be of interest to the other developing countries with ongoing and future nuclear programmes.

2. OUR EXPERIENCE - CASE STUDIES

2.1. From smouldering to high flame - two hot issues put together

In winter 1994 there was an event where two areas of very high public interest - potential danger from nuclear power plant and forecast of future - met together. During public lecture in Lithuania well known Russian astrologer made a prediction of large scale accident in Unit 2 of INPP. Every piece of media put it on their agenda and unfavourable psychological climate was created in the country. Meanwhile Director General of INPP found a constructive way to relieve a tension - he had invited said astrologer for a tour around the power plant and asked for possible provision of further details about the place and character of impending accident. When report that not even minor further revelations were made was published tension went down immediately. But this action by Director General also had two unforeseen developments. First - the ambition of the Head of national regulatory body was badly touched. He was even suggesting that the Government should take some punitive action against Director General for dealing with such unreliable source of information when he should rely on qualified experts of regulatory body. Second development - one French newspaper published an article informing its readers that Russian astrologer has been hired as adviser on nuclear safety matters by managers of nuclear power plant in Lithuania. Nevertheless the attitude of the Ministry of Energy was undoubtedly positive.

2.2. Lack of information creates a misunderstanding between neighbouring countries

In 1996 Head of the Parliament of Lithuania received a very emotional letter from his counterpart in neighbouring Belarus with description of numbers sufferings of the citizens of this country from Chernobyl disaster and requirement to do everything possible to stop construction of a new nuclear facility, not less dangerous than the nuclear power plant - intermediate spent fuel storage - in Lithuania near the border of two countries. We understood immediately that it was our mistake - preliminary information about said storage was not distributed as widely as possible so our neighbours have not been informed that construction of this storage meant taking spent fuel from more vulnerable position inside the storage pools in reactor buildings of nuclear power plant and putting it on the same site into much safer position - into thick walled cast iron containers that would not be damaged even by direct crash of small aeroplane. A single letter from the Ministry of Energy with detailed explanations resolved the issue but it was also good lesson that it was better to take a course of prevention of misunderstanding than to have to justify oneself.

2.3. International media deaf to a different opinion

At the end of 1996 very comprehensive safety analysis report (its volume is about 6000 pages) on Units 1 and 2 of INPP was concluded by a large team of international experts [1]. Many recommendations for safety improvement were provided and main conclusion was made that after implementation of these recommendations there will be no reasons to not operate the plant on safety issues. But in March 1997 well known newspaper “Financial Times” published an article with the heading “Lithuanian N-plant unsafe, say experts” [2] and provided their own conclusions that not only INPP should be closed in nearest future but because the vice-president of large Russian energy utility Rosenergoatom was a member of report evaluation team the report will have implications for early closure of RBMK type nuclear reactors in Russia. The letters of protest to the editors from the experts who had prepared the report themselves did not have any effect. So this is an area in which we are willing to learn an experience of the other countries.

3. POLICY OF TRANSPARENCY

3.1. Government level

3.1.1. Legal framework

Public relations arising during the use of nuclear energy for generation of electricity and heat in the Republic of Lithuania are mainly regulated by the Law on Nuclear Energy, adopted in November 1996. Said Law provides that nuclear facilities in the Republic of

Lithuania shall be owned by the State and nuclear fuel shall be owned solely by state enterprises of the Republic of Lithuania. So at present Ignalina NPP is 100% state owned enterprise and the Ministry of Economy plays a role of formal founder of power plant. Law also provides that in making a decision on the construction of a specific nuclear facility, the Government of the Republic of Lithuania shall take into consideration not only economic and public needs, the principal characteristics of the use of natural resources and their impact on the environment, nuclear safety and radiation protection guarantees but also the opinion of the local authority on whose territory the intended facility will be sited.

3.1.2. Active position

During transition period toward regaining the independence several local politicians have created substantial political capital by fighting against "Soviet time monsters" like NPP and hydro - pumped storage. Sound economic analysis made later proved that these "monsters" were extremely helpful for revival and restructuring of national economy. The construction of power facilities was renewed and political figures that had no positive ideas only the mood for fighting have lost their attractiveness. But the same card is still played outside the country. During preparations to the elections of new Parliament at the end of this year in neighbouring Latvia articles about green leaves of cucumbers becoming yellow during one day with wind blowing from the direction of Ignalina NPP and similar kind started to appear in Latvian newspapers.

Seeking to disprove deliberate misinformation and to dispel unnecessary fears because of ignorance the Government of Lithuania has adopted an active position. In 1993 State Scientific Programme "Nuclear Power and Environment" was approved and during five following years the scientists from different national scientific institutions took an active part in the investigations of possible effects of INPP on the environment and population, including NPP staff. Five volumes of scientific report were published [3]. Though general attitude of population in surrounding regions to further operation of RBMK units while paying serious attention to safety improvement was found to be moderately positive (29% - for, 25% - partially for, 11% - against, 15% - undecided, 20% - did not answer), the results of concluded population poll provided new evidence of the lack of proper information. Though no evidence of any influence of possible radioactive emissions to the health of workers or surrounding population was found, it appeared that 77% of polled persons believe that nuclear power plant poses substantial threat to environment and 73% - to the health of population. 23% of polled persons even believe that operation of NPP made a serious influence on the climate in all territory of Lithuania, 27% - that it increased water contamination. The importance of relevant information is once more shown by the fact that only 7% of polled plant staff believe that the plant poses threat to environment and 40% of polled inhabitants of Visaginas city, where most staff members live, believe to increased health hazard [3, vol. 5., Ch. 2.2].

As one of substantial steps for education of population programme of studies on environment and ecology oriented towards the students of secondary schools was prepared and started [3, vol. 5, ch. 2.3]. It included preparation of educational programmes, purchase and installation of necessary hardware, establishment of summer schools for students, seminars for teachers, publishing series of guiding materials, etc.

Currently the Government is going to approve a new State Scientific Programme oriented to further studies of nuclear facility's impact and education of population.

3.2. Ministry level

During the last two years interest to Ignalina NPP by local and international media increased very much because of the formally expressed intention by Lithuania to join the European Union. Though the legislation of the Union allows for its members to define their nuclear policy by themselves, ensuring, of course, the necessary safety level, there were numerous declarations by politicians of the European Commission that operation of the Ignalina NPP can be serious obstacle on the way of Lithuania towards European Union. The reason is that in the meeting of seven leading world nations (G-7) in 1992 under the influence of recent Chernobyl disaster RBMK type reactors were assumed to be not upgradable to the minimum necessary safety level and despite numerous later investigations of their real safety level by various international teams, earlier adopted opinion is still alive among many politicians. Of course, the decision on the closure of nuclear units should be made by politicians, and Lithuanian Law on Nuclear Energy provides that such decisions shall be adopted by the Parliament. But we stand strongly in the position that these decisions should me made on the base of safety, technical and economic issues but not on emotions. Currently nuclear is the cheapest way of producing electricity, many additional safety measures including modernisation of accident localisation system were implemented and new comprehensive Safety Improvement Programme SIP-2 is on the way [4].

For better information of media and population on nuclear issues the Ministry of Economy has adopted the policy to inform the media about forthcoming events in advance. It allows the journalists to be present during most significant meetings, seminars, discussions and short communications on smaller ones are directly distributed by corresponding staff of the Ministry itself.

This spring before the distribution of the draft of updated National Energy Strategy the material on technical, economic and political issues of INPP closure was prepared by the Ministry for distribution to governmental organizations and the embassies abroad. The draft itself was not only distributed for comments to interested national organizations and public bodies but also sent to European Commission. As a result several meetings and discussions with high level officials of G-7, European Commission, European Bank for Reconstruction and Development followed.

Currently updated version of booklet on nuclear safety issues is prepared for print by Lithuanian Energy Institute. It will be distributed for main governmental and public bodies. Further analysis of economic and social losses in the case of premature INPP closure is performed. We hope that these documents will be helpful in finding mutually acceptable policy on nuclear issues for our society and politicians.

3.3. Power plant level.

For ensuring better communication with the population in July 1995 using the experience and direct assistance of foreign organizations Public Information Centre was created at Ignalina NPP. Preparation of information strategy and purchase of part of equipment was financed by European Bank for Reconstruction and Development. Main task of the Centre is to inform the visitors about the operation of power plant and to provide general information on nuclear energy and effects of radiation.

During three years of its life Public Information Centre has had about 12 thousand visitors. The figure is not very high but the staff is really happy to accept young people whose general interest can later develop into willingness to have a corresponding education and career. Especially popular with the visitors are monitors with direct view of reactor hall, turbine hall, control room and spent fuel ponds.

4. CONCLUSIONS

Nuclear power is always under the very close watch by the media. Pro-active position of governmental institutions and plant public relations personnel can exclude many cases of misinformation, misunderstanding and unnecessary attention. Nevertheless when unforeseen situations happen a lot of ingenuity is needed. Special attention has to be paid to provision of comprehensive advance information on new developments to neighbouring countries.

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THE ATTITUDE TO NUCLEAR ENERGY IN GEORGIA

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Abstract

Georgia, as new independent state, is facing new problems regarding energy sources in the conditions of market economy. Great attention is given by the Government to search for various ways and versions to overcome the energy crisis. While nuclear energy may be an option, for some reasons detailed in the paper, nuclear power plant is not officially considered as an alternative.

1. REALITIES

Georgia is one of the new independent states (NIS), formed (more strictly regained its independence) after disintegration of the former Soviet Union (FSU). It is located in Trans Caucasus on the cost of the Black Sea and has borders with Russia (from the North), Azerbaijan (from the East) and Armenia and Turkey (from the South). Georgia is an ancient country known as early as in antique times. Kolkhida, described in well-known Greece history about voyage of Argonauts for the Golden Fleece is the western part of Georgia adjoining to the Sea.

Before disintegration of the Soviet Union Georgia was rather prosperous country having developed science, culture, industry and other branches of economy. After disintegration of the Soviet Union as a result of rapture of existing economical relations being in most cases unnatural, but strongly necessary for socialist economics, the industry in Georgia, like other former Soviet Republics, has dropped to zero level.

The lack of sufficient inner energy resources in the new condition of market economy led to heavy energetic crisis, which, in its turn, badly affected the vital activity of all branches of economy, human activity and living standard of population within the whole country.

At present, the problem of regular power supply of the country is the vital task and the Government gives a great attention to the search for various ways and versions to overcome the crisis.

At present Georgia needs 18 10^9 kWh electric energy per year at real energy production 8 10^9 kWh per year. Production of electric energy falls mainly at heat electric stations, working on imported fuel (mazut, gas) (40%) and at hydroelectric stations (60%).

Filling of the shortage by means of electric energy purchasing abroad or at the expense of heat electric stations is not acceptable for two reasons. The first, in both cases this is expensive, taking into account that Georgia has not got its own fuel. The second, it is not desirable to make base power supply of country dependent on outer factors.

To cover the deficit, many specialists prefer to build hydroelectric stations. It should be noted that Georgia is really rich with hydro energy, from the total reserve of which (according to different estimations from 32 to 50 10^9 kWh a year) only 8-10% is used. However, in Georgia hydro energy has some apparent disadvantages. First, the Georgian rivers a7re mountain ones and seasonal fluctuations of water debit are quite significant, making hydroelectric stations useless as a base sources in the general system of power supply. Second, Georgia is mountainous and small land country and construction of large water reservoirs capable to provide regular water consumption is impossible and impermissible.

A great attention is paid to the investigation of the possibilities of using non-traditional and renewable energy sources, e.g. wind energy, solar energy, biochemical energy, energy of thermal waters etc. Each of these energies, alongside with their obvious advantages over the other types of energy, has obvious disadvantages as well. At any rate neither of them can compete with heat electric energy and hydroelectric energy today and in the near future (arranging the common system of power supply their contribution can not be more than 10%). But they can be useful for local electric supply, and of course, will have their spheres of application.

The supporters of non-traditional and renewable energy sources, as well as the supporters of hydroelectric energy think that the way of electric energy production, chosen by them is the cleanest from the ecological point of view and harmless for the environment. However, one should note that it is not yet well established how ecologically harmless can be the aggregation of a great number of wind-power installations or solar batteries, covering large areas. Besides, it is obvious that there is no point in searching ecologically absolutely clean methods of energy production. Any human activity no matter how harmless it seems causes certain damages to environment. While planning the activities of any kind the main criteria should be as follows. i) The damages inflicted to the environment should be reduced to the minimum. ii) The benefit from human activity should be more than the damage to the environment caused by this activity, taking into account the cost of the measures minimizing this damage.

Of course the concept of minimum damage is not definite, but we can make it more or less definite proceeding from the principle of reasonable sufficiency.

Lately, a part of scientists and technical intellectuals of Georgia began to consider that the most cardinal solution of energetic problem in Georgia can be the construction of nuclear power plant (NPP). Not taking into account the problems of location and storage of spent fuel and radioactive waste the up-to-date nuclear power plants are, indeed, the most ecologically clean and harmless for environment. As for the problems of spent fuel and radioactive waste themselves, it is not correct to let each country having nuclear power plant to solve these problems by itself. As the nuclear energy is widely used by many countries of the world, this problem should be solved globally.

Unfortunately, the idea of using nuclear energy or constructing a NPP in Georgia is not officially considered as alternative. Moreover, the construction of NPP in Georgia can be prohibited by the law. This is the consequence of sharply negative attitude of a part of Georgian public to any kind of nuclear activity. One should note that this negative attitude is the result not only of the trivial radiofoby, which arose absolutely without any real ground among some people in Georgia after the commissioning of research nuclear reactor at the Nuclear Center of the Institute of Physics of the Georgian Academy of Sciences (start in 1959, shut down in 1988, decision on decommissioning in 1991). Such negative attitude was strengthened by explosions of nuclear weapon and emergencies on nuclear reactors and became more acute due to Chernobyl catastrophe in 1986, consequences of which were noticeable in Georgia.

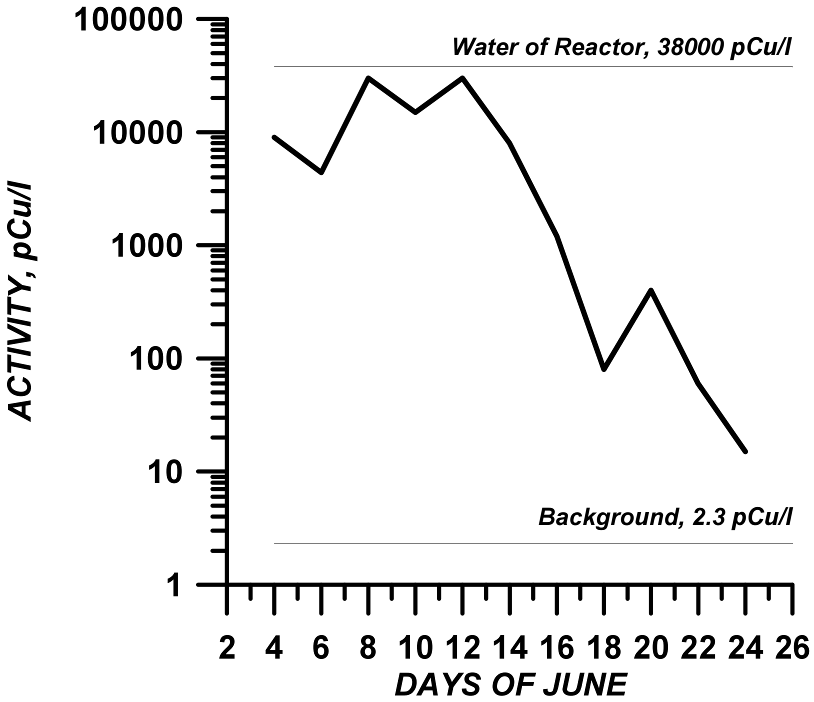

FIG. 1. Total activity of long living radionuclides in atmospheric precipitations (after Chernobyl).

Georgia indeed experienced quite perceptible suffering from Chernobyl. For illustration in Fig.1 we present the measurements of daily average radioactivity of the atmospheric precipitation during the first month after Chernobyl accident. One should pay attention to the fact that activity of atmospheric precipitation on June 8-12 was almost at the level of water activity in the reactor tank operating at the power of 5 MW [1].

The estimations made on the basis of radionuclide composition analysis and the amount of atmospheric falls showed that on June 8-9, 1986 the dose rate of external γ - radiation exceeded the background value three times [2], and the dose of thyroid radiation in children in Tbilisi region was 21 mSv, corresponding to doses characteristic of countries suffered most of all after Chernobyl accident (Bulgaria, Romania, Greece) [3]. One should also note that in the west Georgia (Black Sea coast) which suffered more strongly, the dose rate of external γ - radiation induced by short living radionuclides (products of Uranium fission), exceeded normal background level 30 times [1].

To the above said should be also added the increase of seismicity of Georgian territory from the magnitude of 7 to 8 after destructive earthquake in Spitak (Armenia, 1987), that still reduced the confidence in possibilities of safe exploitation of nuclear plants in this region.

It is natural that in such situation it is very difficult to change the public opinion in favor of nuclear energy. Nevertheless we think that sooner or later (of course sooner is better) one should begin the preparatory work to this direction.

The aim of our participation in the work of this seminar is to study the experience acquired in other countries for overcoming the opposition from public and social organizations while gaining the right for open discussion on nuclear power as an alternative variant of other methods of electric energy production.

2. CONCLUSIONS

No doubt that Georgia is not the only country facing the above described difficulties. We hope that the exchange of experiences, mutual assistance and the desire to work out the optimal strategy and ways of solving this problem by combined efforts will be beneficial for all of us. To familiarize ourselves with the attitude of other developing countries to the development of nuclear energetic in these countries will be equally useful.

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SAFETY, REGULATION AND SAFEGUARDS

(Session 5)

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Key Issue Paper No. 4

DEVELOPMENT OF SAFETY-RELATED REGULATORY REQUIREMENTS FOR NUCLEAR POWER IN DEVELOPING COUNTRIES

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Abstract

In implementing a national nuclear power program, balanced regulatory requirements are necessary to ensure nuclear safety and cost competitive nuclear power, and to help gain public acceptance. However, this is difficult due to the technology-intensive nature of the nuclear regulatory requirements, the need to reflect evolving technology and the need for cooperation among multidisciplinary technical groups. This paper suggests approaches to development of balanced nuclear regulatory requirements in developing countries related to nuclear power plant safety, radiation protection and radioactive waste management along with key technical regulatory issues. It does not deal with economic or market regulation of electric utilities using nuclear power. It suggests that national regulatory requirements be developed using IAEA safety recommendations as guidelines and safety requirements of the supplier country as a main reference after careful planning, manpower buildup and thorough study of international and supplier country's regulations. Regulation making is not recommended before experienced manpower has been accumulated. With an option that the supplier country's regulations may be used in the interim, the lack of complete national regulatory requirements should not deter introduction of nuclear power in developing countries.

1. INTRODUCTION

Regulatory requirements in the form of acts, decrees, notices, guides and standards are tools through which the government or its designees regulate nuclear activities to ensure public safety. They are also tools through which the government can pursue public acceptance of nuclear power. Complete regulatory requirements should be available regardless of the number of nuclear power plants under construction or in operation.

Developing countries planning their first nuclear power plant may have difficulties establishing a regulatory safety regime for the following reasons:

- Regulatory requirements of suppliers evolve continually, reflecting the state-of-the-art technologies.
- Regulatory requirements vary between countries depending on specific conditions.
- Development of nuclear regulatory requirements is technology-intensive, and it takes time to accumulate trained, experienced and competent manpower.
- Development of nuclear regulatory requirements is a multidisciplinary task involving a variety of expertise and organizations, in close cooperation.

Although these are real difficulties, countries without national regulatory requirements can develop them with planned, systematic, effort, using the experiences of predecessor countries.

2. GENERAL APPROACH

2.1. Key considerations

Approaches to the development of national nuclear regulatory requirements differ between countries depending on individual conditions. In some, requirements already exist, especially those related to research reactor operation and radioisotope utilization. Some already have high level nuclear regulatory legislation under which regulation (decrees, government notices, guides and standards) can be refined.

National regulatory requirements should be stable so nuclear power plants can be built and operated with minimal financial risk by the utilities and should be transparent and give assurances for public safety [1]. Key considerations are discussed in the paragraphs below.

2.1.1. Organizational setup

In countries operating or planning nuclear installations, a legal framework should be established providing the regulation and clear assignment of safety responsibilities. Government is responsible for legislation assigning the primary responsibility for safety to the operating organization (i.e., utility) and forming a regulatory body for licensing, regulatory control and enforcement [1]. For the regulatory body, responsibilities for establishing regulatory requirements, licensing, monitoring and enforcement should be clearly defined within the legislative and statutory framework. The regulatory body should be independent from organizations promoting nuclear activities so judgments may be made and enforcement actions taken without undue pressure from interests that may adversely impact safety. This is necessary not only technically but also for public acceptance. Despite this, some countries have vested both regulation and promotion in the same government organization, like an Atomic Energy Authority, at least at the beginning of their nuclear program. But where this has occurred in the past, there is a clear trend towards separate functions.

The existence of a regulatory body should not diminish the basic responsibility of the operator (utility) for the safety of the plant, but should give confidence to the government and the public that the plant is operating safely [2]. The operator cannot take refuge behind inadequate regulatory safety requirements but must set its own rules and requirements, which could be even stricter than those of the regulatory body.

The functions of nuclear safety and radiation protection should be combined in one regulatory authority, though this has only been done in a few countries, often because the radiation protection authority existed earlier and specialization is quite different. However, where these functions are vested in two different organizations, licensing of nuclear installations can be difficult.

2.1.2. Manpower and experience buildup

Developing balanced regulation requires an understanding of plant design and operation, and experience in regulation, and inspection. Developers should have sufficient knowledge to compare regulations from different countries and understand their specific nature. They should have enough experience in regulatory activities to modify imported regulations and adapt them to the local environment and eventually, should be able to perform cost benefit analysis with respect to design changes for safety enhancement.

Regulations developed by inexperienced personnel may simply be a translation of the supplier's regulations or an adoption of international regulations, lacking consistency, and impractical or unsuitable to the local environment. Sometimes, they can be overly strict, unnecessary, or inappropriate, making compliance extremely expensive, if not impossible. Once such requirements exist, it may be difficult or time consuming, to change them.

At the beginning of nuclear power deployment, where both regulatory body and industry lack basic knowledge of nuclear power plant design, construction, operation and regulation, close communication between them is essential. To understand fundamental principles, both organizations may receive training at the same time, with regulators, engineers, designers and operators benefiting from the larger perspective supplied by the international agency or supplier country's regulators.

2.1.3. Efficient licensing process setup

The details of nuclear regulatory requirements are closely linked to the licensing process of nuclear power plants. The licensing process specifies steps to be taken before full power operation of the plants can be approved.

Licensing should be considered an ongoing process, starting from the site license and continuing through decommissioning of the plant. Although in some cases it may be appropriate to issue a site license independently of the type of reactor, a detailed demonstration of nuclear safety should be submitted by the applicant and reviewed by the regulatory body before issuance of a construction permit. Licensing processes vary from country to country and the first formal action may be approval of the safety concept at the issuance of the construction permit.

Regulatory requirements generally support the licensing process, and the details vary for implementation depending on the process. One country may take a one step licensing approach while others require more steps before issuing a full power operating license. There are reasons why each country adopts a different process, and careful study is necessary before the national licensing process can be set up for efficient licensing.

2.1.4. Balance maintenance

A key consideration in the development of safety regulations is balancing between proven technology and innovative development to incorporate state-of-the-art technology while assuring the licensability of new plants. Standardization based on proven technology guarantees performance and leads to reduced risk for the project. However, such standardization may not include state-of-the-art technology, and the technology utilized may be outdated, resulting in low performance and reduced safety. Therefore, the concept should be of evolving safety regulation to accommodate improvements in technology, or to permit innovative technological changes.

It is also important to balance between safety and economics. It is internationally accepted that the most important component of a nuclear power plant operation is safety. However, too much emphasis on safety, may lose the competitiveness of nuclear compared to non-nuclear power. This could cause plant shut down and scraping of plans for further nuclear plants. Requirements must be formulated with careful study of their impact.

Another consideration for regulatory requirements is balance between flexibility and detail. Precise and detailed regulations lead to mechanistic compliance and enforcement, leading to lack of judgment and initiative in plant design, operation and regulatory compliance. This is compounded by the fact that highly specific regulations, once established, are not easy to revise or update. This can lead to high cost or inappropriate compliance. In contrast, results-oriented regulations that allow flexibility as to means of compliance can permit more efficient and economic attainment of regulatory goals.

On the other hand, excessively flexible regulations lack detail and implementation of design even conforming with the requirements may not warrant a license due to differences in interpretation between industry and the regulatory body. It is therefore necessary to bring flexibility to the resolution of licensing issues between the designers and regulators to avoid unnecessary conservatism.

Another consideration is the balance between accident prevention and mitigation in fulfilling the defense-in-depth principle. Principal emphasis is on preventing accidents, particularly those which could cause severe core damage. Provisions for accident mitigation extend the defense-in-depth principle beyond accident prevention, and would substantially reduce the effects of an accidental release of radiation. However, mitigation is more expensive than prevention. To maintain an appropriate cost-effective balance, cost benefit analysis may be used to adjust the emphasis to varying levels of defense-in-depth. A brief description of the defense- in-depth principle is included in Annex I.

One final balance is that between regulating hardware on the one hand and human performance on the other. Recent experience underscores the fact that most accidents, incidents and safety problems in NPPs occur because of human error not through failure of the technology. Regulation should not focus exclusively on redundancies in the plant design, but should also focus on the human factor, emphasizing training, alertness, a culture of safety consciousness and performance. It will not profit to have elaborate defense-in-depth systems, if they are improperly maintained to design specifications or if operators and maintenance personnel are untrained in their upkeep.

2.1.5. Maintaining consistency among different levels of requirements

Even though regulations are developed over time by different groups of experts, they should be consistent. The IAEA (International Atomic Energy Agency) introduced an hierarchical categorization scheme with four levels of Safety Series that may correspond to different levels of regulatory requirements. According to this categorization, the IAEA Safety Series are grouped as follows [3]:

- Safety Fundamentals ; Basic objectives, concepts and principles to ensure safety
- Safety Standards ; Basic requirements which must be satisfied to ensure safety for particular activities or applications
- Safety Guides ; Recommendations based on international experience, related to fulfillment of basic requirements
- Safety Practices ; Practical examples and detailed methods which can be used for the application of Safety Standards or Safety Guides

2.1.6. Harmonization with international guides

International cooperation of utilities, designers and regulators, with support from organizations such as IAEA, OECD/NEA and the European Commission can help harmonize nuclear safety regulation worldwide.

One prominent area to harmonize technical and policy matters related to power plant regulations, is the requirement development to improve safety, especially that related to severe accidents. National nuclear safety authorities regularly participate in initiatives to exchange information and share experiences, and to seek the promotion of harmony for future plants. The IAEA Convention on Nuclear Safety [5] established in October 1996, provides a mechanism for strengthening national nuclear regulatory bodies and fostering commitments to high quality regulatory standards. The IAEA NUSS program on Governmental Organization is another important vehicle.

A good example of international harmonization is the development of the Utility Requirement Document (URD) in the USA and the European Requirement Document (ERD) in Europe. Many utilities of Asia, Europe and the USA have taken part. in drafting and reviewing these requirements and consider it essential that they play a major role in developing requirements for future plants [4].

Harmony should also be achieved to guide discussion of the question of “how safe is safe enough?” Difficulties in defining quantitative criteria should not prevent continuing efforts to demonstrate the safety and economic competitiveness of nuclear power.

2.2. General approach

It is not easy to generalize approaches to the development of national regulatory requirements because situations differ between countries and through time. However, the experiences of established nuclear countries can benefit developing countries intending to invest in nuclear power in the near future. Key steps suggested for consideration are:

(1) Research and study on existing regulatory requirements that may be related to research reactor regulation, radioactive isotope control and radiation protection.

(2) Comparison of the regulatory requirements of predecessor countries and international organizations such as IAEA:

As a first step, regulations and practices of the supplier countries may be used, provided the intent of such regulations and practices are properly understood and interpreted. In the past, several countries importing their first plant used the regulations and standards of the supplier country based on the “licensable in the supplier country” concept. This could pose problems if a subsequent plant is purchased from a country with a different licensing system. Then there is the difficult task of reconciling the two systems or established and enforcing a separate national regulatory regime.

(3) Efficient licensing process setup:

Before developing detailed regulatory requirements, an efficient process suitable to the country’s licensing environment, must be prepared. Detailed licensing procedures and related regulatory requirements should be developed to support licensing.

(4) Development of regulatory requirements using IAEA safety recommendations as guidelines and safety requirements of the supplier country as a main reference:

The development of regulatory requirements is complex, involves different areas of expertise, is technically intensive and requires thorough study and research. The premature drafting of inappropriate detailed regulations can be avoided through a preliminary regulatory regime using IAEA safety recommendation as guidelines.

(5) Manpower training and study of supplier country's regulations:

It is essential that both the regulatory and operating personnel obtain in-depth knowledge and understanding of the characteristics of the plant to be operated as well as the regulatory requirements of the supplier country. Training both regulators and industry personnel may be jointly conducted at the beginning to be more cost effective, especially for plant system design and operating characteristics. It is recommended that no detailed regulatory requirements be established without adequate training in regulatory matters.

(6) Development of regulatory requirements starting from a higher level and maintaining consistency among different levels of regulations:

For a country starting nuclear power, a phased development may be more appropriate although it is more time-consuming and less consistent than if it were done at one time.

With several nuclear power plants on line and local manufacturing, construction and design, it may become necessary to develop domestic regulatory requirements along with industrial codes and standards. It becomes especially important under an active plant standardization program, where a significant portion of design and manufacturing is performed locally. The first step in the development of domestic regulation may be a modification of reference requirements imported for regulation and licensing from the supplier country. Specific articles may be modified part-by-part, adapting to local conditions, but consistency should be maintained at all levels.

(7) Establishment of a set of national regulatory requirements with continuous revision and updating:

Regulatory requirements are subject to continuous revision and updating to keep pace with changes in state-of-the-art technology and government safety policy. However, it may cause difficulties in revising and updating if they are too specific.

3. SAFETY REQUIREMENT DEVELOPMENT FOR NUCLEAR POWER PLANTS

3.1. An approach to nuclear plant safety requirement development

Construction of a nuclear power plant is relatively lengthy, leaving time for the regulatory body to develop regulations, step-by-step, on a priority basis. This also allows some lead time for training regulators and plant safety personnel.

Regulation development should be conducted in harmony with international guides and in accordance with global trends in nuclear technology. Improvements can be made in those of the supplier country to reflect the evolving technology and they can be modified to accommodate local conditions. Regulatory requirements should preserve flexibility so that in licensing, accommodations can be made between the regulatory body and licensee as long as safety is not jeopardized.. Finally, a balance between safety and economics is key in the development of regulatory requirements.

3.2. Key technical regulatory issues

Technical regulatory issues in developed countries may differ from those in countries where the construction of plants is planned or has just begun. Such issues are related to maintaining and upgrading the safety of existing nuclear power plants. With increasing emphasis on competition in the energy markets, technical challenges and the way they are addressed could have serious consequences for the profitability of nuclear utilities. Other technical issues relevant to profitability that could adversely affect safety are those linked to the utility's desire to maximize output or decrease operation and maintenance costs.

Below are key technical regulatory issues under discussion in developed countries [6]:

(1) Aging of plants and requests for plant life extension,
- physical aging of components and structures,
- aging of analytical techniques and documentation,
- aging of rules and standards, and
- aging of technology.

(2) Increasing operational flexibility,
- reduction in the level of conservatism in safety analysis assumptions and
- extending the operational limits close to the safety limits,
- longer fuel cycle lifetime, and
- reduction in the length of outage periods.

(3) Safety margins during more exacting operating modes,
- power up-rating,
- higher burn-up, and
- use of mixed oxide fuel.

(4) Backfitting and safety upgrading programs designed to lower safety standards.

(5) Decommissioning of plants.

These technical regulatory issues could ultimately be important in developing countries. Listed below are key technical regulatory issues needing extensive study and regulatory requirements for licensing future plants:

- Licensing of computer based systems important to safety,
- Reduction of shutdown risk,
- Use of probabilistic risk assessment (PRA) in licensing, and
- Consideration of severe accidents.

These issues are discussed in more detail in Annex II, however, there are other important issues in addition to those above.

4. REGULATORY REQUIREMENT DEVELOPMENT FOR RADIATION PROTECTION

4.1. Approach to regulatory requirements for radiation protection

The objective of radiation protection is to ensure that exposure within the plant and release of radioactive material from the plant is kept as low as reasonably achievable during normal operation, and to ensure mitigation of radiation exposure due to accidents [7]. For plant operating conditions and anticipated operational occurrences, compliance with radiation protection standards based on ICRP (International Commission on Radiological Protection) recommendations ensures radiation protection. That is, the ICRP system of dose limitation provides protection for situations anticipated to occur once or more over the plant lifetime.

Measures are taken to protect workers and the public against the harmful effects of radiation in normal operation, anticipated operational occurrences and accidents. These measures are directed towards control of the sources of radiation, to the provision and continued effectiveness of protective barriers and personal protective equipment, and to the provision of administrative means for controlling exposures. Nuclear installations are designed and constructed based on principles of radiation protection, and radiation protection programs should be established and implemented during operation.

The development of radiation protection related regulatory requirements may be carried out in the following steps:

(1) Study and research on existing regulations developed and implemented for protection against radioactive isotope use and research reactor control,
(2) Study and consultation on the supplier country's regulations, and
(3) Development of national regulatory requirements for radiation protection in harmony with international approaches through the implementation of the ALARA (as low as reasonably achievable) principle. These requirements should comply with the ICRP recommendations (ICRP-26[8] or ICRP–60[9]) and IAEA Basic Safety Standard for Radiation Protection [10].

4.2. Key technical regulatory issues

Radiation protection features are incorporated in the plant design to protect personnel from radiation exposure and to keep emissions of radioactive effluents within prescribed limits in accordance with the ALARA principle. The design ensures that plant components containing radioactive material are adequately shielded. The design of the plant layout complies with radiation protection requirements by the appropriate location of plant components and systems, shielding requirements, confinement of radioactive materials, access control, monitoring and control of the working environment, and decontamination [4]. Consideration is also given to material selection which leads to low residual radioactivity.

Incorporation of the ALARA principle is key to the radiation protection requirement development, and is considered a general safety criterion. Therefore, an analysis of the overall plant design should be conducted to predict radiation doses likely to be received by workers and the public, and should demonstrate that the plant will meet specific ALARA requirements. Implementation of the ALARA principle has been recommended by the ICRP, and basic recommendations are under continuous review to observe all data and information available. Dose limits recommended by ICRP-60 in 1990 are much lower than the ICRP-26 recommendations in 1977. Actually, there has been a trend towards a lower estimated collective dose per nuclear unit over time despite an increase in power capacity [11]. The severity of these limits is such that additional doses to the general public now fall within the rather large variations of natural radiation in different locations in the world [1]. The incorporation of new ICRP (ICRP-60) recommendations into the regulations poses challenges to the design and operation of nuclear power plants, that permit compliance with new requirements without adversely affecting the economics.

5. REGULATORY REQUIREMENT DEVELOPMENT FOR RADIOACTIVE WASTE MANAGEMENT

Development of national regulatory requirements for radioactive waste management is not as imminent as that of other requirements with respect to the introduction of nuclear power, because wastes are produced only after the plant starts operating. However, it is advisable to plan ahead to minimize problems related to repository site selection and public acceptance.

Since many countries manage wastes from the use of radioisotopes in industry, medicine and research even before they embark on a nuclear power program, development can start from a study of existing regulations related to those uses. In the meantime, a comparison of regulations from foreign countries can be made, including supplier countries.

The two basic safety principles related to disposal of high level wastes are: 1) to isolate high level waste from man's environment over long time periods without relying on future generations to maintain the integrity of the disposal system or without imposing significant constraints due to the existence of the repository and, 2) to ensure the long-term radiological protection of man and the environment in accordance with international radiation protection principles [13]. Such basic principles should be supplemented by technical criteria providing guidance on practical means for complying with safety principles. The safety principles and technical criteria are intended to form a common basis for the subsequent development of more detailed and quantitative performance standards, some of which may be site specific.

While national policies differ in classifying spent fuel as a waste product or as a resource for recycling fuel, the safety of spent fuel storage and radioactive waste disposal has been extensively studied at national and international levels. The Joint Convention on the Safety of Spent Fuel Management and on Safety of Radioactive Waste Management[12], opened for signature on September 29, 1997, obliges member states to establish a legislative and regulatory framework, and to take appropriate national measures to ensure the safety of spent fuel and radioactive waste, including trans-boundary movement.

Finally, national regulatory requirements may be developed in accordance with international principles and technical criteria referencing the regulations of a supplier country under the national legal framework.

6. CONCLUSIONS

Approaches to the development of national nuclear regulatory requirements may differ between countries depending on individual conditions, but requirements must exist to ensure public safety. Difficulties arise in the development of these requirements due to their technology intensive nature, a need to reflect continually evolving technology and a need for cooperation among multidisciplinary technical groups.

Key considerations for the development of national regulatory requirements are:

(1) Establishment of organizations for the development of regulatory requirements,
(2) Buildup of sufficient manpower and experience,
(3) Setup of a licensing process to implement the details of regulatory requirements,
(4) Balance maintenance:
   - Proven technology vs innovative development,
   - Safety vs economics,
   - Flexibility vs detail,
   - Prevention vs mitigation
   - Regulating hardware vs human performance
(5) Maintenance of consistency among different levels of requirements, and
(6) Harmonization with international guides.

For this development, it is suggested that requirements conform with IAEA safety guidelines and safety requirements of the supplier country as a main reference, after careful planning, and manpower buildup and with thorough study of international and supplier regulations. No regulation making is recommended before experience has been acquired. With an option that the supplier country's regulations may be used in the interim, nonexistence of complete national regulatory requirements should not deter the introduction of nuclear power to developing countries.

Annex I

DEFENSE-IN-DEPTH PRINCIPLE

The defense-in-depth principle[7] provides an overall strategy for safety and features of nuclear power plant design. When properly applied, it ensures that no single human error or mechanical failure would lead to injury to the public. The central feature of defense-in-depth is multiple levels of protection, and two principles of the concept are accident prevention and mitigation. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment in case these barriers are not fully intact.

The emphasis in the defense-in-depth is one of the primary means of accident prevention, particularly that which could cause severe core damage. Prevention depends on a conservative design of systems, structures and components, good operational practices, quality assurance to verify achievement of the design intent, surveillance to detect degradation and steps to ensure that a small perturbation would not develop into a more serious situation.

Provisions for accident mitigation extend the defense-in-depth concept beyond accident prevention through engineered safety features, accident management and off-site countermeasures. Such mitigation would substantially reduce the effects of an accidental release of radioactive material.

Implementation of defense-in-depth may differ from country to country depending on safety objectives, reactor types and existing regulations, but the fundamental principle is well established and in harmony with international objectives. The defense-in-depth is generally structured in the following four levels of defense [15]: The first three may be categorized as traditional levels, while the fourth treats severe accidents beyond design basis.

Level 1: prevention of deviations from normal operation,
Level 2: detection of deviations from normal operation and provisions to prevent deviations from leading to accidents,
Level 3: provision of engineered safety features to control and mitigate the design basis for accident conditions, and,
Level 4: prevention and mitigation of severe accidents.

System design according to defense-in-depth includes process controls with feedback, to provide tolerance of failures which might otherwise allow faults or abnormal conditions to develop into accidents. These controls protect physical barriers by keeping the plant within well defined operating parameters where barriers are not jeopardized. An important aspects of defense-in-depth is to maintain the balance between prevention and mitigation, especially related to severe accident treatment. Accident prevention is the first safety priority of both designers and operators and can be achieved through reliable systems, structures and components, and procedures. However, no human effort can guarantee the total success of such prevention. Where risk is defined as the product of the likelihood of occurrence of an accident and its potential radiological consequences, the technical safety objective for accidents is to reduce the overall risk to very low levels through defense-in-depth. Cost benefit analysis can be used to adjust the emphasis to various levels of defense-in-depth and to check the balance between prevention and mitigation.

Annex II

KEY TECHNICAL REGULATORY ISSUES FOR NUCLEAR POWER PLANT LICENSING

1. Licensing of computer based systems important to safety

There is an increasing need to replace outdated instrumentation and control (I&C) equipment with digital systems in nuclear power plants worldwide. In the near future, operating plants may face maintenance problems due to obsolescence since I&C equipment manufacturers cannot guarantee spare part supplies over the intended lifetime of these plants [16].

Many I&C systems in use at nuclear power plants are based on analog equipment, and suffer from such deficiencies as follows [17]:

– Increased failure rate due to aging,
– Lack of spare parts, and
– Decreased availability of external technical support for plant maintenance.

On the other hand, digital I&C systems offer the following benefits:

– Reduced maintenance through self-diagnosis and on-line replacement,
– Improved control and safety margin, adaptive tuning and drift-free operation,
– Higher degree of automation, which can eliminate human errors,
– Easier modification of algorithms, and
– Increased reliability and cost efficiency.

Despite many technical and economical advantages from retrofitting digital I&C systems for operating plants and installing new digital systems for new plants, utilities are reluctant to incorporate them due to uncertainties regarding the risk of software malfunction and even more important, the licensing risk in retrofitting and new implementation.

The plant-wide use of digital I&C systems reveals new safety concerns: the potential catastrophic common mode failure of all software based I&C systems. Assurance of reliable performance of all hardware and commercial equipment is also a safety concern while the reliability of software depends mainly on the quality and procedures used in equipment development.

For the expanded use of digital I&C systems, especially those important to safety, like plant protection and engineered safety systems, both regulators and designers must make intensive efforts to adapt and extend the regulatory framework for the safety application of digital I&C systems because current licensing review criteria are mainly based on analog I&C equipment. On the industry side, a consensus approach is needed to help stabilize and standardize the treatment of digital implementation while ensuring safety and reliability. On the regulator's side, new guidelines and regulatory requirements are needed to assess digital implementation.

To incorporate digital I&C systems into nuclear plants, the most significant safety issues that may require resolution in the design and licensing include the following:

- Design against a common mode failure of software based safety systems,
- Quality assurance of software, and
- Use of commercial grade equipment in safety applications.

Protection against common mode failure in digital I&C systems can be attained by simplified safety systems totally separate from non-safety systems, and possibly, alternate protection systems. Software must be developed with sufficient quality to assure safe and reliable systems; this can be achieved by maintaining the defense-in-depth principle, controlling the software development process and verifying that the end product performs satisfactorily. Software quality assurance should entail quality design, software verification and validation, and software configuration management. Of particular importance in the software quality assurance from a licensing point of view is the verification and validation (V&V) of the software. The aim of V&V is to gain confidence in the software, and for effectiveness, the V&V team should consist of people not involved in the design [18].

Use of commercial-grade hardware and software takes advantage of the lower cost and extensive operating history of proven commercial equipment. However, a strict process control is necessary to extensively use this commercial grade equipment and proven technology requirements should be satisfied, subject to approval by the regulators.

2. Reduction of shutdown risk

Traditionally, most attention has been paid to safety during power operations and the defense-in-depth concept has been applied mainly to postulated events occurring from power operation. However, it appears that, the risk of incidents during shutdown and low-power operation has been underestimated. This stems from the false impression that “shutdown” implies “safe”, due to low heat generation [19]. Operators acting under this false assumption during shutdown over the past fifteen years have been involved in a number of incidents. These events have led to the conclusion that there is a high risk of radioactive material release due to a severe core damage accidents initiated during shutdown if not properly mitigated, and available time to restore core cooling may be significantly less than previously estimated. Core damage risk from accidents during shutdown is comparable to that associated with accidents initiated during power operation and can be a substantial fraction of the total frequency of core damage, as high as 35% [20]. Such observations confirm that worker awareness is critical to safety and that the defense-in-depth practice is not as well implemented during shutdown and low-power states as during power operation. This experience serves as a reminder that technology cannot — and should not be expected to — guard against human error, or to serve as a substitute for good practices.

A principal source of risk is the potential for the loss of capability for decay heat removal during shutdown, such as during refueling. There have been several incidents in reactor operating history involving the loss of decay heat removal systems. One type of loss is the failure of one decay heat removal pump while the other is out of service for maintenance. Another type is where the water level is drained too low during mid-loop operation and decay heat removal is interrupted by failure of the decay heat removal pump due to air in the intake lines. For this particular concern, the USNRC issued Generic Letter 88-17 [21] recommends improvement of the reliability of decay heat removal capability during mid-loop operation.

The principal findings from NUREG-1449 [22] regarding shutdown risks are:

(1) Accident sequences during shutdown can be as rapid and severe as those during power operation.
(2) Outage planning is crucial to safety during shutdown.
(3) Poor quality and reliability of reactor vessel level instrumentation is the principal contributor to events during shutdowns, with risks higher during mid-loop operation.
(4) When the containment is closed, it is capable of offering significant protection against shutdown accidents.

Regulatory recommendations in response to the above findings, for the resolution of shutdown and low-power operation, are to require plant operators to [23]:

– Plan and control outages to provide reasonable assurance that key safety functions like maintaining the reactor in a subcritical condition, removing decay heat and maintaining the reactor coolant system inventory will be preserved,
– Establish limiting conditions for operation and surveillance requirements for specific equipment relied on during shutdown and low-power operations,
– Demonstrate by analysis that functions necessary to remove decay heat from the reactor can be maintained during shutdown in the event of a fire, and
– Install instrumentation for monitoring water level during mid-loop operation.

3. Use of PRA in licensing

Regulatory decision making is based on a mix of deterministic and probabilistic assessments which complement each other. Deterministic requirements are applied in the design and operation of nuclear power plants, and the probabilistic approach to regulation is an extension enhancing the traditional deterministic approach. Both are engineering tools, each with its own strength and weakness and used to varying degrees. The deterministic approach for the most part produces safe plants, while the probabilistic approach offers the potential for optimization with respect to both safety and economics.

While current regulatory requirements in most countries are based primarily on a deterministic approach to reactor safety, safety authorities in many countries do require plant-specific probabilistic risk assessments (PRA), and quantitative safety goals set either on core melt frequency or safety function reliability level. The purpose of the PRA is to give an overall view of plant safety by identifying the initiating events of accidents and, describing sequences beginning from initiating events leading to plant damage and radioactive releases. Further, PRA evaluates the plant risk quantitatively in terms of accident frequencies [20].

PRAs are used for several purposes; to compare different designs from the safety point of view and to evaluate design modification and back-fitting. Besides design evaluation, the most common application is in the optimization of technical specifications. The application of PRA insights into technical specifications for shutdown and low-power states is of particular interest. Another growing area of interest is application of PRA to configuration management, where combinations of specific component, train and systems availability, and their associated risk levels are evaluated in real time. This requires a commitment of resources to develop and maintain a so-called living PRA, in which the safety of the plant is monitored continually based on the PRA results. Such a PRA provides information allowing plant operation in a way that will help ensure that risk is at an acceptable level and as low as reasonably practicable at all times. Another area of PRA application is the use to prioritize inspection by the regulatory body. This allows the regulatory body to focus their efforts on those components, systems or topics which are the most risk-significant.

While technical methods or guidance for some applications have been published, neither the use of formal written guidance for applying PRA in specific licensing decisions nor specific plans for developing such guidance has been reported. Several countries are developing general and application-specific guidelines, including acceptance criteria, for using PRA in regulatory matters. One of the guidelines being developed in the USA is that using PRA for categorizing structures, systems and components with respect to safety importance. Several countries are also developing procedures for review of PRA and PRA applications.

For the extended use of PRA in licensing, the following are considered to support the development of review procedures and criteria for regulatory applications of PRA:

- Definition of criteria based on probabilistic considerations to determine when it is acceptable to optimize deterministic requirements,
- Development of technical specifications based on PRA insights, and
- Development of PRA requirements to apply to next generation reactor designs.

4. Consideration of severe accidents

The current design basis approach for existing plants is highly conservative for protection of public health and safety There is a general agreement to preserve this approach, and to add considerations of some event sequences beyond the basic design, and of severe accidents [4].

The severe accidents addressed in the design must be treated with a balance between prevention and mitigation. Prevention is the first line of defense and if successful, also provides investment protection. On the other hand, mitigation addressed in the design to cope with severe accidents is also important and is being effectively increased. However, when mitigation for severe accidents becomes highly complex or difficult to demonstrate, the primary emphasis is on prevention.

It is generally accepted that severe accidents are best handled as a separate category, different from design basis accidents. Nevertheless, accidents should be considered explicitly in the design of future nuclear power plants. Appropriate severe accident sequences should be selected and addressed separately, specifying features preventing or mitigating such sequences.

For consideration of severe accidents, the containment design and its contribution to accident mitigation should be evaluated in the design process. The containment is considered a safety-grade feature for design basis loads, but should also be evaluated for adequacy against severe accident loads. For severe accidents, the containment should meet safety and radiological objectives on a best-estimate basis, i.e., preservation of the containment integrity and tightness against leaks.

Accident management augments design features to prevent degradation of an accident to severe conditions, and to mitigate accidents, if they occur. It includes design features providing grace periods and smooth plant response in transients and accidents, actions taken by operators during the evolution of accidents when conditions exceed the plant design but before a severe accident actually develops, and constructive action by the operators in the event of a severe accident, directed toward preventing further progress and alleviating its effects. Accident management also includes making full use of plant capabilities, if necessary going beyond the intended functions of some systems and using some temporary or ad hoc systems to achieve this goal [7].

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STANDARDS: AN INTERNATIONAL FRAMEWORK FOR NUCLEAR SAFETY

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Abstract

The IAEA, uniquely among international organizations concerned with the use of radiation, radioactive materials and nuclear energy, has statutory functions to establish safety standards and to provide for their application in Member States.[1] The IAEA also contributes towards another major element of the 'global safety culture', namely the establishment of legally binding international agreements on safety related issues.

1. SAFETY STANDARDS

The IAEA develops and maintains a comprehensive corpus of safety standards[2]. These are based on the findings of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and, to the extent possible, consistent with the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP) and the International Nuclear Safety Advisory Group (INSAG). Safety standards are developed in consultation with and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned.

The basic framework for achieving this is established in the form of the hierarchical structure of the IAEA Safety Standards Series and the preparation and review process for individual standards. The hierarchy of the Safety Standards Series comprises:

– *Safety Fundamentals*: these are the Agency's 'policy documents', specifying basic safety objectives and principles. There are currently three such publications, on nuclear, radiation and radioactive waste safety [1–3];
– *Safety Requirements* (formerly known as Codes or Safety Standards): these give detailed requirements for meeting the objectives and complying with the principles. Well known examples include the IAEA Regulations for the Safe Transport of Radioactive Material [4], the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [5] and the NUSS (Nuclear Safety Standards) Codes [6–10]; and
– *Safety Guides:* these provide recommendations and guidance on the means for satisfying the Safety Requirements.

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[1] Statute of the International Atomic Energy Agency, Article III.A.6: "[The Agency is authorized:] To establish or adopt…standards of safety for protection of health and minimization of danger to life and property…and to provide for the application of these standards…at the request of a State, to any of that State's activities in the field of atomic energy."

[2] The term 'standards' is used here in the sense of objectives to be achieved, principles to be followed or criteria to be considered, rather than in the sense of technological norms to be adhered to.

Safety standards are established in five categories: four thematic areas - the safety of nuclear installations (especially nuclear power plants and research reactors), radiation protection and the safety and security of radiation sources, the safe management of radioactive waste and the safe transport of radioactive materials — and a General Safety category, covering subjects relevant to all of the four areas: legal and governmental infrastructure for safety, emergency preparedness and response, and quality assurance.

To ensure the appropriate level of international consensus and technical quality, the preparation and review of safety standards follows a systematic process, including:

- Review and approval of proposals for new or revised safety standards by advisory bodies composed of senior experts representing Member States' regulatory authorities[3];
- Drafting by expert consultants from Member States;
- Review of drafts by the relevant Advisory Committee(s);
- Distribution of drafts to Member States for comment;
- Review and approval by the relevant Advisory Committee(s) and the ACSS; and
- Approval by the IAEA's Board of Governors (for Safety Fundamentals and Safety Requirements) and an internal IAEA Publications Committee.

This process is currently being used to develop a fully updated set of safety standards, to be completed within the next few years. Thereafter, the safety standards will continue to be kept under review, and will be revised periodically. A summary of the current status of the different safety standards is attached to this paper (Annex I).

The Agency produces many other safety related publications; for example, documents in the Safety Reports Series provide detailed information on methods for complying with the safety standards. However, the development of these other publications does not follow the same process used to ensure international consensus for safety standards, and therefore they do not constitute Agency recommendations.

2. THE AGENCY'S APPLICATION OF ITS SAFETY STANDARDS

The Agency's safety standards are binding for the Agency's own operations, including its technical assistance activities. Considerable efforts have accordingly been devoted in recent years to bringing the safety infrastructure in Member States receiving Agency assistance up to the level prescribed by the Agency's safety standards. In particular, Model Project(s) conducted jointly by the Agency's Technical Co-operation and Nuclear Safety Departments have assisted more than 50 Member States in establishing and strengthening basic radiation and waste safety infrastructure for their uses of radiation and radioactive materials. This was achieved by comparing country safety profiles — descriptions of the existing safety infrastructure in the State — to a 'reference' safety profile representing full compliance with the relevant Agency safety standards. Hence, the priority areas for improvement were identified, and action plans were developed and implemented to provide the necessary improvements. In the area of nuclear safety, the Agency has launched an

[3] There are four Advisory Committees - the Nuclear Safety Standards Advisory Committee (NUSSAC), the Radiation Safety Standards Advisory Committee (RASSAC), the Waste Safety Standards Advisory Committee (WASSAC) and the Transport Safety Standards Advisory Committee (TRANSSAC) - and an Advisory Commission for Safety Standards (ACSS), which oversees the work of the four Advisory Committees.

Integrated Strategy for Assisting Member States in Establishing and Strengthening their Safety Infrastructure. The Integrated Strategy uses a similar approach to that adopted in the Model Projects, with the 'reference safety profile' (the 'benchmark' to which country safety profiles are compared) in this case based on the Safety Requirements from the IAEA's NUSS (Nuclear Safety Standards) programme. This strategy is being applied in assisting countries in eastern Europe and the former USSR, and also in some countries of south-east Asia, the Pacific and the far East. In principle, it is well suited for all States with an emerging nuclear programme.

3. NATIONAL SAFETY STANDARDS

IAEA safety standards are not binding on Member States, but national authorities are encouraged to adopt them in national legislation or regulations. For that reason, they are written in a regulatory style, and can provide an internationally endorsed basis for developing national safety infrastructures. In general terms, the hierarchy of the safety standards can be compared to the hierarchy of a national framework of laws and regulations:

– Safety Fundamentals address the type of issues typically addressed by national policy and legislation;
– Safety Requirements can be considered approximately equivalent to national regulations, and are drafted with this in mind; and
– Safety Guides correspond approximately to regulatory guidance for licensees, indicating how they should go about complying with the regulations.

There is at least one further level essential to this framework of standards, namely the practical day-to-day safety tools, such as industrial standards for the design, construction, maintenance and testing of components and structures. Organizations at the national level need to define what type of national industrial standards (e.g. KTA[4], RCC[5], ASME[6]) need to be adopted, and possibly adapted, to complement IAEA safety standards. Other sources of information, such as international standards (e.g. those of ISO[7] and IEC[8]), might also be of use when selecting or developing the best solutions for national circumstances. Other safety related Agency publications also provide information on different tools and methods that are available.

The safety standards are largely expressed in terms of objectives or results to be achieved, rather than the detailed means for achieving them, and therefore different technical solutions can be applied. In developing the standards, this makes it easier to reach consensus between Member States which, in daily practice, use different approaches and solutions. Moreover, requirements and guidance formulated mainly in terms of objectives to be reached do not impede technological developments; the standards can remain valid for a long time, whereas technological solutions often have a shorter lifetime.

Developing a national system of safety standards is a major undertaking, even with the Agency's standards as a reference point. Clearly the range and nature of the safety standards that are needed depends on the scale and nature of the intended use(s) of nuclear technology; a

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[4] Kerntechnischer Auschuss (Germany).

[5] Règles de conception et de construction (France).

[6] American Society of Mechanical Engineers (USA).

[7] International Organization for Standardization.

[8] International Electrotechnical Commission.

large nuclear power programme requires far more than a few hospitals using X ray machines. However, as an example, the safety standards needed for a typical nuclear power programme would include:

- Nuclear safety standards, governing the siting, design and operation of the nuclear power plants and any other necessary fuel cycle installations;
- Radiation safety standards, governing the occupational radiation protection of the people employed in the programme, including dosimetry services, etc.;
- Waste safety standards for the management of the different categories of radioactive wastes (solid, liquid and gaseous), including their disposal, and for the decommissioning of installations at the end of their lives;
- Transport safety standards, governing the transport of new and spent fuel and radioactive waste between facilities; and
- General safety standards, covering
  - i) the legal and governmental infrastructure for implementing all of the above safety standards, including a regulatory system (authorization, inspection, enforcement, etc.) appropriate for the activities being carried out,
  - ii) preparedness for and the capability to respond to accidents or radiological emergencies resulting from any of the activities involved, and
  - iii) quality assurance for all safety related activities.

Furthermore, these safety standards ideally need to be well developed before the programme or installations are in place. Changes in the safety requirements during the implementation phase of a programme are likely to be much more costly, in money, time and effort, than changes before or during the planning phase. Contact between the regulator and the operators should therefore be established at an early stage to develop a common understanding, in advance, of the safety related constraints within which a nuclear power plant should be sited, designed, constructed and operated. Such constraints should be spelt out in the national standards.

In summary, the IAEA has a comprehensive set of safety standards for nuclear power plants. Although they are non-binding in nature, the standards are written in a regulatory style, so that their contents can readily be used in national rules and regulations. The Agency has committed itself to revise and update the whole set of safety standards; in a few years time a comprehensive set of updated standards will be in place, which will be maintained over the coming years with revisions expected approximately every seven years.

4. SAFETY RELATED CONVENTIONS

An increasingly important element in improving nuclear, radiation and radioactive waste safety is the growing system of legally binding intergovernmental agreements. The main such agreements related to safety currently in force are:

- The Convention on Physical Protection of Nuclear Material: this entered into force in February 1987, and now has over 60 Contracting Parties;
- The Convention on Early Notification of a Nuclear Accident: this entered into force in October 1986, and now has over 80 Contracting Parties;
- The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency: this entered into force in February 1987, and now has over 75 Contracting Parties;

– The Convention on Nuclear Safety: this entered into force in October 1996, and now has over 45 Contracting Parties, including 27 of the 30 States that have operating nuclear power plants.

The physical protection, early notification and assistance Conventions have been operating for more than a decade; for example, the Agency typically provides or co-ordinates assistance to States in dealing with accidents involving radiation sources at least once or twice each year.

5. CONVENTION ON NUCLEAR SAFETY

Unlike the three earlier Conventions, the Convention on Nuclear Safety is an ‘incentive’ Convention, in that a Contracting Party’s fulfilment of its obligations under the terms of the Convention is judged only by means of peer review by the other Contracting Parties, rather than by control or sanction. The objectives of the Convention are set out clearly in its first Article:

– To achieve a high level of safety worldwide;

– To protect people and the environment; and

– To prevent and mitigate accidents.

The General Provisions of the Convention can be considered as embodying the basic obligations on Contracting Parties (the remaining Articles being essentially elaboration of these three objectives):

– That each Contracting Party has or puts in place the laws, organizations and measures necessary to achieve and maintain a high level of safety;

– That each Contracting Party review the safety of its existing nuclear power plants takes any necessary corrective actions; and

– That each Contracting Party submit, for review by other Contracting Parties, reports on the measures it has taken to meet with its obligations under the Convention (see below).

The Convention then sets out more specific obligations on Contracting Parties concerning the national safety infrastructure — the legislative and regulatory framework and the regulatory body — and several technical obligations. These technical obligations are modelled to a large extent on the principles set out in the IAEA Safety Fundamentals publication “The Safety of Nuclear Installations” [1], and are designed to represent a legally binding set of ‘benchmarks’ for nuclear safety[9] to which the Contracting Parties subscribe.

The technical obligations cover:

– Responsibility of the licence holder;

– Priority to safety;

– Financial and human resources;

[9] The “nuclear installations” to which the Convention applies are land-based civil nuclear power plants, including any storage, handling or treatment facilities on the same site.

– Human factors;
– Quality assurance;
– Assessment and verification of safety;
– Radiation protection;
– Emergency preparedness;
– Siting;
– Design and construction; and
– Operation.

In each case, the obligation is represented by the statement of a principle (or principles) without elaboration. For example, the Article on human factors states that: “Each Contracting Party shall take the appropriate steps to ensure that the capabilities and limitations of human performance are taken into account throughout the life of a nuclear installation”.

Contracting Parties are required periodically to submit national reports describing the measures taken to meet these technical obligations. These national reports are then distributed for peer review, and discussed in detail at a Review Meeting of the Contracting Parties. Although the Convention does not specifically refer to them, the Agency’s safety standards have been developed in accordance with principles very similar to the technical obligations in the Convention, and therefore are likely to provide an important point of reference; indeed, the Preamble to the Convention recognizes the existence of “internationally formulated safety guidelines which are updated from time to time and so can provide guidance on contemporary means of achieving a high level of safety”. The deadline for submission of the first set of national reports was 29 September 1998, and the Review Meeting to discuss these reports will be held in Vienna, starting on 12 April 1999.

6. JOINT CONVENTION

A fifth Convention, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, was opened for signature in 1997, and will enter into force 90 days after the 25th ratification or the 15th ratification by a State with at least one operating nuclear power plant, whichever is the later. Like the Convention on Nuclear Safety, the Joint Convention is an ‘incentive convention’ by which Contracting Parties subscribe to a set of technical obligations designed to ensure a high level of safety. In this case, the technical obligations are modelled largely on the principles set out in the IAEA Safety Fundamentals publication “The Principles of Radioactive Waste Management” [2], and the text of the Convention makes more explicit reference to internationally endorsed criteria and standards; the Preamble refers to the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [5] and to “the existing international standards relating to the safety of the transport of radioactive materials”.

7. CONCLUSION

The legally binding Conventions therefore complement the non-binding IAEA safety standards by promoting their international application. Together, the safety standards and Conventions provide an international framework for nuclear safety.

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[3] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, NUCLEAR ENERGY AGENCY OF THE ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Radiation Protection and the Safety of Radiation Sources, Safety Series No. 120, IAEA, Vienna (1996).

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[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, NUCLEAR ENERGY AGENCY OF THE ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Governmental Organization, Safety Series No. 50-C-G (Rev. 1), IAEA, Vienna (1988).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Siting, Safety Series No. 50-C-S (Rev. 1), IAEA, Vienna (1988).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Design, Safety Series No. 50-C-D (Rev. 1), IAEA, Vienna (1988).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Operation, Safety Series No. 50-C-O (Rev. 1), IAEA, Vienna (1988).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations, Safety Series No. 50-C/SG-Q, IAEA, Vienna (1996).

Annex I

STATUS OF THE IAEA SAFETY STANDARDS PROGRAMME

September 1998

Legend:

(Blank)	No revision planned
□□□□□□	New document or revision planned
◙□□□□□	DPP in preparation or awaiting approval
■□□□□□	DPP approved by AC(s)
■◙□□□□	Document being drafted
■■□□□□	Awaiting approval of ACs for submission to MS
■■◙□□□	Approved by ACs, submitted to MS for comments
■■■□□□	Awaiting comments from MS/incorporating comments from MS
■■■◙□□	Awaiting approval by ACs for submission to ACSS
■■■■□□	Endorsed by ACSS/Final editing
■■■■◙□	Submitted to BoG/Publication Committee
■■■■■□	Approved by BoG/Publication Committee
■■■■■◙	In print/in translation
■■■■■■	Published in ....

Throughout this report the first column gives the IAEA Safety Series number and the title of published standards. The second column gives the working identification number (NS…) of standards being developed or revised. Bold type indicates standards issued, or to be issued, under the authority of the Board of Governors, others are issued under the authority of the Director General.

General Safety

I. IAEA Safety Fundamentals

Published Safety Standards **Safety Series No. - Title**	**Safety Standards in Preparation** **WID - Title**	**Status / Remarks**	**Committee**
110: The Safety of Nuclear Installations (1993)		The three fundamentals **(Nos. 110, 111F and 120)** to be combined into one document. No plans for revision prior to the year 2001.	
111-F: The Principles of Radioactive Waste Management - (1993)		No plans for revision prior to the year 2001.	
120: Radiation Protection and the Safety of Radiation Sources - (1996)		No plans for revision prior to the year 2001.	

II. Emergency Preparedness and Response

Published Safety Standards **Safety Series No. - Title**	**Safety Standards in Preparation** **WID - Title**	**Status / Remarks**	**Committee**
	NS 43 Int. Requirements for Nuclear and Radiation Emergency Preparedness and Response	DPP approved. ■□□□□□	RASSAC,NUSSAC, WASSAC,TRANSSAC
50-SG-G6 Preparedness of Public Authorities for Emergencies at Nuclear Power Plants (1982)		Revision to start in 1999. □□□□□□	
50-SG-O6 Preparedness of the Operating Organization (Licensee) for Emergencies at NPPs (1982)		Revision to start in 1999. □□□□□□	
109 - Intervention Criteria in a Nuclear or Radiation Emergency (1994)	NS 44 Intervention Criteria in a Nuclear or Radiation Emergency	DPP in preparation. ◙□□□□□	RASSAC NUSSAC
98 - On-Site Habitability in the Event of an Accident at a Nuclear Facility (1989)		Revision to start in 1999. □□□□□□	

III. Governmental Organization (revised safety standards to be published in General Safety category)

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-C-G (Rev. 1) Code on the Safety of Nuclear Power Plants: Governmental Organization (1988)	**NS 180 - Requirements: Legal & governmental infrastructure for nuclear, radiation, radioactive waste and transport safety**	New Appendix on waste safety under preparation. To be sent to WASSAC/ ACSS. ■■■◙□□	NUSSAC, RASSAC WASSAC,T RANSSAC
50-SG-G1 Qualifications and Training of Staff of the Regulatory Body for Nuclear Power Plants (1979)	**NS 247 -** Organization and Staffing of the Regulatory Body for Nuclear Facilities and activities	DPP approved. ■□□□□□	NUSSAC, WASSAC
50-SG-G2 Information to be Submitted in Support of Licensing Applications for Nuclear Power Plants (1979)	**NS 290 -** Documentation in Regulatory Process for Nuclear Facilities (Combining G2,G8 and G9)	DPP approved. ■□□□□□	NUSSAC, WASSAC
50-SG-G3 Conduct of Regulatory Review and Assessment during the Licensing Process for Nuclear Power Plants (1980)	**NS 248 -** Conduct of Regulatory Review and Assessment of Nuclear Facilities	DPP approved. ■□□□□□	NUSSAC, WASSAC
50-SG-G4 (Rev. 1) Inspection and Enforcement by the Regulatory Body for Nuclear Power Plants (1996)	**NS 289 -** Inspection and Enforcement by the Regulatory Body for Nuclear Facilities	DPP approved. ■□□□□□	NUSSAC, WASSAC
50-SG-G8 Licences for Nuclear Power Plants: Content, Format and Legal Considerations (1982)	**NS 290 -**(Combining G2,G8 and G9)		NUSSAC, WASSAC
50-SG-G9 Regulations and Guides for Nuclear Power Plants (1984)	**NS 290 -**(Combining G2,G8 and G9)		NUSSAC, WASSAC

IV. Quality Assurance*

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-C-Q Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations (1996)		No revision is foreseen prior to 2001 for quality assurance publications.	
50-SG-Q1 Establishing and Implementing a Quality Assurance Programme		No revision is foreseen prior to 2001.	
50-SG-Q2 Non-conformance Control and Corrective Actions		No revision is foreseen prior to 2001.	
50-SG-Q3 Document Control and Records		No revision is foreseen prior to 2001.	
50-SG-Q4 Inspection and Testing for Acceptance		No revision is foreseen prior to 2001.	
50-SG-Q5 Assessment of the Implementation of the Quality Assurance Programme		No revision is foreseen prior to 2001.	
50-SG-Q6 Quality Assurance in the Procurement of Items and Services		No revision is foreseen prior to 2001.	
50-SG-Q7 Quality Assurance in Manufacturing		No revision is foreseen prior to 2001.	
50-SG-Q8 Quality Assurance in Research and Development		No revision is foreseen prior to 2001.	
50-SG-Q9 Quality Assurance in Siting		No revision is foreseen prior to 2001.	
50-SG-Q10 Quality Assurance in Design		No revision is foreseen prior to 2001.	
50-SG-Q11 Quality Assurance in Construction		No revision is foreseen prior to 2001.	
50-SG-Q12 Quality Assurance in Commissioning		No revision is foreseen prior to 2001.	
50-SG-Q13 Quality Assurance in Operation		No revision is foreseen prior to 2001.	
50-SG-Q14 Quality Assurance Decommissioning		No revision is foreseen prior to 2001.	

* In the 1996 edition the Code (Requirement) and Guides are in a single document (50-C/SG-Q). The revised safety standards will be published in the General Safety category.

Nuclear Safety

I. Operation of Nuclear Power Plants

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-C-O (Rev. 1) Code on the Safety of Nuclear Power Plants: Operation (1988)	**NS 179 Requirements for the Safety of Nuclear Power Plants: Operation**	Draft arising from MS comments to be sent to NUSSAC for final approval. ■■■◙□□	NUSSAC
50-SG-O1 (Rev. 1) Staffing of Nuclear Power Plants and the Recruitment, Training and Authorization of Operating Personnel (1991)	**NS 287** Staffing of NPPs and the Recruitment, Training and Qualification of Plant Personnel	DPP approved at 5^{th} NUSSAC meeting. Draft safety guide with NUSSAC for review. ■■□□□□	NUSSAC
50-SG-O2 In-service Inspection for Nuclear Power Plants ((1980)	**NS 273** Maintenance, Testing Surveillance and In-Service Inspection of NPPs (Combining O2,O7 & O8)	NUSSAC comments received on first draft. ■■□□□□	NUSSAC
50-SG-O3 Operational Limits and Conditions for Nuclear Power Plants (1979)	**NS 185** Operations - Operating limits, conditions & procedures	To be sent to NUSSAC for final approval. ■■■◙□□	NUSSAC
50-SG-O4 Commissioning Procedures for Nuclear Power Plants (1980)		Revision to commence in 1998. □□□□□□	NUSSAC
50-SG-O5 Radiation Protection during Operation of Nuclear Power Plants (1983*)*	**NS 187** Safety Guide on Radiation Protection and Radioactive Waste Management in Nuclear power Plants (Combining O5&O11)	To be sent to MS for comments. ■■◙□□□	RASSAC, NUSSAC, WASSAC
50-SG-O7 (Rev. 1) Maintenance of Nuclear Power Plants (1990)	**See NS 273** (Combining O2, O7 & O8)		NUSSAC
50-SG-O8 (Rev. 1) Surveillance of Items Important to Safety in Nuclear Power Plants (1990)	**See NS 273** (Combining O2, O7 & O8)		NUSSAC
50-SG-O9 Management of Nuclear Power Plants for Safe Operation (1984)	**NS 250** Operating Organization	To be revised following MS comments. ■■■□□□	NUSSAC
50-SG-O10 Core Management and Fuel Handling for Nuclear Power Plants (1985)		Revision to commence in 1999. □□□□□□	NUSSAC

I. Operation of Nuclear Power Plants (Cont.)

Published Safety Standards Safety Series No. - Title	**Safety Standards in Preparation WID - Title**	**Status / Remarks**	**Committee**
50-SG-O11 Operational Management of Radioactive Effluents and Wastes arising in Nuclear Power Plants (1986)	See **NS 187** (Combining O5 and O11)		NUSSAC
50-SG-O12 Periodic Safety Review of Operational Nuclear Power Plants (1994)		Revision commencing in 1998. □□□□□□	NUSSAC
93 - System of Reporting Unusual Events in Nuclear Power Plants	**NS 288** National Experience Feedback System for Unusual Events in NPPs	NUSSAC comments received on 1st draft. ■■□□□□	NUSSAC
	NS 263 Fire Safety During Operation	Comments received from MS. ■■■□□□	NUSSAC
	NS 251 Modifications to Nuclear Power Plants	NUSSAC comments received on 1st draft. ■■□□□□	NUSSAC

II. Design of Nuclear Power Plants

Published Safety Standards Safety Series No. - Title	**Safety Standards in Preparation WID - Title**	**Status / Remarks**	**Committee**
50-C-D (Rev. 1) Code on the Safety of Nuclear Power Plants: Design (1988)	**NS 181 Requirements on the Safety of Nuclear Power Plants: Design**	Revised following MS comments and sent to NUSSAC for review. ■■■◙□□	NUSSAC
50-SG-D1 Safety Functions and Component Classification for BWR, PWR and PTR (1979)		Some of the content has been included in NS 181 and others in NS 252 & NS 282.	NUSSAC
50-SG-D2 (Rev. 1) Fire Protection in Nuclear Power Plants (1992)		No revision is foreseen prior to 2000.	
50-SG-D3 Protection System and Related Features in Nuclear Power Plants (1980)	**NS 252** Instrumentation and control for systems important to safety in NPPs	With NUSSAC for 1st review. ■■□□□□	NUSSAC
50-SG-D4 Protection against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants (1980)		No revision is foreseen prior to 1999.	

II. Design of Nuclear Power Plants (Cont.)

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-SG-D5 (Rev. 1) External Man-induced Events in relation to Nuclear Power Plant Design (1996)		No revision is foreseen prior to 2000.	
50-SG-D6 Ultimate Heat Sink and Directly Associated Heat Transport Systems for NPPs (1981)	**NS 282** Reactor Cooling Systems in Nuclear Power Plants	DPP approved by NUSSAC in April 1998. ■□□□□□	NUSSAC
50-SG-D7 (Rev. 1) Emergency Power Systems at Nuclear Power Plants (1991)		No revision is foreseen prior to 2000.	
50-SG-D8 Safety-related Instrumentation and Control Systems for Nuclear Power Plants (1984)	**See NS 252** (Combining D3 and D8)		
50-SG-D9 Design Aspects of Radiation Protection for Nuclear Power Plants (1985)		No revision is foreseen prior to 1999.	NUSSAC, RASSAC
50-SG-D10 Fuel Handling and Storage Systems in Nuclear Power Plants (1984)	**NS 276** Fuel Handling and Storage Systems in Nuclear Power Plants	Will be considered by NUSSAC together with NS 181 before submission to ACSS. ■■■◙□□	NUSSAC
50-SG-D11 General Design Safety Principles for Nuclear Power Plants (1986)	**NS 253** Design verification and safety assessment	With NUSSAC for 1st review. ■■□□□□	NUSSAC
50-SG-D12 Design of the Reactor Containment Systems in Nuclear Power Plants (1985)		No revision is foreseen prior to 1999.	
50-SG-D13 Reactor Coolant and Associated Systems in Nuclear Power Plants (1986)	See **NS 282** (Combining D6 and D13)		NUSSAC
50-SG-D14 Design for Reactor Core Safety in Nuclear Power Plants (1986)	**NS 283** Reactor Core Safety in Nuclear Power Plants	DPP approved by NUSSAC in April 1998. ■□□□□□	NUSSAC
50-SG-D15 Seismic Design and Qualification for Nuclear Power Plants (1992)		No revision is foreseen prior to 2000.	
	NS 264 Software for Computer Based Systems Important to safety	To be sent to MS for comments. ■■◙□□□	NUSSAC

III. Siting of Nuclear Power Plants

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-C-S (Rev. 1) Code on the Safety of Nuclear Power Plants: Siting (1988)		No revision is foreseen prior to 2000.	
50-SG-S1 (Rev. 1) Earthquakes and Associated Topics in relation to NPP Siting (1991)		No revision is foreseen prior to 2000.	
50-SG-S3 Atmospheric Dispersion in Nuclear Power Plant Siting (1980)	**NS 182** Dispersion of radioactive material around NPPs (Combining S3, S4, S6, S7)	Work on first draft in progress, to be sent to NUSSAC for review in 1998. ■◙□□□□	NUSSAC
50-SG-S4 Site Selection and Evaluation for NPPs with respect to Population Distribution (1980)	**See NS 182** (Combining S3, S4, S6, S7)		NUSSAC
50-SG-S5 External Man-induced Events in relation to Nuclear Power Plant Siting (1981)	**NS 258** External man induced events in relation to NPP siting	Document under revision following NUSSAC comments. ■■□□□□	NUSSAC
50-SG-S6 Hydrological Dispersion of Radioactive Material in relation to NPP Siting (1985)	**See NS 182** (Combining S3, S4, S6, S7)		NUSSAC
50-SG-S7 Nuclear Power Plant Siting: Hydrogeological Aspects (1984)	**See NS 182** (Combining S3, S4, S6, S7)		NUSSAC
50-SG-S8 Safety Aspects of the Foundations of Nuclear Power Plants (1986)		No revision is foreseen prior to 2000.	
50-SG-S9 Site Survey for NPPs (1984)		No revision is foreseen prior to 1999.	
50-SG-S10A Design Basis Flood for Nuclear Power Plants on River Sites (1983)	**NS 280** Design Basis Flood for Nuclear Power Plants on River Sites	DPP approved by NUSSAC in April 1998. ■□□□□□	NUSSAC
50-SG-S10B Design Basis Flood for Nuclear Power Plants on Coastal Sites (1983)	**NS 281** Design Basis Flood for Nuclear Power Plants on Coastal Sites	DPP approved by NUSSAC in April 1998. ■□□□□□	NUSSAC
50-SG-S11A Extreme Meteorological Events in NPP Siting, excluding Tropical Cyclones (1981)	**NS 184** Extreme Meteorological Events in NPP Siting (Combining S11A and S11B)	Work has begun on first draft to be sent to NUSSAC for review in 1998. ■◙□□□□	NUSSAC

III. Siting of Nuclear Power Plants (Cont.)

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
50-SG-S11B Design Basis Tropical Cyclone for Nuclear Power Plants (1984)	**See NS 184** (Combining S11A and S11B)		NUSSAC

IV. Research Reactor Safety

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
35-S1 Code on the Safety of Nuclear Research Reactors: Design (1992)	**NS 272 Safety Requirements for the Design and Operation of Research Reactors**	Drafting in progress. CS in April 98. TCM in Oct. 98. ■◙□□□□	NUSSAC
35-S2 Code on the Safety of Nuclear Research Reactors: Operation (1992)	**See NS 272**		
35-G1 Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report (1994)		No revision is foreseen prior to 2001.	
35-G2 Safety in the Utilization and Modification of Research Reactors (1994)		No revision is foreseen prior to 2001.	
	NS 259 Safety in the Commissioning of Research Reactors	Endorsed by ACSS for publication. ■■■■□□	NUSSAC
	NS 260 Research Reactors: Maintenance, Periodic Testing and Inspections	Endorsed by ACSS for publication. ■■■■□□	NUSSAC
	NS 261 Research Reactors: Operational Limits and Conditions	Endorsed by ACSS for publication. ■■■■□□	NUSSAC
	NS 262 Design, Operation and Safety Assessment of Spent Fuel Storage for Research Reactors	Endorsed by ACSS for publication. ■■■■□□	NUSSAC

Radiation Safety

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
115 - International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (1996)		No plans for revision before year 2001.	
26 - Radiation Protection of Workers in the Mining and Milling of Radioactive Ores (1983)	**NS 17** Radiation Protection of Workers in the Mining and Milling of Radioactive Ores	New draft being prepared for consideration by RASSAC, before submission to MS for comments. ■■□□□□	RASSAC
89 - Principles for the Exemption of Radiation Sources and Practices from Regulatory Control (1988)	**NS 33** Application of the principles for exclusion, exemption and clearance from Regulatory Control	Initial draft in preparation (TCM, December 1998). ■◙□□□□	RASSAC WASSAC
101 - Operational Radiation Protection: A Guide to Optimization (1990)		Revision to start in 1999. □□□□□□	RASSAC
107 - Radiation Safety of Gamma and Electron Irradiation Facilities (1992)		No revision is foreseen prior to the year 2001.	
	NS 22 Radiation Protection in the Medical Exposure of Patients.	Revised draft considered by RASSAC. Submission to MS is expected in October 98. ■■□□□□	RASSAC
	NS 21 Occupational Radiation Protection in the Decommissioning of Nuclear Facilities	Draft available but on hold. Needs DPP if it is to go ahead.	RASSAC
	NS 69 Occupational Radiation Protection: Application of Principles	Endorsed by ACSS for publication. ■■■■□□	RASSAC
	NS 85 Occupational Radiation Protection: Assessment of Exposure from Intakes of Radionuclides	Endorsed by ACSS for publication. ■■■■□□	RASSAC

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 12 Occupational Radiation Protection: Assessment of Exposure from External Sources of Radiation	Endorsed by ACSS for publication. ■■■■□□	RASSAC
	NS 31 Consumer Products Containing Radioactive Substances	Further explanation to be provided to RASSAC before submission to MS for comments. ■■□□□□	RASSAC
	NS 51 Application of the Principles of Radiation Protection to Chronic Exposure Situations	Not yet started. DPP expected 1998. □□□□□□	RASSAC
	NS 61 Preventing, Detecting of and Responding to Illicit Trafficking in Radioactive Materials	MS comments are being considered. ■■■□□□	RASSAC
	NS 73 Training in Radiation and Waste Safety	DPP agreed by RASSAC (March 1998). ■□□□□□	RASSAC WASSAC
	NS 113 Quality Assurance in Radiation Protection	Action deferred until ACSS advice is available on QA in general.	RASSAC
	NS114 Safety of Radiation Sources	Sent to MS for comment February 1998, but now will be combined with **NS 32**	RASSAC
	NS 32 Extension of the Principles of Radiation Protection to Sources of Potential Exposure (Revision of SS-104, 1990)	DPP in preparation. ◙□□□□□	RASSAC

Radioactive Waste Safety

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
69 -Management of Radioactive Wastes from Nuclear Power Plants - (1985)		No revision is foreseen prior to the year 2001.	
78 -Definition and Recommendations for the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, 1972 — 1986 Edition		No revision is foreseen prior to the year 2001.	
79- Design of Radioactive Waste Management Systems at Nuclear Power Plants (1986)		No revision is foreseen prior to the year 2001.	
105 - The Regulatory Process for the Decommissioning of Nuclear Facilities (1990)		No revision is foreseen prior to the year 2001.	
108 - Design and Operation of Radioactive Waste Incineration Facilities (1992)		No revision is foreseen prior to the year 2001.	

I. Infrastructure

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
111-S-1 Establishing a National System for Radioactive Waste Management (1995)		Will be superseded by **NS 180.**	
111-G-1.1 Classification of Radioactive Waste (1994)		No revision is foreseen prior to the year 2001.	
	NS 286 Application of the Principles of Radiation Protection to the Rehabilitation of Contaminated Areas (practices and interventions)	DPP approved by WASSAC (December 97) and RASSAC (April 98). ■□□□□□	WASSAC, RASSAC
	NS 161 Management of the Removal of Control of Materials from Regulated Nuclear Activities	DPP approved by WASSAC (June 98) , considered by RASSAC (Sept. 98). Initial drafting expected in October 98. ■◙□□□□	WASSAC, RASSAC

II. Discharges

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 285 Discharges of radionuclides into the Environment	Development of the document to be considered further by RASSAC and WASSAC.	RASSAC, WASSAC
77 - Principles for Limiting Releases of Radioactive Effluents into the Environment (1986)	**NS 25** Regulatory Control of radioactive discharges into the environment	To be considered by WASSAC (Dec. 98) for submission to ACSS. ■■■◙□□	RASSAC, WASSAC
90 The Application of the Principles for Limiting Releases of Radioactive Effluents in the Case of the Mining and Milling of Radioactive Ores (1989)		No revision is foreseen prior to the year 2001.	
	NS 62 Effluent and Environmental Monitoring for Radiation Protection of the Public	Draft to be considered by WASSAC (Dec. 98) for submission to MS for comments. ■■□□□□	RASSAC, WASSAC

III. Pre-disposal

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 152 Pre-disposal Management of Radioactive Waste (including Decommissioning)	To be submitted to ACSS, after approval (by correspondence) by WASSAC. ■■■◙□□	WASSAC
	NS 159 Pre-disposal Management of Low and Intermediate Level Waste from Nuclear Fuel Cycle Facilities	To be considered by WASSAC (Dec. 98) before submission to MS for comments. ■■□□□□	WASSAC
	NS 163 Pre-disposal Management of High Level Waste	DPP approved (WASSAC-3). Drafting of document started. ■◙□□□□	WASSAC
	NS 160 Pre-disposal Management of Radioactive Waste from Medicine, Industry and Research	To be considered by WASSAC (Dec. 98) before submission to MS for comments. ■■□□□□	WASSAC

III. Pre-disposal (Cont.)

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 257 Decommissioning of Nuclear Power Plants and Research Reactors	To be submitted to ACSS. ■■■◙□□	WASSAC, NUSSAC
	NS 171 Decommissioning of Nuclear Fuel Cycle Facilities	To be considered by WASSAC (Dec. 98), Before submission to MS for comments. ■■□□□□	WASSAC, NUSSAC
	NS 173 Decommissioning of Medical, Industrial and Research Facilities	To be submitted to ACSS. ■■■◙□□	WASSAC
	NS 284 Safety Assessment for Pre-disposal Waste Management	Reviewed by WASSAC (June 98), to be submitted to MS for comments. ■■◙□□□	WASSAC

IV. Disposal

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 153 Near Surface Disposal of Radioactive Waste	Endorsed by ACSS (June 98) to be submitted to the Board of Governors for approval. ■■■■□□	WASSAC
111-G-3.1 Siting of Near Surface Disposal Facilities (1994)		No revision is foreseen prior to the year 2001.	
	NS 165 Design, Construction, Operation and Closure of Near Surface Repositories	Status of the topic to be further discussed by WASSAC (Dec. 98).	WASSAC
	NS 166 Safety Assessment for Near Surface Disposal	Endorsed by ACSS (June 98) to be submitted to the Publication Committee for approval. ■■■■□□	WASSAC

IV. Disposal (Cont.)

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
99 -Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes (1989)	**NS 154 Geological Disposal of Radioactive Waste**	Revision to start in 1999. ◙□□□□□	WASSAC
111-G-4.1 Siting of Geological Disposal Facilities (1994)		No revision is foreseen prior to the year 2001.	
	NS 168 Design, Construction, Operation and Closure of Geological Repositories	To be considered further by WASSAC in connection with **NS 169**	WASSAC
96- Guidance for Regulation of Underground Repositories for Disposal of Radioactive Wastes (1989)		To be superseded by **NS 153** and **NS 154**.	WASSAC
	NS 169 Safety Assessment for Geological Disposal	To be considered further by WASSAC in connection with **NS 169** ■□□□□□	WASSAC
85 -Safe Management of Wastes from the Mining and Milling of Uranium and Thorium Ores(1987)	**NS 277** Management of Radioactive Waste from Mining and Milling of U/Th ores	DPP approved by WASSAC (May 97). A draft document is being developed. ■◙□□□□	WASSAC

V. Rehabilitation

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
	NS 162 Rehabilitation of Contaminated Areas in Intervention Situations	DPP approved by WASSAC (December 97) and RASSAC (April 98). ■□□□□□	WASSAC, RASSAC
	NS 172 Rehabilitation of Areas with Contamination from Past Activities and Accidents, in Intervention Situations.	DPP approved by WASSAC (December 97) and RASSAC (April 98). ■□□□□□	WASSAC, RASSAC

Transport Safety

Published Safety Standards Safety Series No. - Title	Safety Standards in Preparation WID - Title	Status / Remarks	Committee
ST-1 Regulations for the Safe Transport of Radioactive Material (Requirements) (1996)		Remains current. (Published in E, F, R, S) ■■■■■■	TRANSSAC
7 - Explanatory Material for the IAEA Regulations for the Safe Transport of Radioactive Material	**NS 245 -** Advisory material for the regulations for the safety transport of radioactive material	Final draft being prepared for ACSS consideration. ■■■◙□□	TRANSSAC
37 - Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material	See **NS 245**		TRANSSAC
87 - Emergency Response Planning and Preparedness for Transport Accidents Involving Radioactive Material	**NS 246** Emergency response planning and preparedness for transport accidents involving radioactive material.	Final draft being prepared for ACSS consideration. ■■■◙□□	TRANSSAC

THE INTERNATIONAL ATOMIC ENERGY AGENCY'S SAFEGUARDS SYSTEM

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Abstract

A system of international safeguards has been established to provide assurance that nuclear materials in civilian use are not diverted from their peaceful purpose. The safeguards system is administered by the International Atomic Energy Agency/ Department of Safeguards and devolves from treaties and other international agreements. Inspectors from the Agency verify reports from States about nuclear facilities by audits, observation, and measurements.

1. THE MANDATE AND ITS FULFILMENT

1.1. The beginnings

In 1953 the USA proposed the establishment of an International Atomic Energy Agency (IAEA), which would spread the benefits of nuclear technology in return for an undertaking by each Member State (country) to use it only for peaceful purposes and to accept safeguards to verify this undertaking. After three years of negotiations this concept was eventually reflected in a crucial article (Article III.A.5) of the IAEA's Statute which authorized it "to establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy". The Statute came into force in 1957 and the IAEA began work, in Vienna, the same year.

Representatives of the Member States meet annually in a General Conference. The General Conference, among other responsibilities, elects members of the Board of Governors, which meets about four times per year and has the authority to carry out the functions of the Statute. The Board sets policy, which is implemented by the Secretariat (i.e. staff), headed by the Board-appointed Director General. The Secretariat is in turn composed of six Departments, each headed by a Deputy Director General, one of which is the Department of Safeguards.

From 1957 until 1964 little was done to activate the IAEA's safeguards. By the end of that period all five permanent members of the UN Security Council, China, France, the USSR, the USA and the United Kingdom, had tested nuclear weapons. It was clear that neither strict controls on the transfer of technology nor safeguards applied by exporting countries had been effective in preventing the spread of nuclear weapons.

In 1965 the first major step was taken to develop systematically the IAEA's safeguards by adopting a safeguards system to replace an earlier one which covered only reactors. This new system, which was extended in 1966 and 1968 (IAEA document INFCIRC/66/Rev. 2), is still applied in Safeguards Agreements with non-nuclear-weapon

States that have nuclear programmes and that have not expressly submitted all their nuclear activities to IAEA safeguards. States under such safeguards agreements are India, Pakistan, Israel and Cuba.

1.2. The treaty on the non-proliferation of nuclear weapons

Prolonged negotiations at the United Nations' Eighteen Nation Disarmament Committee finally bore fruit in 1968 in an agreement on the text of a treaty designed explicitly to prevent the spread of nuclear weapons: the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). The NPT was subsequently endorsed by the General Assembly and entered into force in March 1970. In May 1995, The Review and Extension Conference decided to extend the NPT indefinitely.

Each non-nuclear-weapon State that becomes party to the NPT undertakes not to acquire nuclear weapons or other nuclear explosives (Article II). It also undertakes to conclude an agreement with the IAEA for the application of safeguards to all its peaceful nuclear activities with a view to verifying the fulfillment of its obligations under the Treaty (Article III). In return the Treaty recognizes the right of all Parties to participate in the fullest possible exchange of equipment, materials, and scientific and technological information for the peaceful uses of nuclear energy; the Treaty also asserts that all Parties undertake to facilitate those rights (Article IV). The Parties also undertake to pursue negotiations in good faith towards nuclear disarmament (Article VI) and re-affirm their determination to achieve the discontinuance of all tests of nuclear weapons (Preamble); these commitments obviously apply principally to the nuclear-weapon States themselves, who alone, under the Treaty, may develop and test nuclear weapons.

Several of the concepts reflected in the NPT had already been incorporated into the regional Treaty for the Prohibition of Nuclear Weapons in Latin America, which the Latin American countries had negotiated and opened for signature in February 1967. This treaty is known as the Tlatelolco Treaty after the location in Mexico where it was concluded. A similar nuclear-free zone has been established in the South Pacific through the Rarotonga Treaty.

To carry out the safeguards obligations assigned to the IAEA by the NPT it, was clearly necessary for the IAEA to devise a safeguards system appropriate for the entire fuel cycle of the advanced industrial countries that were expected to become party to the Treaty. This NPT safeguards system, which was formulated in 1970 and approved by the IAEA Board of Governors the same year, is set forth in IAEA document INFCIRC/153 (corrected). This is in the form of suggested language for a bilateral agreement between a State and the IAEA for the application of safeguards in connection with the NPT.

The Safeguards Agreements which States party to the NPT have concluded with the IAEA follow very closely the wording of this document. They usually differ only in minor provisions not related to the scope and procedure of safeguards, e.g. the financing of safeguards, the obligation of the State to grant certain privileges and immunities to inspectors, and amendments to the agreement.

The implementation of safeguards which follow the NPT model (INFCIRC/153) is specified on the State level in Subsidiary Arrangements and associated Facility Attachments.

Subsidiary arrangements are a codified set of technical and administrative procedures designed primarily to implement the safeguards procedures laid down in safeguards agreements; they deal with matters such as design review, records requirements, reporting requirements and inspections. They consist of a general part applicable to all nuclear activities of the country concerned and Facility Attachments, which contain specific procedures for each facility.

1.3. The assurance given by safeguards

Safeguards are essentially a technical means of verifying the fulfillment of political obligations undertaken by States in concluding international agreements relating to the peaceful uses of nuclear energy. Today most of these obligations flow from the NPT and similar treaties. The main political objective of safeguards is to assure the international community that States are complying with their non-proliferation and other peaceful use undertakings. By 31 December 1996, 179 States had signed the NPT. 214 safeguards agreements were in force with 131 States (and with Taiwan). The five nuclear-weapon States have made Voluntary Offers to place all or part of their nuclear facilities under safeguards. All five nuclear-weapon States have safeguards agreements under these voluntary offers in force, with IAEA safeguards applied at designated facilities. A complete list of the States and facilities under safeguards can be found in the IAEA Annual Report.

States conclude safeguards agreements voluntarily and the IAEA has no authority to apply safeguards unless the State concerned so requests since the State is obliged to do if it is a party to such legal instruments as the NPT, or Tlatelolco or Rarotonga Treaties. In view of the voluntary nature of this acceptance of safeguards, it is reasonable to expect that the normal results of applying safeguards will be to confirm that there has in fact not been any diversion. Confirmation that this is so results from independent verification by the IAEA inspectorate of declared nuclear material and facilities. The assurance obtained from the IAEA's activities as an independent and objective auditor increases confidence between States.

The carrying out of safeguards activities is also aimed at dissuading any State that might contemplate diversion of nuclear materials or the misuse of nuclear facilities. It follows that, to constitute an effective deterrent, safeguards must be technically capable (and be seen to be capable) of promptly detecting a diversion.

The Agency's safeguards activities thus have two effects:

(1) they increase confidence between States that no nuclear material has been diverted to weapon purposes; and

(2) they deter potential diverters by making it likely that diversion will be discovered and made public.

1.4. Strengthened IAEA safeguards

In 1991 the Board of Governors of the IAEA declared, on the basis of inspections carried out under the terms of United Nations Security Council Resolution 687, that Iraq had violated its NPT safeguards agreement with the IAEA by not declaring certain nuclear materials, activities, and facilities to the Agency. This has initiated a re-evaluation of the Agency's safeguards system, with a view toward acquiring additional relevant information about undeclared nuclear activities and the means to check on them. Increased access to information about nuclear programmes and broader inspector access to sites within States are fundamental prerequisites for a strengthened safeguards system. To obtain this, was the main purpose of Programme 93+2 which in turn resulted in a Model Protocol (INFCIRC/540) to comprehensive safeguards agreements which was endorsed by the Board of Governors in May 1997.

Some other events which have influenced the development of an expanded safeguards system are, e.g.:

When South Africa concluded its Safeguards Agreement with the Agency in 1991, the Agency was confronted with the problem that major unsafeguarded facilities, including one plant for the production of highly enriched uranium, had been operated outside any kind of international control for many years.

In order to verify the completeness of the initial report, an IAEA team made a number of visits to South Africa to consult with officials and to examine historical accounting and operating records of both operating and closed-down facilities.

South Africa's co-operation with the Agency has clearly shown the importance of transparency and increased inspector's access as confidence-building measures in international safeguards.

The DPRK concluded a Safeguards Agreement with the Agency in January 1992 and submitted the initial report in May 1992. During the verification of the initial declaration in 1992, the Agency's analyses of samples indicated inconsistencies that led the IAEA to conclude that more plutonium exists than the declared amount of a few grams.

For quite different circumstances, the cases just mentioned have brought home to everyone concerned the fact that verification of the initial inventory is not easy in States that had extensive nuclear programmes before concluding an NPT safeguards agreement.

1.5. Non-compliance

Detection of diversion must also be seen to entail effective penalties for the diverting country. The IAEA Statute specifies a number of formal sanctions against the breach of a Safeguards Agreement. They consist chiefly of an alert to the international community (the UN Security Council, the UN General Assembly, all IAEA members), curtailment of IAEA assistance, and suspension of the privileges and rights of IAEA membership.

2. SAFEGUARDS IMPLEMENTATION

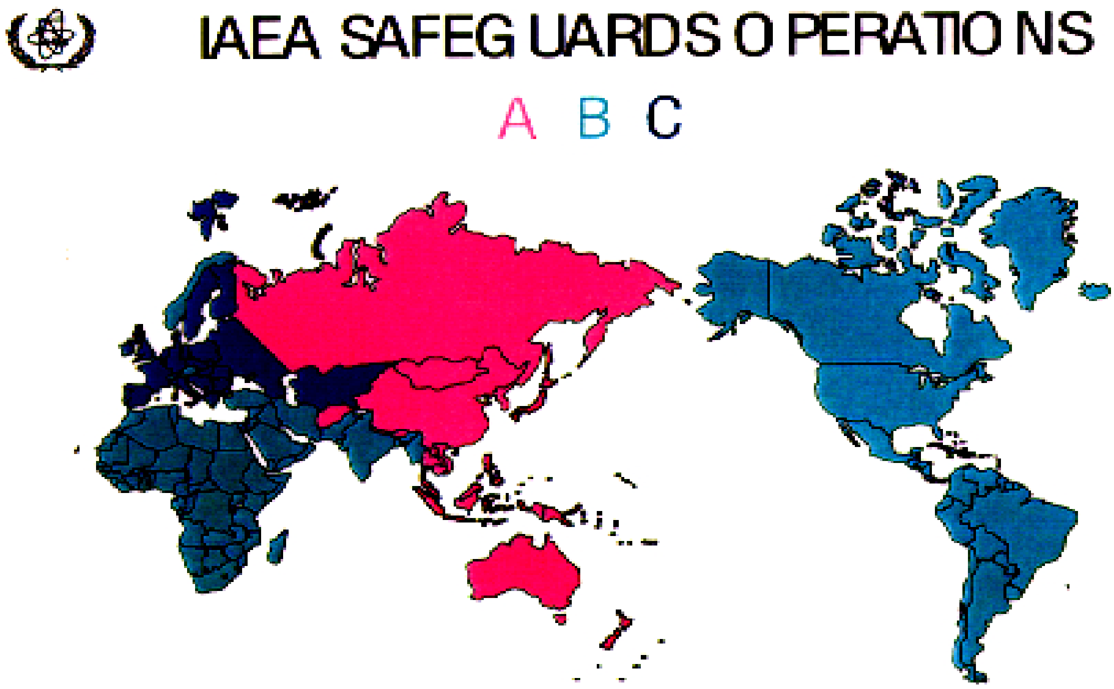
The technical organization for verifying the political obligation not to use nuclear material for weapons, as described above, is the safeguards arm of the IAEA, particularly the Safeguards Department. The work of the Department of Safeguards has been designed to provide continuing assurance to the international community (Fig. 1) that any significant diversion would be promptly detected. At least equally important is that if, as has up to now always been the case, no diversion of safeguarded material has occurred, the IAEA should be able to provide assurance by verifying the correctness of the statements it has received from the State concerning its safeguarded nuclear material and facilities. The political value as well as the effectiveness of the IAEA's safeguards work thus depends significantly on the way in which its detection capability is perceived by those States which expect the IAEA to provide assurance as well as by any State which might contemplate diversion and wished to know how much risk there is of being detected.

The challenge for the future is to ensure that all nuclear material and facilities subject to safeguards are declared so that they can be verified.

A schematic of the Agency's system for safeguards implementation is shown in Fig. 2.

2.1. The technical objective of NPT safeguards

The technical objective of safeguards in agreements concluded under the NPT is defined in Article 28 of INFCIRC/153 as “ the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown and deterrence of such diversion by risk of early detection ”. In Safeguards Agreements concluded under the non-NPT system (INFCIRC/66/Rev. 2) there is no specific definition of technical objective but in practice today essentially the same concepts apply.



NPT and Weapon States

Russia France

United States China

United Kingdom

FIG. 1. IAEA safeguards operations.

The definition given in Article 28 contains two expressions requiring quantification: ‘significant quantities’ of nuclear material and ‘timely detection’ of diversion.

For international safeguards the significant quantity is the approximate quantity of nuclear material which could possibly be used to manufacture a nuclear explosive device. It is of the order of magnitude of 8 kilograms of plutonium or 25 kilograms of highly enriched uranium.

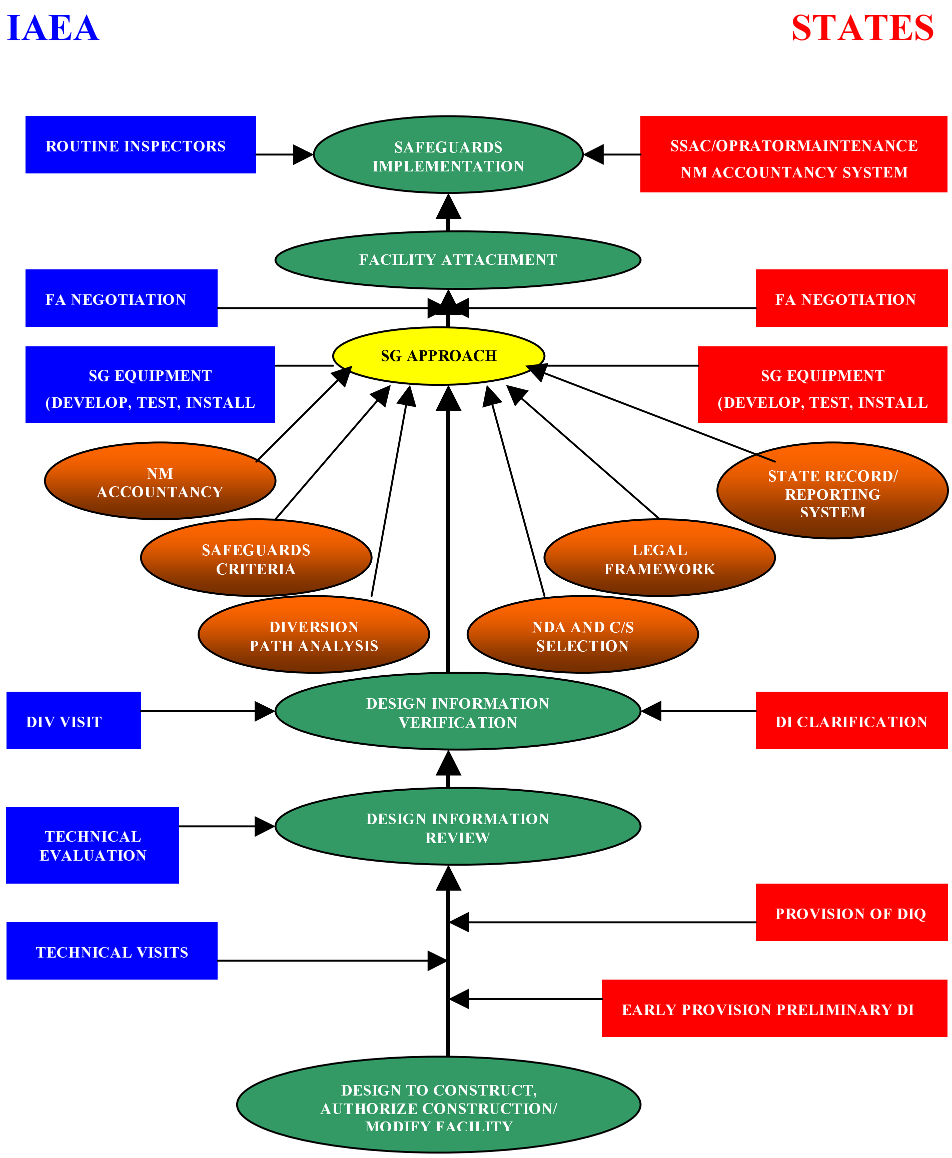


FIG. 2. IAEA's system for safeguards implementation.

Similarly, in the context of international safeguards timely detection can be related to the time required to convert diverted material into the components of a nuclear explosive device (namely, conversion time). The conversion time is of the order of weeks or months depending on the nature of the material concerned (see Table I).

NPT Safeguards Agreements require the State to establish and maintain a national system of accounting for and control of nuclear material (SSAC) within its territory, jurisdiction or control. In NPT States (and increasingly in others as well), the nuclear materials accountancy and verification carried out by the Agency are based on reports submitted by the SSAC as well as on records kept at facilities. It is the responsibility of the national authority to ensure that plant operators comply with the requirements of the Safeguards Agreement. These requirements include proper and accurate keeping of records, and timely and accurate reporting of stocks and transfers of nuclear material according to an agreed format. The national authorities are also responsible for ensuring that IAEA inspectors are granted all necessary access to facilities and material for accountancy verification. They also provide the support the inspectors require to discharge their duties effectively.

TABLE I. SIGNIFICANT QUANTITIES AND TIMELINESS GOALS

Material category	Material type	Significant quantity	Timeliness goal
DIRECT USE MATERIAL	Plutonium * (separated)	8 Kg Pu	1 month
	high enriched Uranium ≥20%	25 Kg U-235	1 month (UNIRR) 3 months (IRR)
	Plutonium in spent fuel	8 Kg Pu	3 months
	Uranium -233	8 Kg U-233	1 month
INDIRECT USE MATERIAL	low enriched ** Uranium <20%	75 Kg U-235	12 months
	Thorium	20 t Th	12 months

* for Pu containing less than 80% Pu-238
** including natural and depleted Uranium

2.2. Tools of the trade

Safeguards practices can be summarized in one word: verification. To verify means "to establish the truth of". In safeguards, to verify is to establish the truth of declarations regarding the amounts, presence and use of nuclear material or other items subject to safeguards as recorded by facility operators and as reported by the State to the IAEA.

Accountancy, together with containment and surveillance, is the fundamental basis on which safeguards verification rests.

The verification process consists of three distinct stages:

(1) The *examination of the information* provided by the State in:
- design information describing installations under safeguards;
- accounting reports listing, primarily, nuclear material inventories, receipts and shipments;
- documents amplifying and clarifying reports; and
- advance notification of international transfers.

(2) The *collection of information* by the IAEA as a result of
- inspections for the verification of the design information;
- inspections to examine local records and reports, to measure the nuclear material, and to examine the results provided by containment and surveillance devices; and
- special inspections in case of unusual findings.

(3) The *evaluation of the information* provided by the State and of that collected by inspectors to determine the completeness, accuracy and validity of the information provided by the State, and to resolve any anomalies and discrepancies.

After the three stages of verification have been completed, statements are provided by the IAEA to the States recording the results of safeguards activities in the State concerned.

2.2.1. Nuclear material accountancy

It is the purpose of nuclear material accountancy to establish the quantities of nuclear material present within defined areas and the changes in these quantities that take place within defined periods of time. The essential steps in such accounting are as follows:

- the nuclear-facility operator identifies and counts or measures the material in the area concerned;
- the operator keeps records of all transactions involving this material:
- the operator prepares accounting reports on these transactions and on nuclear material inventories, and submits these reports via the State to the IAEA;
- the IAEA verifies and analyses the data in these reports to determine their correctness and to estimate the amount of any material unaccounted for and evaluate the causes of any such material unaccounted for.

To make these tasks more manageable, material balance areas (MBAs) are established in nuclear installations. These MBAs are areas into and out of which all transfers can be verified and in which physical inventories can be taken to establish a nuclear material balance. The MBAs are agreed between States and the IAEA and are specified in the Facility Attachments of the Subsidiary Arrangements to the Safeguards Agreements. Within MBAs measurements are made at key measurement points (KMPs), which are locations where nuclear material may be measured for the determination of flow or inventory.

The measurement techniques applied are primarily neutron and gamma techniques, as performed by inspectors on site. Samples for destructive analyses may also be taken and shipped to the Agency's Safeguards Analytical Laboratory (SAL) in Seibersdorf close to Vienna.

2.2.2. Containment and surveillance

Containment and Surveillance measures take advantage of physical barriers such as walls, containers, tanks or pipes to restrict or control the movement of or access to nuclear material. Such measures help to reduce the probability that undetected movements of nuclear material or equipment can take place.

Containment measures may involve the application of devices such as uniquely identifiable tamper-indicating seals to ensure that any access to the sealed inventory would be detected.

Surveillance means both human and instrumental observation in order to verify declared movements of nuclear material and detect and deter undeclared movements of nuclear material. Surveillance shall detect tampering with containment, fabrication of false information or tampering with safeguards devices. Surveillance may involve the use of tamper-resistant automatic cameras or other devices to monitor changes in containment or to observe inventory changes. Personnel may carry out the same tasks by manning key observation points continuously or periodically. Results from the surveillance systems are reviewed from time to time, e.g. every three months.

The IAEA containment and surveillance measures are designed in such a way as to minimize intrusion in the work of a nuclear facility operator.

2.2.3. Measures for strengthening safeguards

The undertakings and obligations described in document INFCIRC/153 (Corrected) are not limited to the nuclear material declared by the State and placed under Agency safeguards; they extend to all nuclear material which should be declared as required by the safeguards agreement.

Measures relating to the early provision of design information and to the voluntary reporting scheme have been implemented to the extent that States have accepted them. This implies that an increased access to information about nuclear programmes and broader inspector access to sites is essential for a strengthened safeguards system. This requirement is laid down in a Model Protocol (INFCIRC/540).

Environmental samples for the establishment of a baseline have been taken at a number of facilities in different countries.

3. TYPICAL INSPECTION ACTIVITIES

Table II describes the various steps involved in a safeguards inspection.

TABLE II. INSPECTION ACTIVITIES

1.	Follow-up on previous inspections.
2.	Examination of accounting records.
3.	Examination of operating records.
4.	Reconciliation of accounting records with operating records.
5.	Comparison of records with reports.
6.	Updating of book inventory.
7.	Verification of inventory changes.
8.	Verification of inventory.
9.	Verification at strategic points other than key measurement points (KMPs) at strategic points for containment and surveillance (C/S) [flow within the material balance area].
10.	Use of surveillance equipment.
11.	Use of seals.
12.	Verification of operator's measurement system.
13.	Evaluation of inventory differences and of accidental losses, retained waste and measured discards in excess of specified limits.
14.	Other activities.

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Key Issue Paper No. 5

PUBLIC INFORMATION

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Abstract

Nuclear power was welcomed from the outset because it promised highly economic and convenient energy, especially electricity. Even today, nuclear projects espoused by developing nations can stimulate enthusiasm and national pride. However, public unease concerning nuclear power safety was magnified by the accidents at Three Mile Island in 1979 and Chernobyl in 1986. The perceived problem of transport and long term storage of nuclear waste has added to public concerns, as has the risk of the possible proliferation of nuclear weapons. Public information strategies must recognize and seek to address these fears by pointing to the many cumulative years of trouble-free nuclear operations and by stressing the strict rules and oversight designed to protect workers and the public from accidents and radioactive releases. It is against this background that the following material has been compiled. It comes from a variety of sources and reflects the experience mainly of industrialized countries that have national nuclear programs. It is important to underline that it is descriptive rather than prescriptive in nature for two reasons: first, the IAEA is essentially a forum for pooling collective knowledge in this as in other fields; and secondly, the IAEA would not presume to offer a universal formula, since national circumstances vary according to specific political, demographic, social and other factors. Hence only certain parts of this paper may be of direct relevance to any given national situation.

1. ROLE OF THE IAEA

The International Atomic Energy Agency has a broad mandate to accelerate the contribution of peaceful nuclear energy applications for the benefit of mankind. This said, it is not the IAEA's role to market the nuclear power option to individual Member States. It can and does provide objective, comparative data on various energy sources, covering their full fuel cycles, both in terms of economics and the impact on health, the environment and society as a whole. It does so to provide a basis on which individual states can assess their energy strategies for the future, recognizing that investments made today may involve assets with a life span of 30-50 years. If countries decide that they wish to have or to retain nuclear as one component in their energy mix, then the IAEA stands ready to provide a range of support services including site selection reviews, training, safety advice, visits by operational review teams on request and basic information such as brochures[1] and videos.

2. FUNDAMENTAL CONSIDERATIONS FOR PUBLIC INFORMATION

The public may have little time or inclination to become familiar with issues like energy choices. They do, however, readily understand basic economic and social needs as well as the

[1] Examples (1997): "Sustainable Development & Nuclear Power" and "Choosing the Nuclear Power Option: Factors to be Considered".

negative effects of chronic shortages. Electricity is one such need. Hence, information efforts related to the introduction or expansion of nuclear power, must clearly state the benefits of meeting demands for electrical power, as an overall national priority and the penalties of her doing so. It may also be necessary to explain how nuclear generation compares with alternative forms of energy in its ability to meet large volume, baseload power needs typical of major industries and expanding "megacities", and in terms of environmental protection against air pollution. Describing the benefits of other peaceful applications of nuclear energy (e.g., in medicine) may also be appropriate.

The reasons underlying a choice to include nuclear in a national energy mix must be the basis for such an information effort. Such reasons may include the need to diversify energy, ensure energy independence, promote technology and quality control in national infrastructures and the desire to avoid environmental degradation by burning fossil fuels.

Ideally, an information campaign should be able to assume a reasonable level of scientific awareness acquired by the population from the educational system. This is not universally the case, however, but it is certainly worthwhile to educate younger generations, tomorrow's electorate, to better understand these complex choices.

Seeing technology in action is also important. Opinion leaders (local officials, journalists and teachers, for example) should be encouraged to visit existing nuclear facilities where possible. When a national nuclear facility has been established, a visitors' programme and visitors center can be valuable. Alternatives might include videos, static or traveling exhibits, information offices, Internet web sites or a nuclear telephone "hot line".

Most opposition to nuclear power plants comes from pressure groups in society. While these views require respect, it is not imperative to confront their public expression on every occasion. The merit of engaging in an adversarial public discussion should be weighed carefully. A better solution may be to involve scientists or academics with no link to the project itself. Speakers engaging in public debates on nuclear matters must have the necessary background and be prepared to cope with opposing views.

3. A POSSIBLE PUBLIC INFORMATION STRATEGY

Development of a strategy means defining goals and messages, who should deliver them to whom, and how. Presenting nuclear-related public information is demanding and time-consuming. It requires accuracy, honesty, openness, and clarity — an ability to translate technical jargon into easily understandable language. If personnel do not have these skills, they should be trained, and be able to train others. A first step is to appraise existing resources, strengths, and weaknesses. For instance, are community and political leaders aware of the issues at stake, and are they supportive, neutral or hostile?

Important messages to include in a public information strategy are :

– How do nuclear power plants work?
– What are the economic features, with emphasis on advantages/disadvantages?
– What safety features are incorporated and are these sufficient for public safety?
– What are the features of such plants compared to more traditional forms of electricity generation?

- What environmental advantages are offered by nuclear power plants in terms of local air pollution control, regional acidification protection or in the context of greenhouse gases and possible global warming"?
- How do air emissions and water discharges differ from traditional plants?

In refining these messages, audiences should be addressed according to their expected knowledge of the subject and specific concerns. Sensitive and patient approach is needed here, with ample time always allowed for questions.

Important as potential audiences for a PI strategy are:

- the media (local, regional, national)
- local, regional and national politicians
- employees in the nuclear industry who serve as informal ambassadors
- labor unions
- the educational/academic community — professors, teachers, students
- economists and business leaders
- banks and financial institutions
- industries heavily dependent on electricity
- people living in the neighborhood of existing and future nuclear facilities
- consumer protection groups
- environmental groups
- women's groups
- police officials (since police may have to handle protests and should therefore be aware of the issues at stake).

It is clear that these groups might be approached differently. However, standard techniques such as seminars, meetings and briefings by qualified personnel would seem to apply for all.

Communication is a two-way process. Hence, participants must be prepared to **listen as well as talk**. This way the concerns of target audiences can be assessed and addressed with less possibility of alienating them. Listening may reveal that concerns expressed are quite different from those anticipated and may require rethinking the information strategy. Thus, while clear, basic messages should be defined and prioritized from the outset, these may be modified in the light of experience.

Media contacts are important because of their wide-array and number of contacts and audiences, many of whom develop opinions largely based on what they see, hear and read. With the media as with everyone, it is important to engage in full and open dialogue on all aspects of a project to help build mutual trust and confidence. To be secretive, on the other hand, risks disclosures that can undermine the success of a project at any stage. It is also a fact that media publicity may affect political decision-making more than information specifically directed toward government officials and elected representatives.

In general, it is advisable to emphasize needs and community and national benefits, rather than dwelling on risks, which may tend to exaggerate their importance. This said, risks should not be ignored, since such concerns are entirely legitimate. To help assuage doubts, a citizens committee may be created composed of leaders from business, labor unions, the scientific community, television shows, civic and women's groups, environmental organizations, the academic world and former government officials. In certain cases, newspapers and magazines may accept articles written by prominent contributors supporting the nuclear case.

Placing paid advertisements in the printed media to underscore a point or allay doubts may also be appropriate. Written information can be produced at various levels of sophistication from cartoon-illustrated books for school children to simple fact sheets and elaborate, illustrated brochures.

4. PUBLIC PARTICIPATION IN DECISION MAKING

Public participation in decision-making differs between countries but there are some pointers of general validity.

Clearly public participation takes place at two levels: the local and the national. The issues are different at each level. At the local level, it is mainly a question of siting and licensing a facility. At the national level, questions about, for instance, the safety or future of nuclear power are raised. There are also differences in the roles played by elected representatives at the local (or municipal) and at the national levels.

Some countries have experienced a widening gap between technological progress and the ability — and willingness — of politicians to decide on such difficult questions as waste sites or nuclear power programs. This leads to the question: If elected politicians are not able and willing to tackle a complex issue at the national level, is volatile public opinion to be the arbiter?

Wide public participation at the local level provides a wealth of experience and many countries require holding public hearings before permitting site use or construction. The forms for hearings and their frameworks vary, but they are consultative and not decision-making. They give the public an opportunity to express their opinions and objections so as to inform authorities, who later decide on the site or license. The public normally has some degree of assurance that its opinions and objections are considered in the final decision.

Experience has shown that the process may have some disadvantages, for example, it may foster confrontational attitudes. Such drawbacks have led to the realization that consultation can backfile. Some countries structure make use of public participation through elected representatives or local committees with close and continuing contact with the electorate. The experience of such committees in France and Sweden has generally been positive.

The nuclear industry and its installations—like any other industry or facilities—has attractive points and drawbacks. It is the task of the public information personnel to explain both aspects carefully and honestly. On one side, nuclear power is perceived as posing unique threats: fear of radiation and its delayed health impacts in the form of cancers which may appear decades after exposure. However, the same can be said about technologies like those of the chemical industry. The unique aspects of nuclear power can on the other hand be interpreted positively, through the stringent international and national principles for the protection of workers and the public. They are advanced and conservative, but may be difficult for non-specialists to comprehend. They are seriously looked upon as models for protection of the environment and of the public in other industrial sectors, notably the disposal of hazardous wastes. In summary, desirable ingredients for public participation are:

(1) Information must be two-way — telling and listening — before plans and positions are fixed. It must be available to all without discrimination and be as complete as reasonably possible.

(2) Transparency should apply to all information and all relevant institutions and to the public consultation process itself.

(3) A common understanding must be developed for discussions, for joint action in problem-solving, and for decision-making. Imposition of a point-of-view by one side is unacceptable, and solutions tolerable to all parties must be found.
(4) Consultation and participation should be seen to be fair to all parties. It must contain possibilities to opt out, select among options or make changes.

When these elements are included, participation in decision-making will be genuine, not one-sided. Media play an important informative and educational role; fairness, accuracy and objectivity are desirable, but not always found.

Finally, for local public participation, some general guidelines of a practical nature can be formulated:

(1) Public consultation should start early — not necessarily, but usually initiated by the project originators — and before site analysis is final.
(2) Consultation could start by involving several municipalities, instead of the one designated as the most promising site.
(3) Local social, economic and environmental concerns must be given due weight.
(4) Fulfilling formal, legal, public hearing requirements is essential.
(5) Costs for such a process may be high, but experience shows that another approach may costs far more due to delays, resistance or even cancellation of a project.

5. CONCLUSIONS

Introduction of high-tech infrastructure projects is a major undertaking everywhere today. It often produces the NIMBY — "not in my back yard" — reaction. To respond to such fears, scientific and engineering expertise should be mustered, and communication and public information must be initiated as equal factors from the start. In view of the public association of nuclear power with nuclear weapons and a perception that nuclear technology is inherently risky, this is especially true for nuclear facilities.

Keys to such a programme involve the following:

- determine attitudes in key sectors of public opinion, define target groups and develop a communication strategy
- assure the availability of adequate resources, in terms of money, materials, manpower and communicators experienced with public interaction, rather than those having a profound grasp of technical detail.

A framework for the development of a strategy should include:

- a focus on society's need for energy and electricity,
- a clear exposition of the specific benefits of nuclear components in the national energy mix, such as financial, employment, enhanced technical and quality control skills, access to technology transfer, protection of the environment, etc.,
- an ability to address public concerns about risks, such as safety and waste disposal,
- prioritizing messages and translating them into a working plan supported both by national authorities and by major stakeholders, such as the electrical utility,
- working from the local level where the facility is likely to be constructed, to regional and national levels.

Within this framework, communication of tailored messages for different audiences can meet specific circumstances and help ensure that the project as conceived can proceed with minimal external opposition and disruption.

A final caveat: communicators can only convey what is being proposed. If the proposal or the decision-making process, is flawed or unacceptable to the public for whatever reason, even the best communications program cannot be relied upon to change their minds.

NUCLEAR POWER: ISSUES AND MISUNDERSTANDINGS

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Abstract

A sizeable sector of the public remains hesitant or opposed to the use of nuclear power. With other groups claiming nuclear power has a legitimate role in energy programs, there is a need to openly and objectively discuss the concerns limiting its acceptance: the perceived health effects, the consequences of severe accidents, and the disposal of high level waste. This paper discusses these concerns using comparisons with other energy sources.

1. RADIATION REALITIES

1.1. Radiation exposures

Fear of radiation effects on health, particularly from severe accidents and radioactive waste, is central to public concerns about nuclear power. A better understanding of radiation and radiation exposure encountered in everyday life is fundamental to a balanced view of nuclear power's health impacts.

Radiation is a fact of life. Radioactive elements have been an integral part of the environment since the universe was created 15 billion years ago. Radiation is a natural component of the air we breath, of the earth we walk on, of the homes we live in, of the food we eat and of human tissues. We are continuously exposed to cosmic radiation, ionizing radiation of extraterrestrial origin, particularly at higher elevations and during air travel.

On a global average, it is natural background radon gas released from the earth that accounts for almost 49% of the radiation exposure an individual receives annually. Additional exposure from cosmic radiation and radioactive materials in the earth and internal to our body, accounts for somewhat more than 40%. The remaining 11% is man-made almost totally due to medical diagnostic X-rays and therapeutic radiation. Radioactive material from past nuclear test explosions amounts to a small 0.2% and nuclear power related activities a minimal 0.006%.

The amount of background radiation depends on location. Many of the millions of Europeans living in high radon gas locations in Austria, Finland, France, Spain, Sweden and the United Kingdom receive 10 to 20 times the global average background exposure than is received by residents of New York City, where radon gas levels are significantly lower. Even these high exposures are exceeded in local areas, such as parts of Brazil and India where the individual exposure is more than 100 times the global average and more than one million times the exposure from nuclear power related activities.

Radioactive atmospheric and ground contamination from the 1986 Chernobyl accident led to widely varying increases in individual exposures. But even in this extreme situation, a comparison to normal daily exposure gives perspective. Since areas affected by the Chernobyl accident are relatively low in radon gas, the current daily individual radiation exposure - even of those living in the areas of highest contamination - is below the daily exposure levels of the many hundreds of thousands of people living in high radon gas locations of Europe.

In fact, for the overwhelming majority of those who lived and will continue to live in the areas of highest contamination at the time of the accident, their accumulated total lifetime radiation exposure will be less than that of Europeans living in high radon gas locations. Although still small, the possibility of radiation induced health effects during a lifetime is on average greater for inhabitants of Europe exposed to high radon than for populations exposed at Chernobyl. A detailed discussion of radiation exposures to the main groups affected by the Chernobyl accident is presented later.

1.2. Radiation health effects

The biological effects of radiation depend on the amount of exposure. Very high exposures can damage or kill a sufficient number of cells to destroy organs and interrupt vital body functions leading to disability or death within a short time. Their effects are well documented. On the other hand, low level radiation related health effects cannot be identified since they principally occur as cancers late in life, leading to premature deaths of several years. They would be an indistinguishable fraction of the anticipated 20% of populations that die of cancer due to multiple other causes - the 20% value itself varies by several percentage points for different populations due to specific environmental, dietary and genetic influences.

To study long-term health effects, over the past five decades the Radiation Effects Research Foundation (RERF) in Hiroshima conducted extensive investigations of the Japanese survivors of the 1945 atomic bomb explosions at Hiroshima and Nagasaki. Some 87,000 people who received relatively high radiation exposures have been continuously monitored. Contrary to initial expectations of high numbers of radiation induced cancer deaths, the study of this Japanese population projects some 600, in addition to some 16,000 anticipated cancer deaths due to other causes - a small 0.7% increase in the anticipated cancer death rate. The several year loss expected in the average life expectancy will not materialize as above average health care for the survivors, though early diagnosis and treatment of medical disorders, including cancer, is leading to increased longevity.

Results of the RERF study have been used to extrapolate effects for exposures close to zero above the natural background radiation exposure. As exposure decreases, the likelihood of radiation induced cancer death is assumed to decrease linearly, only reaching zero at zero exposure above the background. Some scientists are critical of this type of extrapolation assuming that a natural threshold exists for radiation effects with very small incremental doses, above a significantly greater natural background exposure posing no risk at all.

1.3. Radiation from nuclear activities

There has been no credible documentation of health effects associated with routine operation of commercial nuclear facilities anywhere in the world. Widely accepted investigations, such as the comprehensive 1990 U.S. National Institutes of Health (NIH) study involving some one million cancer deaths in people living near nuclear power plants in the United States, demonstrate no correlation between cancer deaths and plant operations. Investigations carried out in Canada, France, Japan and the United Kingdom support the NIH results. A number of widely publicized studies reporting a linkage of radiation from nuclear power activities to occupational or public health consequences, such as the Sellafield occupational exposure study published in 1990, have been shown to be incorrect.

Comprehensive studies of various cancer types carried out by the European Union show wide variability in cancer rates throughout Europe, likely due to environmental, dietary and genetic influences. High incidences of male leukemia are found in non-nuclear power countries such as Denmark, Ireland and Italy as well as in countries with nuclear power, such as France and Germany.

To consider health effects from nuclear power activities, any postulated risks from low level radiation exposures must be put into perspective with the known risks from the toxic pollutants released from other energy production. Unfortunately the task of comparison is difficult, as there is vastly more scientific information about health effects from radiation than from the various toxic pollutants.

1.4. Toxic pollutant health effects

Fossil fuel combustion produces, in addition to CO_2, noxious gases and a wide range of toxic pollutants that are a large source of atmospheric pollution. In general, the level of pollution depends on the quantity of non-combustible material in the fuel, natural gas having the lowest level, followed by oil and coal. The pollution potential also depends on the combustion technology and pollution controls.

Coal combustion always produces gaseous nitrous oxides; sulfur impurities are emitted as gaseous sulfur dioxide. Inorganic impurities are released as a wide range of metals including radioactive elements; the volatile heavy metals, such as mercury, are emitted as vapor, while others such as cadmium and lead largely remain in the ash. The incomplete burning of coal that always occurs adds black smoke - finely divided carbon and hydrocarbon particles known as particulate matter - along with carbon monoxide and a wide range of organic compounds.

As with radiation, health effects from energy related pollutants depend on exposure. For high levels of toxic pollutant exposure there is no doubt about the potential health effects. Acute respiratory disorders are well documented for high levels of atmospheric pollution as are a number of respiratory disorders at more moderate levels. Heavy metal ingestion can cause a wide range of substance specific health disorders. Coal containing arsenic used in the Czech Republic for many years caused high levels of contamination, and arsenic specific health effects have been documented in children living in the vicinity of affected areas.

As with radiation, there are formidable difficulties in developing a relationship between continuous exposures to low levels of pollutants in air, food or water and long-term health effects occurring years later as additional illnesses, including cancer. The higher overall death rates particularly from cardiovascular and pulmonary disorders observed in areas with persistent atmospheric pollution, is a strong indicator that long-term health effects from continuous low level exposures do develop. The World Health Organization (WHO), in their 1997 report on sustainable development, estimates that annual deaths due to indoor and outdoor air pollution from energy related activities account for 6% of the total 50 million annual global deaths.

Multiple indirect health effects from energy related environmental pollution is even more difficult to assess. Acidification of land areas and waters can result in damage to both terrestrial and aquatic ecosystems. It can affect the mobility of some heavy metals such as mercury and other metals of significance in the ecosystem. Lake acidity and increased mercury concentrations in lakes are factors influencing the quantity of mercury accumulating in fish and entering the human food chain.

Health Effects From Fossil Fuel Releases

- Sulfur dioxide (SO_2) - Respiratory irritant, impaired breathing
- Nitrous oxide (NO_x) - Respiratory irritant, infections, pulmonary diseases
- Carbon monoxide (CO) - Fatal angina, various other effects
- Ozone (O_3) - Respiratory irritant, impaired breathing, asthma, edema.
- Particulate mater (PM_{10}) - Various toxic particle (organic matter, carbon, mineral dusts, metal oxides and sulfates and nitrate salts) effects - main mortality factor due to fossil fuels.
- Toxic substances - Heavy metals, specific substance effects.

1.5. A misconception

Although exposure to fossil fuel related toxic pollutants through air and contaminated water and food is a daily experience, there is a widely held public belief that nuclear power is a greater health risk. Concerns about radiation are demonstrated by a common conviction that plutonium - in spent fuel and from reprocessing - can be significantly more harmful than toxic pollutants. Plutonium is not very radioactive - as a long lived material with a half-life of more than 24,000 years it decays very slowly. Its radiation will not penetrate paper. As it is not highly soluble in most forms, it is not very hazardous when small quantities are ingested in liquids because the major portion passes through the body unabsorbed.

In fact, plutonium is extremely hazardous to health only when finely dispersed in sufficient concentration and inhaled, where it - similar to very small particles of inhaled toxic pollutants - passes through the lung tissue into the blood. Fortunately, a scenario to disperse sufficient amounts of plutonium, which is transported in strong structural containers, into the atmosphere to cause significant population health effects would be difficult. By contrast, many energy related toxic pollutants, including easily inhaled particulates that are the main mortality factor due to fossil fuels, have high potential health effects and health related costs.

2. SAFETY AND SEVERE ACCIDENTS

2.1. The safety concept

Nuclear power plants are built to high safety standards. Nevertheless, there have been two serious accidents. The first occurred in 1979 in a widely used reactor type, at Three Mile Island (TMI), resulting in serious reactor core damage, but inconsequential environmental releases. The second occurred seven years later in 1986, at Chernobyl, in a unique reactor type used only in the former Soviet Union, resulting in serious environmental consequences.

Many lessons were learned from these two events. The Chernobyl accident brought out a failing in the graphite reactor design which permitted a rapid power escalation under abnormal operating conditions. The loss of coolant water flow that occurred did not lead to an automatic shutdown required in other reactors. Most importantly, the environmental consequences of the Chernobyl accident compared with the negligible consequences of the TMI accident confirmed the importance of the principal reactor safety concept incorporating three protective barriers to prevent radioactive releases.

The first protection barrier, the ceramic fuel and its cladding, retains the radioactive products of nuclear fission. The second, the strong metallic primary circuit consisting of the reactor vessel and connecting pipes, retains radioactive material released in the event of fuel damage. The final and ultimate barrier, typically a large cylindrical containment of pre-stressed concrete enclosing the reactor primary system - many with inside steel liners and some with double walls, as in a large number of standardized French plants - retains radioactive material that could be released from a primary circuit failure. Lack of a sufficient containment barrier at Chernobyl led to the serious environmental consequences.

Containment designs also exclude external events. Experiments to simulate direct hits from jet aircraft, with high speed projectiles fired into walls of concrete and steel, demonstrate little damage. Containment damage from postulated severe accidents would cause structural cracks, allowing only minimal environmental releases.

2.2. The Chernobyl impact

The consequences of the disastrous Chernobyl accident remain a focus of concern. Some 6 percent of the radioactive contents of the reactor core were released into the atmosphere, with radioactive iodine and cesium of greatest relevance to human health.

The accident resulted in 31 short-term deaths with 28 due to extremely high radiation exposures. An additional 106 people experienced serious radiation effects. Some 200,000 workers, known as liquidators, involved in clean-up activities during 1986 and 1987 received average exposures of 50 mSv, two times the annual occupational exposure permitted and similar to annual exposures by individuals in high radon areas of Europe. A few thousand received greater than 10 times the permitted occupational exposure and several dozen workers received exposures considerably higher. The total number of listed liquidators eventually rose to more than 600,000 with most of the additional individuals receiving limited exposures.

Of the 116,000 inhabitants evacuated from the 30 km exclusion zone around the Chernobyl site, 95 percent received less than the average for the initial group of liquidators. More than 400,000 residents living in areas classified as strict control zones received significantly less than that, their exposure occurring principally during the early months following the accident.

For the 1,116,000 total individuals in the three major groups (600,000 liquidators, 116,000 exclusion zone evacuees and 400,000 residents of strict control zones) who received the highest exposure from the Chernobyl releases, the predicted long-term radiation induced cancer deaths and normally non-fatal thyroid cancers are reported in the proceedings of a 1996 international conference cosponsored by the IAEA, WHO and the European Union (EU). The report projects some 3,500 radiation induced cancer deaths, mainly late in life, in addition to some 200,000 anticipated cancer deaths from other sources - somewhat more than a 0.3% increase in the cancer death rate. The estimate is consistent with the atomic bomb survivor studies which project a 0.7% increase for the survivors who received a larger as well as a more harmful rapid radiation exposure.

The single radiation related health impact observed to date is a sharp increase in thyroid cancers among children exposed to short-lived radioactive iodine. Some 800 cases in children under 15, three of which were fatal, were documented by 1996 with the total incidence of this treatable illness projected to rise to several thousand. There is no evidence to date of an increased incidence of other malignancies including leukemia, the most sensitive indicator of radiation induced effects (UNSCEAR, May 1997).

Numerous reports of cancer deaths for those living in the contaminated zones of Belarus, Russia and Ukraine and among liquidators have not been substantiated. Significant mental health disorders could be a consequence of the accident's broad and severe psychological, economic and social impact. The effects of measures intended to limit radiation exposure causing lifestyle changes through resettlement, changes in food supplies and restrictions in activities were compounded by a deteriorating economic and social environment.

There were short term environmental impacts including lethal exposures to coniferous trees and some small mammals within a 10 km zone from the reactor site. The natural environment had begun to recover visibly by 1989 and sustained impacts on ecosystems have not been observed. An evaluation of long term hereditary effects in plants or animals will take many more years. No statistically meaningful hereditary effects have ever been observed due to human exposure to significant levels of radiation.

2.3. Some nuclear power facts

How likely is another serious environmental release? There are currently 15 Chernobyl type nuclear power plants that have operated on average for about 17 years each. Although some may be shutdown early, others may operate at least through their 30 year design life. No more plants are expected to be built of this type. With the exception of some of the early Soviet designed units, the remaining 427 nuclear power plants in the world have structural containments around the principal reactor primary system components. There has been a large ongoing global cooperative effort to improve the safety of all operating Soviet designed plants including modernization of instrumentation and equipment.

There are already more than 8,000 reactor-years of accumulated operational experience worldwide, equivalent to an average of 20 years of operation for each nuclear power unit. Building on this base of experience, today's reactors incorporate improved safety measures and are designed to exclude an environmental release in case of a severe accident. Designers believe the newest plants would suffer no more than 1 severe core damage accident in 100,000 reactor years of operation and this without a subsequent environmental release.

2.4. Advanced designs

Advanced nuclear power plants with even a smaller severe accident possibility are under development. The full spectrum of advanced designs ranges from evolutionary, with enhanced safety features, to entirely new designs introducing innovative safety concepts. The new concepts include passive - sometimes referred to as inherent - safety features based on natural convection coolant flow, making safety less dependent on active components like pumps and valves and on human performance. A high temperature helium gas cooled reactor with a unique fuel design has been developed and operated. It employs spherical fuel particles coated with layers of ceramic that remain intact and retain virtually all fission products at temperatures as high as 1600^{o}C. Any fuel failure during severe accident conditions would be gradual and a rapid release of fission products would not occur.

Some advanced design characteristics

- Evolutionary - large size (1400 MWe), improved reliability, enhanced safety features;
- Smaller and Simpler - medium size (600 MWe), simplified systems, passive safety features;
- Modular Gas Cooled - variable size (200-400 MW), helium coolant, inherent fuel safety;
- High Temperature Gas Cooled - large size (1000 MWe), high efficiency, helium coolant, inherent fuel safety;
- Innovative - new concepts, passive safety features.

2.5. A developing global nuclear safety culture

Over the years a global nuclear safety culture has evolved through international efforts to strengthen safety worldwide. Binding international agreements, codes of practice, non-binding safety standards and guides along with international review and advisory services now exist.

Binding International Agreements

- Civil Liability for Nuclear Damage (1963) as amended (1997);
- Physical Protection of Nuclear Materials (1980);
- Early Notification of a Nuclear Accident (1986);
- Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986);
- Nuclear Safety (1996);
- Safety of Spent Fuel Management and Safety of Radioactive Waste Management (1997);
- Supplemental Funding (1997).

A Convention on Nuclear Safety entered into force in October 1996. At the first Meeting of the Parties to take place in April 1999, national safety reports covering civil nuclear power operations will be examined and a summary report of findings made available. The recent updating of the international regime for civil liability for nuclear damage that includes a Convention on Supplementary Funding along with the new Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management are further evidence of the growing of legal and other commitments binding countries in nuclear safety.

Nevertheless, the most convincing demonstration of the global nuclear safety culture will be performance of existing plants and avoidance of major future safety events. Through the activities of national regulatory bodies, the World Association of Nuclear Operators (WANO) and numerous national and international utility organizations, the nuclear industry is highly scrutinized to promote safety. The IAEA has developed a broad range of well used safety services allowing international experts to review and advise on safety matters.

2.6. A perspective

Beyond doubt, the Chernobyl accident was a severe accident in all dimensions. A review of other large energy related and industrial accidents is needed for comparative purposes. While the perception of nuclear accidents may not change, such a review offers some perspective. In industry, the well known 1984 Bhopal accident at a chemical plant in India caused some 3,000 early deaths and several hundred thousand severe health effects.

In the energy sector, hydroelectric incidents are not benign - dam failures and overtopping have caused thousands of deaths and massive disruption in social and economic activities with the displacement of entire towns - the Varont dam overtopping in Italy and dam failures in Gujarat and Orissa in India are three such examples, each with several thousand fatalities. Coal mine accidents causing several hundred fatalities are not rare and explosions and major fires in the oil and gas industry have involved both occupational and public fatalities and injuries. A pipe line explosion in the Urals involved 500 fatalities. Energy sector accidents have also led to severe environmental damage, such as the 1989 Exxon Valdez oil tanker accident in Alaska.

If risk assessments considered only short-term severe accident fatalities, data would indicate hydroelectric and gas fuel cycles have led to the largest single event fatalities. However, to draw conclusions about the relative safety of the various energy systems, fatalities and morbidity - occupational as well as public - must be considered over the longer term. This is discussed in a subsequent section on External costs of energy generation. Equally important is the maturity of the technology, the quality and maintenance of equipment and safety and environmental controls.

3. CONCLUSION

For nuclear power to play its legitimate role in the future, acceptance by the public and by political forces is vital. This paper has attempted to clarify some of the issues currently limiting the achievement of this goal.

EXPERIENCE WITH NUCLEAR POWER IN INDIA

(Session 7)

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THE NEED AND THE ROLE OF NUCLEAR ENERGY IN INDIA

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Abstract

The demand for energy in India is growing because of population growth and a developing economy. Commercial energy consumption has increased to about 60 per cent from about 25 per cent in 1950 and the electricity share in total energy consumption is about 25 per cent. The growth rate in electricity generation is expected to be ~8 per cent in the coming two decades, which means that the installed capacity of 90 GW(e) will increase to about 300 GW(e) by 2020. Coal and nuclear energy are the major resources available; oil and gas potentials are very low and do not meet today's needs. Hydroelectric potential in the country has been estimated as 84 GW(e) at a 60 per cent load factor and of this, only about 25 percent has been realized so far. The nuclear resources of India comprise moderate Uranium and large quantities of Thorium. The first phase of a three stage nuclear program, deployment of pressurized hot water reactors (PHWR) has taken off and is poised to grow to its greatest potential by 2010. The second phase, deployment of fast breeder reactors (FBR) will take off from there and the third phase may begin by the middle of the next century. India has established a comprehensive capability in design, construction and operation of PHWR. There are 10 thermal reactors of 200/220 MW(e) capacity in operation and 4 × 220 MW(e) PHWR under construction. The country has expertise in prospecting, mining, extraction, fuel fabrication, reprocessing and radiation waste management. A beginning has been made in the development of FBR technology by construction of a 40 MWt/13 MW(e) fast breeder test reactor (FBTR) and research and development (R&D) facilities.

1. ENERGY NEEDS

India's population has grown from 350 million at the time of independence to 950 million today. This has eroded the impact of the per capita statistics in spite of considerable growth in GDP through agriculture and industry. India supports 16 per cent of the world's population on 2.3 per cent of the land, posing a major challenge to the nation even assuming uniform distribution of world resources. India being a tropical country, the energy requirements should be lower than in developed nations for a similar standard of living. Population` control is the most important challenge for India, to improve living standards and environmental protection.

Commercial energy consumption has increased to 60 per cent from about 25 per cent in 1950. Non-commercial energy comes from burning 250 million t of animal dung, firewood and agricultural wastes [1]. The generation of electricity during last four decades has grown as shown in Figure 1 [2]. Total generation is now 420 TW(h) comprising 336 from thermal components, 74 from hydropower and 10 from nuclear. In spite of this massive increase, the per capita generation is only about 420 kWh, about one sixth of the world average. The nuclear energy contribution has decreased from 3 per cent in 1969 to 2 per cent today and hydro has also decreased from 50 per cent to 24 per cent. There is a peak load shortage of 18 per cent resulting in frequent power cuts and blackouts that affect industry, agriculture and domestic needs. Although development is occurring, about one third of the population still lives under the poverty line of 1 \$/d. Problems of housing, education, water supply, health, transport, communication, etc., have yet to be solved, particularly in rural areas where two

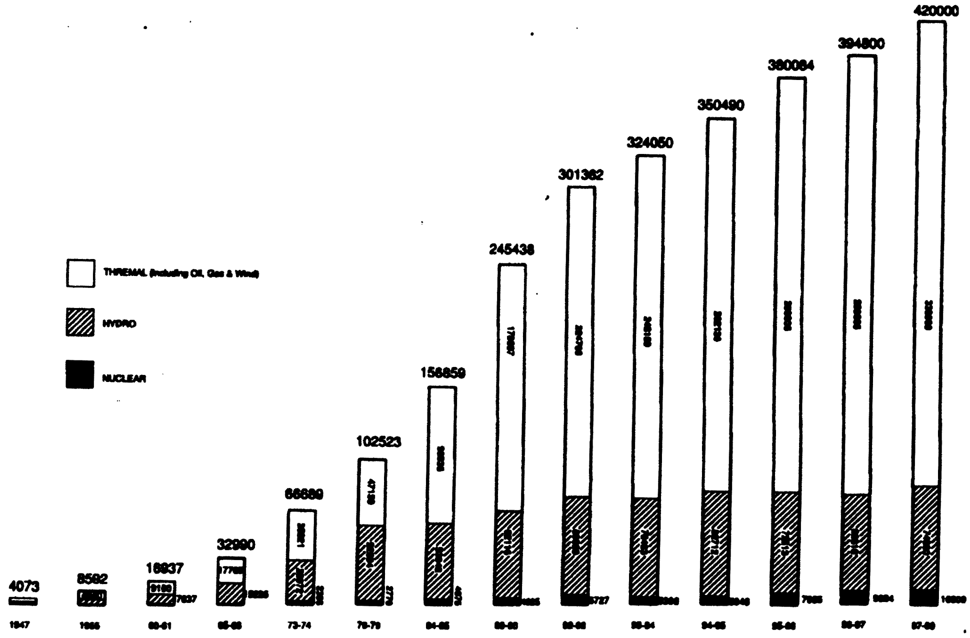

FIG. 1. Growth of electricity generation in million units (bWh).

thirds of the population lives and only 30 per cent of households have electricity. This fact alone shouts loudly about the need for more energy. Government plans to add an additional 40 GW(e) to the existing capacity of 90 GW(e) in the IX plan period (1997-2002). Projections for the year 2020 are in the range of 200-300 GW(e).

2. ENERGY RESOURCES

Energy resources available in India are indicated in Figure 2. It is very clear that coal and nuclear energy through FBR are the only major resources, with oil and gas small contributors. Today, India imports 60 per cent of its oil requirements at a cost of 7 b$. This, apart from energy dependence, causes a considerable dent in the national balance of payments. The production and consumption of oil in the near future is shown in Figure 3. The catastrophic effect on the Indian economy of such large imports is very obvious. There is an urgent need to consider replacing oil by electricity for part of the transport sector, thus reducing pollution. The ministries of transport, civil aviation, railways and power must solve this problem.

Coal is an important energy resource but considering the limited quantity, its other chemical uses, environmental considerations (greenhouse gases and acid rain), and the limitations of mining and transportation, it is essential to reduce its consumption for electricity in a phased manner from the year 2020. The world has realized the necessity of environmental protection. The situation is alarming as illustrated below. In the seventies, thousands of lakes became biologically barren in Sweden as a result of acid rain, largely caused by the burning of oil and coal. USA and Germany have observed forest trees dying because of acid rain [3]. China, which burns about 1 bt of coal/a, mentions that in the eastern part of the country rain water pH is 4. Mumbai, Delhi and Calcutta are included in the list of worst polluted cities of the world. About 4 million children world-wide are affected by respiratory infections, of which 20 per cent die before the age of five. The effects of greenhouse gas releases, acid rain

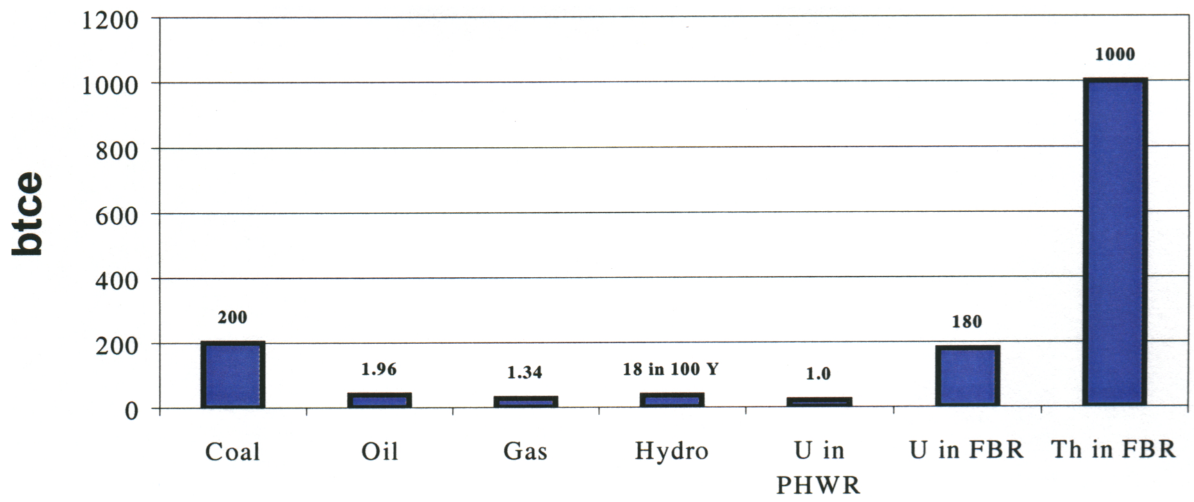

FIG.2. Energy resources of India.

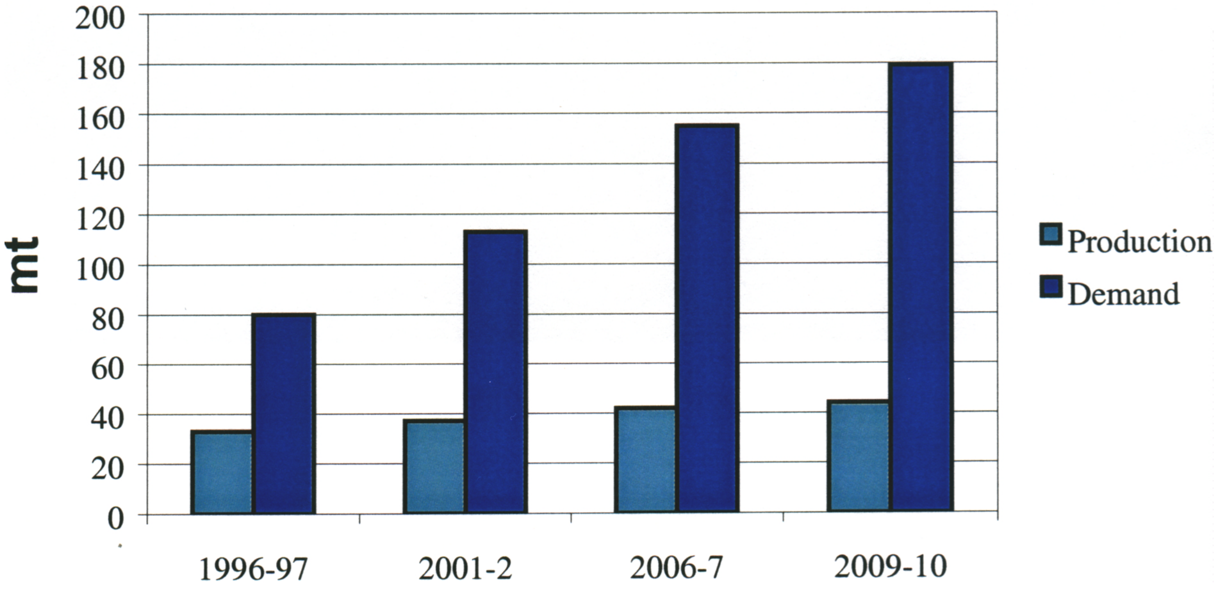

FIG. 3. Crude oil production/demand.

and local air pollution are well known and urgent actions are needed to change this. We have many options for energy but no option for the environment. Life styles also must be changed to emphasise energy conservation. In fact, the UN world commission on environment and development has asked for 50 per cent reductions in energy consumption in the developed countries by the year 2050.

Hydro potential, estimated at 84 GW(e), should be used to the maximum as it has the advantage of being a simple, low cost technology, with potential for irrigation, drinking water, flood control and peak load management. Other renewable energy resources are not indicated in Figure 2 since they are unreliable sources of electricity for industrial use and their contribution is likely to be both small and expensive.

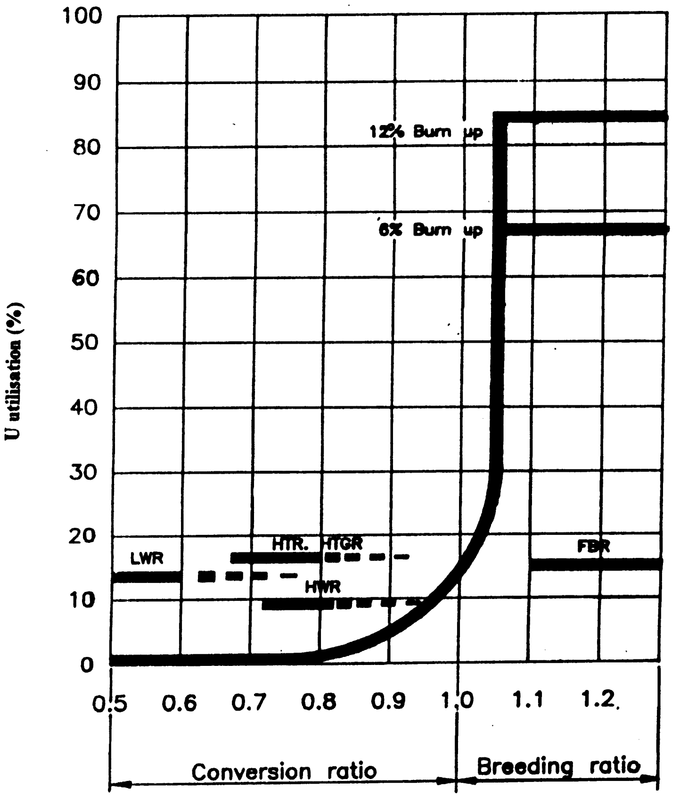

FIG.4. Uranium utilization.

The Uranium (U) resource of India is estimated to be 50,000 t and the Thorium (T) resource 3,50,000 t. India selected PHWR for its first phase of nuclear energy use since it does not require heavy reactor components, uses natural U as fuel, has the ease of heavy water production compared to enriching U, and produces higher quantities of plutonium (Pu). With the available U, about 12 GW(e) of capacity can be installed for a 30-year plant life. The contribution to energy resource solely by the thermal reactors is too small to justify the development of a nuclear energy program in India. Therefore, a once through fuel cycle strategy is unacceptable for sustainable development. When the Pu and depleted U discharged by the PHWR are used in FBR, the utilization of U increases to about 80 per cent, Figure 4.

It can be seen that only about 0.6 per cent of natural U is utilized in PHWR compared to 80 per cent in an FBR. The U utilization is not a function of the breeding ratio but dependent on fuel burnup. The higher the burnup, the lower the loss in the fuel cycle, thereby improving resource use. The FBR resource is comparable to coal if all the available coal is used for electricity. When one considers the chemical uses of coal and removes half of the coal in the indicated and inferred categories, it is seen that the FBR resource is the largest. Therefore, there is an urgent need to deploy FBR early, for the energy security of the country. Thorium should be used only after a large capacity has been realized through the Pu-U cycle.

Diverse energy resources are essential to avoid common cause failures such as those due to monsoons, coal mine and railway strikes and serious malfunctions in nuclear power plants. Coal, hydro and nuclear power provide good diversity for India.

3. DEVELOPMENT OF NUCLEAR ENERGY

India started developing a domestic capability in nuclear energy technology in the 1960s, including design, construction and operation of PHWR. It acquired capability in the technology of the complete fuel cycle i.e., prospecting, mining, extraction, fuel fabrication, fuel reprocessing and waste management. This has been possible because of this policy of domestic development and sustained R&D over 40 years. No doubt there have been delays from inadequate infrastructure and isolation from advanced countries due to the imposition of sanctions against the transfer of certain capabilities associated with nuclear technology.

Today, there are 10 operating thermal reactors in the country, as indicated in Table I.

In the initial years, there were problems due to deficiencies in the conceptual designs and local application of technology. During the last 3 years, capacity factors improved considerably and in 1997-98, it was 71 per cent; 2 units at Narora achieved 90 per cent. Safe operation of nuclear power plants at high capacity is essential for public acceptance. The level of domestic application of technology in the last three nuclear power plants (NPPs) was 90 per cent.

Construction of 4x220 MW(e) PHWR is in progress at Kaiga and Rajasthan and they are scheduled for commissioning in 1999. Due to a paucity of funds, the government did not approve construction of nuclear power plants in the VIII Plan, affecting growth, especially in the industrial sector. The government now realizes this failure and approved construction of 2x500 MW(e) PHWR at Tarapur in the IX Plan. Growth of India's nuclear capacity now depends on the availability funds through the Government and the Nuclear Power Corporation.

India has built eight heavy water production plants and excepting one at Talchar, all plants are working well. When problems occurred in the first 3 plants, confidence in the PHWR program was shaken. Today, we design, construct and operate the plants, and are self sufficient in heavy water (D_2O) production. India exported about 100 t of D_2O to Korea.

TABLE I. OPERATING THERMAL REACTORS IN INDIA

LOCATION	CAPACITIES	TYPE	COMMISSIONING DATES
TAPS	2 × 200 MW(e)	BWR	1969/1969
RAPS	2 × 200 MW(e)	PHWR	1973/1981
MAPS	2 × 220 MW(e)	PHWR	1984/1986
NAPS	2 × 220 MW(e)	PHWR	1991/1992
KAPS	2 × 220 MW(e)	PHWR	1993/1995

Importation of light water reactors (LWR) was considered, to increase the installed electricity capacity and for financial reasons. Implementation of this strategy depends on political issues related to non-proliferation, the comprehensive test ban treaty (CTBT) etc. India signed an agreement with Russia for construction of 2x1000 MW(e) PWR at Kudankulam in the south of India. Commissioning of these plants is expected in the years 2004 and 2005.

In the early stages of the nuclear energy program, reprocessing of spent fuel was considered essential so India built three reprocessing plants (Trombay, Tarapur and Kalpakkam). The plant at Kalpakkam is now in the commissioning stage. Plutonium requirements for the start of the FBR program will be met from these plants. Real challenges to reprocessing technology will come from the requirements of the FBR program to economically reprocess high burnup, short-cooled, spent-fuel with minimum heavy metal loss. Along with reprocessing, radwaste management capability has also been comprehensively attained. The technology of vitrification and storage of high level radioactive waste has been developed and as a consequence, waste management concern is much reduced.

India started the FBR programme at Kalpakkam where a 40 MWt/13 MW(e) FBTR has operated since 1985. It uses a unique fuel of 70 per cent PuC-30per cent UC with sodium as the coolant. The fuel has achieved a burnup of 40,000 MWd/t without failure. Design and development of a 500 MW(e) prototype fast breeder reactor (PFBR) is in progress; construction was approved by the government in the IX Plan and is likely to start in 2001. Large quantities of Pu generated in the thermal reactors will be used in the future FBR that will follow PFBR.

4. NUCLEAR SAFETY

Traditionally, safety receives the most intense attention of all aspects of nuclear technology. Nuclear reactors have operated worldwide with enviable safety records excepting a few isolated accidents. Today, more than 425 power reactors (~8000 reactor years) are operating in the world, producing 1/6th of the world's electricity. This, by itself, confirms that nuclear technology is accepted as a safe resource by the world at large. The safety record of Indian nuclear plants is no exception and experience gained in overcoming the consequences of a few incidents has helped confirm validity of the safety features. Though these safety standards are excellent, there is a need to further improve them to obviate the need for public evacuation after a severe accident, which contributes to the negative public mind-set about nuclear energy.

Important safety issues are radiation effects, radwaste management, decommissioning and accident risks in reactors. These have been adequately addressed and improvements continue.

The radiation doses to operating personnel and the public during normal operation are well within limits prescribed by the Atomic Energy Regulatory Board (AERB). Nowhere in the world have the effects of radiation been noticeable in normal operation of nuclear facilities.

Radwaste management is an important issue in the nuclear program although radwaste quantities are very small, ~ $1m^3$ (~5t) of solid waste/TW(h). This can be compared to 1 million t of CO_2 , 120 t of SO_2, 650 t of NO_X and 60,000 t of ash from an equivalent size coal fired power plant. This comparison considers the latest pollution abatement technology for coal fired plants. Radwaste is isolated from the biosphere while the gases from fossil plants are enter the atmosphere. India developed the technology for radwaste management well in time and new breakthroughs are not required. Further developments are expected in the technology of partitioning and actinide burning which will considerably reduce the storage time.

Decommissioning is neither a hazardous nor a costly operation. The cost of decommissioning is included as a small fraction of generation cost itself.

Though assimilating facts regarding nuclear technology is difficult not only for laymen but for the educated elite, efforts to educate the public should continue. Public acceptance of nuclear energy is important for its growth and transparency in all aspects of nuclear technology is basic for confidence building.

5. ECONOMICS

The economic competitiveness of nuclear energy has been shown in India as well as in other countries. (The economics of nuclear energy in India is covered in a separate paper.) Nuclear electricity costs compare well with those of electricity from coal at distances of 800 to 1000 km from the coal fields. High capital costs, high interest rates and longer construction time for nuclear reactors erode this competitiveness and must be reduced. Today, 210 and 500 MW(e) coal fired power stations are constructed in 30 and 36 months respectively. This poses a great challenge to nuclear power plant (NPP) construction, which takes about 100 months. Similarly, the cost of heavy water and fuel fabrication must be reduced to improve competitiveness. The cost of R & D and decommissioning are included in the unit energy cost of the reactors. It is also worth mentioning that nuclear electricity in India is not subsidized.

6. CONCLUSIONS

India's energy requirements are very large due to a large population. Population control is the best way to improve living standards and environment protection.

Coal and nuclear energy through FBR are the only major resources. Coal alone, if used for electricity generation, will not last beyond the next century. The problems of greenhouse effects and acid rain compel us to reduce coal consumption for power generation.

Indigenous Uranium reserves can sustain only about 12 GW(e) power generation for 30 years. Therefore, FBR must be introduced at the earliest possible time.

India has acquired the comprehensive capability to design, build and operate power reactors and manage complete fuel cycles.

Nuclear energy is economically competitive with alternate sources of energy, however, efforts must be made to further improve it by reducing capital costs and construction time.

Concerns about radiation effects, decommissioning, radwaste management and accident risks have been adequately addressed. Technologies are available for decommissioning and radwaste management and a systematic approach in design and operation to prevent accidents is ongoing.

Nuclear energy is environmentally the most benign compared with other options for electricity generation.

ACKNOWLEDGEMENT

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FINANCING ASPECTS OF NUCLEAR POWER IN INDIA

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Abstract

This paper addresses economic scenarios and trends toward deregulation in India. Growth of the power sector must precede economic growth. Nuclear power growth, now at a rate lower than the average growth of other power, is expected to accelerate over the next two decades. Capacity growth would be funded through equity and debt in the ratio of 1:1. While a substantial portion of the equity capital would be mobilized internally, the initial flow of equity for this growth must come from the Government. The debt capital is to be substantially funded by the domestic capital market and part would flow from external sources.

1. INTRODUCTION

Development of infrastructure is a prerequisite for growth of a developing economy. As a critical part of infrastructure development, power must achieve a high rate of growth to support this. Nuclear power has been identified as a clean and economically viable source of energy, which can contribute significantly to economic development. However, nuclear power needs more capital investment than conventional thermal power. A developing country is faced with a scarcity of capital and therefore must plan a long-term strategy for financing. This paper illustrates the Indian experience in the financing strategies of nuclear power programs.

2. THE INDIAN ECONOMY

India has a developing economy with a gross domestic product (GDP) of (rupees) Rs.12756 billion (US $ 300 billion) at current prices and has been growing at an average rate of about 5 per cent in the last two decades. The average growth rate of the economy in the last five years has been 6.7 per cent. It is poised to grow at the rate of about 7 per cent in the coming years.

The contributions to the economy from the different sectors during 1996-97 at current prices are shown in Table I.

TABLE I. SECTORAL CONTRIBUTIONS TO GDP

Sector	Percent
Agriculture	27
Industry	31
Service	42
Total	100

2.1. Direct savings in the Indian economy

India’s current savings rate at about 26 per cent of GDP, is relatively high compared to other developing countries and can be further increased through tighter fiscal policies and strong structural reforms. Components of the savings include, currency, deposits with banks and financial companies, claims on government, investments in shares and debentures and contractual savings like pension funds, provident funds, etc. Household savings play an important role in boosting growth in the economy. Private corporate saving has also shown a steady increase over the last 20 years though it remains at below five per cent of GDP. Gross saving is expected to increase at about 28 per cent by the year 2000. A part of these savings are directed to the capital market, which includes the equity and the debt market.

2.2. The Indian capital market

The Indian capital market has been instrumental in the economic growth of the country by channeling domestic savings to industrial investment. During the 1980s, the Indian capital market emerged as an important source of funds for corporations in both the private and public sectors. During the period 1988-95, the total volume of capital issues rose nearly five-fold. While in the 80s, the debt instruments played a dominant role in mobilizing resources, during the 90s, the trend has changed and equities emerged as a more popular instrument in resource mobilization. However, during the last 3 years, debt instruments have again become popular. The debt market is expected to grow substantially in volume and will provide debt capital for growth of the power sector, including nuclear power.

3. ENERGY POLICY OF INDIA

The energy policy of the Government of India aims to ensure adequate energy at a minimum cost, achieve self -sufficiency in energy supplies and protect the environment from adverse impact by utilizing energy resources judiciously. The main elements of the energy policy are:

- Accelerated exploitation of conventional domestic energy sources viz.: coal, hydro, oil and nuclear power.
- Energy conservation and management with a view to increasing energy productivity.
- Optimizing the utilization of existing capacity in the country.
- Development and exploitation of renewable sources of energy to meet the energy requirements of rural communities.
- Intensification of research and development in the field of new and renewable energy sources.
- Organization of training for personnel engaged at various levels in the energy sector.

4. POWER SECTOR IN INDIA

Electricity is the single most critical infrastructural input for economic growth of the country. In India, electricity is a resource involving complex decision making that lies in the concurrent jurisdiction of the center and the states. As a result of substantial growth of the power sector, the cumulative generating capacity of the country has increased to about 90000MW(e), supported by a vast network of transmission and distribution systems. The hydro share of electricity generation has decreased from about 54 per cent in 1947 to about 25 per cent now. This is expected to decline further during the Ninth Five Year Plan (1997-2002). The present share of different sources in electricity generation is given in Table II.

While the country faces genuine power shortages in many areas, there are surpluses during the off-peak hours in some regions. The State Electricity Boards (SEB) are at the center stage of the power sector in India, which has about a 70 per cent share of the generating capacity and almost 100 per cent of the distribution of electricity. Due to heavy subsidies in tariffs provided by the SEB for electricity supply to agricultural and domestic sectors, and due to high losses in transmission and distribution, most of the SEB cannot recover the full costs of electricity supplied, resulting in weak financial positions for them.

The demand for electricity is growing at an annual rate of about 8 per cent. To match this demand with the supply of electricity, it is necessary to direct huge investments toward capacity additions, with matching investments in transmission and distribution. Coal and hydro will continue to dominate electricity generation in the country for the next 20 years with nuclear, natural gas and lignite playing a complimentary role. With the large deposits of thorium, nuclear power with fast breeder technology is expected to be important in the future.

4.1. Deregulation

Economic reforms include deregulation of the power sector. While initiatives are on for channeling private investment into power, mainly in thermal power, such initiatives for investment have not begun in nuclear technologies. Even with these initiatives, the actual investment to date is far short of expectations.

A direct result of deregulation of the power sector is increased costs for power. The business risk of a public sector unit engaged in power production is by and large internalized and therefore not directly reflected in the price of electricity. However, with private investors, a part of the business risk is allocated to other agencies at a cost, which would be reflected in the pricing of electricity. However, with increases in efficiency of operation expected of the private sector, the increase in the cost of electricity may not be significant.

5. NUCLEAR POWER

Since independence electricity generation has grown at an annual compounded rate of about 7.5 per cent and that of nuclear electricity at a rate of about 5.6 per cent since 1973-74. With the limited availability of fossil fuels in the country, there was a need for an alternate source of energy to meet long-term energy demands.

TABLE II. SHARE OF DIFFERENT SOURCES

Sources	Percent
Thermal	72
Hydro	25
Nuclear	2
Other	1
Total	100

A nuclear power station comprising twin reactor units of 2 x 200MW(e) was launched at Tarapur (Maharashtra) in 1964. This station has two boiling water reactor (BWR) units using enriched uranium as fuel and light water as moderator. To be self-reliant in nuclear generation, the Department of Atomic Energy (DAE), opted for pressurized heavy water reactor (PHWR) technology in collaboration with Atomic Energy of Canada, Limited, and commenced construction of a power station comprising two units of 220MW(e) each at Rawatbhata in Rajasthan in 1964. The PHWR technology used natural uranium as fuel and heavy water as moderator. To achieve long term self-sufficiency, the DAE established facilities for fabrication of fuel and zirconium alloy components, manufacture of precision reactor components and production of heavy water. Efforts were dedicated to develop manufacturers in the country to produce components like calandria, end-shields, steam generators, fueling machines, nuclear pumps and other critical equipment required for nuclear power stations, conforming to international nuclear standards. With these efforts, development of world class manufacturing facilities in public and private sector organizations could be achieved.

India has developed its own standardized PHWR design of 220 MW(e) with major design improvements in safety systems. The construction of reactors at Narora and Kakrapar was based on the standardized PHWR designs. Presently, five operating nuclear power stations, with an installed capacity of 1840MW(e) are in operation. India has more than 120 reactor years of operating experience and operations have been free from incidents of radiation release. Power generated by these reactor units exceeded 120,000 million units by the end of March 1998. Four units of 220 MWe are in advanced stages of construction. Detailed designs for 500MW(e) of pressurized heavy water reactor series have reached an advanced level of completion. Commencement of construction of 2 x 500MW(e) units at Tarapur has started. Sites for establishing an additional 4 units of 500MW(e) each and 4 units of 220 MW(e) each have been cleared and advance action for procurement of critical items has been taken.

The installation of a sufficient power generation base of PHWR using natural uranium resources available in the country as Stage-1 of the nuclear power program, will provide inputs and impetus for utilization of plutonium in fast breeder reactors (FBR) as Stage-2. The long range potential of nuclear energy in India depends on utilization of Thorium, whose known resources in the country exceed 360,000 tons, which, when used in the breeder reactors, will be equivalent to about 600 billion tons of coal. With the establishment of a 40 fast breeder test reactor (FBTR) at Kalpakkam, a beginning has been made for the second stage of the program. Set up of one unit of a 500MW(e) prototype fast breeder reactor (PFBR) is also planned and the design is fast progressing. India has attained total self-reliance in design, construction, operation and maintenance of nuclear power plants. It has also mastered fuel cycle technologies from mining to fabrication of natural uranium fuel, fabrication of enriched uranium fuel, reprocessing technology, fabrication of plutonium and thorium based fuel required for its future program. The related waste management facilities have also been satisfactorily developed.

5.1. Safety aspects

Safety is given utmost importance during design, construction and operation of the nuclear power plants in the country. These aspects are continuously reviewed by the Atomic Energy Regulatory Board (AERB), an independent body, constituted by the government. Nuclear power plants in India have established a good record of operational safety; there has been accident-free operation for more than 120 reactor years and there has been no injury or casualty due to radiation. Gaseous and liquid releases from the nuclear power stations have been a small percentage of the limits authorized by the AERB. Industrial accident frequency and severity rates for the nuclear power stations in operation and under construction are far below national levels. Codes and standards followed in India conform with international standards including those of the International Atomic Energy Agency (IAEA) and the International Commission on Radiation Protection (ICRP).

5.2. Regulatory environment

There are three distinct regulatory phases: (1) site selection, (2) construction and commissioning and (3) operation of the station. During site selection, the agencies involved in regulation are the Ministry of Environment and Forest, the AERB and the Central Electricity Authority (CEA). During construction and commissioning, the AERB is the regulating agency. During the operation of the station, the AERB, CEA and the Department of Atomic Energy (DAE) regulate activities. While the AERB regulates operations from the standpoint of public safety, the CEA and DAE regulate the distribution of power and pricing issues.

5.3. Attitude of the government and the public

The government of India has extended a high level of support to nuclear power. This support has been translated in terms of budgetary support to the program year after year. Until 1987, the Government met the entire expenditure for the nuclear power program. With the formation of the Nuclear Power Corporation of India Limited (NPCIL) in 1987, part funding for the program started flowing from the capital market as debt capital. However, the entire equity capital for the nuclear power projects continued to come from the Government. During the Eighth Five-Year Plan period (1992-97), the flow of funds from the Government as equity capital was significantly lower than required, due to financial constraints. However, from 1997 onwards, the trend has changed and the flow of funds from the Government has increased.

The public at large in India, has supported nuclear power, as it is perceived as a source of energy with substantial potential available at reasonable prices. However, there are pockets of population critical of nuclear power particularly on safety issues. The limited public opposition is not considered a hurdle for the growth of nuclear power in this country.

5.4. Capital cost of nuclear power projects

The costs of completed nuclear power reactor units shown in Table III have increased unit after unit. If the inflation effect is removed, costs of PHWR until NAPS is fairly stable however, the costs of units from NAPS onwards show large increases from the earlier series.

This is mainly due to inclusion of financing costs of borrowed funds and to changes in design to incorporate the latest safety features. The main reasons for increases in the capital costs are:

- Inflation.
- A stretch in the gestation period and the consequent increase in overhead and financing.
- Increases in the scope of projects due to incorporation of the latest operational and safety features.
- Foreign exchange variation.

TABLE III. COST OF COMPLETED NUCLEAR POWER STATIONS (Rs in Million)

	Cost (book value)			Cost at 1998 rupee value						
	Base Cost	IDC	Total Cost	Base Cost	IDC	Total Cost	Cost / MW		Cost / MW - As % of RAPS-1 cost	
							With IDC	W/O IDC	With IDC	W/O IDC
TAPS 1,2	930	-	930	9580	-	9580	-	29.9	-	-
RAPS 1	730	-	730	8430	-	8430	-	42.1	-	100
RAPS 2	1030	-	1030	8530	-	8530	-	42.6	-	101
MAPS 1	1190	-	1190	8060	-	8060	-	36.7	-	87
MAPS 2	1270	-	1270	6580	-	6580	-	29.9	-	71
NAPS1,2	6530	1080	7610	22920	2260	25180	57.2	52.1	136	124
KAPS1,2	9560	4110	13670	23110	6820	29930	68.0	52.5	161	125

Of the above, the dominant reasons for increases in the capital costs have been inflation and extended gestation periods. Since the formation of NPCIL, debt capital mobilized from the domestic capital market is also used start new projects. The interest on the debt capital during construction is included in the capital costs of the projects. Since the gestation periods of nuclear power projects are long, interest during construction is of the order of 30 per cent of the capital cost. The capital cost of the new nuclear power projects is estimated at about Rs.60000 per Kwe at 1998 prices, based on a twin unit station of a unit size of 500MW(e) and a capital debt equity ratio of 1:1.

A lot of attention is focused on cost reduction of nuclear power projects. Considering that they have a long gestation period and about 50 per cent of the total capital costs are time related, such as overhead, escalation and interest during construction, NPCIL has set out to standardize the designs to enable serial unit construction. With this strategy it is expected that the capital costs of nuclear power projects, in real terms, could be reduced significantly.

5.5. Tariff and pricing issues

Electricity generated is supplied to the State Electricity Boards (SEB) in the region. For this purpose, a bulk power supply agreement is signed between the generating company and the concerned SEB. With clearance of the Central Electricity Authority, the Government specifies the tariff for bulk power and that is based on a `cost plus' principle. While a two-part tariff system is followed for thermal and hydropower, a single part tariff system is adopted for nuclear power. In case of the two-part tariff, fixed and variable costs per unit are separately identified. While variable costs are charged to all the units sold, fixed costs are charged only for normative generation of units above which an incentive is charged for each unit in place of fixed charges. However, a single part tariff system charges a uniform tariff for all units sold.

The element due to the capital charge in the tariff is accounted on the book value of the assets. Due to the high level of inflation experienced in most developing economies, including India, the real term value of the capital charge in the tariff diminishes year after year. Thus, the internal generation of resources after meeting the debt servicing obligations, to be used as equity capital for new projects, diminishes in real term value.

Regarding institutional aspects, the Government enacted legislation to set up an independent tariff regulatory structure at the center and the states. These regulatory authorities are expected to be in position within the next few months and will enhance investor confidence in the power sector. In the long run, this will facilitate mobilization of resources for power development on a much larger scale in the public and private sectors. A time related `availability tariff' system is expected to be operational soon for bulk power supply. This will promote safe and reliable operations of the regional power grids.

5.6. Financing

Like in any other developing country, the Government of India has funded the growth of nuclear power in this country. Until 1987, the Government provided the entire appropriation for nuclear power. Considering the projected growth of nuclear power and the limitations of funding through this route, the Government decided that part of the resources for the program should be mobilized from the domestic capital market. With this in mind, the Nuclear Power Corporation of India Limited (NPCIL) was set up as a company under the Department of Atomic Energy.

With the incorporation of NPCIL, it was recognized that funds for construction of new power stations would be mobilized from different sources, such as: government funds in the form of equity capital, the internal generation of money through the sale of electricity and loans from the domestic capital market. It was also recognized then, that all new nuclear power projects should be built with a debt equity ratio of 1:1.

Since the inception of NPCIL, the company has been able to mobilize funds from the capital market every year. So far, the total direct investments in the nuclear power stations, including the projects under construction, is about Rs.95 billion, which is equivalent to about Rs.200 billion at 1998 rupee value. Out of the total direct investments made so far, about 33 per cent have been mobilized from the domestic capital market, mainly through the issue of bonds. Permission to issue bonds, either by a public issue or by private placement, is given by the government each year, depending on the outlay of the approved capital budget. The issue of bonds by private placement has been found cheaper than the public issue. Therefore, NPCIL has adopted this route for most of its bond issues.

To help NPCIL mobilize debt capital at cheaper interest rates, each year the Government permitted issuance of `tax free' bonds for part of the amount. Until 1991, the Government determined the interest rates, which were 13 per cent for taxable bonds and 9 per cent for tax-free bonds. Until 1991, NPCIL had no difficulty in mobilizing the entire amounts, however, after 1991, the capital market changed and demands for the bonds diminished. To improve marketability, the Government deregulated the interest rates and tenor of the taxable bonds and left them to NPCIL to decide based on the market but interest rates of the tax-free bonds had an upper limit of 10.5 per cent. Even with these steps, there were difficulties in marketing the bonds from 1991 to 1993. A credit rating of the bonds was done by a reputable credit rating agency to further improve marketability. Further, it was decided to enlist the bonds in the National Stock Exchange, to ensure liquidity for the investors in NPCIL bonds. With these steps, demand increased and funds have been mobilized each year in sufficient volume and at reasonable cost.

6. PROJECTED GROWTH OF NUCLEAR POWER

The present installed capacity of nuclear power in India is 1840MW(e). There are 4 units of 220 MWe each in advanced construction, with completion in about 2 years. Nuclear power capacity is expected to grow to about 20,000MW(e) by the year 2020 (Figure 1) i.e., at an annual compounded growth rate of 11 per cent. This is significantly higher than the average growth rate of the total power sector during that period. The share of nuclear capacity is expected to grow from the present level of about 2 to about 5 per cent by the year 2020. This additional capacity during the next two decades would be pressurized heavy water, light water and fast breeder reactors. A detailed plan for the period to 2020 is not yet complete, however, one for the next decade indicates an additional capacity of about 4800 MW(e).

6.1. Fund requirements

Projected capacity additions in nuclear power for the next 22 years require more than Rs.1000 billion at 1998 rupee values, equivalent to about 23 billion US dollars of 1998. In addition, 15 billion rupees would be needed for additional fuel fabrication facilities. It is expected that the installed heavy water capacity would support projected additions. The investment during the 9th Five-Year Plan 1997 to 2002) would be Rs.66 billion, for which there are detailed plans. To meet the target of 20000 MW(e) by 2020, the investment beyond 2002 must be augmented from Rs.13 billion per year during the 9^{th} plan period to Rs.52 billion.

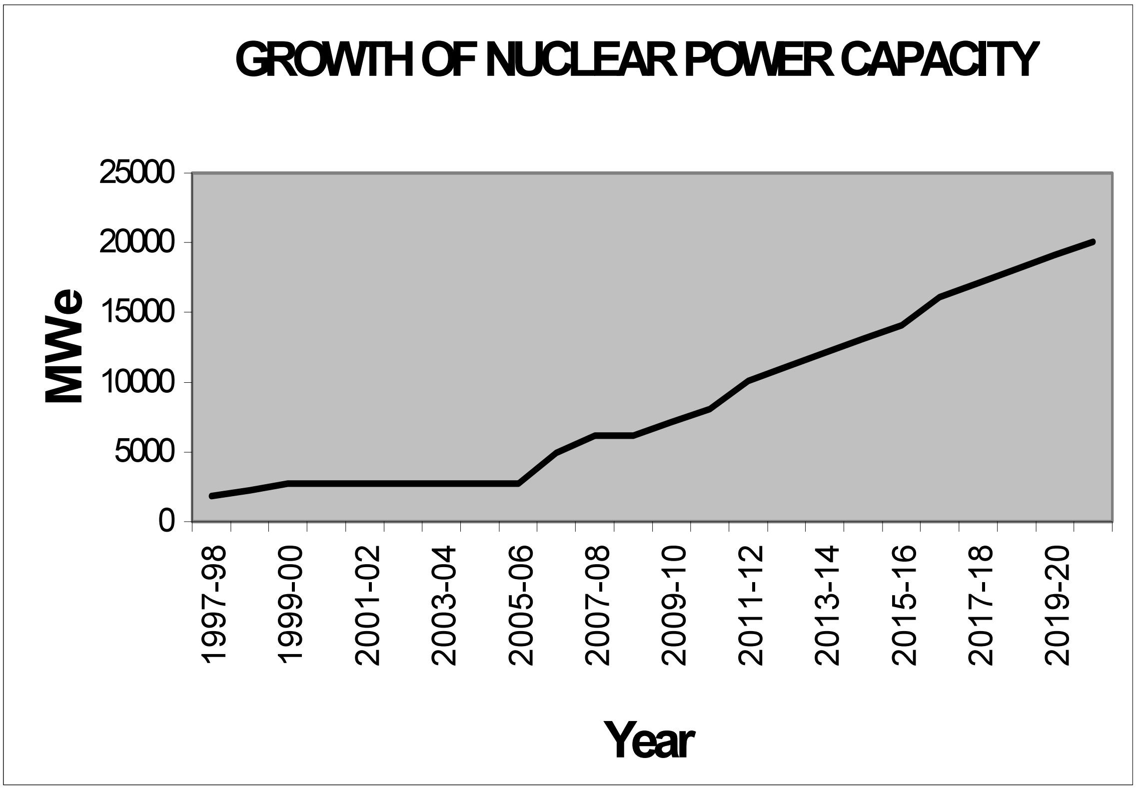

FIG. 1. Projected growth of nuclear power.

6.2. Debt equity structure

Considering the development of the nuclear power industry in the country and operational constraints, it was decided that new projects should be implemented with a conservative debt equity structure of 1:1. This ratio was adopted to reduce interest during construction. The lower ratio would help reduce fluctuations in the internal generation of resources with respect to variations in the performance of the nuclear power stations.

6.3. Projected sources of funding

Projections of fund requirements and likely sources are shown in Figure 2. With a conservative debt equity structure for funding projected capacity additions, the required capital would be about Rs.500 billion. Of this, a substantial portion, of the order of Rs.350 billion, could be generated internally by operating nuclear power stations. The balance of Rs.150 billion is expected from the Government through budgetary support. While Government funds towards equity capital would flow during the first 10 years, the internal generation of resources could be utilized in the later years. Considering the present constraints of nuclear power regarding the flow of material and technology from external sources, capital for the projected growth is not expected from external sources. Considering the regulatory environment in the nuclear power sector, it is uncertain whether equity capital could be mobilized from the domestic capital market as well.

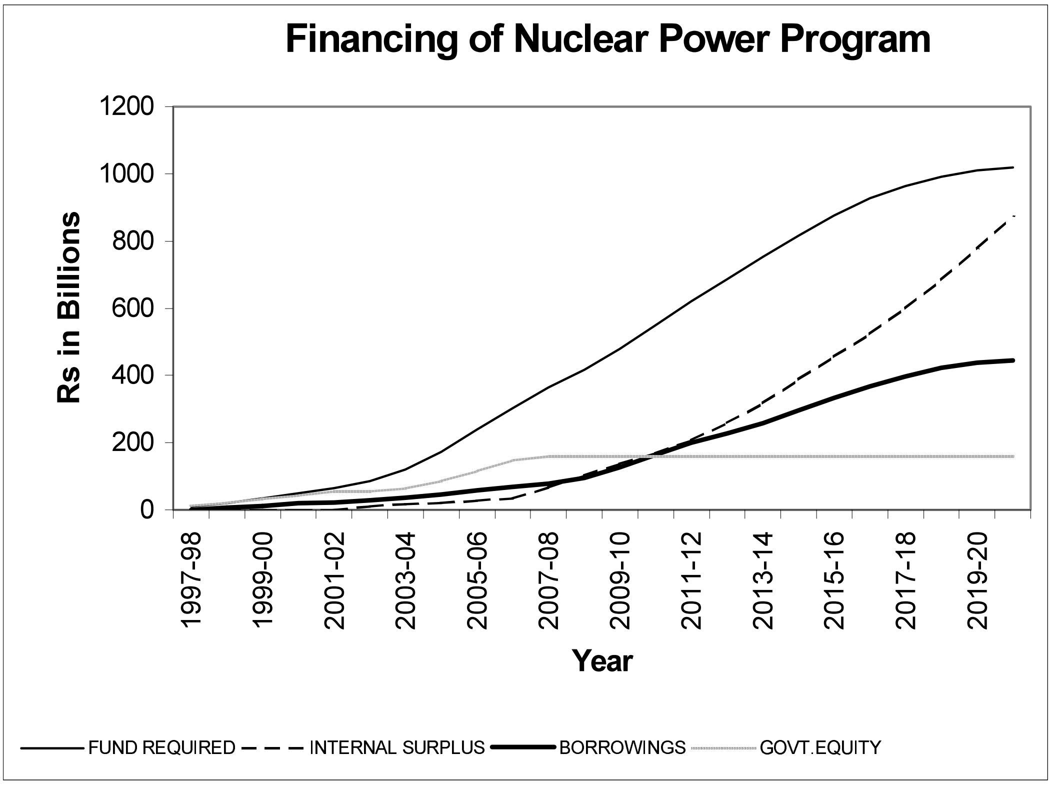

FIG. 2. Projected sources of fundings.

The debt capital for future growth amounting to about Rs.500 billion, is expected to be mobilized essentially from the Indian capital market. The Indian debt market during the last three years has grown at a phenomenal average rate of about 50 per cent and during 1997-98, the market attained a mobilization volume of about Rs.310 billion. It is expected that the future debt market will grow at about 20 per cent in the short run and about 12 per cent over the longer term.

Various options available to mobilize the debt capital for growth of nuclear power are:

- Issue of bonds in the domestic debt market.
- Syndicated term loans from banks and financial institutions.
- External commercial borrowing.
- Issue of bonds in the international markets.
- Credit extended by the suppliers.

Mobilization of funds through bond issue in the domestic market is a popular route to mop up resources. Interest rate of the bonds would be determined by prevailing market conditions at the time of mobilization. To increase the marketability, a credit rating of each issue is necessary. The credit rating of the NPCIL bonds is expected to improve to achieve the highest credit rating in a few years. It would therefore be possible for NPCIL to mobilize the required quantum of funds from the capital market at reasonable costs.

Considering the long gestation of nuclear projects, it is desirable to obtain long term funds. The main sources of long-term funds are pension and provident funds, which can be attracted through issue of long-term bonds in the domestic market. In the recent past, NPCIL issued bonds with a maturity of 10 years. It is expected that, with the growth of the debt market in the country, it would be possible for NPCIL to issue future bonds with more than 10 years maturity. It is also expected that, to help the nuclear power sector mobilize resources at reasonable costs, the Government of India would extend permission to issue tax-free bonds.

It is possible to obtain long term loans from banks and financial institutions for specified projects after evaluating financial viability. In a syndicated loan, it would be feasible to pre-determine the schedule of draw of funds depending on projected requirements for the project. The credit evaluation and the associated documentation for a syndicated loan would be more rigorous and voluminous. It would be necessary to secure the loan with some of the company assets. Normally, the cost of a syndicated loan is higher than funds mobilized through issue of bonds.

Funds could also be mobilized through external commercial borrowing (ECB) normally having a maturity of up to 7 years. The cost would be in the region of 100 to 150 basis points over a bench marked interest rate such as the London International Borrowing Rate (LIBOR). Since borrowing is in the foreign exchange, interest payments as well as repayment must be in the foreign exchange. Therefore, ECB exposes the company to the risks associated with foreign exchange variation but could be preferred provided the exchange rate of the rupee is reasonably stable. It is expected that once the exchange rate stabilizes, a part of the debt capital for nuclear power programs would flow from the ECB, provided costs are lower than domestic borrowing after adjusting for the projected exchange rate variation.

The international bond market presents an opportunity for funding nuclear power projects since it provides long term finance of maturity of more than 10 years. However, the ability of the company to gain access to the international bond market depends primarily on the credit rating of the country and the company. Therefore, this could be considered only after the credit rating of the country improves.

Another source of funding is credit from foreign suppliers of equipment or plants, where suppliers arrange long term financing through institutions in their country. Many countries have government supported financing arrangements to promote export and these could fund the supply on credit. Interest rates and repayment terms could be negotiated as part of the contract for the supply. Like other forms of external debt, this source will also expose the company to the risks of exchange rate variations.

7. CONCLUSIONS

The Indian nuclear power program is based on pressurized heavy water reactors. The nuclear power program has been funded mainly the Government of India through its national budgets. Until now, the nuclear power sector has grown at a moderate rate, lower than the average growth rate of the power sector in general. However, it is poised to grow at a higher-rate to achieve a long term target of 20000 MWe by the year 2020. Funding for the projected growth is about Rs.1000 billion, of which about 50 per cent will be mobilized as debt from the domestic capital market. The balance of funding as equity capital is expected to come from budgetary support of the Government as well as the internal generation from operating nuclear power stations.

DEVELOPMENT OF DOMESTIC CAPABILITIES FOR THE INDIAN NUCLEAR PROGRAMME

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Abstract

India, has an extensive programme for nuclear power that is self reliant to achieve long term energy security. This paper describes the Indian experience in structuring and implementing the national nuclear programme turned to its natural resources.

1. INTRODUCTION

Nuclear energy is important to ensure long term energy security for India. The Indian domestic reserves of uranium are rather small, and those of thorium quite high. To fully exploit these resources, India has adopted a three-stage nuclear power program, based on a closed fuel cycle. These three stages are depicted in Figure 1.

In the first stage, construction and operation of natural uranium based pressurized heavy water reactors (PHWR) are envisaged. Indigenous resources can support about 10,000 megawatt electric (MW(e)) of installed capacity through use of PHWR without plutonium recycling. The second stage is based on fast breeder reactors (FBR) fuelled with plutonium from reprocessing spent PHWR fuel. These reactors will breed plutonium and uranium-233. In the last stage, reactors operating on thorium and uranium-233 will be constructed.

Currently, India operates eight PHWR and two boiling water reactors (BWR) having a total rated installed capacity of 1840 MW(e). Four reactors of 220 MW(e) are under construction, and additional 220 MW(e) and 500 MW(e) reactors are planned. A 40 megawatt thermal (MWth) fast breeder test reactor (FBTR) is in operation, and the design of a 500 MW(e) prototype fast breeder reactor (PFBR) is near completion. Design of a thorium fuel based advanced heavy water reactor (AHWR) is underway.

2. AN OVERVIEW OF THE EVOLUTION AND GROWTH OF THE INDIAN NUCLEAR POWER PROGRAM

2.1. Research and development

2.1.1. Bhabha Atomic Research Centre

The Indian nuclear program began in 1945 with the establishment of the Tata Institute of Fundamental Research (TIFR). In 1957, research and development specific to nuclear energy was shifted to the newly established Atomic Energy Establishment Trombay (AEET), renamed Bhabha Atomic Research Centre (BARC) in 1967. Over the past several years, a multidisciplinary infrastructure for conducting research and development (R&D) in nuclear sciences and engineering has been set up at BARC. This includes several research reactors, a large number of laboratories and other research facilities dealing with basic as well as applied sciences, and engineering development. Most of the other units of the Indian Department of

Atomic Energy (DAE), dealing with various aspe of the nuclear power program, originated at BARC. Table I is a chronological summary of important milestones, reached by BARC.

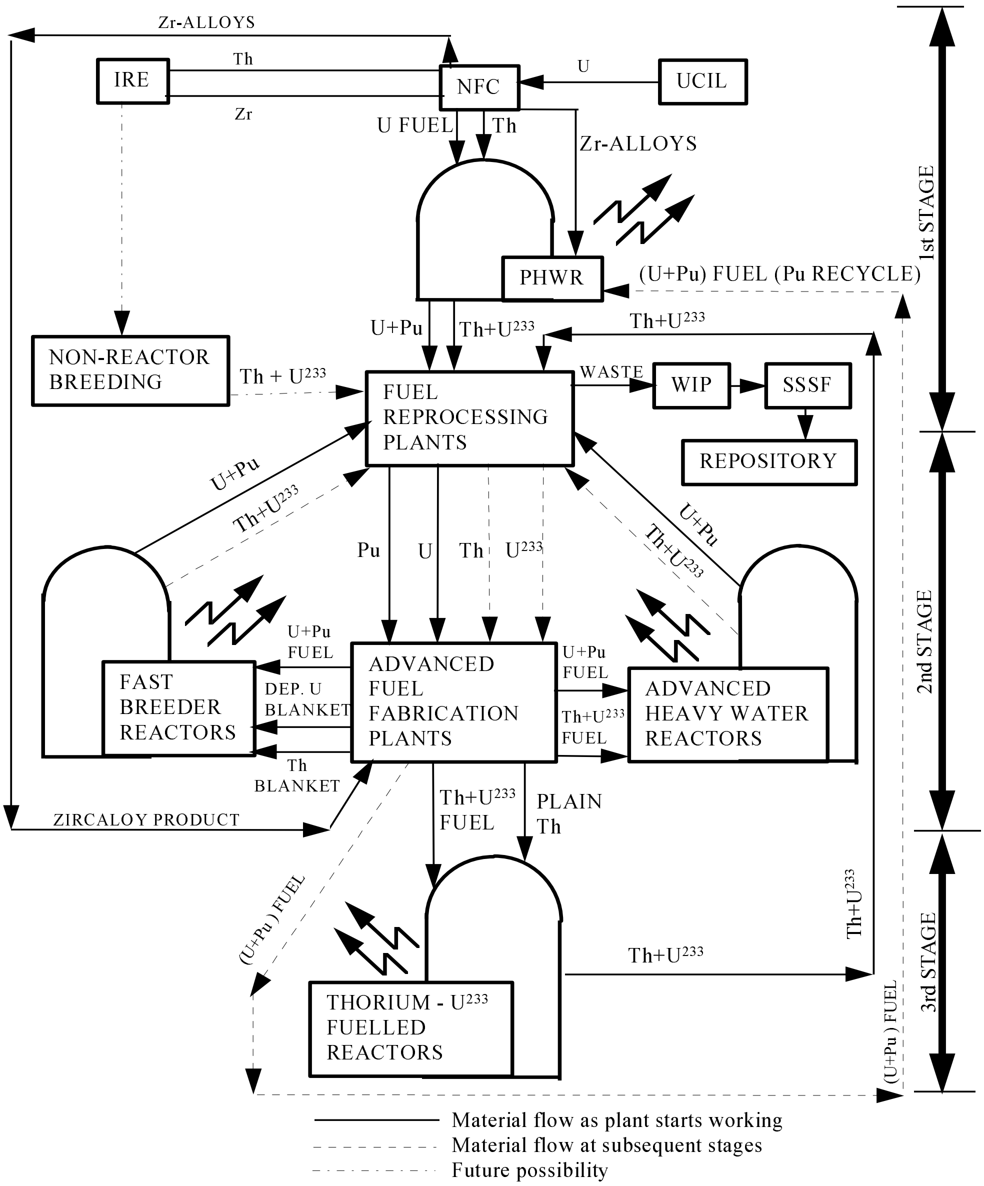

FIG. 1 Phases of the Indian nuclear program.

2.1.2. Indira Gandhi Center for Atomic Research

Initial R&D on fast reactors, including sodium technology, was started at BARC. Realizing the importance of fast reactors in the overall nuclear power program of India, work started in 1971 to set up a Reactor Research Centre (RRC) at Kalpakkam, essentially to develop fast breeder technology. RRC was renamed Indira Gandhi Centre for Atomic Research (IGCAR) in December 1985. Research and development for the fast reactor programme is now mainly conducted at this Centre, which has modern facilities to develop and test fast breeder reactor materials, components and systems, including those to work with high temperature sodium.

TABLE I. SOME MILESTONES REACHED BY BARC

1955	Thorium Plant starts production
1957	Apsara: a one MW swimming pool type research reactor, goes critical
1959	Uranium Metal Plant produces nuclear grade uranium
1960	First lot of 10 fuel elements for Cirus reactor is fabricated
1960	Cirus, a 40 MW natural uranium fueled, heavy water moderated reactor, goes critical
1961	Zerlina, a zero-energy experimental reactor, goes critical
1961	Construction of Plutonium Plant starts
1970	Uranium-233 is separated from irradiated thorium
1971	Plutonium fuel for Purnima reactor is fabricated
1972	Purnima-I, a plutonium fueled low power experimental; reactor, goes critical
1979	Plutonium-uranium mixed oxide fuel is fabricated at Trombay
1982	Reprocessing plant at Tarapur reprocesses uranium oxide fuel discharged from Rajasthan Atomic Power Station
1984	Plutonium-uranium mixed carbide fuel for FBTR is fabricated at Trombay
1984	Purnima-II, a U-233 fueled homogeneous reactor, goes critical
1985	Waste Immobilization Plant at Tarapur is commissioned
1985	Dhruva, a 100 MW natural uranium fueled heavy water moderated reactor goes critical
1989	Technologies developed at BARC used to rehabilitate MAPS-1 & 2 following failure of moderator inlet manifolds. This was the first instance of major R&D support to solve inspection and maintenance problems in power reactors, followed by many others
1990	Purnima-III, a U-233 fueled reactor, goes critical
1992	Kakrapar Atomic Power Station Unit 1, with partial thorium loading designed by BARC, goes critical
1996	Kalpakkam reprocessing plant is cold commissioned
1996	Kamini, a 30 kWth U-233 fueled reactor, designed to provide neutron radiography services, goes critical at Indira Gandhi Centre for Atomic Research
1998	Feasibility report of the thorium fuel based advanced heavy water reactor is prepared based on extensive initial studies

2.2. Commercial nuclear power plants

2.2.1. Nuclear Power Corporation

During the late fifties, the Atomic Energy Commission (AEC) determined the economics of the generation of electricity through atomic power reactors. AEC had drawn up a strategy for a three-phased nuclear power program, already described, starting with PHWR.

Initially, work on the PHWR program was done at BARC. In 1967, the Department of Atomic Energy formed a Power Projects Engineering Division (PPED) with responsibility for design, engineering, procurement, construction, commissioning, operation and maintenance of atomic power plants. With the proposed expansion, a Nuclear Power Board (NPB) was formed in 1984 to implement the program. One division of NPB was devoted to design and construction of 500 MW(e) PHWR units. The Nuclear Power Board was converted into a Corporation and the Nuclear Power Corporation (NPC) was registered as a Public Limited Company in 1987.

2.2.2. Tarapur Atomic Power Station

Tarapur Atomic Power Station (TAPS), based on BWR, was an exception to the three stage nuclear power plan drawn up by the AEC. This deviation was to acquire experience managing nuclear power station construction and operating nuclear power units, and because power shortages in the western region could be most economically reduced by building a nuclear power plant. This station, built by General Electric Co. of USA on a turnkey basis, started commercial operation in 1969. The construction of TAPS was very useful to acquire experience in the construction and operation of nuclear power plants.

2.2.3. Pressurized heavy water reactors

In parallel with the construction of TAPS, work started on a second nuclear station near Kota, Rajasthan, as a joint Indo-Canadian venture. The first unit of this station started commercial operation in 1972. This was followed by the construction of one more reactor at Rajasthan and two more reactors at Kalpakkam. The emphasis at this stage was to increase local participation in design, equipment manufacture and construction. A standardized Indian version was designed at this point and the same design was used from Narora onwards.

A chronological account of the construction of operating Indian nuclear power plants is in Table II. It also shows performance statistics of these plants for the previous financial year.

On the route from Rajasthan-1 to Kakrapar-2, designs of the PHWR have been progressively upgraded to further improve their safety, economics and reliability. At present, four units of 220 MW(e) PHWR are in advanced stages of construction at Kaiga and Rajasthan. A large program of construction of additional PHWRs of 220 MW(e) and 500 MW(e) capacities has been chalked out. Four units are now in an advanced stage of planning for construction. The design of the 500 MW(e) PHWR was fully developed within India.

2.3. Fast reactor program

Studies on content of the FBR program and the type of test reactor to be built were undertaken in the early sixties. A collaboration agreement was signed in 1969 with France for technical know-how to build a test reactor in India similar to the French reactor RAPSODIE. To gain experience with the steam generators and power plant, it was decided to add these facilities to the FBTR.

The construction of the FBTR was started in 1974 and completed in 1984. After commissioning various systems in 1984-85, the FBTR went critical in 1985. The reactor produced nuclear steam in January 1993 and reached a milestone when the power level was increased to 10.5 MWt in December 1993. Rolling of the turbine using nuclear steam was achieved in 1996 and the reactor was connected to the grid on the 11th July 1997.

Critical components of FBTR such as reactor vessels, rotating plugs, control-rod-drive mechanisms, sodium pumps, steam generators and component-handling machines were manufactured in India with know-how from France. Only 20 per cent of the total cost of the reactor was in foreign exchange, paid mainly for know-how and raw materials. Sodium for the reactor was procured from local suppliers and purified in IGCAR.

TABLE II. OPERATING NUCLEAR POWER PLANTS IN INDIA

Code	Name	Type	Net MW(e)	Gross MW(e)	NSSS supplier	Commercial operation	Capacity factor for 1997-98 (%)
IN-1	TARAPUR-1	BWR	150	160	GE	OCTOBER 1969	84.2
IN-2	TARAPUR-2	BWR	150	160	GE	OCTOBER 1969	68.1
IN-3	RAJASTHAN-1	PHWR	90	100	AECL	DECEMBER 1973	36.5
IN-4	RAJASTHAN-2	PHWR	187	200	AECL/DAE	APRIL 1981	UNDER COOLANT CHANNELS REPLACEMENT
IN-5	KALPAKKAM-1	PHWR	155	170	DAE	JANUARY 1984	48.9
IN-6	KALPAKKAM-2	PHWR	155	170	DAE	MARCH 1986	78.1
IN-7	NARORA-1	PHWR	202	220	DAE/NPCIL	JANUARY 1991	90.0
IN-8	NARORA-2	PHWR	202	220	DAE/NPCIL	JULY 1992	89.0
IN-9	KAKRAPAR-1	PHWR	202	220	DAE/NPCIL	MAY 1993	48.5
IN-10	KAKRAPAR-2	PHWR	202	220	DAE/NPCIL	SEPTEMBER 1995	62.6

Fabrication of mixed carbide fuel of high plutonium content at BARC was an important achievement. Since the agreement to obtain highly enriched U from France did not materialize, it was decided to develop high plutonium content carbide fuel. Earlier, mixed oxide fuel with high plutonium content was found chemically incompatible with sodium, which the fuel would contact in case of a breach in the cladding tube. This locally designed and developed mixed carbide fuel set a record when used as a driver fuel for the first time in the world. The first core was designed as a small core of 25 sub-assemblies since behavior of the fuel was not well known. The core was designed to generate 10.5 MWt of power at a peak linear heat rating of 320 W/cm. Based on the results of detailed post-irradiation examination of fuel, carried out at a burn-up of 25000 MWd/Te, the small core of the FBTR is now licensed to operate at a linear heat rating of 400 W/cm up to a burn-up of 50,000 MWd/Te. Other highlights of the operation of the FBTR are excellent performance of the sodium pumps, intermediate heat exchangers and the steam generator.

Design, associated R&D and the development of manufacturing technology for a 500 MW(e) prototype fast breeder reactor (PFBR) is now in progress. Unlike FBTR, PFBR is planned without any foreign support. For this reactor, construction will begin in a couple of years and commissioning is likely in ten years.

2.4. Advanced heavy water reactor

An advanced heavy water reactor (AHWR) is currently under design and development at BARC. This reactor system will expedite bridging the gap between the first and the third stages of the nuclear program, taking advantage of experience with the PHWR. The reactor is designed to produce most of its power from thorium, aided by a small input of plutonium-based fuel. The reactor will have several safety features, such as passive safety systems not requiring either external power or operator action for activation. For example, the primary circulation system does not contain pumps; it is driven by natural two-phase convection. At the current stage of development, the feasibility study for the reactor, establishing a preliminary design supported by first order analytical and experimental work has been completed and detailed design is underway.

3. EXPERIENCE WITH TECHNOLOGY TRANSFER

3.1. Tarapur Atomic Power Station

As part of the turnkey project for TAPS, complete technical documents and all equipment were supplied, erected and commissioned by the consultants. The foreign contractor trained technical personnel. This turnkey project was completed expeditiously and plant performance guaranteed by the contractor. This technology transfer depended on the contractor for problem solving, spares, fuel, etc. In addition, due to lack of knowledge about the basis of design, ability to upgrade the system was initially constrained. It took some time before dependence on the foreign contractor of the turnkey project could be relinquished.

3.2. Rajasthan Atomic Power Station

In the case of RAPS-1, technology transfer was in the form of design documents, design drawings, equipment supply, training of operational personnel and manufacture of equipment. This resulted in better understanding of design and manufacturing. The PHWR program was driven by a need to develop self-reliance; this need became urgent following the sudden withdrawal of consultant support in 1974. With the availability of comprehensive R&D support, local infrastructure to supply key inputs and progressive maturity of the Indian industries to manufacture nuclear components, it became possible to master the technologies associated with design, manufacture, construction and operation of these reactors. Over time, imports were reduced from 90 per cent for TAPS to about 10 per cent for newer PHWR.

3.3. Fast breeder test reactor

India entered into a collaboration agreement with the Commissariat a l'Energie Atomique (CEA), France, in 1969. Under this agreement, CEA provided the basic design of

Rapsodie and the steam generator (SG) design of Phenix. CEA also consulted on design when required. Indian engineers carried out many design modifications and responsibility for these FBTR modifications rested with India. The Department of Atomic Energy (DAE) was responsible for construction. French responsibility was limited to providing manufacturing know-how, to the extent that it was available. There were two types of manufacturing know-how agreements:

First, where French companies provided only documents and trained Indian engineers on their shop floor for 3 to 4 months. This covered reactor assembly components, intermediate heat exchanger (IHX) and SG. There was no on-the-job training since no FBR components were being manufactured by French industry at that time.

Second, where one prototype component was manufactured in France by French industry in the presence of Indian engineers (DAE and Indian industry) such as one sodium pump, one expansion tank meant for a secondary sodium pump and, partly, one control rod drive mechanism (CRDM). The additional four sodium pumps, with vessels, and seven CRDMs were manufactured by Indian industries. The grid plate, some parts of the pump and CRDM were manufactured in France.

On the whole the experience was satisfactory and Indian industries absorbed the technology of manufacture of FBR components. No know-how documents were received with respect to commissioning and operation of the plant.

All relevant challenges for the operation of FBTR and development of PFBR were successfully met through work at IGCAR and BARC. These included, as already described, the tricky problem of developing a local substitute for the highly-enriched uranium based fuel for FBTR, originally envisaged as being imported.

The full range of FBR technology has been assimilated through in-house development of related expertise and technologies, and setting up R&D laboratories dedicated to the FBR program at the Indira Gandhi Centre of Atomic Research (IGCAR). These include the capability of analysis of reactor behavior under steady state and transient conditions, reactor physics modeling, shielding design, and thermal hydraulic studies. It also includes establishing experimental test loops for corrosion studies, engineering development programs related to sodium pumps, PFBR steam generators, all aspects of the design, metallurgy and fabrication of special steels, and establishment of fuel reprocessing technology together with immobilization and disposal of nuclear waste generated from these reactors.

4. CREATION AND UPGRADING INFRASTRUCTURE DEDICATED TO THE NUCLEAR POWER PROGRAMME

4.1. Nuclear fuel

The creation of domestic capabilities for nuclear fuel fabrication started with half of the initial fuel requirements for RAPS at BARC. For continued production of nuclear fuel for the PHWR programme, a production facility -Nuclear Fuel Complex (NFC)- was constructed based on the technology developed at BARC. The facilities at NFC were commissioned between 1971 and 1974. The oxide fuel for PHWR is manufactured at NFC from the yellow cake (uranium concentrate) obtained from the Uranium Corporation of India Ltd. An enriched fabrication plant for the fuel for TAPS reactors was also established at NFC.

The in-pile irradiation experiments carried out at BARC during the 1980s gave confidence in the design and fabrication capability for plutonium based fuels. This led to the establishment of the Advanced Fuel Fabrication Facility, which fabricated the MOX fuel for loading at TAPS reactors.

4.2. Heavy water

The PHWR based power programme uses heavy water as a moderator and coolant. Construction of the first heavy water plants in India began in 1975 with equipment imported from France and Germany. Subsequently, these plants were designed and constructed with Indian technology and equipment. The Heavy Water Board operates eight heavy water plants. The plants at Kota and Manuguru are based on a hydrogen sulfide-water exchange process developed locally, while those at Baroda, Hazira, Tuticorin, Talcher, and Thal are based on an ammonia-hydrogen exchange process. The Nangal plant uses a hydrogen distillation process. The heavy water production capacity is adequate to meet the programme planned for nuclear power generation in the foreseeable future, and has enabled export of heavy water.

4.3. Special materials and structural products

Apart from fuel, NFC also produces core structural components for the entire nuclear power programme of India. The NFC processes zircon sand through a series of chemical and metallurgical operations using locally developed flow sheets to finally produce zirconium alloy pressure tubes, calandria tubes, fuel cladding and several other products. The Nuclear Fuel Complex has diversified its activities to make seamless tubes of stainless steel, carbon steel, titanium and other special alloys of nickel, magnesium etc. by hot extrusion and cold pilgering processes. Apart from the Department of Atomic Energy, customers of the Nuclear Fuel Complex include several segments of Indian industry. NFC is also upgrading its fabrication processes and the development and fabrication of high-tech process equipment.

The Indian Rare Earths Limited (IRE) was established to separate nuclear materials from indigenous ores.

4.4. Development of materials for prototype fast breeder reactors

Whereas most materials used in the construction of FBTR were imported, it has been the Indian objective to develop local sources. The Indian steel industry can produce austenitic stainless steel of grades 316LN and 304LN to the required quality. A programme to produce modified 9Cr-IMo steel tubes for PFBR steam generators is under way. Tubes of this material have been satisfactorily produced for replacement in the FBTR steam generator. Welding consumables in austenitic stainless steel and modified 9Cr-IMo can be produced in India.

PFBR steam generator tube lengths are very long (23 m) to minimize the number of tube to tubesheet welds. Orders have been placed with the NFC for production of tubes of these specifications. The production of clad tubes and hexagonal wrapper for PFBR has also been entrusted to the NFC. Clad tubes have been satisfactorily produced and the development of hexagonal wrapper is in progress.

4.5. Control and instrumentation

Realizing that ionizing radiation and nuclear particles can be detected and measured with electronic devices, a small group was set-up in BARC to carry out R&D in electronics.

This group became the nucleus for subsequent activities at Trombay and resulted in the formation of a production facility, - Electronics Corporation of India Limited (ECIL) in April, 1967. Today, in addition to meeting the special requirements for the nuclear programme, ECIL serves a number of core sectors of the economy including defense, space, steel, telecommunication, thermal power plants and petrochemical plants.

4.6. Back-end of the nuclear fuel cycle

The technology for reprocessing nuclear fuel was developed in India entirely by local efforts. Today, India has three reprocessing plants to extract plutonium from spent fuel, one at Trombay, a second at Tarapur and a third, recently cold commissioned, at Kalpakkam. The third plant at Kalpakkam incorporates a number of innovations such as the hybrid maintenance concept in hot cells using servo-manipulators and engineered provisions for extending plant life. This plant will reprocess fuels from PHWR as well as FBTR located at Kalpakkam.

For waste management, plants have been set up to dispose of all types of wastes and are operating successfully. Treatment of reprocessed wastes has received considerable attention because they contain nearly 99 per cent of the activity generated in the nuclear fuel cycle. Based on years of developmental studies, a long-term action plan has been formulated for management of these wastes. It consists of solidification of medium level wastes in a suitable matrix, in reliable containers and burying them in totally waterproof concrete tile holes with protective barriers. High level waste is immobilized by vitrification in a glass matrix and doubly encapsulating the solidified mass in corrosion resistant containers called canisters. The sealed canisters are continuously cooled during interim storage and surveillance in an engineered storage facility for 20 to 30 years. The proposed ultimate disposal of the cooled solidified waste is in deep underground geological formations with added protection barriers.

A waste immobilization plant (WIP) has been set-up at Tarapur incorporating complete remote operation and maintenance. A facility for interim storage of the vitrified waste from this plant has also been built nearby. Based on initial successes during the early runs, one waste immobilization plant is under construction at Trombay and another at Kalpakkam.

4.7. Manufacturing technology

4.7.1. PHWR components and equipment

Due to the sudden imposition of an embargo on the supply of equipment, Indian industry was compelled to face the problem of the manufacture of major equipment for PHWR in 1974. Indian manufacturers and the DAE began this as a joint effort to ensure quality standards for components and equipment. Indian public sector undertakings also played a key role in supply of major equipment such as steam generators, turbo-generator and other electrical equipment. Critical components, such as end-fittings and fueling machines were initially manufactured at BARC, in its Central Workshops, but this technology was subsequently transferred to industry.

4.7.2. FBR components and equipment

When Indian industries first began manufacture of nuclear components of PHWR during the mid -sixties, they were new to the quality requirements of nuclear jobs. The quality requirements of FBTR were more stringent than those for PHWR because of thin walled structures with much more exacting criteria for the acceptance of welds. At this point, some industries were still low on the learning curve with respect to PHWR jobs. Through continuous close interaction of the IGCAR with the participating industries, the know-how associated with the manufacture of FBTR components was readily assimilated. The overall operating experience with FBTR components built in the country has been very satisfactory.

The PFBR has a large scale-up factor compared to FBTR and design features differ in many areas. Because of its pool-type design, validation through prototype testing in sodium is needed for critical components like shutdown mechanisms and fuel handling machines. In addition, there is a need for state of art in manufacture and inspection of critical PFBR components. This is done by some initial development work to provide feedback for design modifications and to help minimize manufacturing schedules for actual components. In view of these factors, prior-manufacturing development for critical items had been planned.

Technology development for main vessels consisted of manufacture of a sector involving pressing of dished end petals and rolling of large diameter thin walled shells with a strict tolerance on forming dimensions. Considerable knowledge has been gained through this exercise and minor design changes to use forging instead of buttering to minimize distortion, and revisions in forming tolerances are being incorporated. Technology development of sodium pumps involved developing local suppliers of stainless steel castings, machining to close tolerances and heat treatment of shafts. As a further example, work is in progress to manufacture steam generators in Cr-Mo steels. The tube to tubesheet weld joint is an internal bore welded joint with a raised spigot. The manufacturing technology involves machining tubesheet with the spigot, welding of the tube to tubesheet to very strict requirements, forming shell pull-outs, and postweld heat treatment of the completed steam generator. All the key areas of manufacturing have been qualified.

Work is underway to develop technologies for a large number of other critical components. These consist of sectors of the top shield; the shutdown mechanism, comprising the control and safety rod drive mechanisms and diverse safety rod drive mechanism; the fuel handling machines, comprising the transfer arm for in-vessel handling and the inclined fuel transfer machine; sectors of grid plate; sectors of the control plug; and forming of tees and bends of the secondary sodium piping. This extensive exercise of technology development is expected to lead to optimizing design of critical components, which could be manufactured locally within the scheduled time.

5. THE ROLE OF R&D IN DEVELOPMENT OF LOCAL CAPABILITIES

This R&D has led to the development of self-sufficiency in technological areas important to the Indian nuclear power programme. It has also led to creation of an R&D infrastructure that can respond to challenges for the development of next generation nuclear energy production systems.

These R&D capabilities were initially directed toward the basic design, construction and operational safety related tasks for the Indian PHWR and FBR, and to develop infrastructure to support this programme. In the area of reactor physics, for example, a large spectrum of reactor physics codes were developed to calculate criticality, burn-up physics, reactivity coefficients, and other parameters for control, operation, fuel management, reactor dynamics and safety. In fuel technology, as already indicated, development of natural uranium, and mixed oxide and mixed carbide type fuel elements using uranium, plutonium and thorium, has been a priority since beginning the programme. This work covers out-of-pile and in-pile tests followed by post irradiation examination (PIE). A large strength lies in the area of metallurgy and materials sciences at BARC and at IGCAR. For example, R&D was done at BARC to develop parameters for manufacturing Zr-2.5%Nb pressure tubes using the hitherto untried pilgering route. In engineering development, several major experimental facilities were established to generate characteristic data, validating design, and testing the performance of major components, equipment and systems of PHWR and FBR. For example, fueling machines were performance tested at BARC and also used for training personnel.

In consideration of limitations on the manufacturing capability for nuclear components in early stages of the programme, extensive support to prove manufacturing methods, test components to assess suitability for reactor use, and provide continued support for trouble shooting etc. was provided by R&D units of DAE. For example, the manufacture of Zr-2.5% Nb pressure tubes was carried out at NFC, using process parameters developed at BARC. The end fittings for PHWR were initially manufactured at BARC and now are made by industry. Irradiation experiments on fuel and structural materials provide data for study and design of new materials for reactor use. For the 500 MW(e) PHWR, a large volume of analytical and experimental studies in fields ranging from material science to development of components such as rolled joints for coolant channels and reactor control system, were conducted at BARC. This was a planned R&D programme providing support for the design of this reactor.

R&D support for operating the PHWR was initiated to support reactor physics computations for core management and water chemistry related consultant services. R&D participation has progressively grown to include troubleshooting and support for ageing management of key components. To tackle some fuel handling related incidents at power plants, many unusual operating procedures were tried on the fueling machines at BARC before application. Repair of the inlet manifold at Kalpakkam units 1 and 2, and replacement of a sparger at TAPS are two examples of using R&D to solve operating plant problems. A large component of current activities relates to the management of ageing of coolant channels of early generation PHWR. This spans development of analytical methods for degradation modeling and associated experimental work, post-irradiation examination, development of in-service inspection technologies and equipment, and development of technologies and equipment for life extension and replacement. A technique for large-scale chemical decontamination of the primary heat transport system of PHWR was developed locally and successfully applied.

Most current R&D relates to developments to improve performance of future reactors. For example, an improved fuel manufacturing process, such as a combined sol-gel microsphere pelletization, low temperature, oxidative sintering (SGMP-LTS) process has been developed for fuel fabrication. A recent technology upgrade in control and instrumentation relates to the development of fault-tolerant microcomputer-based systems for nuclear power plants. These systems will be incorporated in the new PHWR at Kaiga-1 & -2 and Rajasthan -3 & -4. In addition, R&D programmes addressing fuel cycle and reactor technology related developments for thorium utilisation, and the AHWR, are in progress.

6. DEVELOPMENT OF TRAINED MANPOWER

When work on atomic energy and research in nuclear sciences began in India, there were not many universities or educational institutions with a curriculum sufficiently broad and advanced to produce manpower with the needed expertise. Hence, a training school was started to provide one-year intensive training in all branches of nuclear science to graduates in science, engineering and life sciences. This training school has functioned for more than forty years and has trained more than 6000 scientists and engineers. Graduates occupy important positions not only in the DAE, but in other R&D laboratories. The Nuclear Training Centres, established by NPCIL, train personnel for reactor operation. A similar training programme is given on all plants types such as research reactors, heavy water plants, reprocessing plants etc. The availability of a pool of qualified manpower in all disciplines, and at all levels, has contributed to successful development of local capabilities of the Indian nuclear power programme.

7. CONCLUSIONS

For a large developing country like India, with an extensive programme for nuclear power especially tuned to match its natural resources, the attainment of self reliance has been a necessary goal to achieve long term energy security This study provides an account of the Indian experience building local capabilities in deployment of nuclear energy. A review exhibits key elements of the strategy for development of self-reliance. These are listed below:

(1) Establishment of an R&D based infrastructure to enable:
   - tuning the programmes and technologies to suit domestic resources and capabilities,
   - developing a full understanding of the technologies to deploy nuclear energy, even where some elements are initially imported, and to use this understanding to establish local capabilities,
   - filling gaps in the supply of critical materials, components and technologies and transferring the associated technologies to industry, and
   - providing cost-effective local solutions to enable sustained development of a large, long term nuclear power programme.

(2) Creation of a pool of trained scientific and technical manpower through dedicated training centers.
(3) Acquisition of imported technologies, where available, under terms enabling their development using local capabilities, and to optimize them for Indian conditions.
(4) Close interaction with industry to develop local capabilities and upgrade technology.

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SAFETY AND REGULATORY REQUIREMENTS OF NUCLEAR POWER PLANTS

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Abstract

A pre-requisite for a nuclear power program in any country is well established national safety and regulatory requirements. These have evolved for nuclear power plants in India with participation of the regulatory body, utility, research and development (R&D) organizations and educational institutions. Prevailing international practices provided a useful base to develop those applicable to specific system designs for nuclear power plants in India. Their effectiveness has been demonstrated in planned activities of building up the nuclear power program as well as with unplanned activities, like those due to safety related incidents etc.

1. INTRODUCTION

The Indian nuclear power program was launched with twin unit 210 megawatt electric (MW(e)) boiling water reactors (BWR) at Tarapur, with criticality of unit-1 reached in 1969. Subsequently the program has been based on pressurized heavy water reactors (PHWR). Eight PHWR units of 220 MWe each are operating at four stations, namely, Rajasthan Atomic Power Station (RAPS), Madras Atomic Power Station (MAPS), Narora Atomic Power Station (NAPS) and Kakrapara Atomic Station (KAPS). Four more units of this capacity are in the final stages of construction at Kaiga and Rajasthan and work on two units of 500 MWe is being initiated this year.

The primary responsibility for safety of the nuclear power stations in India lies with the Nuclear Power Corporation of India Limited (NPCIL). As the regulatory body, the Atomic Energy Regulatory Board (AERB) sets safety objectives and audits their application in various stages of site selection, design, commissioning and operation. The evolution of safety practices and regulatory functions in India is briefly described in this paper.

2. SAFETY IN THE NUCLEAR POWER PROGRAM

The two units of 210 MWe BWRs at Tarapur and the first two units of 220 MWe PHWR at Rajasthan were introduced into the nuclear program on a turnkey basis with limited Indian participation in design. The safety related requirements for these units were set at prevailing international standards.

Design and development for the next two units of PHWR (Madras Atomic Power Station [MAPS]) involved safety related modifications apart from other changes due to site specific conditions. The major safety related developments in MAPS included double containment over the cylindrical portion, and introduction of a vapor suppression system. All heavy water heat exchangers were cooled in a closed loop system to avoid discharges of radioactivity to the external heat sink in case of heat exchanger leaks.

Based on the successful design and development for the MAPS reactors, the Department of Atomic Energy took up design for standardized 220 MWe units. The following were the design objectives:

– Introduction of additional safety requirements emanating from licensing reviews of previous units
– Incorporation of changes from international developments including the lessons learnt from the Three Mile Island (TMI)-2 accident (USA)
– Designs development by R&D Groups of DAE
– Synergistic interfacing with the country's industry.

During this time, international and domestic safety requirements were in a state of flux. IAEA began issuing codes of practices and guides for nuclear power plants (NPP) and the Department of Atomic Energy-Safety Review Committee began work in parallel on codes of practices for siting, design, QA and identified guides required for PHWR to be built in India. Based on these evolving safety requirements, the following broad safety features were provided in the standardized 220 MWe reactor units:

– Double containment, with vapor suppression pool.
– Two independent and diverse, fast acting shut down systems- supplemented by Automatic Liquid Poison Addition System (ALPAS); an automatic boron addition system to guarantee prolonged shutdown for xenon decay and cool down loads. ALPAS is backed by gravity addition of Boron - a defense in depth approach for station blackout conditions.
– An emergency core-cooling system with high pressure and intermediate pressure injection provided prior to low pressure, long term cooling.
– A small-leak handling system using a heavy water (D_2O) inventory.
– A closed loop process water system for all heavy water heat exchangers, to ensure containing the radioactivity in case of a tube leak.
– The process water supply to all safety-related heat exchangers required for decay heat removal backed up by diesel driven water pumps as a defense in depth approach for station blackout.
– Filling up of the calandria vault with water, replacing air as used in earlier reactors, to eliminate generation of Argon 41 activity and to act as heat sink for severe accident scenarios.
– The annulus CO_2 gas monitoring system to monitor leakage on line, in the pressure bearing zirconium alloy coolant channel. (Coolant channels are the pressure bearing components in a PHWR core, concentrically placed in calandria tubes, with CO_2 in the annulus to thermally insulate the moderator from hot coolant in coolant channels.)
– Coolant channel material modified to Zr 2.5% Nb for better corrosion and hydriding resistance. Four tight fit garter spring spacers to ensure a continued positive gap between the coolant channel and calandria tube and avoid formation of a local cold spot (undesirable in Zr Alloys as it promotes local hydriding).
– A supplementary control room for shutdown and decay heat removal in case the main control room becomes unavailable.
– Improvements in layout, shielding design and ventilation to reduce man-rem.

Design improvements in the standardized version of the 220 MWe units continue from unit to unit. The underlying principle in strengthening designs lies in emphasizing accident prevention by adherence to Safety Standards as well as on accident mitigation to cover postulated accident scenarios.

3. EVOLUTION OF REGULATORY PRACTICES

During early development, Divisions in the Bhabha Atomic Research Centre (BARC) engaged in safety and regulatory aspects, increased their cadre of trained manpower through basic and advanced training programs. This increased expertise to conduct regulatory functions. The safety-related *ad-hoc* committees conducted reviews earlier. As the number of operating installations in the DAE increased, a Safety Review Committee (DAE SRC) was formed in 1972 to review safety of the installations; it was vested with powers of the competent authority. This formally began the regulatory process in India.

In 1983, a significant expansion of the nuclear program was announced along with institutionalizing regulatory and safety functions. For this purpose, an independent regulatory body, the Atomic Energy Regulatory Board (AERB) was formed in November 1983 under the Atomic Energy Act, 1962. The mission of the Board is to ensure that use of ionizing radiation and nuclear energy in India does not cause undue risk to health, safety and environment. The three broad responsibilities of AERB are:

i) Preparation of safety codes, guides, standards and technical regulations relating to nuclear and radiation safety.
ii) Opening operational channels for the approval of specifications for nuclear facilities to grant authorization at different stages, viz., site evaluation, construction, operation, final shutdown and decommissioning.
iii) Maintain surveillance of facilities under construction and in operation.

4. ORGANIZATIONAL STRUCTURE OF AERB

AERB has a full time Chairman, Vice Chairman and a Secretary with three part-time members from outside the DAE. It has two major review committees: the Safety Review Committee for Operating Plants (SARCOP) and the Advisory Committee on Project Safety Review (ACPSR), which oversees plants under project/pre-operational stages.

The AERB conducts regulatory functions through technical divisions. These are divisions in the areas of nuclear safety, radiation safety, operational plant safety and industrial safety. A Directorate of Regulatory Inspection and Enforcement (DRI&E) within AERB carries out inspection and implementation, assisted by a Reactor Installations Division (RID) and Industrial and Radiation Safety Division (ISRD). The organizational structure is shown in Figure 1.

AERB gets technical support from research organizations, technical and academic institutions such as Bhabha Atomic Research Centre (BARC), the CSIR Laboratories and the Indian Institutes of Technology (IIT) etc. to accomplish reviews and assessments for granting authorizations. In addition, AERB is aided by academic and research institutes and consultant organizations for technical evaluation of systems and independent inspections in critical areas.

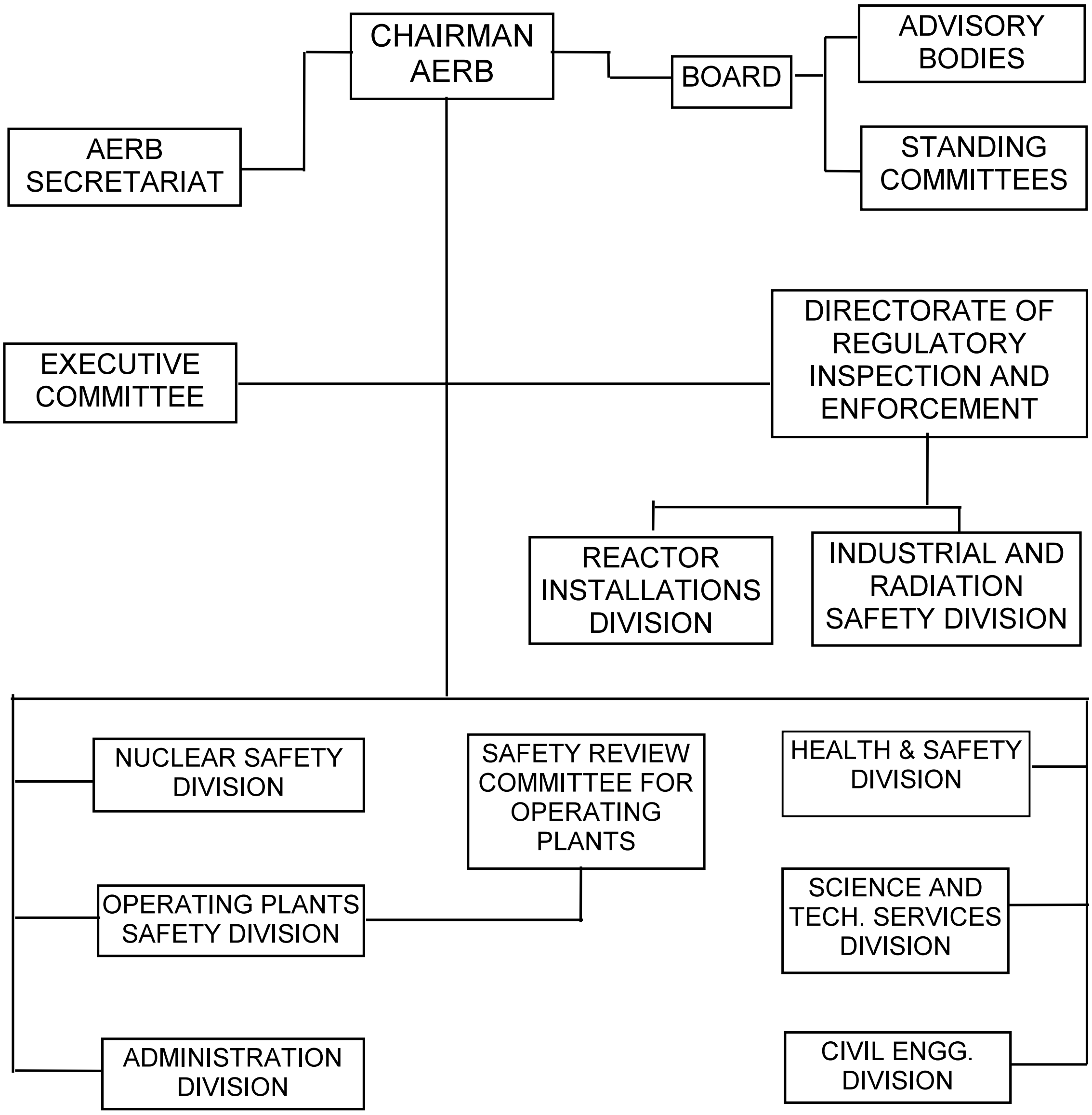

FIG. 1. Organizational structure of AERB.

5. SAFETY CODES, GUIDES AND STANDARDS

Our experience so far shows that safety requirements are being spelt out in appropriate safety codes, guides and standards for siting, design, construction, commissioning, operation and decommissioning of NPP. This also keeps in view international recommendations in corresponding IAEA documents and local conditions. AERB has formed committees to prepare such essential codes and guides for issue and implementation as intended. The process of upgrading is ongoing. The regulatory body also issues policies in both radiation and industrial safety areas. By now all codes of practices and a few guides have been issued.

6. AUTHORIZATION PROCESS FOR NPPS UNDER CONSTRUCTION

Control over safety in siting, construction, commissioning, operation and decommissioning is maintained primarily through formal clearances authorizing actions and stipulating specific conditions for the applicant (NPCIL). Following are major steps for authorization of a NPP:

(1) Site approval;
(2) Review and approval of safety systems design;
(3) Authorization for commissioning;
(4) Authorization for operation; and
(5) Authorization for decommissioning.

A list of stages at which supporting documents are required to be submitted for authorization of commissioning and operation of PHWR follows:

(1) Hot commissioning/conditioning of primary heat transport system;
(2) Fuel loading in the core and heavy water addition to storage and cooling systems (except core);
(3) Initial approach to criticality, including heavy water addition to the core;
(4) Low power physics calibration experiments;
(5) Phased power generation tests at 25, 50, 75 and 100 per cent of rated power; and
(6) Operations at rated power.

The Advisory Committee on Project Safety Review (ACPSR), which consists of a Chairman and members from different disciplines and expertise, conducts the review. Some members are from organizations other than Department of Atomic Energy.

7. REGULATORY ACTIVITIES DURING OPERATION OF NPP

7.1. Organizational structure

A Safety Review Committee for Operating Plants (SARCOP) evaluates performance and enforces radiological and industrial safety in operating units, including public sector undertakings of DAE. SARCOP involvement is comprehensive, covering safety of operating personnel, members of the public and the environment.

7.2. Functions of SARCOP

SARCOP enforces safety standards stipulated by AERB for operating units of DAE. It also undertakes safety surveillance in these units, and reviews proposed, safety-related changes in design and safety-related incidents.

SARCOP appoints Unit Safety Committees for individual operating stations. These committees continuously monitor safety status of their respective operating units and submit reports/recommendations to SARCOP. To carry out its functions, SARCOP seeks support from advisory committees or working groups from time-to-time. Non-compliance with SARCOP directives by operating units of DAE is reviewed and, if necessary, restrictions or suspension of operations of the facility are imposed.

8. REGULATORY/UTILITY INTERACTION

The experience of safety and regulatory review has been instrumental in formalizing safety criteria and procedures in NPP as well as in other nuclear installations. Technological innovations continue the evolution of safety criteria. Examples of technological updates are:

- Advances in use of computers in plant control;
- In-service inspection techniques; and
- Life extension assessment of operating units.

AERB keeps pace with these requirements and has conducted safety related engineering studies with the help of experts outside DAE and in educational institutions.

The regulatory review of projects and operating plants has been streamlined. Interaction between the regulatory body and the utility is important to maintain a high level of safety assurance. This is necessary with both planned and unplanned activity. Two typical cases illustrating this are described below.

8.1. Narora fire incident

A major fire incident occurred in Unit-1 of Narora Atomic Power Station on 31.3.93, resulting in a complete station blackout - unavailability of all power off and on-site. Operators left the control room due to smoke. Core cooling was maintained by thermosyphoning on the primary side and providing a heat sink to the secondary side of the steam generator by water addition using diesel driven fire pumps. Manual addition of boron poison to the moderator was used to assure the reactor was in a safe shutdown state. These actions followed station black out emergency procedures. There was no loss of life or injury to personnel and no radiological impact, either in the plant or in the public domain. On the International Nuclear Event Scale (INES) the incident was rated at level 3. An incident of such magnitude was unprecedented in the history of the utility as well as the regulatory body.

Power station authorities communicated with headquarters and with the regulatory body while the incident was still unfolding. The Regulatory Board acted promptly and formed an investigating committee consisting of experts from the regulatory body and the utility, some of whom had participated in the design review of the station. Pending detailed investigation, the AERB also placed a hold on start-up of the Unit-2. The Committee's investigation indicated that root causes for the incident were as follows:

- A turbine blade in the last stage of the LP rotor failed due to fatigue. This was identified as a generic problem with that particular turbine blade design. Vibrations during the turbine blade failure led to generator failure and the consequent burning of escaping hydrogen and oil caused large scale burning of cables in the area.
- The complete black-out occurred due to the cable fire which escalated due to ineffective fire barriers, together with inadequate physical separation in redundant safety related cables leading to station power supplies.

On recommendation of the investigation committee, AERB took the following major actions:

- Unit-2 of NAPS was permitted to restart in October 1993, after implementing the Investigation Committee's recommendations. Important among them were modification of turbine blades, refixing of qualified fire barriers, segregation of safety related cables, improved habitability of control rooms and improved fire detection and suppression.

- Unit-1 was permitted to restart in January 95, after restoration of the affected systems and implementing the recommendations of the Investigation Committee. In view of the very long shutdown, and several important modifications to the plant, a detailed procedure for re-commissioning and start-up of Unit 1 was prepared and approved by AERB. AERB also carried out a special inspection to ensure that all the modifications were executed before clearance for operation.
- NPCIL was required to shutdown each operating PHWR Station (having turbine generator [TG] sets supplied by the same manufacturer) for thorough inspection of turbine generators and associated components.
- NPCIL was required to implement other recommendations under schedule, particularly regarding fire fighting and cable separation which were equally applicable to other PHWR stations.

8.2. En-masse coolant channel replacement at RAPS Unit-2

The coolant channel pressure tubes are made of Zircaloy-2 in some reactors. Zircaloy-2 is a material whose corrosion rate and associated hydrogen pick up rate increases after about nine years of irradiation, resulting in degradation of the mechanical properties. Dislocation of spacers separating the pressure tube and the calandria tube, can result in contact between them aggravating the situation at local points of contact. This imposes a limit on the useful life of reactor pressure tubes.

After operating for 8.5 Effective Full Power Years, the Rajasthan Atomic Power Station, Unit-2 (RAPS-2) was shut down in July 1994 for pressure tube inspection. Subsequently, a decision was taken for *en-masse* coolant channel replacement in this reactor.

This was the first-ever replacement in India and coupled with the fact that the other six reactors with Zircaloy-2 pressure tubes would require *en-masse* replacement in due course of time, the regulatory approach has been cautious and based on the following concerns:

- Radiation exposure to personnel should be based on ALARA principles.
- Damage to calandria tubes, bearing sleeves and other reactor components, which will remain in service, should be avoided.
- Radioactive waste generated from this activity must reach safe disposal.
- Adequate records should be created for QA and future reference.

In light of these concerns, the regulatory body decided that after completion of each of the following stages, a detailed review should be conducted and subsequent work resumed only after obtaining clearance. A committee of selected experts was specifically formed for this purpose. These stages are:

- Cutting, removal and disposal of the first five channels from the reactor, after qualification of tools, procedures and personnel on mock-up.
- After cutting and removal of all pressure tubes, inspection of calandria tubes and reactor internals and assessment of their health based on the inspection data. All inspection tools and methods qualified on mock-up.
- Installation of first five pressure-tubes after qualification of tools, procedures and personnel on mock-up.
- Completion of work for reinstallation of coolant channels.

It was also decided that significant upgrading of the units should be undertaken during these long outages. In this connection, separate clearance from AERB was required for all modifications to safety systems. AERB also stipulated that upon completion, regular licensing procedures be followed for a new reactor.

The regulatory requirements were successfully met by the utility. The unit has since been re-commissioned with all planned safety upgrades well within stipulated man rem projections. Both these cases demonstrated the effectiveness of the safety and regulatory potential and the satisfactory interface between regulator and utility.

9. CHALLENGES AHEAD

The PHWR program is being extended to include 500 MWe unit size of PHWR and construction of two such units is being initiated this year. The basic principles of safety design of 500 MWe are identical to 220 MWe. The safety upgrading involves design changes for a larger core size and larger coolant inventory. This in addition to use of current regulatory practices and state-of-art technologies such as control and instrumentation, seismic design, safety analysis and defense in depth. The next stage of the Indian Nuclear Power Program is based on fast breeder reactors. A fast breeder test reactor (FBTR) of 40 MW thermal capacity is already in operation. The design of the first 500 MWe prototype fast breeder reactor (PFBR) is under review by the regulatory body. Codes and practices for design and QA for this type of reactor have been issued.

Regulatory review of 500 MWe PHWR and 500 MWe PFBR designs further increased responsibilities of the AERB. AERB review teams by now well trained and experienced and with a wide up-to date knowledge base from national and international feed back will be able to carry out these assignments.

Induction of PWR of 1000 MWe capacity of Russian VVER type in the Indian nuclear power program is also planned. Even though the safety fundamentals remain the same in all NPP, the review team must gear up to understand application of safety requirements to systems, components and structures of a different type. A committee has been formed by AERB to see through the process of regulatory review of this type of reactor.

10. CONCLUSIONS

Evolution of safety and regulatory requirements in India has been possible through close cooperation amongst designers, R&D groups and regulators. The NUSS Codes and Guides published by the IAEA have been helpful in developing the national requirements for safety and regulation.

Development of the nuclear power program in India has successfully demonstrated the institutionalization and standardization of regulatory processes however, this is a continuously evolving field. As regulatory review is multi-disciplinary, utilization of resources from the utility, R&D and educational institutions along with the regulatory body was necessary. This also contributed to effective manpower training. The benefit has been that manpower in all sectors of nuclear power development and implementation was exposed to the intent of regulatory requirements. An evident safety culture has emerged from this experience.

Meeting safety and regulatory requirements is technology intensive. The role of research and development and industry is essential to execute safety and regulatory requirements. The founders of nuclear power in this country ensured development of all required technologies.

Organizations like the IAEA do a commendable job of channeling international cooperation for development of nuclear power by providing the knowledge for safety objectives and principles. Similar support on technology, manpower training, safety analysis tools and hardware will enhance safe nuclear power generation in developing countries.

PUBLIC INFORMATION: PERCEPTIONS IN DEVELOPING COUNTRIES

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Abstract

This paper on Public Information examines special aspects concerning the public perception of nuclear power in developing countries which could influence the strategy and approach.

1. INTRODUCTION

It bears repeating that developing countries must urgently increase electricity production to increase development. From an analysis of data, it is seen that to raise the life expectancy to the levels in developed countries, the per capita electricity consumption must increase by a factor of 8 to 10. Developing countries may not aim that high, on the grounds that either those consumption levels are irrelevant or need not be as extravagant, however, an increase by a factor of 2 or 3 is unavoidable. Hence it is imperative at this stage to deploy all sources of energy and develop them to the maximum. However, a strategy for a sustainable energy future should be less dependent on fossil fuels because of environmental effects, among other things. A 1000 MWe coal plant emits 6 million tons of carbon dioxide per year in addition to sulfur dioxide, nitrogen oxides etc. The full chain release of greenhouse gases is infact smaller for nuclear and wind energy than for alternative energy sources such as solar photovoltaic (because of releases during silicon chip manufacture).

While the installation cost per kilowatt (kW) is greater for nuclear power, a large part is due to redundant and diverse safety mechanisms. However, the unit cost decreases in a few years of operation because of the small amount of fuel used, unlike fossil-fuel plants. When comparing the costs of different sources, one must also consider the cost of the effect of fossil fuel on health. It is an incorrect impression that nuclear energy is being phased out worldwide - 36 plants are presently under construction and growth is especially high in Asia.

The main thrust of public awareness in the west is to counter public opinion against nuclear energy. This is perhaps irrelevant in most developing countries and certainly in India. A few individuals publicly speak against nuclear energy, but this does not translate into public opinion. Some groups oppose nuclear power but these are few and small in size. Anti nuclear sentiment does not seem to be a serious problem at present in developing countries. The current goal should be to give enough information to develop proper perceptions.

2. PUBLIC PERCEPTION IN DEVELOPING COUNTRIES

In many developing countries a general awareness of the dire requirement for more electricity does seem to exist. Therefore, criticism against nuclear energy is not as vociferous as in some highly developed countries. It is reasonable to expect that launching a new and sophisticated technology in a developing society would boost the morale of the public. If questions related to the need for electricity and the merits of different options are adequately addressed, it should be possible to muster public support and keep an element of reasonableness and practicality in the public response.

The perceived needs of the western world are often irrelevant in developing societies and imposing these perceptions on developing countries can distort the perceptions. It is accepted that risk tolerance in an affluent society and a developing country is quite different. Decision-makers must recognize that some of the apprehensions may not be relevant or affordable due to the need for electricity. They must appreciate the need to invest in nuclear energy because the technology is relatively easily available in developing countries, as in India.

However, substantial input is required to show the inevitability of nuclear power, its safety record, sound technology to deal with waste and the necessity of its use for ecological reasons. It must also be demonstrated that it may not be more expensive in the longer term.

It is useful to demonstrate to the public that benefits of radiation and radioisotopes to society in agriculture, industry and health care are linked to the development of nuclear power technology. This may not only help remove apprehensions about radioactivity but may make nuclear energy more acceptable. A link of this kind can be established, especially if the population around the nuclear installations acknowledges the economic and social benefits.

Methods of improving public awareness are essentially the same everywhere. However, the priorities and emphasis are determined according to the individual country and adjusted for the target groups. It is not as important to look for new ideas as to increase inputs and often these do not demand larger financial resources but human resources. Part-time personnel are unlikely to yield the best results. Dedicated teams are required.

3. PERCEPTIONS AND ACTIVITIES IN INDIA

In India, there is no sizable weight of public opinion against or major problems in acceptance of nuclear energy. Therefore, it may not be necessary to approach the issue too defensively or assume problems of the developed countries in public acceptance. It is important to distinguish between public awareness and public acceptance and they should be dealt with in the right context. The term public acceptance is relatively defensive. Public opinion could well be more supportive than just accepting nuclear power.

The target groups to be addressed are:

- the general public,
- the community of students and teachers, to multiply the effect,
- opinion-makers, including authorities in local, State and central governments, and public leaders and journalists,
- decision-makers.

In the past year or so the DAE and its units throughout the country, have been reaching out to the public. About 13 exhibitions have been held. One of the events organized along with other scientific departments was the exhibition carried in two trains - one going from west to east and the other from north to south. Through this exhibition alone 10 million persons were reached. Through the other 12 exhibitions, it is estimated that 0.32 million persons were contacted. Much of this crowd was from the community of students and teachers, with an average residence time in the exhibition of about 45 minutes. About 14 seminars and workshops were organized, many of which were designed to demonstrate the activities of the DAE to participants from academic institutions and about 500 teachers attended. A few of these seminars were conducted in local languages. Popular lectures were organized in about 6 centers of DAE.

Four Essay Competitions were organized during this period with an aggregate participation of over 1000 students. Similarly, about 8 quiz competitions were organized for students on subjects related to DAE. Safety awareness programs were also presented at some plants. At least 7 Units of DAE organized social functions like blood donation, tree-planting etc. In this effort to reach out to the public, several DAE units opened themselves to the general public and provided an opportunity for them to see the high technology work being done. The total number of days on which DAE units opened themselves is estimated at 125 in this period. Tens of thousands were attracted by this opportunity.

Special arrangements are made to interact with the population in the vicinity of nuclear establishments, particularly the atomic power stations. Extending support to community welfare efforts such as education, health care and recreation created the interface. Drinking water facilities and other infrastructure such as roads and transport also increased the interaction between the power station management and population in the surrounding areas, leading to better understanding and awareness of activities in the nuclear power sector.

Public awareness has also increased as non-power applications of radiation and radioisotopes in agriculture, health care, water resources management, industry and food preservation are making a clearly visible impact. Geographic spread as well as quantitative increase in the number of users has brought the public more in tune with the atomic energy program in India and informed the public on constructive applications.

Over 55 000 consignments of radioisotopes and related products were supplied to over 900 user institutions in the country in 1997. About 33 per cent was for industrial users, 46 per cent for medical and 21 per cent for research and agriculture. In the field of diagnosis and treatment, 26000 patients were examined for thyroid function alone, cintigraphic imaging studies and treatment of thyrotoxicosis, thyroid cancer and bone metastasis in the Radiation Medicine Centre. About 1.35 lakh cartons of medical products and over 20 lakh midwifery kits were sterilized to meet the needs of the rural programs. Seventy-three remotely operated radiographic cameras were supplied to research institutions.

Direct benefit to the population is the best vehicle for information dissemination. It also generates the more fervent and vocal supporters for the nuclear program.

4. CONTRIBUTIONS OF IAEA

This Seminar could well be considered as meeting part of the resolution on strengthening the IAEA's Technical Cooperation with Developing Countries (TCDC) activities. In this resolution, it was requested that the IAEA strengthen technical cooperation in production of electricity with considerable stress on TCDC.

To determine the role that can be played by the IAEA, I am tempted to quote the Chairman, AEC, India, from his speech at Vienna celebrating 40 years of IAEA. This sums up the attitude for establishing nuclear power in developing countries. (The)"developing world should not be denied the right to strive for a reasonable quality of life which can be assured in the future only through nuclear power. The doubt in some quarters about the need for nuclear power expansion comes from the surfeit of energy in developed countries and the unfamiliarity with nuclear technology in most developing countries. This hesitation to initiate a nuclear power program should not be compounded by fears about safety and by uneasiness about commitments under comprehensive safeguards agreements, as reinforced by Program 93 + 2 of IAEA. In fact, IAEA must play an important role in removing such inhibitions of newcomers to the field of nuclear power. Technology, equipment and information on Research and Development in the nuclear power field, particularly those related to safety, must be readily and freely disseminated without being hindered by arbitrary export control regimes. This should be put across clearly to decision makers".

The IAEA could consider developing the following dimensions in its programs:

i) Model public information capsules dealing with radiation, reactors, waste management, benefits of peaceful applications of atomic energy in electricity production, health care, agriculture, food security, industrial applications, water etc., especially emphasizing the relevance of atomic energy in the context of sustainable development,
ii) Dissemination of authentic information for the public on incidents which may attract public interest,
iii) Success stories in developing countries with high societal impact,
iv) Confidence building messages based on IAEA activities about nuclear technology, particularly for its propagation in developing countries beginning nuclear power programs.

5. DIFFERENCES IN PERCEPTIONS

There are some important messages in the keynote paper to be considered by the developing countries. For instance, the argument that if superpowers can have nuclear accidents, how can we be sure it won't happen to us? This does not necessarily frighten people in developing countries like India or at least it need not, if communication is clear, possibly along the following lines:

i) For instance, in India, it has been observed in the last 50 years that operators at all levels stay with their jobs in the nuclear power industry for almost an entire lifetime. Hence, the effect of training and retraining is much greater.
ii) As most developing countries have the nuclear power program in the public sector, and this may continue for sometime, the tendency to cut corners in procedures and costs is less.
iii) Safety is a matter of culture and takes time to develop, along with the time needed for technology to mature. Those that started nuclear power programs later or have progressed at a slower rate, as in most developing countries, have the advantage of inheriting much available knowledge. Since it is recognized in the nuclear field that an accident anywhere is an accident everywhere, sharing knowledge has been less restrained in nuclear safety related subjects, although there is scope for improvement.

While public concerns were undoubtedly heightened by the accidents at Three Mile Island (USA) and at Chernobyl (Russian Federation) these should be, put into perspective by comparing the limited damages, in terms of human life, that have occurred compared to accidents in other human activities like in dams, mines etc. It must also be emphasized that the radiation, even from the worst accidents, has had limited health effects.

The advancement in packaging for transportation and the kind of assurances that can be given against environmental pollution through accidents in transportation is quite impressive and should be conveyed to the public, the opinion makers and the decision makers.

Storage of nuclear waste has proven technology available today. In developing countries, nuclear power production generates such small quantities of waste that it can be stored in your pocket, as it were. Hence, it becomes much easier to allay such fears. Also, some developed countries have had military programs that have been nastier polluters.

6. CONCLUSIONS

The objective of the IAEA is to accelerate and enlarge the contribution of atomic energy to peace and prosperity throughout the world. From the point of view of developing countries, nothing can meet this objective better than generation of nuclear power. Much more is required than tinkering with peaceful application by setting up equipment here or a nuclear gauge there. Just for this, if nothing else, it may be worthwhile for the IAEA to hold the hand of developing countries wishing to set up nuclear power production facilities. The point is well taken that IAEA need not sell the idea, however, it must not only prove the advantages of nuclear power but take steps to make it a feasible option for any member state interested in it. Not only should the work IAEA has done in promoting nuclear power become better known to developing countries, IAEA must also identify and communicate success stories from developing countries which have adopted nuclear power. It must be brought out more explicitly how IAEA can support developing countries in overcoming initial apprehensions and hurdles. Attention must be paid to all the steps between accepting the importance of nuclear power and actually setting up production units. This needs expertise ranging from technology development to financing and equipment. The IAEA is ideally suited to provide linkages between those that seek nuclear power and those that seek customers.

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WHY NUCLEAR POWER — THE INDIAN CONTEXT

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Abstract

India has made tremendous achievements in increasing electricity generating capacity since independence 50 years ago. The growth rate of electricity production has been greater than the world's average growth rate of electricity. In spite of this, the gap between demand and supply continues to exist because the population of India is large. The development of the nation is affected by this gap. Energy generating resources per capita for this large population are limited. Achieving the desired electricity generation levels is feasible only if India develops techno1ogies to use all renewable and non-renewable resources. Nuclear power has a prominent role to play in this regard. Our resources of uranium are limited but of thorium quite large. Such a resource pattern necessitates adopting breeder technology and thorium as a fuel. This paper describes the status of resources in India and the nuclear power program adopted to use them.

1. ENERGY SCENARIO

Man's energy prior to the industrial revolution came mainly from direct sunlight, combustible material such as firewood and animal dung, personal physical reserves and the exertion of domestic animals. As development occurred, his energy needs also increased. He found different energy resources such as coal, oil, natural gas and uranium to provide for these increasing needs. In the process of development, he showed a preference for more convenient forms of energy, i.e., oil for transportation and electricity for many other applications. In 1950, not many years ago, the world consumed only 70.86 ExaJoules (Exa is 10E8) of energy whereas in 1991 energy consumption was 356.47 ExaJoules. In 1950 the world's electric power generating capacity was only 155 GWe, whereas in 1991 it was 2842 GWe, an 18-fold increase in 40 years. The share of electricity of total energy consumption in 1950 was only 13 per cent whereas in 1991, it was 32 per cent. Thus, while total energy production increased five times, electric production in the same period increased 18 times, since it is a preferred mode of consumption.

It is well known that energy consumption, especially of electricity, is an indicator of the state of national development. This fact is illustrated by the per capita energy consumption of developed and developing nations. The relative per capita energy consumption patterns amongst some countries are compared to India as reference below:

India	1
China	2
France	13
USA	25
World	5

Electricity production in India increased 62 times, from 1,336 MWe in 1947 at independence, to 85,000 MWe now. Overall energy consumption in the same period increased 15 times. Even with this tremendous increase, the impact on development has been limited due to simultaneous population growth. To reach the world average per capita energy consumption, India must develop each and every resource available, including nuclear power.

2. RESOURCES

Energy is produced from renewable and non-renewable resources. Renewable energy resources are hydro, wind, sun, sea waves, etc., and non-renewable resources are coal, oil, natural gas and uranium. Excepting hydro, use of all other forms of renewable energy are presently in their infancy in India, with many limitations on commercial production.

Development of human society the world over depends on non-renewable energy sources. These national resources in energy equivalent content in Exajoules divided by the population number, termed the R/P ratio or resources per capita, is an important parameter with which to measure the potential for development. For comparison, the status of conventional resources in India per capita *vis-à-vis* the rest of the world is given in Table I.

From the above figures it is seen that quantities of conventional resources in India are far below world values. Due to scarce non-renewable resources, India must develop nuclear power to reach a reasonable level of development. Nuclear fuel available as uranium and thorium from sources presently exploitable is given in Table II.

It is seen from the above that uranium supplies are meagre compared to total world resources but at the same time, India's thorium resources are abundant. India's nuclear power program is therefore drawn with this base of distribution.

3. INDIAN NUCLEAR POWER PROGRAM

Based on the considerations above, a three stage nuclear electric power program has been envisaged for India.

Stage I Pressurized heavy water reactors (PHWR), using natural uranium as fuel to generate power and produce plutonium in the spent fuel.

Stage II Fast breeder reactors (FBR) using as fuel the plutonium extracted by reprocessing the spent fuel of PHWR. These reactors would induct thorium at the appropriate time to yield additional fuel using thorium as a breeding material.

Stage III Thorium based reactors fuelled by Uranium-233 obtained from reprocessing irradiated thorium from the FBR. These reactors would irradiate more thorium to breed nuclear fuel for subsequent nuclear power plants.

TABLE I. R/P RATIO (Joules per capita)

	India (10E9)	World (10E9)	Ratio
Solid	1445	4298	0.34
Liquid	39	1053	0.04
Gas	32	876	0.04
Hydro	293	623	0.47

TABLE II. URANIUM AND THORIUM QUANTITIES IN INDIA

	India	World
Uranium (Tonnes)	70,000	4,023,948
Thorium (Tonnes)	306,330	2,202,080

Under the first stage, a series of pressurized heavy water reactors (PHWR) are being set up using natural uranium as fuel. However, the present proven, indicated and inferred natural uranium resources in the country can sustain only about 10 to 15 GWe of PHWR. The second stage hence envisaged the utilization of PHWR plutonium in FBR, which can breed more plutonium from U-238 than they themselves use for power production. This paves the way for additional FBR to be set up using the excess plutonium. It appears technically feasible to develop the FBR electric generation capacity to as much as 350 GWe. Subsequent growth and consolidation in the third stage of the program will be accomplished through thorium resources.

It should be emphasized that the 10 to 15 GWe that can be sustained by PHWR is in fact negligible compared to the projected demand and hardly justifies substantial investment in the nuclear power program. It is only by utilizing breeders and thorium that investment in the nuclear power program in India can be justified.

4. PRESENT STATUS

In India, nuclear power was ushered in in the mid-sixties with the setting up of two boiling water reactor (BWR) units at the Tarapur Atomic Power Station (TAPS), a turnkey contract executed by the General Electric Company (GEC) of the United States (US). These reactors were built to gain operating experience in nuclear power plants.

India launched its pressurized heavy water reactor program with Rajasthan Atomic Power Station (RAPS), with the design prepared by the Atomic Energy of Canada Limited (AECL) based on the Douglas Point Reactor. Construction of the next two 220 MWe Units of Madras Atomic Power Station involving total indigenous effort started even before RAPS Plant was fully constructed and commissioned. Many design changes were incorporated in the Madras Atomic Power Station (MAPS). Narora Atomic Power Station (NAPS), where design of practically all systems has been modified relative to MAPS, demonstrated the maturity achieved in the field of PHWR design in India. Kakrapar Atomic Power Station repeated the standardized NAPS design. Four more units of this type, two at Kaiga in Karnataka and two at Kota in Rajasthan are presently in the final stages of construction. One of the guidelines in evolving the design of Narora Atomic Power Station was that this standardized design of 220 MWe PHWR would subsequently be scaled up for 500 MWe PHWR. The design work for the 500 MWe PHWR is now practically complete. The construction of the first 500 MWe is to be taken up shortly at Tarapur (TAPP-3&4).

In developing the above, India has achieved domestic capability in all the aspects of nuclear power including fuel cycle technology from uranium mining to waste management. Now, the mainstay will be the use of thorium. Work on thorium cycle has been initiated. To gain experience and perfect the technology, thorium fuel bundles are loaded in KAPS-1 and KAPS-2 reactors for initial flux flattening. Toward this accomplishment, a research reactor fuelled with Uranium-233 called KAMINI has been built and is successfully operating.

Meanwhile, to bridge the energy gap of supply and demand, two units of 1000 MWe Russian VVER type are planned for construction at Kudankulam in Tamil Nadu.

A fast breeder test reactor (FBTR) of 40 MWe was built and is successfully operating at Indira Gandhi Research Center (IGCAR), Kalpakkam. The design of the first 500 MWe prototype fast breeder reactor (PFBR) is in final stages with construction to be taken up in the next couple of years. This will mark the beginning of the second phase of the three-stage nuclear power program in India.

5. CONCLUSIONS

Development depends on energy availability. In this respect the late Dr. Homi Bhabha, father of India's nuclear energy program, said "No power is costlier than no power." His view was that development is important irrespective of its cost. Since other forms of non-renewable energy sources in India are insufficient to meet the demand targets, it must depend on nuclear power. The available resources are uranium and thorium. To utilize the vast resources of thorium, Dr. Homi Bhabha formulated the three-stage nuclear power program. Presently, the technology required for the first stage has been fully developed. For the second stage, R&D is underway and for the final stage, preliminary studies on thorium have begun.

Hence it is imperative that India pursues more vigorously than at present the three stages envisaged by Dr. Bhabha, that the 3rd stage of Th^{232} - U^{233} is reached soon so that future generations are not left helpless without electricity – the power is at the tip of the finger.

IAEA can help the developing nations realize their energy programs allowing free flow of information and having coordinated approach to development of fast breeder reactor and fuel cycles with thorium as fuel.

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PANEL SESSION

Session Chairperson

S.R. HATCHER
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Session Co-chairperson

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PANEL SESSION

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Y.S.R. PRASAD (India)
M. ROSEN (IAEA)
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The main points made by the seminar chairperson, session co-chairperson and the members of the panel, together with the highlights of the open discussion, are presented in the Summary. However, since the open discussion covered so many relevant points and in such a variety of approaches, it is felt to be important to provide a clear record of the comments made. Therefore the discussion is reproduced here with only minor editing to clarify the comments.

A. Kakodkar (India) agreed in general with the panel's comments. The IAEA has had a program of small and medium reactors for many years. Nuclear power has shown very rapid growth rates in Asia where industrialization is taking place, so extrapolating that, wherever industrialization sets in and there is no other energy alternative, that could certainly bring in nuclear power in the developing parts of the world today, or tomorrow, or at some time in the future. For an Agency like the IAEA, where we, the nuclear technologists, come together and work together from all over the world, the question is, "Are we here to follow the industrialization and then support nuclear power?" We can all support nuclear power. But can we be happy in fulfilling our role in that manner? That is my appeal to all nuclear technologists in the world, particularly from the developing countries, and particularly to the IAEA. Our role should be to lead the situation. We should prepare countries which are not embarked on nuclear power and which need nuclear power. Economic forces will dictate that it will happen. As technologists, it is our duty and certainly it should be part of our role, and it is the mandate of the IAEA to work on strategies that will bring in nuclear power ahead of industrialization, to bring it in so that it will trigger industrialization.

Developing countries should use nuclear power, and the spin off benefits will help them industrialize. It will bring in the quality culture to industry. It will prepare industry for other sectors of technology and industry. That should be the objective in the IAEA program. The time has come when we must address ourselves to this need. There are several solutions, both technical and nontechnical, short term and long term, and the IAEA is an ideal platform, where on some solutions direct action can be taken. If we simply leave nuclear power to market forces, then it will certainly grow when the market becomes favourable. It takes time. If we need some technological solutions in twenty-five years, are we going to allow the situation to drift until then? What can we do with the existing technologies? We should debate some of these issues and offer guidance to the IAEA for the long term.

As has been said from the panel, an international project should be promoted, perhaps beginning by defining what kinds of reactor systems we should have, and find technical solutions by collective thinking. In the short term, we need to look at the existing technologies. As to externalities, are we making an economic comparison purely as a utility, or as an electricity generating system that takes into account such things as mining, right through to the end, to the environmental impacts that need to be brought in. There are several IAEA programs that examine these and we should make it available, focused to the governments of the developing countries. The short term economical comparison will always lead to the choice of gas. But then, as the intellectual people of the world should we not talk about sustainability, or is it just a word? Are we not here to define a set of rules which can drive the world in the right direction in the long run? The time has come when we should examine these ground rules.

The chairperson expressed the opinion that taking externalities into account is important, but it is also a very difficult question. He wondered what approaches other participants felt that governments might take to do this. Certainly in North America there is a strong lobby from business and the fossil fuel industry against carbon taxes, since the economy will suffer, and employment will be adversely affected. Governments therefore tend to shy away from such politically unpopular action as imposing carbon taxes. Some have suggested instead that incentives be given to the non-carbon generators. Creating a level playing field in accounting for external costs and managing energy wastes will be a hotly debated topic for governments.

C.S. Karim (Bangladesh): There is strong government support for nuclear power in Bangladesh, but we face a lot of problems. When a developing country goes to a supplier there are a lot of questions asked. It appears that there is a lot of apprehension and uncertainties in their minds regarding proliferation, safety (whether developing countries can operate nuclear plants safely particularly after Chernobyl), cost overruns, adequate infrastructure, risk of financing, export credit guarantees, economic viability, cross boundary effects of accidents, and elementary questions, such as whether nuclear can compete with solar. It is very difficult to get international financing, it's very difficult to get export credits, and the OECD consensus financing rules make it difficult. Whether the World Bank or other international financial institutions put some money into that, whether they put or do not put their moral support in favour of nuclear power is essential, because developing countries have to depend on such sources for all development activities. If you use excess money for nuclear power plants, then they will stop financing for other projects. Questions such as whether nuclear power is a good option, whether it is environmentally friendly, whether it is an option for developing countries, should be answered through international agencies, such as the IAEA. That would help dispel some of the doubts and uncertainties.

The chairperson commented that this reinforced the point that there are limited financial resources in the international development institutions, and there is an allocation system for the capital available. Projects must line up for this, which makes it difficult to get financing for large projects, such as nuclear projects. This in turn comes back to the need to get a product that competes in the marketplace to be able to tap the traditional capital markets. As long as countries are forced to go to the aid agencies or the export/import credit system, there will certainly be a constraint on the amount of nuclear capacity built.

M. Rosen returned to the question of the level playing field and commented that the nuclear industry makes a mistake when it tries to compete in operations and maintenance costs etc. Short term economics is only one way to examine the question. There are other factors that go into real economics for the long term. For example, security of supply is an economic consideration. Environmental impact is an economic factor. Resource depletion is an economic factor. We should always counter economics criticisms with questions such as "What is the answer to security of supply, what is the answer to externalities, what is the answer to resource depletion?" The response may be that governments do not want to face these questions today, and short term economics do not allow us to face it today. But people must be made aware that only part of the question has been dealt with.

V. Orlov (Russian Federation) proposed some general approaches, including environmental impact. The best idea in nuclear fuel was formulated by Enrico Fermi in 1944 — breeding and fast reactors. Now fast reactors can solve all these problems of economics, environment, including radioactive waste, safety, non-proliferation. We must now find the way to develop this technology. The Russian Federation has wide and successful experience in this field. Not all past ideas for fast reactors were the right ideas. The original FBRs were designed with a high breeding ratio — that was a mistake and led to expensive reactors with insufficient safety. Now we must develop other types of fast reactors for other criteria, such as safety, economics, non-proliferation, waste minimization. Developing countries can follow the lead of the industrial countries, but the industrialized countries must not repeat the mistakes of the early fast reactors. The Russian Federation has 14 years of experience with a concept that can solve these problems. Now is the time to launch an international project to elaborate the scope and the requirements for future nuclear technology, and to choose the technology that will satisfy these requirements. He suggested that only one technology can satisfy all these requirements. Then we should organize, maybe with the IAEA, a common international project to develop this technology, together with the developing countries. The Russian Federation is ready to give its experience and thinking.

The chairperson commented that this is an interesting proposition and that he had been interested in Professor Adamov's proposal for the lead cooled fast reactor at the IAEA General Conference in September of this year. He shared the Russian view that the lead cooled fast reactor may have better prospects for commercial use than some of the other fast reactor proposals.

B.J. Csik (IAEA) referred to a meeting at the IAEA together with the General Conference in 1998, at which presentations were made by fifteen countries on their national views on nuclear power. What came out very clearly, both at that meeting and again at this Seminar, was that on the basic issues of the need for power, growing populations, environmental protection, there is practically universal acceptance. The consequence of the acceptance of these facts is the formulation of strategies, policies, on a national level. That is when the question comes up "Is nuclear power a viable alternative or not?", and that is where opinions differ widely. At one extreme the argument is made that it is an absolutely necessary inevitable alternative. At the other extreme, it is considered not viable because the nuclear risk cannot be accepted. And between these two extremes are all the other arguments. The conclusion is that people who make policies and then strategies for implementation, such as subsidies or taxation, have not been at either of these meetings and these are the people that we have to reach somehow. The IAEA cannot possibly reach the level of the schoolteachers or the general public. It is not equipped to do so. Neither is an atomic energy research institute. We simply do not reach the decision makers, who have misconceptions, and who are possibly receptive to a clear and honest discussion. If they are not receptive, it is useless, because they have already made up their minds and they are not interested in facts, they are against something, but that is rare, because on this level people who make policy and who make strategies are intelligent people, and they are receptive to argumentation. This where we should concentrate our activities, to reach the international community of policymakers and decision makers. These people should come to the IAEA to receive such information exchange so that they can form their policies and inform their governments in a much better way.

The chairperson responded that the timing of this is appropriate because the world is now engaged on the question of reducing carbon dioxide emissions. We have the series of Conferences of the Parties to the United Nations Framework Convention on Climate Change, and the next one takes place in Buenos Aires in November. Expanding on the previous speaker's remarks, he gave as an example the position of the United States in 1997, when the Administration would not entertain the notion that nuclear power had any place in the future energy supply. Since the Kyoto Protocol, that has started to change. Now the Administration admits freely that they must keep the current nuclear plants operating, they must move forward with licensing for the extension of plant life, so that plants do not have to shut down at the end of their original design life, in the next ten to twenty years. They have not yet reached the point of acknowledging the role of new nuclear plants for the future. But a number of us will be interacting with policymakers. All participants in this room might take the opportunity to interact with their government representatives that will be going to Buenos Aires and one more time make the arguments that we have been hearing here this week.

A.K. Anand (India) pointed out that the long term economics of nuclear power are satisfactory when one takes into account the environment. But short term economics seems to be the problem. If governments tax CO_2 , SO_2, NO_x, etc., then the economics will change. Nuclear power will become cheaper and competitive. What can the nuclear community do to help? We have increased the cost of nuclear power by making plants safe, safer and safer. Collectively we should look at the question of real safety. Even highly respected senior regulators are asking "Do we really need this? Do you really need that?" Perhaps we ourselves have made short term economics not viable for nuclear power. The average casualties in nuclear power is an order of magnitude lower than for any other power generation. We should further develop the analysis of comparative safety. Instead of continually making plants more complicated, can we not make nuclear power plants simpler and safer? If we do that, then nuclear power will flourish.

The chairperson agreed that simplification is the only way to get around this question. It is difficult to turn the clock back on the regulations that exist today, but we must come up with simpler designs that can be treated within the regulations that we have now. We can achieve economic gains in that way.

Y.M. Ibrahim (Egypt) noted that for financing aspects, in all countries there is a new sort of energy like the independent power producers (IPP) formed as a result of privatization. But these are for conventional resources. But there are no nuclear projects by IPPs. He invited the IAEA to try to issue a new document on utility requirements for the developing countries. This document should contain a new sort of contract, between the country and the IPP, including the competitiveness of the project. The country commitment would be for the safety and third party liability. He also commented that for public acceptance in some developing countries, decision makers have the image of Chernobyl. We need data and information to convince the decision makers that nuclear is safe. As M. Rosen had suggested, perhaps the IAEA could help in arranging meetings with decision makers to provide this information.

M. Rosen (IAEA) commented that one of the real problems in the nuclear industry is that it speaks to itself. In this audience we are speaking to the believers. That does not convince the people that one really has to get to. One has to speak to Ministers, to utilities that operate coal plants, to the regulators, to explain the facts. The audience should not be the American Nuclear Society or the European Nuclear Society — it should be the World Energy Council, the Mechanical Engineering Societies, the Electrical Engineering Societies. At meetings we should get a few good speakers together and go to the media, not expect the media to sit through the conference. They should go to the ministries and speak to the people there.

V. Nadkarni (India) reminded the audience that there is an in-built adversarial mechanism in the media. They need to question. Therefore the media distrusts all sponsored programs and attempts to coopt the media. When you have independent questioning, when you have people who are shown the facts with a complete sense of transparency and trust, then people who are critics might become your supporters. The fact that greater exposure to radiation levels, living in a house that has radon emitting materials rather than living next to a nuclear power station, now this type of fact is totally denied when it is presented. While I was traveling to come to this Seminar with my wife, who has a Ph.D. in social sciences, I mentioned to her that this is the kind of anomaly that exists, when you show the kind of exposure that you get over the life from natural radioactivity, compared to the kind of sliver that you get even when you are working inside a utility, she just disbelieved me initially. She said that there must be something wrong with this. I said that the argument is buttressed even by the analysis of cancers found in the Hiroshima survival population. Now the problem is the public at large is unable to grasp mathematical and statistical concepts. And I feel as a communicator, that it is our need to present this information in very animated and very lively concepts. The problem is that we have linear discourse, which goes sequentially. What we need to do is to present this in a holistic manner with a visual and even shocking startling manner, for example where you have cartoon characters and big apples and clockwork oranges and things like that. Now, this is sometimes looked down upon by the scientific and technical fraternity, as being non-serious, as being trivial, but the point is that to catch the attention of school children and housewives, and people who don't want to know about these things, you need to be really innovative and you need to get the closer cooperation of people who are experts in the field who are not afraid to talk but who are also willing to come down from their pedestals as it were, to the level of the common person, and address their very real fears. Now the fact that you mentioned that you have a zero impact attitude, which is unrealistic, now this is something that is really hard to get across, even among people who have Ph.D.s in communication. This will be the challenge that your fraternity faces. How to get this message across, because we are all in this together.

The chairperson fully agreed that we really have to put more effort into school programs, because we are not going to turn the full public around in a matter of a year or two, no matter what techniques we come up with. It's very important though that our coming generations have a better understanding of science and technology in general, and how nuclear fits into a part of that. So teacher training is far more productive than even for us to go to classrooms because you have the amplification of a teacher talking to hundreds of students whereas when one of us goes to a classroom we talk to 30 or 40. As to the presentation methods, one of the things that the American Nuclear Society found quite effective was a comic book on nuclear technology, aimed at explaining facts to schoolchildren. If we cannot learn to communicate with the public at their level of interest, then we will never get to the situation where politicians get feedback from the public to give them the confidence to make the right decisions.

P.E. Juhn (IAEA): Public acceptance is an important factor, but when you introduce a nuclear power program in developing countries, public acceptance does not matter because if you talk too much about public acceptance, you interfere with the people resident in that area where you select the site. Then it becomes difficult for them to understand — it's impossible for them to understand. The people who govern the country and who know the facts should decide and go ahead. It is the only way to implement a nuclear power project. The local people never understand and never accept. Once one area accepts, neighbouring provinces want more. In Korea we have a certain problem these days, to subsidize the people who locate near the nuclear power plant. Then they get certain benefits, in terms of money, say within a five kilometer boundary. Then outside the boundary there are lots of demonstrations demanding why we are not getting that kind of benefit. Once you get too involved with the residents you cannot have a nuclear power project. Good leaders are like de Gaulle in France in 1973, who discussed the issue and concluded that France would have no fossil fuel plants any more, only nuclear. This is why France developed nuclear power more than all the other countries in Europe. France is now selling 20% of its nuclear electricity to neighbouring countries. That really helps reduce carbon dioxide emissions in Europe. Good leaders should lead their countries without too much interference from the public. This is the time of the buyer's market. If you want nuclear power you should negotiate with supplier countries and get nuclear power plants in a very economic way. If long term loans are at 6%, why not get for 5%, or 4%? Now is the time to negotiate.

R. de Préneuf (France): I would like to give to give some more precision on the French situation. We are not subsidizing the local residents to make them accept nuclear plants. But in a sense we are. Municipalities that accept nuclear plants collect higher taxes, and people can see the difference in public facilities, like schools, sports facilities and so forth, even the road maintenance is involved. So it's a way among others to have these power plants accepted. Sometimes you have competition among municipalities to accept power plants. One more comment. I agree with Mr. Juhn, that if you try to demonstrate too much you do not succeed, or you demonstrate that it is dangerous because you have to demonstrate that much. The best demonstration that we can make is to have no accident at all, and twelve years after Chernobyl the credibility of the industry still suffers from this accident. If we have no accidents, then in the long run, if it is economical, it will win. Over demonstration may slow down the process.

N.K. Jhamb (India): A single point that attracted my attention and which requires very focused attention is the observation of Mr. Rosen regarding misunderstanding of nuclear power and the safety implications flowing from it. As soon as this misunderstanding is pierced, there will be a very accelerating role for nuclear power in the global energy scenario, as it would help reduce many of the costs of nuclear power itself considerably. But it is agreed that it is very difficult to sell it to the non-nuclear community. The difficulties arise because there is a communication gap between the two. Whereas the nuclear community talks about the external exposures, the general public at large have fears of internal exposures, because for any active material going into the body, there is no time, shielding, distance, there, because the body has no mechanism, even for the very low active sources to guard against it. So this is the area where the two are not able to communicate with each other. When people see that the ICRP is always reducing limits, they wonder why the limits are being reduced when the risk is very low. We must resolve the communication gap amongst the nuclear community first, before it can be communicated to the public.

Second, I agree with the projection for the future that there will be an accelerating role for nuclear power, worldwide. But in the present context, we are discussing nuclear power in developing countries. Developing countries are capital scarce countries. Capital intensive, large nuclear power stations in capital scarce countries run the risk of high cost and time overruns, because of capital scarcity itself, and that results in even higher cost nuclear power. This is especially so in today's context of highly volatile financial markets, volatile interest rates, volatile exchange rates, which may make these countries face fierce strains from the vagaries of the volatile financial market. They are afraid that servicing of debt may become difficult in the future. On the technological front, this is a very high tech, complex technology. Unless there is a capability generated and built up to service this technology, there is an in-built technological trap itself, of technological obsolescence, problems of spills, technical dependence, and the follow up political frictions that may result from this. So capability to service this technology is a necessary part. Mr. Kakodkar has suggested how to make this technology an engine of economic growth worldwide. So taking all these three or four points together, I see an opportunity for IAEA. It is the opportunity to have a global high voltage electrical transmission grid, integrated into the various countries and funded by a stable financial force, rather than the volatile financial markets, because along this path, the unit cost of electricity may be the same, and it will give more stable energy flows. Nuclear power will be the natural low cost choice along this corridor. It will be natural because it is from low cost international funding of international institutions, low cost construction from reliable suppliers, least gestation periods, standard designs, and economies of scale. This is an opportunity, whose feasibility needs to be explored. A feasibility study may show this to be a natural solution to all the various problems that we have been discussing in the last four or five days.

H.-H. Rogner (IAEA): Right now, about 60 000 MW(e) capacity are being added to the global electricity system per year. Each kilowatt is a specific investment decision, taken by a variety of stakeholders, including utilities, banks and so on. These investments adhere to existing environmental and other codes and standards, because they would not otherwise obtain an operating license. The investor looks at this from the vantage point of "How long do I have a stake in this project?" And he will evaluate this from the standpoint of whether any of the conditions around the project will change or not. Now, with the comparative assessment project at the IAEA (DECADES), we try to assist the investment decision to show where, along the full chain from resource extraction to electricity generation and waste disposal, environmental interaction, emissions pollution and so on, occurs. So far, I am not aware of one single investment decision that was based on environmental standards other than those that were legislated. People look at the results and say "Oops, if something comes that's where we might tweak the system a little and get around it" but I'm afraid the environment is not a part of the decision making process. Next, when M. Rosen used the example of a car, the car was competitive before and after the catalyst or the airbag. And if the nuclear power industry could have had the productivity gains of the car industry, we wouldn't be sitting here. Then we would be back to where we hopefully were when electricity was too cheap to meter. Unfortunately that is not the case.

J.J. Fletcher (Ghana): Mr. chairperson, you made a point about encouraging the use of a joint project between countries. This is a very appealing proposal as far as we in West Africa are concerned. I would propose that the IAEA encourages the AFRA program to undertake a program like "Understanding the issues" and "Planning for Nuclear Power" in our member states, because every year they have a reporting to the OAU and in these reports the ministers and the ambassadors meet and try to understand what is happening. If the IAEA encouraged AFRA to have such a program our politicians would get better understanding and we would be on the bandwagon of these nuclear power projects in no time.

T.K. Rao (India) argued that designs have become so complicated by adding several systems, by way of increasing safety. Yet we have experience of 40 years, and no incidents have taken place over 40 years of operation. Therefore, if you reduce some systems, the basic cost can be reduced. Once the basic cost is reduced all the overhead costs, financing costs, which are about 50% of the total cost, are also reduced. Under these circumstances, why has the ICRP 60 recommendations tightened the radiation dose limits from 5 rem to 3 rem? This means increasing a lot of features in the reactor designs, like additional shielding requirements. If all these systems, which are not really needed, are eliminated, the cost will be reduced, not only initial costs, but operating costs well. That means, in short, that we have to have experts look into and reduce unnecessary systems that are more than are needed for safety — then the costs will come down.

The chairperson noted that the whole question of the linear hypothesis for the health effects of low level radiation are being challenged quite strongly by some members of the medical and the health physics community. I don’t think that we are quickly going to see a roll back of the ICRP recommendations, but we are going to see a stimulated debate on whether we are regulating to the right standards, or whether we are being over conservative because of the current ICRP recommendations, and paying a high societal cost for this.

A.M. Khan (IAEA): I would like to hear some views on regional fuel cycle centres and effort on nuclear power plant design and development, because that would not only be helpful in technology transfer to many countries, which do not have the know how or capability for individual adaptation or absorption. Secondly, it would remove fears of proliferation in relation to fuel cycle facilities. Thirdly, it would pool resources, financial and manpower resources of many countries, which do not have large enough resources for running independent programs like some of the larger countries.

M.S.R. Sarma (Indian Nuclear Society): Mr Kakodkar made remarks about standardization. It is a very good idea to have a standardized unit. But when it comes to the size, small is beautiful. If you have to have a number of small units to get the same output it is really troublesome and irksome to operate them. So the size has to be optimal, not necessarily the smallest. It is of course governed buy the size of the grid. Although 100 MW(e) may look attractive, if the grid needs 400 or 500 MW(e), then to have four 100MW(e) units or two 200 MW(e) units, is a decision one has to make, and certainly more pieces of equipment will add to the problems of maintenance and operation. The same thing applies in the case of safety. Adding equipment per se does not necessarily enhance safety. We should not necessarily delete equipment, but certainly before you add equipment, you need to be very careful because added equipment does not necessarily add to safety. Another point raised is about nuclear power preceding industrialization. Before you get into the nuclear power business, even if it is a total scientific program, subsequently it has to be maintained by the local industry. So there must be a certain capability in the fabrication, manufacture and servicing, and this warrants the industrialization to some extent preceding nuclear power. In the case of India, it has been able to stand on its own feet because there was some industrial capability existing in the country.

A research reactor, preceding nuclear power is a very good experience, it gives a good training ground, and is a useful way of introducing safety culture into a country's nuclear community. Countries that do not have nuclear power yet should start with a research reactor as their fist unit.

In public acceptance, media are the opinion makers, so we have to go out of the way to cultivate the media — that means we have to bring them periodically to tell them what is happening in the unit, in a language that they understand, as Mr. Nadkarni said, come down from the pedestal. It is the responsibility of the utility to explain to the media. It cannot be one short deal but a continuing. At the same time, I would also implore the media to exercise some discretion in publishing the news. That is not to say don't publish the observations, but before you draw a conclusion and an inference think twice, ask some people who are knowledgeable in the areas, otherwise that leads to headlines that to retrieve from the situation is a Herculean task.

K.I. Han (Republic of Korea: It is necessary to have some type of research reactor to train people and understand the basics, but the Republic of Korea did not take that path when it deployed nuclear power plants. The Republic of Korea bought nuclear power plants and got technology transfer. Then we went to localization and self reliance on technology in design as well as manufacturing and construction, and in that respect we wanted to do our own design and design changes. Design changes and improvements definitely require some kind of research that supports design change to meet the safety requirements and improve performance. So it should go together, but that does not mean that at the beginning it is necessary to have all the safety related research and performance before we really deploy nuclear power plant.

L.C. Longoria (Mexico) raised the question that if most of the industrialized countries have stopped their nuclear programs, why should the developing countries continue to pursue it? The decision will be based on economics and public opinion. Every country will look at its energy situation and the demand and supply and will have to make a decision. The decision makers will take into consideration many things. Public opinion is one of the most important ones. In order to overcome the problem of public opinion, and be able to take the cost of public opinion, they will have to base their decision on economics, and be able to demonstrate to the people that it is cheaper and better. Every country will look at its energy situation, but one of the key issues will be, and will continue to be in the short and long term, economics. As long as the nuclear energy is not cheaper than the other sources, it won't be a clear option, especially for the politicians to make decisions.

Unidentified speaker: We have the right to be optimistic about nuclear power in developing countries. Taking into account all the figures and advantages that lead us to be convinced on nuclear power. But in the same point that Mr. Rosen made, we have to convince not the people that are already convinced, we have to convince other people that are not convinced. Public opinion also means politicians, because politicians are an expression of public opinion. So, we have to be realistic in pointing out some other features that may not be so optimistic. First, the financing of nuclear power in developing countries is very hard. We have heard some experiences here from developing countries on the state of their nuclear power programs, with financing problems. In the future, for many countries with a deregulated market for electricity, the nuclear option will have to compete, not with coal but with gas. So we have to develop more efficient nuclear stations to compete with gas. But no matter if statistics show that future needs for energy could lead to the nuclear option, public opinion is a greater concern than in the past, even in developing countries. In developing countries, public opinion looks at what is going on in developed countries. If, developed countries have stopped development because of public opinion, why should developing countries do something different? If we don't have the right answer for these issues, nuclear power will be threatened by other options. No matter if nuclear power has economic advantages, policy makers and politicians and decision makers are willing to pay higher costs but not to fight against this risk of public opinion.

The final point is what are developing countries to do with waste? In the same way, public opinion in developing countries looks at the developed countries and asks "What are they doing with their waste?" So if it nuclear power demands a high technology development for waste management, this is an added consideration.

The chairperson commented that there is a strong consensus on the need for economic competitiveness, but there is also a strong concern about our lack of success at public information. We are going to have to deal with this much more effectively than we have done in the past.

K.J. Sebastian (India): Nuclear power, being comparatively more capital intensive, has to be taken in a long term view to be economically viable. To take a long term view in economics, the cost of resources has to be lowered. This is one of the problems faced in the developing countries, where capital is scarce. So they tend to take a short term view.

M. Rosen (IAEA) felt that the concentration on economics is dangerous because the real question is need. You can have as many tomatoes as you want at the cheapest price, but if nobody wants the tomatoes, they won't buy the tomatoes. The same is true of nuclear power. Economics are clearly important. The need plays a major role. And need has to do with the environment, security of supply, and resource depletion. You need that message to the public, just as well as short term economics. A final comment on the waste. There is no question that with the small quantifies of waste being generated, the future solution will necessitate regional depositories. There is absolutely no sense for a small country to bury high level waste. A regional depository may take twenty or thirty years, but the advantage with high level waste is that you can store it. There are many safe ways to store it — above ground in pools. You can wait twenty years but eventually there will be a political decision to regionalize the storage of high level waste.

The chairperson observed that the other side of the coin on economics is that there certainly has to be a need. And when the need is established, the customer is going to buy the cheapest product that will fill his need. That's our problem at the moment- we don't have a that cheap product to fill that need.

K.I. Han (Republic of Korea): Based on Korean experience in public acceptance, governments said that there will be some delay on some plants, and then we had people who were very silent until that time, but who were in favour of nuclear. Because if they took advantage of having nuclear power plants, they made a plea to the government "Please don't delay the nuclear power plant construction." So there are people who are silent and that is very important in the future for the nuclear community.

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