Nuclear Research Centres in the 21st Century

Final report of a meeting held in Vienna, 13–15 December 1999

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FOREWORD

During the last fifty years, a large number of countries have established nuclear research centres (NRCs) with the mission of (1) developing indigenous expertise in nuclear science and technology, (2) training scientists/engineers for research and development on nuclear power reactors and applications of radioisotopes and radiation, and (3) facilitating commercial exploitation of nuclear technology. Many research centres have developed nuclear expertise on all aspects of nuclear science and technology through setting up and operating large nuclear facilities like research reactors, accelerators, fuel cycle facilities and the like. NRCs have been the cradle for a host of industries dealing with peaceful uses of nuclear energy. By virtue of their multidisciplinary nature, nuclear research centres have also been strategic elements of technology development in many countries and a number of industries have benefited by association with NRCs. For technologies which have already been deployed, there is a belief that less R&D from NRCs is required. Further, incidents like the Chernobyl accident have prompted many countries to re-evaluate the need for nuclear power. With increasing pressure on resources, the NRCs are facing a difficult situation in many countries, particularly in the developed countries. Government support and funding are dwindling and the infrastructure for nuclear R&D has aged as have the personnel. There is an apprehension that nuclear expertise itself may dwindle with time and the benefits of the nuclear science and technology may not be available in the future. The technology is less than 50 years old and there are many new avenues demanding R&D input. Co-operation among NRCs is one route to meet these challenges.

Research and development in nuclear science and engineering has an international outlook. The IAEA has been active in promoting international co-operation ever since its formation more than 40 years ago. The Director General of the IAEA therefore felt that it would be useful to bring senior managers from NRCs together. Towards the end of the last millennium attention was focused, in many areas, on changing times. In the field of nuclear technology, there were a number of major conferences addressing this issue (IAEA Conference on Nuclear Power in the 21st century — Challenges and Opportunities, Mumbai, India, in October 1998, and American Nuclear Society Conference Global 99 on Nuclear Technology Bridging the Millennia, held at Jackson Hole, USA, in September 1999. While the technology issue was discussed in these conferences, the general issues relating to NRCs were not the subject of discussion at any forum.

To focus on these issues senior managers of nuclear research centres from 25 Member States were invited for an exchange of ideas regarding:

- Orientation of the programmes of NRCs in the current environment,
- Challenges faced by NRCs,
- Interaction of NRCs with their governments, industry, academia and public,
- Ways in which mutual collaboration could be used to enhance the technology,
- The possible role of the IAEA in this respect.

Accordingly, the scope of the meeting was defined as follows:

1. Past and present situation of NRCs

- R&D programmes and the related finances, manpower and infrastructure
- Strengths and limitations.

2. *Challenges faced by NRCs*

- New directions
- Examples of successful orientation
- preservation of expertise.

3. *Interaction of NRCs with their environment*

- Social and economic sector
- Academia
- Public.

4. *Collaboration and co-operation*

- North–South and South–South
- IAEA role.

5. *Other issues considered relevant*

All participants gave their country's views on these and related topics. There was extensive discussion on the subjects. The sections of the report giving highlights of presentations, summaries of discussions and recommendations were finalized at the meeting. D.D. Sood of the Division of Physical and Chemical Sciences was the Scientific Secretary of the meeting and was the IAEA officer responsible for this publication.

The 44th General Conference of the IAEA passed a resolution (GC(44)/RES/23) which calls for strengthening co-operation between nuclear research centres in the area of the peaceful applications of nuclear technology. This resolution reaffirms the recommendations of the meeting. The Member States and the IAEA will now explore ways in which this co-operation can be strengthened. In the 2002–2003 Programme and Budget cycle the IAEA has also initiated a subprogramme on Management and Preservation of Knowledge in Nuclear Science and Technology, in which facilitating close co-operation between NRCs and the academic institutions is an important element.

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HIGHLIGHTS

Opening session

The Director General of the IAEA, Mohamed ElBaradei, opened the meeting. He welcomed the participants. In his address, he mentioned that the role of the IAEA is to ensure that nuclear technology is harnessed for the benefits of Member States with a high level of safety and exclusively for peaceful purposes. With regard to the future of nuclear technology there are many challenges ahead. Since the Chernobyl accident nuclear power is facing problems in many countries but, in view of its environmentally benign nature, the ‘climate change’ issue and the ‘Kyoto Protocol’ on green house gases have provided a new window of opportunity. He mentioned the importance of public acceptance, economic competitiveness and the perception that waste is still an unsolved issue. Safety in nuclear facilities has significantly improved after the Chernobyl accident but there is still room for improvement with regard to safety culture. Issues in waste management/disposal include retrievability, transmutation and public acceptance. In power reactor technology, the focus is on innovative reactors which are economic, inherently safe and proliferation-resistant. The IAEA has been working on the development of safety standards and the latest topic of interest is safety standards for nuclear waste. The IAEA’s safeguards system has worked well to ensure that nuclear technology is being used only for peaceful purposes, but incidents in Iraq and the Democratic Peoples Republic of Korea have highlighted the need for detecting undeclared nuclear activities. The safeguards system has accordingly been overhauled by making it more advanced and intelligent through an Additional Protocol to Safeguards Agreements which will enable the IAEA to detect possible undeclared activities. Universality of the safeguards system is still an open issue. In the area of public acceptance, it is necessary to make people aware of the advantages of nuclear technology. Dissemination of authentic information is very important. Also there is a need for transparency in our operations. Another major problem facing the nuclear industry is that at present the technology looks stagnant. However, it is a young technology and should continue to go through the process of development. The availability of human resources is another serious issue. Nuclear power reactors and associated facilities require skilled manpower for decades to come. Preservation of expertise is essential as nuclear energy is likely to be one of the engines for development in the future. The IAEA has called this meeting to address these complex issues facing nuclear technology and the nuclear research centres.

The DG mentioned that this is the first meeting of managers of nuclear research centres called by the IAEA and hopes the participants can find ways to contribute to the solution of many of these issues. The IAEA as a global centre for nuclear co-operation would welcome suggestions regarding its role in the process. He wished the participants successful deliberations and looked forward to their report.

The Chairman, P.J. Fehrenbach (Canada), followed DG in setting the tone for the meeting. In his opening address he dealt with the Canadian experience as seen through the perspective of Chalk River Laboratories of the Atomic of Energy Canada Ltd. He described how the role of the AECL Nuclear Research Centres in Canada has evolved as nuclear technology has progressed over a period of slightly more than 50 years. From a situation of strategic scientific research, it is now a multi-billion dollar nuclear industry in the fields of nuclear fuel supply, nuclear power, and isotopes and radiation for industry and medicine. In addition, he elaborated on the key role of the research centres in bringing about the CANDU reactor design, which Canada’s engineering community considers as one of Canada’s outstanding engineering accomplishments in the first 100 years of engineering in Canada. Furthermore, he described the current R&D challenges to be addressed in connection with maintaining the design and licensing basis of this technology, in development of new reactor designs for research, isotope production, and electrical power generation, in maintaining and further improving safety aspects of nuclear power, in materials research, in infrastructure developments, and in maintaining a core of skilled man-power. He also discussed the increasingly applied focus of the nuclear R&D programmes in Canada over time. He ended his talk by giving a glimpse of the role nuclear research centres could play in the 21st century vis-à-vis the development of strategic knowledge base in nuclear technology, development of trained man-power and infrastructure for studying and handling of radioactive materials, and contributing to the further implementation of nuclear technology in areas of energy generation, nuclear medicine, and industrial applications.

During the course of discussion at the meeting, it became evident that all participants felt strongly that nuclear research centres (NRCs) are very important for countries' social and economic development. For countries with nuclear power programmes it is obligatory to maintain the necessary nuclear technology infrastructure to support those programmes and investment, and NRCs play an important role in that preservation. For countries without nuclear power programmes there is also a need for NRCs to introduce and support other non-power aspects of nuclear technology to solve societal issues. The IAEA should be available to assist NRCs in shaping, evaluating, and fulfilling their missions. The detailed discussion and recommendations in each of the sessions reported below reflect these general conclusions.

Session I: Past and present situation of nuclear research centres (NRCs)

(Co-chairman: M. de la Gravière (France). Keynote speaker: K.F. Fouche (South-Africa). Rapporteur: H. Vera Ruiz, IAEA)

All presented their experiences in their respective countries. Nuclear research centres have been active in pursuing the R&D related to nuclear technology, power production, materials science, isotope production and other applications. Some of the NRCs continue in the same vein whereas some other NRCs are diversifying to non-nuclear research areas as well as trying to establish a privatized commercial nuclear industry. The salient points of each presentation are summarized below:

M. de la Gravière emphasized that France has a long term vision on the benefits of nuclear technology. For consolidation of activities, two of the 11 nuclear research centres in France are being closed down. He discussed in detail the activities at CEA, Cadarache, which has a work force of 4500 and annual budget of 2.2 billion French Francs. With 18 major facilities, the Centre is pursuing R&D in nuclear reactors and fuels, safety, nuclear fusion, waste and effluent treatment, basic research and industrial applications. New facilities being planned for operation in the next 7 years include: experimental research reactor for validating nuclear fuel design, nuclear reactor for submarine application, a waste processing and storage facility and a radioactive effluent treatment plant. He briefed the participants about the National Institute for Nuclear Science and Technology which trains engineers as well as technicians. He projected the partnerships with three regional universities and some of their national laboratories as another key factor for manpower development.

K.F. Fouche (South Africa) spoke on the "Evolution of the Atomic Energy Corporation of South Africa". In the sixties the programme evolved around the 20 MW SAFARI-I reactor, a 3 MeV Van de Graaff, a small Tokamak and a uranium enrichment programme. With the setting up of the 2×980 MW(e) nuclear power station there was a need for indigenous production of enriched uranium fuel for the research and power reactors. This resulted in a large expansion of the programme, particularly in the front end of the fuel cycle. As a result of the decision to stop expansion of the nuclear power programme and the ready availability of fuel for the power reactors on international markets, the production plants and development programmes were closed. Personnel was reduced by 80% in the process. The existing facilities have been redirected to a strong commercial programme for fluorochemicals and radioisotope production. As an example of a nuclear spin-off he mentioned that the nozzle technology used in the enrichment programme is now being used for the commercial production of dust separators. With the current strength of 1580 personnel, the Centre has a budget of US$ 80.5 million, more than half of which comes from commercial sales. He emphasized that research projects are either commercially driven, with profitability of products as a criterion, or of an institutional nature dealing with reactor and radiation applications, nuclear waste and training with societal needs as criterion.

D.S. Gemmell (USA) presented the case of the Argonne National Laboratory as a typical example of NRCs in the United States of America. At Argonne, there has been a reduction in funding for reactor development. The energy research effort has been redirected to include alternate energy sources (e.g. advanced batteries and fuel cells), and environmental management (waste disposal, environmental risk and economic impact assessment etc.). Over the past two decades, the research programme of the laboratory has undergone a major change in emphasis. The original mission, which was to lead the nation’s effort in the development of peaceful applications of nuclear power, has evolved and diversified into a wide range of programmes in basic research, energy science, environmental management and non-proliferation. The laboratory operates several large facilities (e.g. APS, IPNS, and ATLAS) for the benefit of scientists who come from other US institutions and from abroad. The laboratory is also undertaking the instrumentation development and construction for the spallation neutron source to be built as a multi-laboratory project at Oak Ridge National Laboratory.

M. Fan (China) described the activities of China Institute of Atomic Energy. The Institute has three reactors (largest 15 MW), low energy accelerators, 30 MeV cyclotron and 14 MeV linac. The areas of current research are nuclear and condensed matter physics, radiochemistry, reactor engineering, research and development of isotopes for the health care sector and safety aspects. The research reactors and cyclotron meet the Chinese need for isotopes in medicine and other applications. New major facilities under design/construction include China Advanced Research Reactor (60 MW), and China Experimental fast reactor. China has helped developing Member States by supplying neutron source reactors. China is also studying the potential of accelerator driven systems for spent fuel management by transmutation. With the limited funds available, China is focusing on those key areas which have socio-economic impact.

W. Scholtyssek (Germany) presented a review of the work at Forschungszentrum, Karlsruhe, which started its first research reactor in 1961. Over the years the centre developed advanced technologies in the areas of fast reactors and reprocessing. Start up of 20 MW(e) fast breeder and WAK reprocessing plant were significant achievements, and construction of 300 MW(e) SNR 300 was completed in 1985. Chernobyl accident in 1986 brought a complete reversal in the programmes of the centre, which had to abandon its nuclear emphasis to respond to public pressure, even having to drop “nuclear” from the name of the centre. Therefore, the current programmes include research in nuclear waste management, source term & consequences, accelerator driven systems, and nuclear fusion. Typical areas of non-nuclear research are: nano-particle technology, micro systems, medical technologies, astrophysics, and high pressure and high temperature physics. He felt that, despite unfavourable public opinion on nuclear power, it is essential to continue with research, to maintain safe operation of the existing facilities and efforts should be made to sustain and transfer the know-how through co-operation with international partners.

K. El Mediouri (Morocco) presented a case of an upcoming institution in a developing country, such as Morocco. It was indicated that the mission of the Moroccan NRC is to promote nuclear energy, development of nuclear technology and work on the beneficial uses of radioisotopes. To this effect, the construction of a nuclear research centre based on the operation of a 2 MW-TRIGA reactor will be completed in 2001. In this presentation the important role being played by the IAEA was emphasized.

Session I: Summary of discussion

In some countries, like the USAA, Germany and South Africa, there is a diversification in their focus from nuclear science research to related fields of technology, and even the inclusion of non-nuclear programmes. In some other countries, like France and Canada, the change has been towards consolidation of activities and a stronger focus in support of nuclear power development. France is also putting emphasis on transfer of technology to industrial companies or SMEs (small and medium enterprises).

Many NRCs have emphasized the utilization of nuclear research reactors as an area of major concern. Utilization programmes include neutron physics, fuel and reactor core component development, radiochemistry, production of radioisotopes and environmental research.

It was pointed out that over the years there has been a continuous reduction in the allocation of funds for nuclear research, which has driven changes in programme priorities. Public acceptance of nuclear technology is still a major issue and international collaboration efforts should be focused to address this problem by ensuring that the benefits of nuclear technology are widely communicated and understood. In this connection, it was mentioned that the IAEA might play an important role, in addition to international co-operation among NRCs.

One of the key areas of R&D in NRCs in the 21st century will continue to be development of technologies and strategies for nuclear waste management. It was observed that there is a reduction in the trained man-power in nuclear technology which must be addressed.

It was observed that a number of existing NRCs were established many years ago and require ongoing refurbishment.

Specific comments which emerged on certain issues of importance are as follows:

Basic and Applied Research: After a prolonged discussion on the respective need for basic versus applied research in NRCs, it was concluded that the role of NRCs was primarily mission oriented research to develop science and technology satisfying socioeconomic needs rather than curiosity driven research. The balance of activities between basic or applied research in fulfilling the NRC mission would depend on the particular need and circumstances of each country.

Priorities: It was pointed out that scientific research in countries with limited resources should contribute primarily to the development of scientific understanding and skilled research staff in that country, to meet the needs of that country towards the development of a scientific and technical resource base. However, there should be activities that can contribute to solution of socioeconomic problems.

International co-operation: International co-operation could be used more effectively, particularly in generic and non-commercial areas, to increase the cost effectiveness of the research performed by NRCs and reduce the need for duplication of expensive facilities and infrastructure.

Human resources: There was general concern for the availability of staff trained in nuclear science and technology. A new vision of the future role of nuclear technology needs to be developed and communicated in order to interest young people so that they choose nuclear science and technology as a career path.

Partnership with universities and industries: It was agreed that partnership with universities, other research institutes and industries can be valuable for extension of the capabilities of NRCs in the fields of basic and applied research. Education partnerships with Universities and other educational institutions can also be valuable in fulfilling the training requirements of NRCs.

Public acceptance: To increase and/or maintain public investment in nuclear research centres, it was necessary to increase the awareness of the benefits of nuclear science and technology to society in general and to the host country in particular. Perceived misconceptions continue to dominate in the minds of the public. It is in the interest of each NRC that there should be a concerted effort to inform the educated and common man about the beneficial aspects of nuclear science and Technology to provide some balance to the negative aspects of atomic energy which are exaggerated in the media. Here again, IAEA can have a major role in achieving this change.

Role of the IAEA: Most of the members pointed out that the IAEA could play a catalytic role in assessing the existing expertise on nuclear technology, facilitating maintenance and transfer of know-how among the developed and developing Member States, particularly in specific issues like waste management and the vast beneficial applications of radioisotopes in industry, health care, etc. It was felt that such efforts have better credibility if an international body like IAEA takes the lead.

Session II: Challenges faced by NRCs

(Co-chairman: I.D. Abdelrazek (Egypt). Keynote speaker: Y. Sato (Japan). Rapporteur: B. Dodd (IAEA**)**

In his address Abdelrazek reviewed the history, background and capabilities of the two NRCs of AEA, Egypt. The centres employ 2000 people who carry out research in engineering, physics, chemistry and life sciences. Applications of radioisotopes and radiation is the major focus of their mandate. Development of technology for heavy water production is being pursued. He identified the biggest challenge as that of funding for NRCs. Four probable roles for NRCs were presented in detail. These were: act as consultants, help introduce new technologies, develop human resources, and upgrade local industry.

Y. Sato (Japan) reviewed the history, background and capabilities of the several Japanese NRCs and focused his presentation on the topic of the Session by taking Japan Atomic Energy Research Institute (JAERI) as a typical example of Japanese NRCs. He mentioned that JAERI promoted wide range of R&D from basic research to engineering research and also from photon physics to nuclear technology. These include nuclear safety research, high temperature gas cooled reactors, light water reactors, fusion reactors and advanced energy system in engineering field. In the basic research field, advanced science research in neutron science, science of the photon and synchrotron radiation research, and high grade calculation science have been started to diversify the R&D activities of JAERI. About 34% of Japan's budget of US$ 3.3 billion for nuclear R&D goes to JAERI, which employs 2347 people. Points discussed under the new situations surrounding JAERI included: Government reorganization of the nuclear activities, preservation of expertise and diversification of research, new relationship with industry and universities, and international collaboration. The incident at Tokai-mura and its influence on the nuclear industry were also briefly mentioned. It was stated that the two main categories of current and future activities of JAERI would be nuclear energy research and advanced science research.

S. Paiano Sobrinho (Brazil), in his presentation, discussed the history and the current situation regarding a medium-sized (about 500 employees) NRC in Brazil (CDTN). He mentioned that the focus of CDTN is on nuclear and related technologies. A few points from the paper were highlighted. Challenges discussed included introduction of quality management for research and development, obtaining funding and, maintaining the knowledge base as people age. The importance of involvement of the centre in projects like the IAEA sponsored DECADES, intended to supply technical, non-biased information for decision makers concerning different alternatives for electricity generation, was mentioned. It was said that IAEA projects, like 'Life Management of Reactor Components', are helping to shape the area of materials engineering at CDTN. Public acceptance was mentioned as a key factor for the future of NRCs.

F. Moons (Belgium) briefly presented his paper regarding the SKN-CEN NRC. He mentioned that 600 employees at the centre have a budget of 75 million Euro, half of which is earned by contract work. Major facilities include a high flux reactor BR2 and an under ground laboratory for studies on high level waste disposal. Traditional research projects include nuclear safety, radioactive waste disposal, radiation protection and safeguards. Novel research projects are started on special aspects of nuclear issues and on aspects of nuclear medicine, e.g. the production of ^{188}W. A brief description was given of the accelerator based spallation neutron source under design for which specific research is devoted to a window-less source design, the fast core configuration, the cooling and the selection of structural materials.

A.M.R. Nahrul Khair (Malaysia) discussed the challenges faced by NRCs based on the Malaysian experience. This was a small part of his more general paper. The 1994 strategic plan developed for MINT was used as an example of self evaluation and analysis. Key common challenges were identified as sustainability and relevance. Each of these was expanded and covered in more detail in his presentation. MINT's successful technology-to-market concept was presented in some detail.

L.C. Longoria Gandara (Mexico) in his talk covered a brief history of the Mexican Nuclear Research Institute and focused on the recent changes to the NRC's mission and activities. Areas of responsibility included radioactive waste management, isotope production, nuclear medicine, food irradiation, tissue banking and environmental analysis. Challenges to NRCs mentioned in his presentation included the fiscal realities of competition for R&D funding, as well as the supply and demand for services.

Session II: Summary of discussion

A current challenge of NRCs is to attract new talent to maintain knowledge and expertise. Another current challenge being faced by NRCs is to maintain public support and funding for their activities by convincing their stakeholders of the continued need and relevance of their activities. In this context, relevance has two main aspects: one relating to commercial/industrial interests and the other relating to societal needs.

A related theme was the organizational aspects of the management of NRCs and the need for strategic planning. Such a plan should have an appropriate balance between the potentially income-producing activities, applied research, and basic research.

For many NRCs a new strategic plan with a greater focus on mission-oriented research might mean a change in culture for its scientists. It is management's role to help staff make these changes. Another challenge being faced is general management of change.

Session III: Interaction of NRCs with their environment

(Co-chairman: J. Abriata (Argentina). Keynote speaker: I.S. Chang (Republic of Korea). Rapporteur: R.F. Kastens (IAEA**)**

J. Abriata of Argentina opened the Session with a presentation on the experience gained by the Bariloche atomic centre (CAB) during the past 40 years. He explained the focus of specific activities and interactions with society at large, with examples for the social, economic and academic sectors and linkages with the public. The CAB has experienced success in applied research and advanced technology in the nuclear and non-nuclear fields, with recognized contributions to the local economy and its welfare. Participation by local non-profit organizations and foundations, such as for science and technology, have been key outreach goals for CAB, as well as meeting technology transfer and innovation requirements of third parties. Many of these activities reflect problem oriented approaches in areas such as materials science, technical assistance to customers at nuclear power plants, computer science, mechanical engineering, forensic technology, non-destructive testing services to the oil industry, services for the medical community and legal norms for technology transfer activities within Argentina. This service based approach has brought realization by the community that the CAB is an important public investment that produces benefits ranging from waste management to even forest fire control. Both human resources and infrastructure have been strengthened through interaction with the academic sector. The academic community has also recognized benefits from its interactions with CAB, particularly in the disciplines of mathematics, physics and engineering. Periodic seminars have made important contributions to this alliance with academia. The engagement of public interest has focused on concerns about safety and the contribution of nuclear science and technology to public welfare. The media has been supportive in influencing public knowledge about the mission of CAB, particularly about the goal of protecting the environment, and the public has reacted positively by encouraging solutions to environmental problems.

I.S. Chang of the Republic of Korea stated that KAERI's operating environment has been shaped through interactions with its four principle stakeholders: the Government of the Republic of Korea, the nuclear industry, academia and the public. KAERI enjoys strong support from the Government by virtue of its management structure, mid and long term nuclear R&D programmes and its support services for establishing and implementing nuclear policies. An R&D Fund established by the Government, based on the contribution from nuclear electricity generation , is a good source of financing for the Institute. In addition, KAERI pursues a policy of full engagement with the nuclear industry by utilizing its resources to support commercialization objectives including: technical self-reliance, joint R&D services and technology transfer activities to industry. These opportunities stem from pursuing a well integrated and financed nuclear power programme extending beyond 2015. Interaction with academia strengthens human resources and institutional capabilities. KAERI undertakes joint R&D projects as well as staff exchange and education programmes with Korean Universities. Interaction with the public has been shaped by the failure in 1990 to realize selection of the nuclear waste disposal site. Its public awareness strategy emphasizes openness to the public, a low-profile approach and active engagement based upon the philosophy of "go and meet" the public. Chang concluded with the observations that is was vital for NRCs to interact and adapt to their environment with particular attention to public awareness. NRCs in developing countries are in a good position to promote their nuclear industry and forge close relationships with industry and academia to maintain their competitiveness and financial stability.

B. Majborn (Denmark) explained the interactions of Risø National Laboratory (RNL) in four key areas of its operating environment: Research, education, industry and governmental authorities. Research plays a key role in shaping Risø's environment and its participation in national and international programmes and co-operation agreements with universities and other research institutes are particularly important. Some recent initiatives include the Joint Centre for Polymer Research, and joint programmes for materials research and biomedical optics with the Technical University of Denmark. Risø staff also provide technical resources for universities, for example for courses in reactor physics and plasma physics. Joint appointments of research professors are another way Risø has strengthened its interaction with academia. Advisory liaison committees with industry is another key mechanism for interaction focused on industry. Collaborative research projects and joint venture activities are also pursued. Risø has a four year management performance contract with the Government. Risø's services include surveillance of environmental radioactivity, storage of waste, preparedness planning, nuclear safety and radiation protection. Collaboration between Risø and other NRCs has emerged as an important initiative, particularly within the European Commission research programmes.

H. Afarideh of the Islamic Republic of Iran presented a comprehensive programme of research activities founded upon six special function centres. These include the gamma irradiation centre, laser research centre, Yazd radiation processing centre, nuclear fusion research centre and, nuclear research centre for agriculture and medicine. Most of these centres focus on the production of goods or services to meet the domestic market. Currently over 65 medical centres in Iran receive products from these centres reaching 5000 patients every day. It is through these products and services that public awareness of the importance of nuclear science and technology is strengthened. This service orientation has resulted in timely delivery of products such as radiopharmaceuticals and a high level of end user satisfaction. Interaction with the international community is particularly important on matters of licenses and QA/QC. AEOI places great emphasis on north-south co-operation and looks to the IAEA to play an active role and facilitate such co-operation. Interaction with academia forms the basis for developing human resources and institutional capacity. AEOI looks to IAEA for continued support in strengthening its research capabilities.
F. Pazdera of the Czech Republic outlined the experiences and challenges of the Nuclear Research Institute Rez which was restructured in the mid-80s and now focuses on a specific mission oriented support function, services and products for industry and the public. NRI's most important interactions are with the Czech University system which is the source of young specialists and the basis for many joint research activities. The Scientific Council of the NRI is a key mechanism for achieving its research goals. Public relations is a fundamental activity for shaping NRI's environment. NRI organizes "open door day" and direct contact with mass-media. Future collaboration focused on WWER reactor operation and technology transfer to developing countries is viewed as particularly important, as is increased state financial support.

K.M. Akhtar of Pakistan explained that collaboration was a key mechanism for interaction with PINSTECH's environment. A policy of sharing facilities, experience and expertise has been pursued with active arrangements with PAEC establishments, national R&D organizations, universities, students and faculty members, and international and bilateral organizations including the IAEA. No major change was expected in this strategy, but greater emphasis would be placed on a user-oriented, flexible and diversified programme of activities. Commercial activities were expected to increase non-government revenue. Akhtar concluded with a global perspective that organized NRCs into groups according to common interests and problems: developed NRCs, developing countries with active nuclear power programmes, developing countries with no immediate programme for nuclear power. NRCs often possess the highest technical expertise, advanced equipment and know-how in the country. NRCs in the 21st century must have well defined goals, balance between basic and applied R&D, commercially viable R&D, qualified staff and long term budget commitment.

C. Tuniz of Australia illustrated ANSTO's transition from a traditional NRC to a nuclear science and technology organization, meeting the requirements of its major stakeholders: government, research and academic community, industry and the public. ANSTO's business plan comprises of four major components: 1) to provide scientific and technical advice across the nuclear fuel cycle, 2) to operate large nuclear science and technology based facilities for the benefit of industry and Australian R&D community, 3) to undertake research on specific topics to advance the understanding of nuclear science and the nuclear fuel cycle, 4) to apply resulting technologies and other relevant, unique capabilities to focused R&D and other scientific activities to increase the competitiveness of Australian industry and improve the quality of life of all Australians. The changes in culture and management structure involved in the transition were also discussed. ANSTO's strategy incorporates a project-based, outcome-driven approach, based on a matrix structure to manage resources and interdisciplinary R&D projects. Tuniz presented also ANSTO's strategy for developing public acceptance.

Session III: Summary of discussion

A common understanding of the operating environment emerged reflecting the importance of interaction with four key stakeholders: governments, industry, academia and the public.

Several examples of successful interaction were founded upon *continuous* contact with stakeholders.

In addition to a national awareness of the benefits provided by nuclear technology, it is fundamentally important for the local community to understand the socio-economic benefits of NRCs. Many of the successful interactions with the public are also associated with the practice of openness. Transparency promotes understanding and public acceptance.

Demonstration of relevance is a critical management objective for NRCs.

Specific comments which emerged on certain issues of importance are as follows:

Opponents: Opposition by the public to nuclear science and technology is often *not* based upon merit, but further interaction does not always create understanding. The back-end of the fuel cycle is both an example of the problem and a subject for new dialogue strategies.

Collective action: It is a collective responsibility to explain nuclear technology and energy to our constituents.

Benefits: Understanding the benefits of nuclear science and technology is a key message for the public, which, as a matter of human nature, is constantly determining the cost-benefits of everyday activities.

Accuracy: Accuracy and good practices are an important means of influencing public opinion. NRCs should be known by journalists for providing correct information on nuclear matters, so that key journalists ask NRCs when they need information.

Multipliers: Public demonstration, particularly activities related to safety, is an important objective for reaching the multipliers of public awareness: journalists, educators, public interest organizations. It was suggested that the IAEA and NRCs target these multipliers in their information and outreach campaigns.

Outreach: The IAEA has undertaken activities to improve public outreach and awareness through PA Seminars. Last year 4 seminars were presented and members of the panel were invited to propose such events in their own countries.

Public interaction: Proactive interaction with the local, regional, and national public is a necessary function of NRCs to promote public support of NRC activities and nuclear technology in general through an awareness of the benefits locally and globally of nuclear technology.

IAEA: One role of the IAEA can be to assist NRCs in developing a strategy and mission, consistent with their environment. Another possible IAEA role is related to global environment, health, safety etc. The IAEA could also facilitate interaction between NRCs and other nuclear-related international organizations.

Session IV: Collaboration and co-operation between NRCs

(Co-chairman: A. Kakodkar (India). Keynote speakers: G. Nefedov and A. Zrodnikov (Russian Federation). Rapporteur: G.V. Iyengar (IAEA).

The co-chairman, A. Kakodkar, set the tone with his presentation on nuclear research centres: a) their evolution in the Indian context, and b) collaboration opportunities. He mentioned that there are six main nuclear research centres out of which two, namely: Bhabha Atomic Research Centre (BARC) and Indira Gandhi Centre for Atomic Research (IGCAR), carry out technology development for nuclear applications in power and non-power areas. He mentioned that the programme profile of NRCs is determined by the state of industrial infrastructure and the nuclear programme of the country. He drew the attention of the participants to the fact that, in the early years of the development of nuclear energy, the NRCs in almost all the countries were built around research reactors. BARC has been the mother institution and spawned the birth of many industrial and research facilities by farming out technologies which had matured or specific research areas which needed enhanced focus. He mentioned that in developing countries NRCs have to carry out research, development, demonstration and deployment of technology. Projecting the need for long term focus, he enumerated the role of NRCs in nurturing the knowledge pool and applied research and technology development. He referred to the mind-set that not much research is necessary in nuclear technology, pointing out that many areas of new thrusts are developing and require new research efforts. In the area of nuclear power, he cited development of advanced reactor concepts, new fuel cycle technologies and spallation based systems as disciplines requiring large effort. There was also a constant need for R&D input for non-power applications in industry, food, health, and environment. He highlighted the role of research centres as providers of basic links between researchers, and stressed the need for collaborations between institutions. He singled out sharing of costs, resources and complementary strengths, among others, as the driving forces for international co-operation between the NRCs. He concluded by emphasizing the need for establishing Joint Resources Centres, paving the way for sustainable technical co-operation among developing countries, and that the IAEA had a very significant role in creating mechanisms to accomplish this goal.

The key note speech was shared by G. Nefedov and A. Zrodnikov from the Russian Federation. Nefedov addressed the issue of nuclear research centres co-operation and IAEA's role. He first outlined the transformations taking place in developed countries regarding the development of nuclear power production . In some countries there are attempts to completely phase out nuclear power due to several reasons: low cost of organic fuel, accelerated shift to use gas for the electric power production, reduction of electric power consumption demand and on-going privatization process in the energy sector of the industrially developed countries. However, he asserted that in spite of predictable reduction of NPP share in the world electric power production, absolute NPP capacity will rise by the year 2010, and will be 400 GW as against 345 GW now. In context of the efforts needed to achieve the reduction of CO_2 discharge to the recommended level, he stated that it would be very difficult to accomplish it without resorting to nuclear power. He also referred to the shrinking size of the numerous NRCs in the Russian Federation, and pointed to the need for sharing the effort between the nuclear centres through close co-operation. The IAEA's role in this process was recognized. The IAEA, being one of the most competent international organizations in the field of nuclear energy, should take the role of initiator and co-ordinator of such co-operation among the 130 Member States. He also suggested that the IAEA should consider the issue of periodic meetings of the NRC managers to resolve problems that may come up in developing the mechanism for interactions.

Zrodnikov extended the lecture to include Goals and Fields of Co-operation. He first outlined the activities of the Institute of Physics and Power Engineering (IPPE). Listing the 10 greatest projects of IPPE, he mentioned that the world's first NPP was credited to IPPE. Under international missions for NRCs he set the following priorities: sustainable economic development, global ecology, health care and food, and education. Enumerating the new challenges that lie ahead for the 21st century, he listed the following: creation of advanced small and medium reactor systems for use in developing countries (technology focus); involvement of international community through early engagement and co-operation (policy focus) and, achieving non-proliferation objectives while providing needed energy source to developing countries. For future co-operation areas he singled out: nuclear power engineering, ex-weapon materials management, radioactive waste management, radiation technologies for industry and nuclear medicine and radiopharmacy, and education through staff training, among others. He welcomed the IAEA to initiate collaboration and co-operation between NRCs, and formation of a senior advisory committee under the supervision of the DG.

S. Bhattacharyya (USA) began by stating that, in considering the most fruitful topics for international collaboration, preference should be given to areas that are currently the major stumbling blocks for the nuclear power option. The considerable intellectual and physical capital of the NRC's could then be focused on problems that need resolution for the nuclear power option to progress. This would also be a proactive way for the NRCs to help their own cause, because there was considerable sentiment supporting the premise that the future of many of the NRCs were coupled to the exercise of the nuclear power option in the future. Bhattacharyya next reiterated that the main reasons for collaboration are: a) Nuclear issues are large and require major commitment of fiscal and human resources to tackle. Sharing of resources and risk is beneficial. b) The erosion of the nuclear infrastructure in many NRCs dictates the need for utilization of international facilities, wherever available. c) The complementary capabilities of the various NRCs can be exploited effectively. There is also an advantage to bringing in varying viewpoints in the approach to large problems. The areas that he proposed as suitable for international collaboration are:

- Basic nuclear data and methods — This includes measurements and evaluation of data and cross comparison of analytical methods.

- Waste disposal (waste burning and repository issues and technologies) Example of work in this area are joint development of ATW technologies and in basic data needed for repositories.

- Reactor systems D&D — This is a very large field and is likely to cost hundreds of billions of dollars over five decades. The key issues are safety and cost effectiveness. Collaboration on technology development/deployment and operational procedures would be useful. Research reactor D&D could be of particular interest here.

- Development of next generation nuclear power system concepts that incorporate the features of competitive economics, non-proliferation, passive safety, waste minimization and the lessons learned from this generation of reactors.

- Nuclear applications (including fusion technologies, space nuclear power and propulsion, isotope production, radiopharmaceuticals, sterilization, etc.). These items address some near term needs or can be a means to attract new entrants to the field.

Bhattacharyya concluded by stating that international collaboration in many of these areas is currently ongoing. There are various mechanisms for enabling and expanding such interactions, and the IAEA could play a significant role in this regard.

N.M. Lynn (UK) presented "Some Thoughts from the UK". After a brief introduction, noting the move of his Centre, the Department of Nuclear Science & Technology, from its original site in Greenwich, London, to HMS SULTAN in Gosport, and the closure of their research and training reactor JASON, he reviewed the status of NRCs, related institutions and the diminishing pool of research reactors. His remarks covered the stagnant nuclear power industry, ageing staff and the facilities, the ever-shrinking pool of qualified personnel and shortfall in the new entrants to the field of nuclear energy. On a positive note, the efforts on the educational front by the university sector, for example, the Universities of Birmingham, London and Surrey, to attract more students to the nuclear power and research sector were presented. These included work on nuclear code development, analysis of reactor experiments, decommissioning and safeguards, among others. On the commercial front, a centre for excellence in radiochemistry has been established, British Nuclear Fuels Ltd at Manchester University, together with Westlakes, an environmental study centre in the Lake District. NAILS, the Nuclear Academic Industry Liaison Society, has been established to promote university and commercial collaboration. He concluded his talk with a series of questions NRCs will have to address, for planning their development into the next century.

S. Soentono (Indonesia) presented "The Challenges Faced by Nuclear Research Centres in Indonesia". Soentono noted that Indonesia needs to co-operate with other countries to support its nuclear research and development programme in various fields due to the fact that Indonesia has to overcome the chronic challenges caused by the monetary turmoil. Hence the NRCs in Indonesia are facing new realities leading to programme reorientation. Added to the economic crisis, issues due to misperception, misleading information and unbalanced understanding have further aggravated the problems faced by the NRCs. Co-operation is being sought for disseminating nuclear related technical information especially on the benefits derived by the use of nuclear methods in food safety and human health areas. The assistance by the IAEA in these matters is recognized to be of great value to NRCs in Indonesia.

P. Yamkate (Thailand) presented a brief account about Thailand's nuclear research centre. The first Thai Research Reactor (TRR-1) was built in 1962 for the Office of Atomic Energy for Peace (OAEP), and was later upgraded in 1975. This facility is providing a number of services to academicians, researchers, medical doctors and industry, based on nuclear-based analytical techniques such as neutron activation analysis, tracer techniques and industrial radiography. A second research reactor of 10 MW capacity is being planned to enhance these applications. The staff strength is 500 and the budget is US$ 45 million. Presently, the OAEP manages a modest scale operation. The vision for the future is established but not implemented in full scale. OAEP recognizes the role of IAEA in providing assistance for various R&D programmes in many sectors via Technical Co-operation Programmes and Regional Co-operation Agreement (RCA).

T. Dolan (NAPC/IAEA) presented an account of a proposed research and development (R&D) co-operation programme, which was proposed by scientists from developing countries (not by their governments). The scientists suggested that the current technical co-operation project mechanisms and Co-ordinated Research Projects (CRPs) are insufficient to meet all the needs of developing Member States for R&D co-operation. CRPs are expensive, can only accommodate a few topics, and require 2–3 years to initiate. A new mechanism with a low cost to the IAEA would have the best chance for acceptance and implementation. A proposal from Argentina, refined by an Advisory Group Meeting and a Consultant Meeting, was described. In essence, a group of scientists in various countries would write a proposal and submit it via their governments to the IAEA. The IAEA would act as a facilitator, organise peer review of proposals, provide an example contract for the multilateral collaboration, help set priorities to achieve required objectives, monitor progress, and distribute the technical reports to interested laboratories world wide. If need be, the IAEA could also act as the manager of funds in some cases, but the resources have to come from the participating countries. Thus, the IAEA would facilitate collaborations that might otherwise be difficult to organise, and its participation would assure governments that the research is worthwhile and is being well monitored. This concept promotes strong international co-operation, multidisciplinary team work, and cost-sharing, and IAEA role would be essential for its success.

T. Tisue (TCPC/IAEA) dealt with some general concepts adopted by the IAEA in presenting nuclear technological applications to the world at large. He stressed that in planning nuclear applications the end-user should be included from the outset, and aspects of patenting, licensing, if any, should be dealt with systematically. He drew attention to criteria to be adopted in formulating project design, suggesting strong linkages to solving high priority problem in national programmes. He gave a brief description of the planning tools available at the IAEA referring to the concept of country programme framework. He concluded, referring to reactor utilization projects, by stating that evidence based priority setting is critical to successful planning.

M.R.F. Raynal (NEFW/IAEA) discussed the issue of collaborative projects for nuclear research centres and IAEA on demonstration of long lived and high level radio active waste disposal technologies in underground research laboratories. The objective of this presentation was to outline the scope, and work plan of international co-operation under the IAEA auspices, and the discussion began with a list of underground research facilities for radioactive waste disposal around the world. The IAEA programmes on both low level and high level radioactive waste disposal studies for the year 1999–2000 were illustrated. These included those dedicated to methodological developments in the past, and new ones aimed at validating the earlier concepts that were now mature. Reference was also made to TC projects, namely the AFRA "bore-hole disposal concept" and the assistance in deep disposal siting projects in Argentina and China. Initiatives for new collaborative projects were mooted. The objective of proposing to develop collaborative projects was to follow the recommendations made by the SEG, PPAS and the WATAC and to respond to the interest expressed by the Member States. The IAEA programmes to implement various collaborative plans, foreseen for the year 2000, were briefly discussed stressing the need for close collaborations between NRCs.

P. Menut (NEFW/IAEA) highlighted the connections between the IAEA and NRCs in the area of nuclear fuel cycle and waste technology. Following a brief introduction to the current state in nuclear fuel cycle and materials section highlighted by a number of IAEA CRPs, the emphasis was placed on the following issues: evaluation of the safety, environmental and non-proliferation aspects of partitioning and transmutation of actinides and fission products; aging of materials in spent fuel storage facilities; modeling of transport of radioactive substances in primary circuit for water cooled reactors, among a number of other issues. Activities going on under the proposal on partitioning and transmutation of radionuclides in USA, France, Japan and the Russian Federation were described. He stated that the IAEA may have a role in promoting co-operation between the national projects on the subject of transmutation through programmes on the development of the new reactors or accelerators that could be used in this field. Further, a number of areas was identified where the IAEA can strengthen its connections with the NRCs.

P.E. Juhn (NENP/IAEA) presented the scope for NRC co-operation in the area of reactor development. Following a brief introduction about the worldwide prospects for nuclear power, the current IAEA activities and future directions in the field of nuclear power planning, implementation and performance, and reactor technology development were mentioned. The emphasis was placed on the following activities: (1) nuclear desalination of seawater and small and medium size reactor development, (2) hybrid system for transmutation of long lived radioisotopes, and (3) technology development for proliferation resistance innovative reactors and fuel cycles. He also informed about on-going CRPs Development of a Strategic Plan for an International R&D Project on Innovative of IAEA on items (1) and (2) above, and the result of Advisory Group Meeting on Nuclear Fuel Cycles and Power Plants, which was held in October 1999 with participation of 13 Member States. For pooling resources and sharing of benefits, international co-operation between IAEA and the NRCs was suggested in particular in the area of thorium utilization, accelerator driven systems, innovative liquid metal (such as lead) cooled reactor development and actinide transmutation. Development and utilization of small and medium size reactors, which produce electricity as well as heat for seawater desalination, were emphasized particularly for use in developing countries.

In brief presentations Fouche made reference to the pebble bed modular reactor being developed by South Africa in collaboration with a number of countries. The South African Government sought IAEA help in the techno-economic and safety evaluation of this project. Abriata presented an account of the R&D efforts on nuclear materials in Argentina, and referred to a special issue of a publication in this context. He stated that collaboration between NRCs would be very fruitful. Chang presented an optimistic scenario in which the need for new research reactors will grow in the future. In the meanwhile, he made a plea to maximize the use of existing research reactors. In this context he stressed the need for an international collaboration mechanism in terms of joint utilization of research reactors, sharing of related technologies and training of related manpower. He suggested that after consultation with the MS, the IAEA should consider launching international projects in some areas such as production of radioisotopes, material irradiation testing, etc. He drew the attention to the concept of International Nuclear University (INU) as presented by him to the IAEA General Conference. He emphasized that KAERI, along with the IAEA, would be willing to take a leading role of elaborating and realizing the concept of the new mechanism including the inception of INU. Dodd (NAPC/IAEA) touched upon international collaboration between nuclear research centres and the role of research reactors. He outlined the current IAEA activities through: IAEA-wide strategic plan for research reactors; strategic utilization plans for each research reactor facility; increased research reactor database availability and usefulness; availability of regional and world research reactor list servers, among other issues. He stressed that international collaboration can be still further enhanced under the auspices of the IAEA.

Session IV: Summary of discussion

There was a broad agreement voiced by all the speakers, and the rest of the participants, that interactions between the NRCs are beneficial.

The benefit of collaborative efforts between NRCs was stressed in the interest of bringing together multidisciplinary expertise and teamwork, stopping the erosion taking place in the pool of experts in several sectors of nuclear technology, and taking advantage of the complementary skills.

Collaboration on technology development for safe, economic, proliferation-resistant advanced or innovative reactor systems and fuel cycles was advocated. Collaboration on deployment of small and medium size reactors, particularly for use in developing countries, was also advocated.

Specific comments which emerged on certain issues are as follows:

Finding solutions: NRCs are finding solutions for numerous issues, including non-power issues. NRCs have a special responsibility in attracting new people by offering innovative opportunities. Collaborations between NRCs, and use of the IAEA's CRP mechanism, are useful but do not meet all the needs for collaboration. Development costs could be reduced by cost-sharing via collaborations. Demonstration of radioactive waste disposal was suggested as an excellent opportunity for international collaboration led by the IAEA.

Funding constraints: Many governments and stakeholders are reluctant to support programmes, for which short term benefits cannot be demonstrated or shown to exist. While short term work cannot be ignored, governments and NRCs should also concern themselves with long term objectives.

Collaborations: Nuclear technology has benefited from its very early days by collaboration, but there is a decreasing tendency in the number of collaborations between NRCs. It was agreed that NRCs benefit from co-operation with each other, but the existing mechanisms should be expanded and new mechanisms should be explored.

Topics for collaborations: There were frequent references to food, health, water, environment, education, and energy production in this context. These were considered to be useful headings for categorizing potential topics for collaboration. In this context it was recognized that national missions of NRCs will vary from country to country, calling for a variety of projects relevant to the needs of each country. During the meeting several suggestions were presented, (listed along with the recommendations) but it was recognized that this topic needs further groundwork.

Shared objectives of NRCs: NRCs have an obligation to maintain knowledge and expertise in nuclear science and technology. Some NRCs have an obligation to prepare/educate researchers for the future. All NRCs have an obligation to communicate the benefits of nuclear science and technology. These are important areas for international collaboration.

RECOMMENDATIONS

The meeting came up with a number of recommendations, for the consideration of the authorities in the NRC, national Governments and the International Atomic Energy Agency, which may address various issues. These are:

1. To remain relevant in the 21st century, NRCs must continue to respond to the needs and priorities of their environment, which includes Government, Industry, Universities/research institutes, and the public (including professional societies).

- Government priorities include strategic R&D to address national societal needs, such as energy, water, health, environment, food supply, education, and materials.
- Industry priorities are usually represented by short term needs. Partnerships with industry in joint R&D projects are a useful and necessary mechanism to respond to industry needs. In most cases NRCs should complement rather than compete with commercial companies that are already in similar development activities.
- Partnerships and collaboration with universities/research institutes can provide an extension to the basic research capabilities of both NRCs and universities/research institutes. It is also a method to influence and promote the development of new scientific talent in nuclear technology, and an effective extension of the NRC role in developing an infrastructure of trained nuclear specialists.
- Proactive interaction with public at local, regional, and national levels is a necessary function of NRCs to promote public support for their activities and nuclear technology in general through the awareness of the benefits, locally and globally, of nuclear technology.

2. NRCs should play an important role in mission-oriented research relevant to the needs of their countries. NRCs are uniquely placed to perform research in nuclear science and technology, and so this should be an important part of their activities.

3. A priority of the NRC R&D should be the development of scientific understanding and of skilled scientific and technical staff in the area of nuclear technologies.

4. Collaborations with other national and international research centres are a useful and necessary extension of NRC capabilities. National and international collaboration should be used by NRCs to increase cost-effectiveness and impact, reduce the need for duplication of expensive facilities and infrastructure. (Suggestions on topics for collaboration given in Annex I).

5. One role of the IAEA could be to assist NRCs in developing a strategy and mission consistent with their environment. Use of the IAEA's Country Planning Framework can be quite helpful in the strategic planning and clarifying the roles for NRCs in some countries, as requested. The strategic plan of NRCs should address the challenges faced by them.

6. The IAEA should take the lead and play an active role in collecting, collating and providing information on the global and regional benefits of nuclear technology to assist NRCs in communicating such information to their public stakeholders.

7. The IAEA can play a valuable role in facilitating interaction between NRCs on joint projects of mutual interest and benefit in the area of nuclear technology development and application. Some topics suggested during the meeting are listed after the recommendations. These would require further elaboration

8. A new role for the IAEA could be to co-ordinate demonstration projects of global significance in key areas of nuclear technology. Some proposals regarding the same are given in the final part of the report.

9. The IAEA could facilitate interaction between NRCs and other nuclear related international organizations. Another possible IAEA role could be to assist NRCs in contributing to other international agencies' activities related to global environment, health, safety etc.

10. The IAEA should convene a subsequent meeting within 6 to 9 months to discuss in more detail means and topics for collaboration.

11. It was considered that this meeting was a useful forum to share issues and ideas and it is therefore recommended that the IAEA convene future meetings of this type every 3–4 years.

Annex I

Suggestions of topics for collaboration among NRCs

1. Innovative reactors with features like: economic competitiveness, passive safety, proliferation resistance, and waste minimization.
2. Technologies for waste management and disposal including repository issues.
3. Joint demonstration facilities for waste management under the auspices of IAEA.
4. Transmutation of long lived actinides and fission products.
5. Ex-weapon material management.
6. Decommissioning and dismantling of nuclear reactors and fuel cycle facilities.
7. International nuclear university.
8. Joint resource centres.
9. Setting up of large facilities like spallation neutron sources.
10. Materials science and nuclear materials.
11. New mechanisms for research and development co-operation programme.
12. Information dissemination regarding nuclear issues to public
13. Information exchange among NRCs.
14. Radiation technologies for industries.
15. Radiation/radioisotope based medical diagnostics and therapy
16. Agro-ecology
17. Study of global climate change using isotope techniques.
18. Opening up of large nuclear facilities for R&D by other Member States

The nuclear research centre at Bariloche, Argentina

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Abstract. The nuclear research centre at Bariloche (CAB) is one of the four centres under the Atomic Energy Commission of Argentina (CNEA). The research programme of CAB addresses various issues like nuclear reactor development, nuclear fuel and fuel cycle, applications of radioisotopes and radiation, and waste management. There is also a basic nuclear science component. The human resource development in the areas of physics and nuclear engineering is done in an associated Balseiro Institute which has undergraduate and graduate programmes as well as doctoral and postdoctoral research. The Centre interacts well with the society and provides services in the nuclear area. It has a close interaction with the nuclear sector of Argentina as also with many international organisations. Regulatory control over the Centre is carried out by the Nuclear Regulatory Authority of Argentina.

Introduction

The Atomic Energy Commission of Argentina (CNEA) is constituted by four centres dedicated to nuclear studies. These centres are located in Bariloche (Province of Rio Negro), Constituyentes (Buenos Aires), Ezeiza (Buenos Aires), and Pilcaniyeu (Rio Negro). The four centres are similar in their structure and have complementary roles in order to fulfill the global objectives of CNEA. In what follows I will refer only to the nuclear centre located in Bariloche, namely the Bariloche atomic centre (CAB).

Early developments in Bariloche took place in 1955, mainly in the area of the formation of human resources. At present the CAB is a high complexity nuclear and non nuclear research centre, with excellent scientific and technological backing, capable of dealing with the most diverse problems faced by the CNEA. At the moment the CAB has more than 120 researchers, 60 high qualified technicians, and 80 undergraduate students. The total staff distribution of the CAB is shown in Fig. 1, which also includes administrative and service employees.

The infrastructure available at the moment at the CAB is quite diverse, and its main components and laboratories are described below.

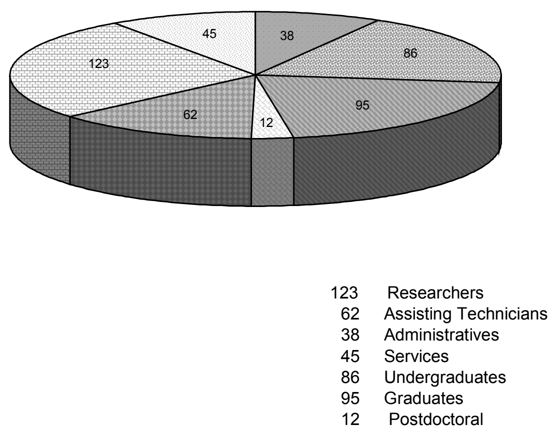

FIG. 1. Human resources at the CAB-IB.

- The RA-6 Nuclear Research Reactor, which has been designed and built in Argentina. The purpose of this reactor is to carry out teaching, training, research and development tasks in the field of nuclear engineering. It is an extremely versatile reactor, useful for very different requirements.
- The RA-6 is a 500 kW power reactor of the pool type, easy and secure to handle. The reactor itself possesses a wide array of equipment, both nuclear and conventional, a control room for training of personnel, and a nucleus of variable configuration
- A Freon Loop, which consists of a thermohydraulic circuit working at adequate pressures and temperatures in order to simulate operating conditions similar to that of nuclear reactors.
- A Linear Electron Accelerator of 25 MeV, used as a pulsed source of neutrons for study of materials, analysis by activation and irradiation studies.
- A Neutron Activation Analysis laboratory, supplemented by gamma spectrometry and appropriate outlying facilities.
- A vibration analysis laboratory totally equipped for anticipated diagnosis of failures and maintenance of rotating machinery.
- A nuclear materials laboratory, which has extensive experimental facilities for the characterisation of thermal properties of materials of nuclear interest up to very high temperatures.
- The laboratory for nuclear materials also includes facilities for thermogravimetric analysis, differential thermal analysis and dilatometry. It also has excellent facilities for the characterisation of powder materials, where particle size and specific area can be determined. Other facilities allow for the microstructural analysis of metallic alloys, ceramics and glasses, including the determination of materials phases and microhardness. It is also possible to carry out programmed thermal treatments at very high temperatures, in vacuum or in oxidant or reducing atmospheres.
- Equipment is also available for chemical analysis by means of atomic absorption, spectrophotometry and chromatography.
- A full equipped transmission and scanning electron microscopy laboratory.
- A laboratory for the study of the physical and chemical properties of materials. This laboratory is very complete and offers a variety of installations for the production of metallic and ceramic materials, as well as equipment for experiments in mechanochemistry (nanoparticles). Systems are also available for the production of controlled gaseous atmospheres, thermogravimetric analysis, automatic equipment for gaseous and cathodic hydruration as well as measurements of hydrogen absorption and desorption, dynamical spectroscopy of hydrogen desorption, and gas chromatography.
- A metallurgical laboratory, fully fitted with a complete array of basic equipment for routine metallurgical study of materials. This includes equipment for the absolute determination of hydrogen content. It has the necessary infrastructure for the production of refractory metallic alloys at a laboratory scale, and their detailed metallurgical characterization.
- A computer and software laboratory, for modeling of engineering systems and computational mechanics, which has very modern equipment, useful for carrying out complex scientific and technological computations.
- An extremely well equipped laboratory of atomic collisions and atomic physics, including electrostatic accelerators, collimated ions, and low energy accelerators. It also has an atomic force microscope, AES, XPS and LEED equipment, and sophisticated high vacuum infrastructure.
- A low temperatures laboratory, with complete equipment for research in superconducting materials, Helium 3 and Helium 4 cryostats, and calorimetric, magnetic and resistivity facilities. It also has high and low field SQUID magnetometers, cathodic erosion

machinery for the production of multinetwork thin films, and a laboratory for the production of superconducting materials.

- A laboratory for the study of the Properties of Metals, which includes a complete experimental set up for the production and characterisation of metallic samples, including thermodynamic, structural, physical and mechanical properties.
- A laboratory for magnetic resonances, fully equipped, covering wide ranges of frequencies, temperatures and magnetic fields.
- A laboratory for the study of optical properties of materials, equipped with Raman spectrometry, an optical cryostat and different types of laser systems.
- Extensive and modern calculation facilities appropriate for the areas of statistical physics, elementary particles and fields, theory of solids, and fusion and plasma physics problems are available.
- The library of CAB contains 17 200 books and 650 journals in the area of physics, chemistry, materials, and nuclear engineering. This library is considered one of the best in the country and amply satisfies the needs of CAB and CNEA.

General technical programs

One of the functions of CNEA is the development of advanced technologies in the nuclear field for peaceful applications. At the moment several high-priority, specific programs, are being developed at CNEA. These programs are listed below:

- Reactors and nuclear power plants, which include developments in the area of innovative and advanced reactors, and research reactors.
- Nuclear fuels and cycles, including the development of processes, new types of fuels and high density fuels for research reactors._
- Radioisotopes and radiations, which include the development of new products of medical use, industrial and agricultural applications, and the study of the therapy of brain tumors by boron neutron capture.
- Waste management and decommissioning, including low, medium and high activity wastes, burning of actinides, decommissioning of nuclear power plants, and soil remediation.
- Basic nuclear sciences.

Within the programs outlined above, the CAB deals with a wide range of specific problems. Among them we can mention the following research and development programs, most of which are carried out in collaboration with the other three centres of nuclear studies of CNEA.

Research and development programs at the Bariloche atomic centre

- Reactors. Design and detailed engineering of innovative and research reactors, experiments with research reactors, neutronic design criteria of reactors, development of codes for neutron transport, simulation and analysis of accidents, reliability of processes and safety in reactors, design of safety systems, analysis of critical design items, revision and validation of reactor modeling, analysis of power plant dynamics and operation supervision, analysis and design of nuclear reactor thermohydraulic systems, economic and control management
- Fuels design of high density fuels based on silicides, design of new fuels for research and power reactors, development of neutron probes, optimization of methods for obtaining uranium mixed oxides, vibrational analysis and remote monitoring of fuels, zircaloy

hydruration, kinetics of hydruration, hydrogen influence on the mechanical properties of zirconium based alloys.

- Radioisotopes and radiations. Brain: tumor therapy by boron neutron capture, implementation and starting up of the gamma detection system in the RA-6 reactor, beam and dosimetry optimization, experiments with phantoms, operation and procedure protocols, modeling and codes for patient treatment planning. Activation analysis for elements traces. Design and modeling of radioactive material containers. Radiation sensors by means of paramagnetic resonance spectrometry.
- Wastes. storage and immobilization of radioactive wastes in glasses, irradiation effects on glasses, isotopic composition and waste criticality, burning of actinides.
- Basic nuclear sciences. Basic research in physics, in the areas of solid state, low temperatures, magnetic resonance, atomic collisions, surfaces, metals and alloys, elementary particles and fields, and nuclear data.
- Basic research in physical chemistry, in the areas of thermochemistry, interaction of gases with metals, hydruration of metals, properties of metallic oxides, and properties of interfaces.
- Research and computational modeling in fluid dynamics, computational mechanics, mathematical aspects of computational modeling and simulation, computational modeling of thermochemical properties.

The matrix relation between the CAB infrastructure and its research and development programmmes is schematized in Figure 2

Other technical activities at the Bariloche atomic centre

Based its specific activities within CNEA, the CAB actively interacts with society in general. Among the types of activities developed in this sense, we can mention the following:

- Technology transfer and technological innovation tasks in nuclear and non nuclear fields, as required by third parties.
- The human resources and infrastructure of the CAB help to resolve the most diverse technological problems faced by other public entities or private companies.
- Some of the tasks performed correspond to the solution of a number of problems in the area of materials science, development of pilot power plants, technical assistance to nuclear power stations, computer science services, forensic technology, consultancy and technological planning, specific technical training, metrology, services to the oil industry, services in the area of medical supplies and instruments, and contributions to the study and improvement of legal norms for technological transfer activities within the country .
- Contribution to the formation of human resources in other regions of the country in the areas of physics and engineering, mainly by teaching advanced courses.
- Training at the CAB of human resources that do not belong to CNEA, in areas of nuclear interest.
- Courses given at the CAB for improvement of the teaching of mathematics, physics and engineering, aimed at high school teachers across the country, which include training in the experimental area.
- Periodic seminars on education in physics and engineering for the general public.
- Organization and management of scientific and technological meetings of all type in the Bariloche area.
- Assistance to the community of Bariloche in questions of safety and environment, mainly in what refers to the handling of toxic wastes, forest fires and other public emergencies .

		R&D Programmes at CAB-IB			
		REACTORS	FUELS	R & R	WASTES
I	RA-6	X		X	
N	FREON LOOP	X	X		
F R	LINAC	X	X		
A	NAAL			X	X
	AEROSOL. CHARACT.			X	X
S T	VIBRATION	X			
R U	NUCLEAR MATLS.		X		X
C T	ELECTRON MICRO-SCOPY		X		X
U R	PHYSICAL CHEMISTRY OF MATLS.		X		X
E	METALLU-RGICAL LAB.	X	X		
	COMPUTA-IONAL MECHAN-ICS	X	X		X

BASIC NUCLEAR SCIENCES: ATOMIC COLLISIONS, LOW TEMPERATURE, METALS, MAGNETIC RESONANCE, OPTICAL PROPERTIES LAB., THEORETICAL PHYSICS.

Fig. 2. Matrix relation between CAB infrastructure and R&D programmes.

In summary, the interaction of the CAB and CNEA with society in general is very intense and covers very diverse aspects.

The scientific and technological know-how of the Bariloche atomic centre and CNEA, and their readiness to collaborate, are widely acknowledged by society in general, and has fostered strong links with the community. Moreover, the nature of the activities at CAB has had over the years a positive influence on the public opinion, encouraging young people to look for new and promising possibilities in their professional development.

Challenges for the future

The CAB is faced with important and immediate challenges. Among them we have:

- To continuously establish new goals and orientations in their lines of work to satisfy the requirements of CNEA, bearing in mind that change is the only constant.
- To maintain and increase the potential for response to the demands of the CNEA in its traditional areas, especially in what refers to its high-priority programs.
- To find means for the preservation of the know-how and the scientific and technological infrastructure developed over the years.
- To be appropriately qualified to satisfy non nuclear technological demands.
- To generate the necessary connections with other nuclear centres, national and foreign institutions, and with other government organizations and private companies, in order to work co-ordinately on the type of scientific and technological problems which, because of their nature and magnitude, require such co-operation.
- To maintain an appropriate balance and connection between scientific and technological research, and between technological and economical development, aimed at the efficient and cost-effective resolution of interdisciplinary problems in nuclear and non nuclear fields.
- To identify future lines of work with the highest probability of being future high-priority needs of the CNEA.
- To promote the incorporation of young professionals to maintain the optimal average age among the personnel, and therefore the associated push and creativity towards the specific objectives of CNEA and CAB.
- To contribute to improve state policies in the area of nuclear technology to satisfy the needs of society.
- To optimize the use of the available public funds, generating the necessary actions that will guarantee the adequate completion of the tasks assumed. To consider their eventual re-structuring in order to keep adapted without loss of efficiency to possible adjustments in the resources assigned by the country.
- To improve co-operation with other foreign organizations with similar objectives.
- To maintain the recognition and international and regional leadership gained in the fields of science and technology, in particular in nuclear matters, in order to advise, participate and contribute to meet the international and regional challenges presented to CNEA.
- To promote in the media and other spheres of public influence the knowledge of the CAB and CNEA and their role as parts of society. This includes explaining their mission of contributing to guarantee in the near future the supply, as well as the completely secure handling, of nucleoelectric power and related technologies.
- The importance of the above goal has strongly to do with the protection of the environment at world level, in which CNEA and CAB are strongly involved. This is a problem that goes beyond the limits of our country and accounts for the need of urgent international co-operation.

National and international co-operation

At the international level, the CAB collaborates and participates in a variety of projects and events, both in nuclear and non nuclear fields. The character of this international co-operation is, on the one hand, to offer and contribute to the formation of human resources, and, on the other hand, to collaborate on equal footing with developed countries in R&D. This international co-operation is carried out in many cases with the participation of IAEA. For example, through this IAEA, five international scholarship holders were trained in Chemistry, Materials Science, Research Reactors and Neutron Physics during 1995–1999.

During 1997–1999, thanks to scholarships offered by CNEA, five postgraduate Latin American students specialized in Nuclear Energy and its Technological Applications, while during 1998–1999 six undergraduate students of the same origin were received at the CAB. Concerning international projects, there has recently been participation in the International Working Group on Fuel Cycle Options, as well as in co-ordinated research programs related with Fusion and Heavy Water Reactors.

Excellent bilateral cooperative relations exist with Germany, the USA (DOE.), Norway and Romania, focused mainly on nuclear-related areas.

The CAB regularly carries out and participates in the organization of international events in science and technology related with nuclear and non nuclear problems, which have always been of great success.

At the national level, there is an important nuclear sector external to CNEA consisting of state and/or private companies involved in the nuclear industry. The CAB interacts strongly with these companies, providing technological backing under the form of technical consultancies and services. Briefly, the following companies belong to the Argentinean Nuclear Sector:

- NASA, which manages the two Argentinean nuclear power stations in operation and a third power station under construction,
- CONUAR SA, a nuclear fuels manufacturer,
- INVAP SE, a company of applied research and advanced technology in the nuclear and
- ENSI SE, a heavy water production
- FAE SA, a company for the production of special alloys, mainly zircaloy,
- DIOXITEK, which runs a production plant for uranium dioxide of nuclear quality,
- FUESMEN, specialized in nuclear medicine,
- NM SE, specialized in engineering services in connection with ionizing radiations and exploitation projects of uranium minerals.

Finally, the Nuclear Regulatory Authority (ARN) should be mentioned. This is an independent national organization with which the CNEA and CAB strongly interact concerning the control, regulation and inspection of its entire nuclear installations and activities. In this way the CAB makes sure, and also gives assurance to the community, of the detailed compliance to all the conditions of safety, care and protection of persons and the environment demanded by society and national law .

Appendix

RECENT PUBLICATIONS BY THE BARILOCHE ATOMIC CENTRE

For the benefit of the reader, and as a specific description of some of the activities performed at the Bariloche atomic centre, below is given a set of recent publications. These publications should provide an overall picture of the current fields of interest at the Centre. For each cited publication, the author signaled in bold may be addressed for additional information. All the signaled authors have the following address: *Centro Atómico Bariloche, 8400 Bariloche, Rio Negro, Argentina; Phone (54) 2944 445100.* Alternatively, the following common e-mail address could be used: webmaster@cab.cnea.gov.ar

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Nuclear research centres in the 21st century: The Australian experience

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Abstract. The main mandate of the Australian Nuclear Science and Technology Organisation (ANSTO) is to provide benefits of nuclear science and technology to a variety of applications in agriculture, medicine and industry. It is expected that HIFAR reactor, which will complete 47 years of operation, will be replaced by a new multipurpose reactor in 2005. ANSTO also has a strong programme on accelerators for producing medical radioisotopes and for physics research. In the area of environment, ANSTO's programme includes isotope studies related to global climate change, pollution monitoring, and coastal and marine chemistry. ANSTO would continue to work for the improvement of the quality of life of all Australians.

Evolution of the Role

- 50s–60s towards nuclear power
- 70s end of the nuclear option
- 80s search for a new mission
- 90s re-focusing
- 2000 the nuclear renaissance

The transition from Australian Atomic Energy Commission to ANSTO

- Commercialisation
- Project proliferation
- Internal competition
- Competition with other R&D institutions
- Capability/technique driven activities

Current Focus

Core business areas

- International strategic relevance of nuclear science and technology
- Core facilities operation and development
- Application of nuclear science and technology to natural processes
- Treatment and management of man-made and naturally occurring radioactive substances
- Competitiveness and ecological sustainability of industry

International strategic relevance of nuclear science and technology

- Advice to government
  - Fuel cycle, safety, uranium mining, waste management,
  - IAEA Matters
  - International and regional co-operation
  - Training
  - Safeguards

- Bilateral co-operation

Core facilities operation and development

- HIFAR (1958–2005)
- Replacement Research Reactor (2005), an advanced facility for isotope production and neutron science
- Accelerators for medical products and scientific and industrial research
  - National Medical Cyclotron
  - ANTARES Tandem accelerator (AMS, IBA, microprobe)
  - Van de Graaff accelerator
  - Tandetron (2002)

Application of nuclear science and technology to the understanding of natural processes

- Global climate change
  - Radionuclides in Antarctic ice-cores
  - Southern-hemisphere glaciations
  - Terrestrial sediment records

- Atmospheric pollution

- Coastal and marine chemistry

Treatment and management of man-made and naturally occurring radioactive substances

- Synroc-based waste forms

- Spent fuel

- National radioactive waste repository

- Maralinga

- Uranium ore processing

- Radionuclide distribution and control in mineral processing

Competitiveness and ecological sustainability of industry

- Contribute to the development of critical technologies
  - Development of advanced ceramics
  - Treatment of arsenic and other toxic contaminants

- Provide scientific and technical advice and services
  - Radiation technology and standards

- Supply radioisotopes and radiopharmaceuticals for medical, industrial and environmental use

ANSTO towards the future

- Project-based organisation: the best team for the job
- Matrix structure: managing resources & R&D projects
- Learning organisation
- Outcome driven research

New facilities

- Australia's next generation neutron source neutron beams to probe the materials of the 21st century
- The Australian National Tandem for Applied Research
- Ultrasensitive environmental monitoring for safeguards
- Long-lived radionuclides in climate studies
- Nuclear microscopy

ANSTO's mission

- To provide expert scientific and technical advise across the nuclear fuel cycle
- To operate nuclear science and technology based facilities
- To undertake research on specific topics to advance the understanding of nuclear science and the nuclear fuel cycle
- To apply resultant technologies and other relevant, unique capabilities to focused R&D to increase the competitiveness of Australian industry and improve the quality of life for all Australians

The Belgian nuclear research centre

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Abstract. The Belgian nuclear research centre is almost exclusively devoted to nuclear R&D and services and is able to generate 50% of its resources (out of 75 million Euro) by contract work and services. The main areas of research include nuclear reactor safety, radioactive waste management, radiation protection and safeguards. The high flux reactor BR2 is extensively used to test fuel and structural materials. PWR-plant BR3 is devoted to the scientific analysis of decommissioning problems. The Centre has a strong programme on the applications of radioisotopes and radiation in medicine and industry. The centre has plans to develop an accelerator driven spallation neutron source for various applications. It has initiated programmes to disseminate correct information on issues of nuclear energy production and non-energy nuclear applications to different target groups. It has strong linkages with the IAEA, OECD-NEA and the Euratom.

Introduction

The Belgian nuclear research centre (Studiecentrum voor Kernenergie • Centre d'étude de l'énergie Nucléaire, SCK•CEN) is an institute under the tutorial of the Belgian Federal Minister in charge of energy. More than 600 highly qualified researchers and technicians realise an annual turn-over of 75 million Euro, 50% being covered by a governmental subsidy and 50% earned by contract work and services for the Belgian and foreign industry and the European Union.

The situation for SCK•CEN as a nuclear research centre is rather unique. The Centre is nearly exclusively devoted to nuclear R&D and services. We live in a country with a mature nuclear industry, no nuclear defence research demand, and a society with an askance attitude towards technology in general and nuclear in particular.

However R&D, or science are not specific domains but are dimensions, being imperatively ubiquitous. As in the past, part of it can be performed at universities, however, hands-on experience, broad ranging know-how and multidisciplinary approach flourish best around rather heavy infrastructure, e.g. reactors, hot cells, waste storage labs. Power plants do have (part of) this infrastructure but they don't have the mission to perform research.

Preservation and increase of knowledge is a prerequisite for a nuclear society. This transgresses the operating time span of present day nuclear infrastructure, by the requirement to monitor the long living tail of nuclear waste.

Notwithstanding the multiple international co-ordinating organizations e.g. IAEA, OECD/NEA, Euratom, the proliferation threat forces co-operation through bilateral agreements. A more elegant way, also putting to a test our training and education schemes, is to run our larger facilities under the auspices of such international organizations.

Past and present situation of the nuclear research centre

Since its foundation in 1952, SCK•CEN acted as an attraction pole for other R&D and industrial nuclear facilities: Eurochemic, a multinational project for demonstration of reprocessing technology, co-ordinated by OECD/NEA, the IRMM, Institute for Reference Materials and Measurements, part of the JRC, the companies FBFC, Belgonucléaire and Belgoprocess.

As of the late sixties, SCK•CEN started some diversification which gradually extended to areas of alternative energy forms, environment, advanced ceramic materials, handling of chemotoxic wastes, etc. SCK•CEN has been subject of subsequent restructurings and is now (again) exclusively devoted to nuclear R&D and specific services requiring the use of its nuclear oriented infrastructure.

Neither a mature Belgian nuclear industry, nor a nuclear defence development program is driving for nuclear R&D. The main research projects and the associated infrastructure is briefly as follows.

MAIN RESEARCH PROJECTS:

- *Nuclear reactor safety* — reactor pressure vessel steel embrittlement, corrosion of reactor internals, materials for fusion reactors, high burnup and mixed oxide fuels, dosimetry and reactor core validation.
- *Radioactive waste research* — research on the disposal of high level radioactive waste and of spend fuel in geological clay formations, the decommissioning of nuclear installations and the study of alternative waste processing techniques such as transmutation.
- *Radiation protection and safeguards* — site and environmental restoration, emergency planning and response, radiobiology and scientific support to programmes of international organizations.

MAJOR INFRASTRUCTUR

- The *underground laboratory Praclay/Hades* at a dept of 225m below the SCK•CEN site, allows the study and demonstration of the feasibility of the disposal of heat generating waste in clay.
- The *high flux reactor BR2* is used for tests on structural materials and fuel in normal and accidental conditions for all types off reactors, for the fusion program and for the production of radioisotopes and silicon doping. After an intensive refurbishment program, the reactor restarted in April 1997 and is again at disposal for international programmes for several years.
- The *BR1* is natural uranium, graphite moderated, air-cooled research reactor. Its stable neutron flux makes it extremely appropriate for benchmark and calibration purposes.
- The *VENUS zero-power critical facility* allows the detailed analysis of core configurations, including MOX-fuel and is intensively used by international programmes on core code validation and on pressure vessel dosimetry.
- The *PWR-plant BR3*, is considered as an European pilot project for the scientific analysis of decommissioning problems, such as the realistic assessment of costs, doses and waste production, and the demonstration of new techniques.

Challenges faced by the nuclear research centre

Our mission statement reads:
"Through research and development, education, communication and services, SCK•CEN shall innovate with a perspective of sustainable development in nuclear safety and radiological

protection, industrial and medical applications of radiation and the back-end of the fuel cycle". To accomplish this mission some activities, in addition to the R&D, being pursued by the Centre include:

Medical application of radiation

SCK•CEN has an historic jurisdiction on radiation protection, waste management and radiation sources. This expertise is offered to the growing number of medical applications of ionising radiation. In a concerted effort with the medical community opportunities have been defined, e.g. with respect to the research and development of the application of new radioisotopes and the optimisation of medical exposures.

Societal aspects: offer nuclear issues as a challenge to the academic world

Nuclear management has to consider daily non-technical factors, such as risk perception, ethical and legal issues. Such encounter has often been considered as a confrontation between science and emotions. SCK•CEN supports a scientific analysis of those societal aspects, in a dialogue between nuclear scientists, engineers and academic researchers in social sciences. A program has been set-up with reflection groups on the ethics of radiation protection and the role of scientific experts and well-targeted research projects on the ethics of waste disposal management, sustainable development, risk perception in emergency management and legal accountability.

Communication, information and training: transparent to present and next generations

The nuclear community has difficulties to find confidence among several groups of the society and observes a decreasing interest of the young generation to develop a nuclear career. SCK•CEN is taking initiatives to disseminate scientifically — correct information to different target groups on the basics and the living issues of nuclear energy production and non-energy applications. The actions include an invitation to an open dialogue with all the stakeholders.

SCK•CEN offers also its know-how and infrastructure to maintain, in collaboration with the universities, an adequate and attractive nuclear training program. It is a strategic decision to continue SCK•CEN's young scientists program, offering opportunity to prepare doctoral and post-doctoral works at SCK•CEN in close collaboration with universities.

The Myrrha project: a multipurpose neutron source

SCK•CEN is developing a small-scale (a few tens of MW) accelerator driven system, Myrrha. Early 2001, the board of directors might decide to start the detailed design of Myrrha or to continue at a lower level in the European context. Meanwhile, specific research is devoted to the feasibility of a windowless spallation source design, the fast core configuration, the cooling and the selection of structural materials. Generic R&D work is fitted in the European 5^{th} framework program and in the initiative of Italy, France and Spain to develop a demonstration type transmutator, to be operational around 2015. Myrrha has to be considered as an essential step in this international programme.

Myrrha is to be considered as a multipurpose neutron source that might replace the BR2 reactor, with a reduced operating cost. The Myrrha design has also to look at the opportunity for medical applications, such as proton therapy. Although, Myrrha is presently the only tangible large infrastructure project. Management continuously solicits other new competing ideas and proposals.

Interaction of nuclear research centres with their environment

The diversification towards non-nuclear in most (nuclear) research centres reflects as well the industrial maturity of the nuclear industry as the evolving attitude of society towards industry and science.

The "de minimis" scenario for the nuclear society in general and for research centres in particular is the preservation and increase of knowledge. This transgresses the operating time span of present day nuclear infrastructure, by the requisite to monitor the long living tail of nuclear waste.

Monasteries testimony on the proposition that knowledge preservation, transfer and increase only prosper around facilities in operation with sufficient intake of young people. Education and training might be sufficient for knowledge preservation, additional knowledge increase requires new objectives, new projects, new challenges.

However present day trends are no longer along large endeavor e.g. breeder reactors, large tokamaks or supercolliders. Larger than 1 billion euro investments are no longer accepted, trends are towards back to basics, and small is beautiful. More tolerated are medical R&D, fuel back-end studies, optimization of existing nuclear hardware and flirting with overlapping research areas e.g. space, astro- or subatomic physics.

Otherwise formulated, nuclear research centres no longer experience a strong industry-pull, but develop appealing new projects such as accelerated driven systems or high temperature reactors, in order to generate new ideas and focus research. The "Myrrha" initiative fits in here.

Collaboration and co-operation

Nuclear research always has had an international outlook, evidenced by the multiple co-ordinating organizations e.g. IAEA, OECD — NEA, ICRP, Euratom. However, defence and high level waste disposal are still booked under strict national sovereignty.

A second paradox is the economical trend towards globalisation and the political strive for regionalism.

The end of the cold war set free an immense inventory of fissile material, nuclear infrastructure, waste and human capital in the advanced countries coupled with the demand and the urge of emerging countries for energy and international esteem.

SCK•CEN has no strategy in dealing with collaboration and co-operation. This is more dealt with in an opportunistic way. Thoughts could be given to throw open our major labs e.g. the BR2 reactor, the hot cells, the Hades/Praclay underground clay laboratory, the ADS design project Myrrha, by running them under the auspices of international organizations as mentioned above. Scientist secondments of participating countries are a presupposition. Basic as well as specialized nuclear education and training can be warranted. Taken hostage by the proliferation threat, present day co-operation is mainly bilateral, multiplying the administrative effort to keep them going.

The experience of CDTN/CNEN, Centro de Desenvolvimento da Tecnologia Nuclear: A medium size nuclear research centre in Brazil

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Abstract. At first a university research centre, then a captive research centre of the state owned company in charge of establishing a nuclear industry in Brazil, then a research centre of CNEN (the Brazilian Nuclear Energy Authority), nearing its 50th anniversary, CDTN has a rich experience. even keeping the project portfolio around a number of traditional nuclear energy areas such as nuclear reactors, materials, environment, process engineering, waste management, radiological protection, the institution experienced an evolution in the substance of the proposed projects. This evolution represents the different institutional insertions, but the major changes occurred at a time when, due to a lesser demand from the nuclear sector and other factors, the explicit idea of producing outputs for the benefit of society received a large acceptance from the employees. The challenges to the institution at this time are commented upon. Retirements, coupled to the lack of job openings, work together for the decrease in the staff number, one major challenge. Up to a certain point, private companies have been hired to fill some of the organisational needs, but it is felt that a limit to this policy is being reached. It is argued that, even in the absence of a strong demand from the energy generation sector, a number of opportunities are still available to a NRC in a developing country. maturity of nuclear energy and applications of radiation tend to transfer the focus of the activities from the fundamentals of nuclear science and technology to quality related issues, a requirement of the modern times. quality systems cannot substitute for the in depth knowledge of the fundamentals.

Past and present situation of CDTN/CNEN

CDTN was founded in 1952 at the University of Minas Gerais, the result of the vision of a few persons. At that time, the presence of large amounts of uranium minerals in the State of Minas Gerais was taken for granted, given the existence of already known large Thorium ad Uranium deposits as well as many other minerals. Hence the name of the new Research Centre, Instituto de Pesquisas Radioativas.

During the sixties, CDTN remained as a small institution (staff, by the end of 1972 was of 130 persons, including many activities which today are given to external contractors). It was a time of discovery, learning the essentials of nuclear physics, nuclear reactor physics, nuclear radiation detection, radiological protection and small scale essays of uranium ores. Several persons of the staff were trained in France and several French researchers were invited to Brazil. By the end of this period, efforts were made in order to provide the Institution with a sub-critical heavy water facility and a thermal-hydraulic laboratory. The heavy water facility is presently being decommissioned. The thermal-hydraulic laboratory is still active, although concerned with research topics related to PWR Reactors.

American influence, started with the acquisition of the TRIGA Reactor. It was also strong during the 1970s, mainly due to the adoption of PWRs as a choice for nuclear energy supply.
A third external influence became important at the end of the 70s as a consequence of the signature of a comprehensive treaty on nuclear energy between Brazil and FRG. As a captive Research Centre for NUCLEBRAS[1], and in constant contact with German companies like

[1] NUCLEBRAS, the state owned company in charge of developing the nuclear industry in Brazil, was closed in 1989. The same activities, were taken by INB, Indústrias Nucleares do Brasil. Erection and operation of power reactors are presently a task of ELETRONUCLEAR, also a state owned company.

KWU and Research Centres like KFA-Juelich and KFK-Karlsruhe, a new culture was shaped at CDTN. Waste Management activities, started at that time, are very important up to now and there is no end in sight for them. Studies of Th-U reactor fuels were successfully accomplished in the framework of cooperative research programs. An Environmental Engineering Group was included into the Organization Chart as early as 1980. Meteorology was also introduced, due to sitting and licensing requirements of nuclear power units and fuel cycle facilities[2]. A good deal of co-operation was also established in topics like power reactor core calculations, reactor accident analysis, criticality studies. An effort to help the development of the jet nozzle Uranium enrichment process, also a joint effort with FRG, did not succeed. The ultra-centrifugation method, developed independently in Brazil at the same time, by other laboratories than CDTN, proved to be more economical for the required amount of enriched uranium (SWU).

Basic training of power reactor operators, started in the 1970s, is still going on. Nearly two hundred persons from the staff of ANGRA I and ANGRA II nuclear power units as well as from the licensing staff of CNEN were trained at the 100 kW TRIGA Mark I, Research Reactor. This small, robust system is probably the best option for teaching the basic concepts of reactor physics and operation.

CDTN into the 1990s: Manpower, programmes and infrastructure

In the beginning of the 90s, the intensity of the collaboration with FRG was sharply reduced, and a lesser demand from services by the nuclear industry, then under very heavy criticism from segments of the population, produced almost a vacuum into the institutional Research Program. Again under CNEN-the Brazilian Nuclear Energy Commission administration, CDTN started to look for ways of using the knowledge acquired into the nuclear field, as well as for alternative lines of research. Internal discussions at that time resulted in the formal draft of the institutional mission:

- To perform R&D in the nuclear and related fields, delivering knowledge, goods and services for the benefit of Society.
- Quality related issues, not only in the traditional sense of quality assurance, but “total” quality, quality involving all aspects of the Organisation and the perception that we must give some kind of return to Society as a whole became a strong feeling within the institution.

Human resources

CDTN staff, which was under 150 persons by 1970, increased to a peak of 540 around 1984, then decreased to 390 today, in despite of the admission of nearly 100 during the nineties. Retirements, due to soft legislation, and also for fear of new restrictive government legislation, were the main cause for staff reduction in the nineties. Perspectives for new job openings are virtually non existent at this time, due to severe restrictions into the Federal Budget.

A policy clearly established during the nineties by CDTN management was one of having the people to look for completion of their academic education. Accordingly, the number of Ph.D.s existing at the beginning of the decade was increased fourfold, being an institutional goal to

[2] Concern with the environment was present from the beginning, motivated by the study of underground water at the dry northeastern Brazilian regions.

reach 40 next year. Besides this, in despite of many retirements, it was possible to keep the number of persons holding a M.Sc. degree around 100. This was perceived as a condition for being consistent with the institutional mission and also as a condition for survival in the near future.

Staff reduction was up to a certain point compensated by handing few activities to private contractors, such as cleaning, physical security, air conditioning equipment, computer servicing. The productivity of the personnel was clearly increased with the introduction of a computer network accessible to all. Now, a critical point is being reached in which new ways of dealing with this situation must be found. The promising alternatives are in the sense of making partnership with the local universities, in a way that a certain number of students can develop their projects in our laboratories. Accordingly, we have several agreements with local universities, by which we also present joint project proposals to several research financing organisations.

CDTN programmes

CDTN technological projects and activities are organised around the following programmes:

- nuclear reactors
- materials science and materials engineering (including reactor fuel)
- environment
- process engineering
- waste management
- radiological protection
- human health.

The above classification is rather concerned with the purpose than with the nature of the involved technologies. The absence of a program of radioisotope applications, for instance, means that these techniques are spread through de remaining ones.

It has been a consistent policy of CDTN, in the nineties, to recognise the importance of using the laboratory infrastructure and human resources for the benefit of Society, even if the nature of the problem is such that nuclear techniques are not directly required. Nuclear techniques seldom appear or are used alone, they are frequently associated with other technologies aiming at producing results for a given problem. Hence, the expression related technologies which appears into our mission statement. Recently, this practice, which is common to other CNEN NRC' s in Brazil, has been formally endorsed by CNEN, our Mother Institution.

Infrastructure

The most important piece of infrastructure is still the 100 kW TRIGA Mark I Reactor. This reactor will complete 40 years from the first criticality in the year 2000. In the last five years, investments of nearly 500 000 US$ were made in order to have the physical installations complying with modern safety requirements. The original control desk was replaced by a new, modern one, made by IEN, one of the CNEN institutes. The scope of the works included a control room with an insulated atmosphere, the replacement of the electrical wiring of the building, adding new features to the air conditioning system and reworking of the internal reactor hall surfaces. The power increase of the TRIGA Reactor to 250 kW is in an advanced stage, pending only a survey of the fuel elements in order to detect eventual surface defects and the approval of the Safety Analysis Report.

One of the newest and most expensive laboratories is a modern system for Surface Analysis of Materials. Several techniques of surface analysis can be available from this laboratory. On a current basis, the same group also operates a modern Moessbauer system.

This year, a very low background laboratory, for environmental levels of tritium counting was added. Money for civil works came from the Brazilian Government, while the main counting equipment has been donated by IAEA. Several other modern equipment are available on a partnership basis with UFMG, the Universidade Federal de Minas Gerais. Examples of this are an electronic micro-probe and a scanning electron microscope.

A list of the other main CDTN laboratories and equipment is given in Annex 1.[3]

Main current projects and activities

Many projects are into the portfolio of CDTN at a given time. At this moment, the most relevant ones are:

1. TRIGA reactor nominal power increase from 100 to 250 kW; the first criticality of this system is dated in the logbook of the reactor supervisor as of November 1960.
2. CAFÉ, a thermal loop for irradiation of fuel and materials samples at the 5 MW pool reactor of IPEN, one of the NRCs of CNEN; pressure and temperature equivalent to those existing in a PWR reactor are to be obtained, although the neutron and gamma radiation levels are supposed to be smaller; other Brazilian research centres are also involved into this project;
3. Participation, together with other Brazilian institutions of the nuclear area, into the HALDEN reactor project, Norway; activities concerning reactor fuel element, man-system interactions and life management of reactor components are the main interest at this time.
4. Life management/life extension of power reactor components, a project supported after several years by IAEA, to which credit is a reformulation of the programme in materials engineering of CDTN;
5. Evaluation of Waste Management techniques which uses cement and bitumen as materials for waste immobilisation; evaluation of alternative matrices for the same purpose; presently, three studies are being performed under contract with the power station operator, concerning the use of cement and bitumen as matrices for waste immobilisation; this same group has had the opportunity to work a few times under contract for industrial waste process development;
6. Immobilisation of Radium-226 needles, formerly used by industries and hospitals; besides the internal programme, CDTN has been acting in several Latin-American countries, as a partner of IAEA, for the same purpose.
7. Radiation dose evaluation for nearly 5000 workers from CDTN, hospitals, industries and universities; calibration of radiological protection equipment;
8. Diagnosis of Leishmania by the use of P-32 detectors; this project also partially sponsored by IAEA;
9. Participation in DECADES, an IAEA partially sponsored project, intended to compare all the parameters involved into different energy generation alternatives;
10. Laboratory scale studies of advanced research reactor fuel;

[3] More detailed information on the available equipment and techniques can also be found at CDTN home-page.

11. Participation, together with other local institutions in several projects concerning Human Health and the Environment: air pollution studies by small pig-iron producing industries, Hg poisoning due to improperly conducted Au mining operations, etc.
12. Dissemination, among the entrepreneurs community, of the technique of gamma irradiation. Courses, conferences and advice are available to entrepreneurs and persons from the community; CDTN has already concluded plans for having his own pilot facility, a 60 000 Ci gamma irradiator. Some help on specific licensing issues of gamma-irradiators has been provided to the licensing group of CNEN. CDTN is co-ordinating the IAEA/ARCAL project dedicated to look at the legislation concerning gamma irradiation.
13. Studies for the management of underground water resources. The IAEA is a traditional partner of CDTN in the use of Tritium and stable isotopes (^{2}H, ^{18}O) techniques. CDTN has a Tritium laboratory operating for several purposes for 30 years. Presently, in order to be able to determine very low levels of natural Tritium, a new, small laboratory has been erected. IAEA donated the counting equipment. Government resources were used for the civil works. Inside the new counting room, the radiation background is only 2% of external levels, so far without the use of the sophisticated coincidence apparatus.
14. Studies of micro and nano-structured materials are currently undertaken at CDTN materials laboratories; in some cases, concepts of materials science are employed to evaluate alternative materials for waste immobilisation. In other cases, nano-structured materials are studied because of its future potentialities, even if direct connection with topics of nuclear energy is not clear.
15. The materials programme at CDTN ranks among the ones with the largest capacity of converting from nuclear to non nuclear technologies; in the beginning of the 90s, due to a very small demand from the nuclear area, in a short time, the same people and the same equipment gave origin to very nice projects, concerned with autonomous process for the development of zeolytes and alumina. An Image Analyser Software, conceived initially for the study of fuel element micro structures was improved to become a general image analyser. Applications of this code in medicine and by industry have been registered.
16. The centre has a large experience in processing (pilot scale) uranium ores. Flotation and column flotation techniques were developed up to a point in which CDTN can be considered a national reference on them. The demand from the nuclear area ceased nearly 10 years ago, and the available expertise and equipment were converted to process of different ores. In some cases, processing of industrial wastes by this technique allows the economical recovery of some of the industrial waste contents. Industrial companies are the major segment of clients for this technology.

Challenges faced by CDTN

The quality issue

Being a NRC, Quality Assurance was not a new issue to CDTN. From the 70s non-destructive essay techniques like ultrasonic waves, Eddy current, gamma-radiography and other were available on a current basis at CDTN. Presently, private companies have taken over these activities and we at the research centre are trying to connect robot arms to the transducers in order to do the same operations in hostile environments. It is generally accepted that the nuclear energy programme contributed much to the introduction of quality assurance in Brazil.

Now, in the 90s, one started to speak of “total” quality, in the sense that quality must be spread over the whole of the organisation. At the beginning, a somewhat rigid approach was tried at several places, but soon a more flexible (in my opinion) management philosophy began to be accepted. Also based in international practices (the Malcolm Baldridge premium), the new model, now under the title of “Prêmio Nacional da Qualidade” (PNQ) is less prescriptive, more apt to get a positive response from a community of scientists and technologists. Under this concept, an organisation is evaluated by the following criteria:

- leadership
- strategic planning
- focus on the client and on the market
- information and analysis
- human resources management
- process management
- results of the organisation.

The difficulty (and presumably the merit) with this philosophy of management is that it is necessary to involve everyone from the organisation, a task not always easy to accomplish. In matters of science and technology management, CDTN has joined efforts with other research centres in Brazil. An experimental project in quality management, also based on the PNQ scheme, co-ordinated by ABIPTI, (a national association of technological research centres), is under way.[4] Assuming that all the schemes of quality management intend to increase the long term chances of survival and growing of the organisation, which will ultimately depend on its output, as a depart point for the strategic planning of CDTN[5] we have postulate that our output must have some attributes:

Quality, of products and services, translated into calibrated instruments, trained people, certified laboratories, good and readable reports delivered in due time, etc.

Originality, measured by the number of papers published by peer reviewed magazines, number of patents, and other;

Institutional image as perceived by clients and/or the general public.

Anyway, it must be kept in mind that nothing can substitute for the true knowledge of the scientific and technological issues.

Budget

In despite of the fact that that the yearly budget contains a statement for resources coming from the supply of special services to industries and other organisations, it is rather a fixed number. This practice, which is related to legal dispositions, does not help in motivating the scientists and technicians to transfer more of their knowledge to Society. We know that this is not exclusive of Brazilian organisations. Exceptions are being admitted at a few institutions, but so far they have not reached CDTN or CNEN.
Gross budget number for 1998 was around US$ 18 million. Resources from research financing organisations and invoices from selling special services accounted for nearly 9% of this total.

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[4] ABIPTI herself is affiliate to WAITRO, the corresponding international association.

[5] At this moment we are at CDTN recycling our strategic planning. Employees are asked to contribute, on a voluntary basis, forwarding their viewpoints on the strengths and limitations of the organisation and what are the challenges and opportunities presented by the external environment.

Library

Keeping updated collections of scientific magazines is a permanent challenge for a research centre in a developing country, specially for a interdisciplinary institution. The purchase of books or pieces of new equipment many times can be postponed for the next year, but the same is not true for scientific magazines. From a top level of 150 publications in the seventies, CDTN Library is today struggling to keep some 100 titles on a current basis. The electronic libraries show some promises for the future, but so far, when available in electronic versions, scientific magazines bear the same or slightly higher prices than the paper version. This is a universal problem with no easy solution.

Holding to the fundamentals

Nuclear energy and applications of nuclear radiation are already on a mature phase. Probably due to this, and to the fact that nuclear equipment is more and more apt to be used by the lay person, my personal feeling is that there is a tendency among the technologists to learn only superficially the fundamentals of nuclear energy and those of nuclear radiation detection. As a result, a loss of expertise may happen, with a potential for the introduction of safety issues and superficial interpretation of experimental results. We look at this as a challenge and also as an opportunity to the NRCs.

New directions

Looking for new directions, one should not miss the IAEA document GOV/1999/37, "Medium Term Strategy", although in this discussion paper we rather speak of our own experience.

At this moment, CDTN and other NRCs in Brazil benefit from the fact that the nuclear energy programme has been reactivated. ANGRA II, the second nuclear power station, (1200 MW(e)) is nearing conclusion and many admit that the third power station will also be erected. The fuel element company (INB) is in the final stages of incorporating the reconversion to UO2. The potential interest in high burn-up fuel and in Life Management of Reactor Components offer good opportunities, even for the small research centre, provided that the expertise is there. This means that a number of issues in nuclear power are or will be available to the research centres: the waste management problem, environmental monitoring, modernisation of control rooms designed in the 70s, issues related to safeguards measurements, particular cases of accident analysis, etc.

In Brazil, even in the absence of strong nuclear energy programmes a large space is available for the research centre. Medical applications of radioisotopes for diagnosis and therapy, specially short lived radionuclides, present an increasing demand. Over 1,4 million medical procedures a year are performed in Brazil[6] and it would be desirable to double this number in a short time, if we intend to reach levels of advanced countries and even of our neighbour Argentina. The search for more and more sophisticated ways of producing and applying radiopharmaceuticals certainly offers opportunities for the medium sized research centre. The

[6] Most of the radiopharmaceuticals used in Brazil are prepared by the Instituto de Pesquisas Energéticas e Nucleares-IPEN, one of the CNEN institutes. Part of this material is imported. Short lived materials are produced in a cyclotron.

presence of medical professionals is of paramount importance in this line of work, but other specialists are required as well.

The area of energy generation presents opportunities as well. If the country foresees an interest in nuclear power generation, the follow-up of other countries initiatives on concepts of advanced reactors, safeguards, non-proliferating reactor fuel, extended fuel burn-up, Life Management Studies, are certainly relevant tasks. Similarly, it would be worthwhile to speculate on the impact of some of the new technologies on power generation at large (superconductivity, microelectronics, solar energy).

Environment is an area where new opportunities of using the skills learned in the nuclear field arise everyday. Besides that, it is quite probable that the energetic options in the future will be strongly influenced by multi-parameter evaluation of the different alternatives. Involvement of the NRCs in initiatives like the DECADES project and many other research opportunities will always be beneficial to the country.

If the NRC has a good tradition in materials science and/or materials engineering, the lack of demand from the nuclear field would be replaced in a short time by many other possible clients. Some of the accomplishments of CDTN in this area were already mentioned. Process Engineering, if concerned with ore processing, would always have good opportunities in countries having ore deposits of economical interest. The column flotation technique offers good opportunities even for the recovery of certain materials present in industrial waste.

Waste management, which includes also a philosophy of waste classification and interim storage, already is a capacity sought for by the market. New directions for this CDTN group would be quickly found, if necessary.

Human health, or more precisely, the use of nuclear radiation in topics related to human health, is new as a research area at CDTN. When this group started, a few years ago, we required that only projects presenting a relevant use of nuclear radiation should be proposed, so that our work would be complementary rather than a duplication of the research already performed at the Brazilian universities. Given this orientation, a few projects were already presented, and interesting results are being displayed, at a cost/benefit relationship very favourable.

Radiological protection specialists are already in great demand from the general public, hospitals and State Authorities. On a first moment we see our duty as one of attending to a diversified demand in personal and environmental dosimetry and safety inspections of new laboratories and clinics; steps are being taken to transfer this activities to the private initiative and keeping the ones which requires investments not affordable by small companies. In due time, this should enable us to do some more research work in the area.

Conclusion

Maturity of Nuclear Energy as well as the eventual phase-out of the nuclear option may pose a problem to nuclear research centres, in the sense that their projects might become out of context in both cases. Our experience at CDTN is such that, as soon as the research centre becomes involved with technological issues of the community, its expertise will be of invaluable help and the non-nuclear projects will find a place side to side with the nuclear ones. There are conditions to be fulfilled if this outcome is desired. The first one is that a certain number of interdisciplinary persons be available among the body of researchers. Interdisciplinary projects are among the ones who offer good opportunities at reasonable costs for a developing country. Up to now, interdisciplinary experience was possible only by uniting a large number of specialists from different areas. From now on, with the almost universal policy of job curtailment, the research centres must be able to find this kind of generalist professionals, coming out of the graduation and post-graduation university courses.

Cultural issues and insufficiency of seed money may nullify efforts of the organisations to put forward joint projects and programmes. Enters into evidence the interdisciplinary professional who is able to put forward joint inter-institutional projects. This kind of person would be the one able to find new clients, new partners as well as to smooth the cultural differences among groups.

Coming to the issue of the international co-operation, we at CNEN/CDTN are proud that we have been able to establish a partnership with the IAEA in order to help some Latin-American countries to store in a safe way the existing inventory of Ra-226 needles. This is a material no longer in use worldwide and poses severe risks to workers and to the community. On occasion, our experts in hydrology have been able to act as IAEA experts in African countries. We are also very keen on having been able to get technical support and sometimes equipment from IAEA. Our previous explanation evidenced only partially the number of projects in which this help came and was useful. By making their resources (including expertise) available, the developed countries are major contributors to the IAEA projects. Enhancement of their support could make a positive difference in the developing countries.

Nuclear research centres do have a role in disseminating balanced, non-partisan and non-emotional information relative to the merits and challenges of nuclear energy. At CDTN, we have been concentrating our efforts into two areas: (1) objective technological information, collecting data from several energy alternatives, such as the model of the DECADES and other similar projects; (2) information to the lay person, via television interviews, visits of students, and so. In the last three years, an open-door event was held, with the participation of 1500/2000 visitors each time.

ABBREVIATIONS

ABIPTI, Brazilian association of technological research centres
ANGRA 1, ANGRA 2, Nuclear Power Stations in Brazil, PWR type
BNL, Brookhaven National Laboratory
CDTN, Centro de Desenvolvimento da Tecnologia Nuclear, one of the CNEN nuclear research centres
CNEN, Comissão Nacional de Energia Nuclear (the Brazilian Nuclear Energy Authority)
DECADES, an IAEA project aimed at evaluating different energy alternatives
FRG, Federal Republic of Germany
IAEA, International Atomic Energy Agency
INB, Indústrias Nucleares do Brasil, state owned company presently in charge of fuel element fabrication and the exploitation of Uranium reserves
IPEN, one (the largest) institute of CNEN

KFA, Kernforschungzentrun Anlage, Julich, Germany
KFK, Kerforschungzentrum Karlsruhe, Germany
KWU, Kraftwerk Union
NUCLEBRAS, Empresas Nucleares Brasileiras, the State owned company formerly in charge of establishing the industrial nuclear energy sector
PNQ, Prêmio Nacional da Qualidade, the national award for excellence in management
PWR, Pressurized Water Reactor
UFMG, Universidade Federal de Minas Gerais
UFZ, Umwelt Forschungszentrum, Leipzig-Halle
WAITRO, World Association of Technological Research Institutes

Annex 1

CDTN MAIN LABORATORIES AND INSTALLATIONS

Corrosion
Dimensional Metrology
Dosimeter calibration (including radiation sources donated by IAEA)
Environmental radiometry analysis
Gamacell
Gas adsorption
Hydrology, Geohydrology and Sediment Evaluation
Image Analyser Software
Materials and Nuclear Fuels (chemical processing of fuels, ceramic and polymeric materials, ceramography, pelletization and sintering of ceramic materials, fuel pellets and fuel rod fabrication, flash laser)
Mechanical essays (Instron type machines for tension/deformation curves, materials fatigue, Charpy instrumented machines, fluence machine, 1000 kN Kratos machine, rotative fatigue machine, etc)
Mechatronics
Metalographic analysis
Non-destructive essays
Nuclear Measurements
Physical essays of ores (lab and pilot scale)
Preparation of ore samples for analysis and pilot runs
Radiobiology
Radiochemistry (neutron activation, gamma-ray spectrometry)
Solvent Extraction and Leaching
Stress and vibration analysis
Surface Analysis and Mössbauer technique
TRIGA Reactor
Thermal-hydraulics
Tritium (non-environmental) and Carbon-14
Waste management (waste immobilisation by cement, bitumen, and polymers, leaching)
Welding, Mechanical Works, Mechanical Projects
Chemistry Laboratories *(atomic absorption, liquid and gas chromatography, potentiometry, UV-VIS spectrometry, X-Ray fluorescence spectrometry, Gravimetry, Volumetry, electron microprobe, ICP-AES,...)*

Nuclear research centres in the 21st century: An AECL perspective

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Abstract. The nuclear energy programme of Canada started at Chalk River Laboratories with the setting up of Zero Energy Experimental Site in 1945. One of the early research reactors of Canada, the National Research Universal (NRU) continues to provide 70% of the world requirement of isotopes for medical and industrial applications. A CANDU prototype (208 MW(e)) came on line in 1967 and based on this concept, Canada has a large nuclear power programme. The role of nuclear research centres has evolved with time starting with strategic research in the initial phases through to implementation of technology, building and supporting industry, and carrying out advanced technology development. Most of these centres have important assets in terms of licensed sites, trained personnel, research reactors, shielded facilities and expertise for handling large quantities of radioactivity and high tech laboratories for advanced R&D. These centres would, therefore, continue to play an important role in emission free and economic energy generation, nuclear medicine, food irradiation and industrial applications. Nuclear research centres in different countries are at various stages of development and have many unique features. However, there are generic issues and much will be gained by developing a shared vision for the future and implementing programmes in a collaborative manner.

Historical perspective in Canada

- Nuclear technology in Canada began more than 50 years ago at Chalk River Laboratories
- Progressed from scientific discovery to multi-billion dollar per year Canadian industry in nuclear power, uranium supply, and nuclear medicine
- Role of AECL laboratories has evolved over time
  - strategic development role, basic science in physics and chemistry
  - development of facilities, technology and techniques
  - training of industry experts
  - applied development of nuclear power and nuclear medicine
  - development of domestic nuclear industry
  - support of commercial reactor technology
  - advancement of reactor technology to next generation
- High degree of international co-operation during pre-commercial development decreases as commercial implementation proceeds
- 1945 Sept. 5 First sustained fission reaction in Canada achieved in ZEEP (Zero Energy Experimental Pile)
- From those early days came larger and more powerful research reactor designs:
  1947 NRX (National Research Experimental)
  1957 NRU (National Research Universal)
- NRX and NRU have been key facilities in development of CANDU design
- NRU produces ~70% of world radioisotope supply for medical and industrial applications
- NRU continues to be used by AECL and NRC for CANDU fuel and materials testing and for advanced materials research
- 1962: First CANDU prototype, Nuclear Power Demonstration (NPD), feeds nuclear-generated electricity to the Ontario grid
- 1967: A larger CANDU prototype, the 208 MW Douglas Point generating station supplies electricity to the grid

- 1971: The first of the Pickering a 520 MW(e) commercial scale CANDU reactors go into operation
- 1987: The CANDU nuclear power system is cited as being one of Canadas 10 most significant engineering accomplishments during the first 100 years of engineering in Canada
- 1994: Dr. Bertram Blockhouse shares the Nobel Prize for Physics for work on the applications of neutron beams performed at Chalk River in the 1950s

Current roles of AECL laboratories

- Maintain design and licensing basis for domestic nuclear technology
- Advance the technology for next generation reactor designs
- Develop new products and services
- R&D to resolve operating issues for existing CANDU plants
- International collaboration in "non-commercial" R&D
- Support Government public policy role in nuclear technology

Status of AECL laboratories

- Reduction in R&D programs since 1985 — more applied focus
- Closure of AECL White shell Laboratories underway
- – consolidation of some facilities and programmes to Chalk River
- Chalk River infrastructure refurbishment underway
- NRX in phase 1 decommissioning, NRU to be shut down by 2005
- Other R&D business tenants at CRL
- Proposing replacement Canadian Neutron Facility jointly with National Research Council of Canada
- Respective roles of Government and AECL under review

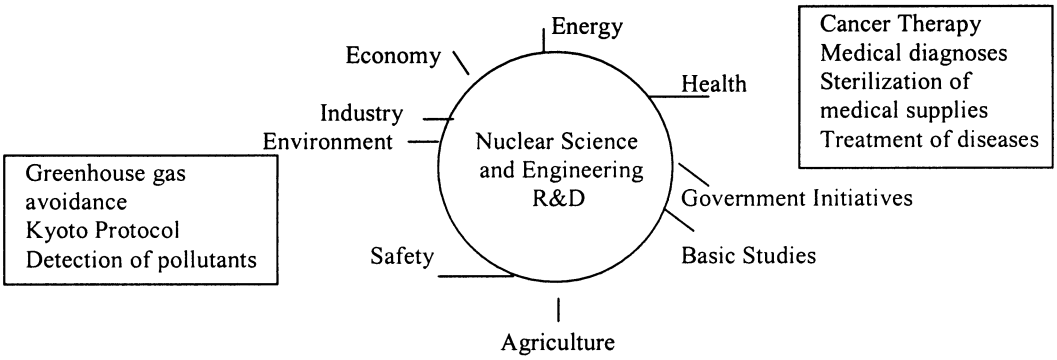
Characteristics of NRCs today

- Licensed site(s)
- Research reactor(s)
- Shielded facilities (hot cells)
- Infrastructure for handling radioactive and fissile material
- Radioactive analysis and test facilities for chemistry, corrosion, etc.
- Associated facilities for thermal hydraulics, fuel development, materials research, component development and qualification, etc.
- Highly trained, specialised staff

Current challenges for NRCs

- Maintaining licensed site has significant fixed cost component
- Ageing facilities and infrastructure requires investment
- Cost of historic waste management and decommissioning
- Continued government investment in nuclear research centre programmes
  - Basic science & training
  - Build & support domestic industry
  - Long term or pre-commercial R&D

Contributions of nuclear science and engineering R&D to Canada (R&D advisory panel report)



- Public acceptance of nuclear technology — need to communicate benefits of nuclear technology
- Need new vision for next century

Nuclear technology in 21st century

Important continuing role:

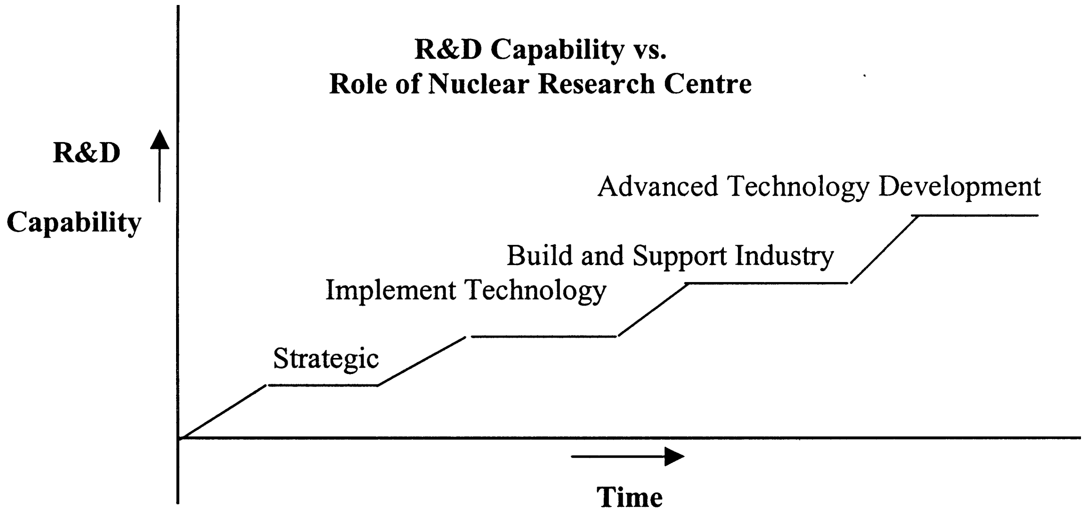
- Large scale, clean (emission free), economic energy generation
  - electricity, transportation, industrial
- Nuclear medicine
  - isotopes, accelerators, BNCT, etc.
- Food irradiation
- Industrial applications

Role of NRCs in 21st century

- Role determined by scope of desired nuclear technology application within country
  - develop strategic knowledge base
  - implement nuclear technology applications
  - build & support domestic nuclear industry
  - advanced nuclear technology development
- Roles likely to evolve with time and experience
- Different level of Nuclear Research capability required for different roles

Possible vision for NRCs

- Infrastructure and technology base as national Resource
  - licensed site & key nuclear facilities
  - training resource for nuclear industry infrastructure
  - support the design and licensing basis of domestic or imported technology
  - perform long term or pre-commercial R&D
  - provide public policy support for nuclear technology



- Industry funded R&D to advance domestic nuclear products
- Utility funded R&D to support domestic nuclear power plants
- Multi-use of site "nuclear capabilities" by other tenants (share fixed costs)
  - isotope production (business partnerships)
  - neutron scattering (academic partnerships)
  - applied science partnerships (on-site institutes)
  - industrial processing of "active" materials & commercial R&D
- Expand international R&D collaboration on generic topics
  - e.g. radiological sciences

A way forward

- Participating countries at various stages of nuclear development
- Each will have unique history & path to follow
- Many issues are generic and common to all
- Much to be gained from sharing
  - History and current situation
  - Issues and challenges for future
  - Realities of current environment
  - Potential for international collaboration
- Develop shared vision for the future
- Co-ordinate communication of benefits of nuclear technology to public.

The Canadian neutron facility for materials research (CNF)

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Abstract. Canada has plans to set up a Canadian Neutron Facility (CNF) of 40 MWt capacity for materials research and nuclear fuel development. The CNF will be a part of the international network with other large neutron facilities in France, the United Kingdom and the USAA. Canada may consider offering this facility for international research under the IAEA auspices.

Background

In the past five decades, Canada has been well positioned internationally in the field of advanced materials research — both for the Canadian nuclear industry, for other industrial applications and for university research. This capability was due in part to the availability of the NRX and NRU research reactors and in part to the foresight of the research community and the Canadian government in designing and constructing these world-renowned facilities at AECL's laboratories. The important contributions to the study of materials by neutron scattering at AECL's laboratories were recognized in the award of the 1994 Nobel Prize in Physics to Dr. Bertram Brockhouse. And the CANDU® reactor grew out of the research reactor capabilities into an environmentally-sound electricity generator which produces 14% of Canada’s electricity and whose international sales substantially benefit the Canadian economy.

In recognition of the finite lifetimes of NRX and NRU, AECL and the scientific and industrial community have been exploring replacement scenarios since the 1980s. NRX is already permanently shut down, and NRU will not operate beyond 2005. In 1994 AECL produced a formal document on the case for the replacement of NRU. The replacement research reactor was a key item of discussion during AECL’s comprehensive Program Review in 1995. The conclusion was that a new research reactor was critical to ongoing CANDU business as it was needed for many research programs including materials research and fuels and fuel cycles.

CNF proposal

The National Research Council of Canada (NRC) and Atomic Energy of Canada Limited (AECL) are jointly proposing to the Canadian government the Canadian Neutron Facility for Materials Research (CNF) to support next-generation neutron-based materials research and innovation in Canada. The proposal is brought forward with full regard for academic, research and industrial stakeholders.

The purpose of the proposed CNF is two-fold:

- to provide the advanced materials research capability to meet the needs of Canadian universities and industry,
- to provide an essential testing facility to advance the CANDU power reactor design, to support existing CANDU reactors, and to have CANDU technology available to Canada in the future to provide environmentally-sound electricity.

The CNF will be a national facility generating unique information on the structure and performance of materials in a wide range of industrial applications, using neutron techniques. As well as being a cornerstone of CANDU reactor development, the CNF will support the development of the totally new fields of science and technology that will drive Canadian industries of the next century.

General description of CNF technology

The CNF reactor is based on AECL's well-established MAPLE technology and is a 40 MW_t pool-type reactor. The reactor assembly is located at the bottom of a 15.6-metre-deep light-water-filled pool. The core is separated into two halves, with the space between containing three horizontal test sections, each capable of being fitted with a full-diameter CANDU fuel channel, holding three CANDU fuel bundles per channel. Cooling systems can simulate current and advanced CANDU conditions. Key systems include the fuel, the process and service systems, the control system, and two independent shutdown systems. The reactor uses low-enriched uranium fuel, satisfying international nuclear non-proliferation guidelines. The fuel generates a flux of fast neutrons in the core and a high thermal flux in the surrounding heavy water reflector tank; a maximum unperturbed thermal neutron flux of 4×10^{18} neutrons.$m^{-2}.s^{-1}$ is achieved.

For CANDU reactor applications, the neutrons in the reactor core are used to irradiate advanced fuels, materials, components and coolants in test sections that reproduce a nuclear power reactor's operating environment. For advanced materials research, the beams of neutrons are guided to experimental stations outside the reactor core, where they are used as powerful probes of materials.

General description of R&D capabilities

CANDU support and development

The neutrons in the reactor core are used to irradiate advanced fuels, materials and components in test sections that reproduce a nuclear power reactor's operating environment. Additionally, the effects of different cooling conditions and chemistry can be simulated. After irradiation, these materials are examined and tested in shielded "hot cells" to obtain information on their performance under power reactor conditions. Irradiation research and proof-testing has, and continues to be, an essential element in ensuring a successful CANDU nuclear industry, supporting existing reactors as well as advancing the technology.

Advanced materials research

For advanced materials research, beams of neutrons are guided to experimental stations outside the reactor core, where they are used as powerful probes of materials. The neutron-beam instruments in the CNF will provide Canada with state-of-the-art capabilities in wide-ranging fields of science and engineering. Most importantly, the cold neutron source, a new capability for Canada, will open new research opportunities for Canadian scientists, particularly in the emerging fields of bio-materials and polymers.

International co-operation

The CNF will be part of an international network that includes the Institut Laue-Langevin reactor in France, the ISIS spallation source in the UK and the SNS being designed in the

USAA. The CNF neutron beam laboratory will be Canada's doorway to a worldwide network of neutron users and scientific expertise. And the CNF will be of real importance to the CANDU reactor users around the world. No one laboratory can provide all the instruments needed to solve every problem.

At present, about half of the neutron beam experiments performed at the Chalk River Laboratory are collaborations with foreign scientists and engineers. In the future CNF, foreign visitors will continue to bring cutting-edge projects to the Canadian laboratory, and provide cross-fertilization of ideas between international and Canadian scientists in new areas for both nuclear and advanced materials development.

CNF costs and schedule

The construction cost of the CNF is $466M in escalated dollars through the 72-month initial project schedule, of which approximately $250M will be allocated to the base CNF Reactor, $108M to the Beam Facilities and $108M to CANDU Support and Development Facilities. An additional 36 months will then be required to complete the beam facilities, all with the stated $466M. The CNF will cost approximately $14M annually to operate. Annual costs for CANDU support and development programs, and for the Neutron Beam laboratory, will be approximately $15M and $8M, respectively. The Canadian government is currently considering the CNF Proposal.

The China Institute of Atomic Energy

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Abstract. The China Institute of Atomic Energy (CIAE), established in 1950, carries out multidisciplinary research in nuclear science, technology and engineering. It has three research reactors and ten low energy accelerators. The focus of its nuclear energy related R&D is on reactor engineering and technology. In the area of nuclear techniques for applications, R&D is carried out on accelerators, isotope production, nuclear electronics and utilization of radioisotopes and radiation. There is also a strong programme in basic nuclear physics and radiochemistry. New major facilities under construction in CIAE include China Advanced Research Reactor (flux $8 x 10^{14} n/cm^2/sec$) and China Experimental Fast Reactor. China has been successfully using the products of its R&D for a variety of applications in medicine, industry, materials science etc. A dynamic research programme is tuned to attract young talent to CIEA and there is good collaboration with the Beijing University. CIEA has been an active participant of RCA programmes of the IAEA and has been a resource for many developing countries. The management expects the Institute to be a leading multidisciplinary institute in the field of nuclear science, technology and engineering.

Past and present situation of China Institute of Atomic Energy (CIAE)

R&D programs and the related finances, manpower and infrastructure

China Institute of Atomic Energy is a multi-disciplinary research institute in nuclear science, technology and engineering. It was established in 1950. Since the construction of the heavy water research reactor and the cyclotron constructed in 1958, CIAE has been a Chinese core institute and played a pioneer and leading role in related research fields. The main activities of CIAE are oriented towards the following: R&D and application of nuclear energy and nuclear techniques; fundamental research of some hi-tech and basic science on nucleus, especially low energy nuclear physics and radiochemistry; promotion of non-nuclear application for national economy in combination with the technical advantages of the institute.

CIAE is composed of five departments: nuclear physics, reactor engineering and technology, radiochemistry, nuclear technique and computer applications, isotope. two divisions: health physics and radiation metrology, two shops: machine and electronic instrument and two centres: centre of scientific and technological information, centre of education and training.

CIAE is equipped with three research reactors; four zero power facilities; around ten low energy accelerators: 30 MeV high intensity cyclotron, 13 MV tandem, 14 MeV electron linac and so on.

The major research fields of nuclear fundamental research are experimental and theoretical physics, nuclear data measurement and evaluation, condensed matter physics — application of thermal neutral scattering, intense particle beam, laser physics and fundamental chemistry. R&D of nuclear energy focuses its studies on reactor engineering and technology. Research activities are conducted in the area of experimental and theoretical reactor physics, nuclear material, nuclear fuel element and its post-examination, thermohydraulics, hydrochemistry and sodium technology, The interest is also concentrated to the development of nuclear power reactor technology and its safety, nuclear chemistry and radiochemistry.

The activities on applications of nuclear techniques are R&D of accelerator technique and irradiation technique, nuclear electronics and detector techniques, radioisotope and stable isotope production.

Nuclear techniques for general purposes are: health physics, radiation protection, radiation metrology, computer and computational mathematics. CIAE also has the activities on applications of non-nuclear techniques such as fine chemicals, oxygen-measuring devices for industrial furnaces (ZrO_2) and so no. Graduate school, and nuclear industry school are located in the same area. Training courses on special topic are held now and then.

The publications and journals in Chinese or in English organized by CIAE: Science and Technology of Atomic Energy, Chinese Journal of Nuclear Physics, Nuclear Chemistry and Radiochemistry, Isotopes except annual report of CIAE. Total employees of CIAE are 3500 and half of them are scientists or engineers.

Strengths and limitations

The knowledge and experiences accumulated in 50 years have helped CIAE play an important role in nuclear science of China and make influence in the world. The heave water experimental reactor and the cyclotron put into operation in 1958 in CIAE were the symbol of China entered the Atomic Age. Many outstanding scientists have been training and making their contribution to the courses. There were 23 outstanding scientists who made a historical contribution to the R&D of atomic bomb, missile, satellite praised by Chinese Government. 7 of them have worked in CIAE. China wishes to contribute back to the world by leading the advancement of nuclear science and technology and by promoting the safe and peaceful use of nuclear energy for the betterment of mankind. CIAE becomes a largest consultant organization for such purpose. The operation and utilization experiences on the research reactor have made help for trouble shooting in nuclear power plants. The isotopes produced by reactors and accelerators are widely used for medical or industrial purposes.

CIAE is a research institute on fundamental nuclear sciences. Now the Chinese government pushes all research work to serve the industrial and economy and uses their research results to promote product quality and improve the social living standard. Of course that is complete right. Unfortunately, the results from fundamental research are not so easy to transfer to industry. Therefore it is not easy to get benefit from industry. Meanwhile the financial support from the government reduced year by year in real value estimation. China is one of the most dynamic countries in the world in the course of economic progress. The average income of China increases rapidly also. Many managed well enterprises can attract bright professional people to join. The income of CIAE staff is increasing in recent years, but it is not compatible with managed well enterprises. The brain drain becomes a serious problem. The fundamental research is a kind of job with creativeness. Young talents are really required for CIAE. D & R of CIAE are limited by such difficulty now and in near future if the situation is not changed essentially.

Challenges faced by CIAE

New direction

Currently, with twenty-first century, many challenges lie ahead. CIAE’s major strategy is to seek the new type of nuclear energy according to the development stratagem of energy source of China in long term. Fast breeding reactor is under construction. The purpose of the project is to solve the fuel shortage problem.

Accelerator drive system (ADS) might be a way to explore new type of nuclear energy source. The preliminary research work on ADS has started this year. The future aims might toward spent fuel transmutation, or energy production if it is possible. So far the target is limited to build a strong intensity accelerator injector (2.5 MeV, peak current 60 mA).

Peaceful use of nuclear science and technology to enhance quality of humankind life is our objects. Environment protection, new material served for the people's living condition and isotope production and R&D of applied electronic instruments based on radioisotopes are the main interests of CIAE. In these fields, radiation technology used for coal fired flue gas treatment is proposed. Radiation disinfecting of Chinese herb medicine, radiation has also applied for sterilization of medical supplies, food irradiation and so on.

Innovation in basic science and nuclear technology are expected in 21st century by use of high intensity neutron flux. CIAE has launched 60 MW China Advanced Research Reactor. The neutron flux will be 8×10^{14} /cm^2/sec. The future research is continued on the mechanism of the enhancement of neutron diffraction, structure analysis and dynamical properties of superconducting material, particularly high “T” materials, magnetic materials, hydrogen storage materials as well as various crystals and amorphous materials.

To enhance the fundamentals research a Radioactive Isotope and Nuclear Structure Study Facility (RINSS) is proposed. The project will base on an existing HI-13 tandem accelerator that put into operation in 1987. It will be extended to combine with other two new accelerators: The pre-accelerator will be a 100 MeV high beam intensity proton compact cyclotron, A superconducting linac will used as a booster. The proton cyclotron will be used for R&D of radioactive isotope production, study of nuclear structure and radiation physics if it operate along. And the cyclotron will be used for the production of radioactive nuclei to be isotopically separated by an on-line mass separator and injected into the pre-existing HI-13 tandem accelerator for RIB experiences with lower energy. A superconducting heavy ion linear accelerator (LINAC), booster, high intensity and high energy resolution RNBs of A ~up to 140 can be obtained with energies above the Coulomb barrier (ISOL).

Examples of successful orientation

Part of fundamental research of CIAE transfer to application is a successful orientation. Nuclear techniques are oriented towards the research, development and application of accelerator and irradiation techniques. Co-60 source irradiation, radiation chemistry and irradiation technology are the successful example. NTD mono-crystal silicon and its processing, nuclear well logging, industrial testing and measuring devices (e.g. radiography accelerator, radioisotope instruments etc.) nuclear electronics and detectors (e.g. smoke- and temperature- sensitive detectors as well as their measuring and control system and other relevant fire fighting products: fire alarm systems), nuclear analysis (neutron activation analysis and ion beam analysis), electron magnetic separators and stable isotope production, etc.

R&D of radioisotopes, radioactive source, labeled compounds and radioimmunoassay kits have brought significant benefits to CIAE. More than three thousand hospitals in home and abroad use isotope products produced by CIAE. Social opinion supports such actions since it provides variety of nuclear medicine for therapy or diagnostic. Meanwhile one-fifth budget of

CIAE comes from the isotope products for medicine or industrial use. Many electronic instruments based on radioisotope applications are originated such as radiotherapy simulator, bone densitometer, teletherapy unit, instrument for prostate hyperplasia treatment and so on.

Research reactors made all isotopes only in CIAE five years ago. Thanks to a 30 MeV cyclotron put into operation in 1995, many short live time isotopes have been producing. Some medium life time isotopes have been exported to developed countries except varieties of short lifetime isotope supply for the hospitals in China, like ^{18}F, for PET.

Nuclear safety is one of the largest concerns of public. Safety of nuclear power plant is a sensitive point. CIAE has made every effort to help the nuclear power plants in China get highest reliability and utmost safety. CIAE play an advisor roles when a new nuclear power plant is proposed. Experts from CIAE are sent to the nuclear power plants whenever they have engine trouble or maintenance requirement. CIAE experts are successful to help them solve many operation problems.

Some critical and fuel tests have been taken in the research reactors of CIAE. The spent fuel has been checked in CIAE. Proposal of decommissioning of research and power reactors have been put forward. Successful experiences on reactor physics, nuclear material, nuclear fuel element and its post-examination, thermohydraulics, hydrochemistry and sodium technology plus many test facilities like nuclear material laboratory with nuclear fuel assembly and material testing hot cell, fuel assembly testing loop, sodium dynamic corrosion testing loop, re-submerged heat transfer testing loop have proved CIAE has ability to design new type reactors. Now there are two reactors are under construction in CIAE: China Advanced Research Reactor (CARR) and China Experimental Fast Reactor (CEFR). It should be noted that CARR would use low enrichment uranium (LEU) as fuel. The enrichment will be lower than 20%. And the neutron flux will be 8×10^{14}n/cm^2/sec. That is a tough design task!

Works on health physics serve for radiation protection and environmental protection of the institute. The assessment of environmental impact is also conducted in CIAE. Environmental radiation continuous monitoring system with high pressure ionization chamber.

Preservation of expertise

Basic research:

Nuclear physics including experimental and theoretical, nuclear data measurement and evaluation, condensed matter physics with thermal neutron scattering, intense particle beam and laser physics have made excellent progress, such as in-beam spectroscopy, heavy ion fusion reaction, light particle nuclear reaction, polarization phenomena, measurement of cross section of neutron nuclear reactions, secondary neutron energy spectra, nuclear fission, neutrino measurement, theoretical calculation of nuclear data, nuclear microscopic optical potential, few-body and nuclear matter problem, nuclear high spin states, reaction mechanism of intermediate and high energy heavy ions, non-equilibrium process in nuclear reaction as well as the basic problem of nuclear force and elementary particles. Theoretical research of condensed matter and free electron laser are also being conducted. Further research on the mechanism of the enhancement of neutron diffraction, structure analysis and dynamical properties of superconducting materials, high power electric pulse, production of intense particle beam and its transmission and interaction with matter, excimer laser pumped by intense electron beam.

Radiochemistry:

Concerning with chemistry: actinides chemistry, especially transplutonium chemistry, fission chemistry, co-ordination chemistry and separation chemistry. Also methods of waste treatment, liquid or solid

Reactor technology and related research:

Various tests are being conducted at hot-laboratory for nuclear fuels and materials irradiated in reactors. Production of silicon semiconductor is also carried on reactor applications. Neutron scattering experiments: by examining the status of scattered neutron as a material, or materials' atomic/molecular structure and kinetic status can be determined by computer analysis. Neutron activation analysis is also preserved to be developed.

Interaction of CIAE with their environment

Social and economic sector

CIAE has tried to change its part of fundamental orientation towards to applied science in last more than ten years. Thus social and economic environment is important to CIAE. CIAE has been promoting joint venture in home and abroad. CIAE has superiority of know-how over other social or economy enterprises. But the enterprises have advantages in management and financial ability. To transfer the know-how into the production, it is our basic police to collaborate with social and economic sectors to form hi-tech industry. CIAE now set up few joint-stock corporations with other industrial enterprises. CIAE is responsible for R&D of hi-tech. The fire alarm system product is one of examples.

Academia

Talent problem, especially young, becomes a bottleneck for the development of CIAE. To attract more bright young talent to join us a few academics centres are set up with universities. For example, CIAE and Beijing University have set up a nuclear science centre. The students from the university join us to do research work and CIAE becomes their practice base. Once the students are interested in the job though their thesis, they would like to join CIAE. Even the students just do their thesis in CIAE and do not intend to join us, some technical tasks can be complemented since their thesis are connected with our research work. Good relations have been established with some other institutes because the new scientific points with creative power usually happen in the intersect of two or more disciplines.

Public

Public opinion influences the support from the government and other resources. We have tried hard to win the public support. Public is afraid of safety problem happen. Public is afraid of radioactivity near their home. They are against reactors being built once some nuclear accident happens anywhere in the world. We have to do explanatory statements to the public. Of course, it is most important for public understanding to keep safety for our nuclear facilities. Open days of CIAE help public to understand us.

Collaboration and co-operation

North-South and South-South

Collaboration on safeguard with research institutes of US is an example of North-South collaboration. Also collaborations of CIAE and many institutes of the world have been established. There are many exchanges of scientists with Europe, the States, Russian and Japan every year.

Miniature neutron source reactors developed by CIAE as collaboration projects have been installed and operated in Pakistan, Iran, Syria, Ghana, and Nigeria. The 15 MW experimental heavy water reactor operated in Algerian is considered as an example of South-South collaboration. Besides there is a zero power reactor assisted by CIAE works in Iran. All are united to realize the full potential of the 21st century in partnership with CIAE.

IAEA role

CIAE has been cooperating with IAEA well since China affiliated IAEA. CIAE has played an active role in the regional co-operation programs in Asia (RCA). Collaboration of CIAE and IAEA has increased year by year. Fruitful results have been obtained both by assistants from IAEA or contribution to IAEA from CIAE.

CIAE cooperating with IAEA to organize seminar on related specialty topic were 13 times and participates were 261 in last decade. And same time IAEA and CIAE co-sponsoring international training classes on nuclear technology were hold 11 in CIAE, 161 students came from abroad. 253 experts from CIAE attended IAEA activities supported by IAEA, including scientific inspect, meeting, workshop or training. Near 20 experts from CIAE carried out the program abroad supported by IAEA about $100 k in last ten years. CIAE got budget of TC program from IAEA is about $1M during the decade. During 1999–2000 financial year there are three TC projects: Study on nationwide monitoring of size fractionated air particle matter using nuclear analytical technology; Development of radioactive label peptides for tumor diagnosis; Using radiotracers to determine residual oil saturation. Total budget of the projects is around $500 k. The collaboration of CIAE and IAEA help the use of atomic energy for the peaceful purpose in China.

Meanwhile many other actions are assisted by IAEA. Such as miniature neutron source reactors installed in Syria, Ghana, Nigeria is the projects supported by IAEA.

Other issues considered relevant

With the 21st century near at hand, our aim is to make CIAE become world-class multi-disciplinary research institute in nuclear science, technology and engineering. Now China is one of most dynamic countries in the world, but it is still a developing country and financial support to CIAE is limited. With economy progress of the country, CIAE itself renovation, research orientation towards to peaceful use, globalized management concept, armed with top-class technology CIAE would become a initiative pioneer and great support in the nation’s economic development.

Meeting on NRC would provide a chance to exchange the idea and opining how to manage the NRC well. 21st is a new century full of hope of human being. NRC should use their advantages in hi-tech to help the world to realize their dream! We, CIAE will do our best!

Nuclear Research Institute Rež:
Its past and present and future challenges

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Abstract . The paper gives an overview of the history of the Nuclear Research Institute Rež development over forty years of its existence. Its present activities are discussed in some detail. These historical and present activities represent the basis for discussing:

- challenges faced by the NRI
- interactions of NRI with their environment
- collaboration and co-operation

nuclear research centres would continue to be the main source of expertise for power plant operation, radiation and isotope applications, regulatory practices and waste management. Future developments should ensure viability of these centres.

History and present activities

In the beginning, the Institute of Nuclear Physics of the Czechoslovak Academy of Sciences was founded on June 6, 1955 as a centre of all nuclear activities to support their rapid development which had at the time begun.

Subsequently, at Rež near Prague a number of original facilities: 2 MW research reactor, cyclotron, hot and semi-hot laboratories and some other were constructed in a very short time, indeed (for details see the Appendix).

As a result of fast advancement of nuclear power the Institute with 1450 employees, was on January 1, 1972 divided into two unequal parts. The larger one (1050 employees) predominantly engaged in applied research was transferred as the Nuclear Research Institute under the competence of the Czechoslovak Atomic Energy Commission; the smaller part — basic physical research — remained within the Academy of Sciences as two of its Institutes.

On December 31, 1992, the NRI, along with all applied research organisations, has been privatised and became the NRI Rež plc. Present NRI shareholders are actually its main customers: the state (Czech Republic), Czech Power Company (ÈEZ, a.s.), Slovak Power Company (SEP, a.s.) and ŠKODA Nuclear Machinery (a minor shareholder is village Rež.

The NRI activities have always followed the national programme of peaceful use of nuclear energy and the necessary development of the relevant scientific issues has always had a necessary priority. During its forty-five years of existence the Institute's orientation was developing along with the development of Czechoslovak (Czech) nuclear programme, and especially its nuclear power part.

The following diagram summarises the main R&D topics (as well as service oriented effort) pursued by the NRI over 40 years period, as its was summarised at the occasion of its 40th anniversary. In the periods of 1955 — 1972, i.e. when NRI had been an Academy of Sciences Institute, its operation was completely covered by the state budget. Since 1972 up to 1992 the

Institute was operated as a state subsidised organisation (no depreciation, completely state-financed investment and state subsidies for operation of the large facilities). The R&D projects were, with a few exceptions completely covered by the state (Nuclear Safety Research Project, etc.), were as a rule financed by the state (50% of costs) and industry.

At the 1992 transformation, there are no direct state subsidies, as it is common for all applied research institutions in the Czech Republic. This situation is, however, being reconsidered in connection with the preparation of a new state research policy. Thus, the Institute financial sources are either contracts with individual customers, contracts with the state administration bodies awarded as result of a specific tender, or the state financial support for R&D activities (usually limited by up to 50%, as it had been in the past). Revenues from the contracts with the Czech customers in 1998 represented 50.3% and state resources — of 15% order of the total revenues (see enclosed Annual Report 1998).

Such transformation was accompanied (in 1989 — 1993) with reduction of the Institute's staff from 1050 to 600, partially due to outsourcing of some service activities and partially due to an increased staff efficiency.

Current main activities of the Institute are well supported by a number of special facilities:
- experimental reactor (10 MW) with several material testing loops (PWR and BWR simulation),
- zero-power reactor (LR-0),
- cyclotron (for production of PET radiopharmaceuticals),
- electron accelerator,
- Co and other irradiation sources,
- facility for testing the large components integrity,
- molten salt loop for material testing,
- unique system of hot and semi-hot laboratories,
- experimental facilities for nuclear waste solidification (bituminization, cementation and vitrification),
- technological halls,
- laboratories specifically equipped for the production of radiopharmaceuticals, including cyclotron ones (PET),
- analytical and a number of other well equipped laboratories.

These activities are oriented on the following fields:
- support for safe operation of Czech nuclear power plants,
- support of the Regulatory Body activities,
- support for the Waste Management Agency,
- contract based R&D and services for foreign organisations,
- production of radiopharmaceuticals,
- services for basic research,
- know-how transfer to non-nuclear industry (chemical, oil processing, aircraft industry),
- technology supplies,
- support of the governmental activities in relevant policy development.

A major part of this effort are services and production, nevertheless, R&D remain a significant part of the Institute activity. R&D is financially supported by the Czech government, and recently also by the EU (within the framework of 5th EU Framework

Programme). This activity is of course greatly benefits from the international, multilateral and bi-lateral co-operation, as it always had been.

Challenges faced by the NRI

As with many other nuclear research centres, our Institute faces many challenges and connected with them difficulties, some of which are common and some of them are specific.

Our first and most important challenge is to provide such a support to Czech Operator of nuclear power plants (WWER) which shall assure their safe and efficient operation and optimum life utilisation. Along with that we shall participate in maintaining the infrastructure necessary for adequate safety culture and long term needs of the nuclear industry.

According to the state energy policy, the Czech Republic will in the years 2015–2020 need a new electricity generating capacity (as a result of service life exhaustion of many coal-fired plants as well as of exhaustion of the national coal resources). One of the answers to such demand is an innovative nuclear power plant. It is vital importance that Czech industry will participate in such project by supplying some of components. The NRI itself should take part in the global effort directed towards development of a new nuclear source.

Similar challenge represents the back-end fuel cycle. Since the state guarantees the waste management, the first priority is an optimal strategy which recently became a most difficult task concerning both its timing and option selection. No less important is again to assure sufficient participation of the local industry.

Similar challenges as in the nuclear energy exist in:
- radioisotopes application in the health care,
- industrial application of the radiation technologies,
- non-nuclear applications for other industry branches.

Again the same as all other nuclear centres we have to deal with old burdens and liabilities, including research reactor spent fuel.

As an example of successful orientation we could present recent commissioning of our PET Centre (operated in co-operation with Prague hospital Na Homolce).

Interactions of NRI with their environment

For the NRI a most important interactions are those with the Czech universities from where the Institute recruits its young specialists, and basic research (Academy of Sciences). The tool the NRI uses to achieve the related goals is the Scientific Council of the NRI, several members of which come from the universities and Academy of Sciences. It is worth mentioning that The NRI has a detached workplace at the Prague Technical University.

At present, public relations become one of the critical issues of any activity with high-tech having its associated degree of risk. From time to time, the Institute organises „open door day“ for the public when they have an opportunity to visit our facilities. The NRI gradually increases its co-operation with mass media, inviting reporters to the Institute and providing them with the relevant information.

Collaboration and co-operation

In addition to the existing co-operation the NRI is looking forward to strengthen its co-operation in:

- Region-based co-operation, namely focused on WWER reactors operation and
- Technology transfer to developing countries (as an example — our radiochemicals production technology transferred to Egypt).

Other issues

The most important issue, as we can at present identify, is to increase the state financial support of nuclear research centres to assure that the nuclear expertise acquired is preserved and enhanced, so the young generation of scientists, educated and trained in such centres, is prepared to take over and continue our effort in the future.

Conclusions

Experience of the NRI forty years development is in many features similar to that other large nuclear centres. For future development, it is to be very important that such centres should keep their position as main sources of the relevant expertise, especially in the nuclear countries.

To achieve this goal it is necessary to:

- formulate new goals,
- establish international co-operation among the Centres, and
- provide adequate financial resources.

Appendix

THE HISTORY OF NUCLEAR SCIENCE AND TECHNOLOGY IN THE NUCLEAR RESEARCH INSTITUTE REŽ

The NRI in Fifties

Year	1955	1956	1957	1958	1959	1960
Personnel Number	183	466	549	633	716	833

Milestones and topics:

- **June 6, 1955** — NRI Establishment
- NRI enters the framework of the Czechoslovak Academy of Sciences in 1956
- Construction of U-120 Cyclotron laboratory, laboratories for physical research and radiochemistry, linear accelerator laboratory
- **Sept. 25, 1957** — Research reactor VVR-S put in operation

Programmes:

- Development of devices for radioactivity measurement
- Radiochemistry, uranium refining and metallic uranium production, radioisotope separation
- Exploratory studies on power reactors
- Neutron physics, neutron diffusion in water and graphite
- Beta- and gamma-spectroscopy development
- Cosmic rays studies

The NRI in Sixties

Year	1962	1964	1966	1968	1970
Personnel Number	1083	1216	1299	1350	1404

Milestones and topics:

- The hot, semi-hot and alpha-chemical laboratories opened in 1962

Programmes:

- Theoretical and experimental reactor physics, thermal reactor calculations, fast reactor calculations, shielding calculations and experimental verifications
- Reactor technology, heavy water reactors calculation, power reactors operation safety, sodium thermokinetics
- research, studies of organic-cooled heavy water reactor
- Alternative reactor studies
- Reactor materials research, studies of non-metallic reactor fuels, study of clad metallic fuels, research of steels for reactor pressure vessels
- Study of chemical extraction processes for uranium separation from plutonium and fission products
- Spent fuel reprocessing, PUREX method and dry fluoride method
- Fluoro-compounds production for industrial non-nuclear purposes
- Waste management

- Radiation chemistry
- Nuclear spectroscopy
- Low temperature physics and technology

The NRI in Seventies

Year	1972	1974	1976	1978	1980
Personnel Number	1068	1067	1066	1064	1065
Costs (Thousands Kcs)	66.600	139.964	158.936	175.806	236.584

Milestones and topics:
- **Jan. 1, 1972 — The** NRI splits. The greater part under the name NRI with applied research and technology supporting power production is subordinated to the Czechoslovak Atomic Energy Commission, the other part with basic, mainly physical research remains in the framework of Academy as the NPI.
- **July 1, 1973** — Heavy water zero power reactor TR-0 put in operation

Programmes:
- Development of fast breeder reactor for Czechoslovakia, core studies, shielding, experiments on sodium loop and pipeline, complex calculations of fast power reactor, accident and transient processes assessment, thermo- and hydrodynamic experimental research on fuel assemblies, sodium device development,
- Research and development support of A-1 (NPP with a heavy-water gas-cooled reactor) with an aid of the reactor TR-0
- NPP fuel cycle studies, ceramic fuels for fast reactors, mixed fuel preparation using sol-gel method
- Studies of cladding materials in the conditions of fast reactors cores, studies of Zr-alloys
- Spent fuel and radioactive wastes management
- Water chemistry of light water reactors
- Radiation chemistry
- New types of semiconductor detectors development
- Activation analysis
- Services for health institutions, radioisotope production, research, development and production of radiopharmaceuticals and Ir wires for application in medicine and biology
- Application of the sol-gel method in non-nuclear fields

The NRI in Eighties

Year	1982	1984	1986	1988	1990
Personnel Number	1055	1042	1040	1034	892
Costs (Thousands Kcs)	188.023	171.080	159.147	184.292	221.961

Milestones and topics:

- **July 7, 1983** — light water zero power reactor LR-0 put in operation
- **Aug. 8, 1989** — light water research reactor LVR-15 put in operation
- Semi-hot metallurgical line for irradiated reactor materials testing opened
- A mobile calcination unit for rad-wastes solidification developed and manufactured in 1984

Programmes:

- Research, development and services for NPP with WWER reactors, reactor physics, measurements of basic physical parameters of hot zones with WWER fuel assemblies in the LR-0 reactor
- Reactor materials research, reliability and life-time of reactor pressure vessel and fuel assemblies in operational conditions
- Reactor safety, codes development
- Studies of fast reactor hydraulics
- Studies of radioactive wastes management from Czechoslovak NPP, solidification, vitrification, safety assessment of repositories for low and intermediate level waste
- Services for health institutions, radiopharmaceuticals production, irradiation of materials and instruments for medical use
- Irradiation of art monuments, foodstuffs, cable insulators ageing
- Production of semiconductor detectors

The NRI in Nineties

Year	1992	1994	1996	1998	
Personnel Number	737	597	599	625	
Costs (Thousands Kc)	271.663	266.500	395.100	433.300	

Milestones and topics:

- **Dec. 31, 1992** — privatization of the NRI
- A new Quality Assurance Manual issued in 1998
- A facility for stress corrosion cracking testing has been designed, built and exported to Mexico
- A new reactor water loop RVS-4 put in operation in 1998

Programmes:

- Theoretical and experimental reactor physics, fluid flow and heat transfer, reliability and risk analyses, thermal hydraulic analyses, severe accident analysis, fuel behaviour analysis, neutron and photon transport computations, research on accelerator driven transmutation technology applicability, spent fuel storage analysis
- Integrity and materials research, elaboration of a new Supplementary surveillance programme, evaluation of irradiation stability of reactor pressure vessel cladding in-440 reactors, studies of steam generator tubes degradation, assessment of the secondary piping integrity
- Experiments and measurements on the reactor LVR-15, water chemistry and material testing, corrosion tests, neutron fluence determination for the surveillance programme, gamma spectrometry, experimental verification of the epithermal neutron beam characteristic for boron neutron capture therapy
- Fuel cycle chemistry, fluorine chemistry , research on preparation and behaviour of suitable fluoride melt mixtures for the accelerator-driven homogeneous transmutation reactor technology, separation of radionuclides by extraction methods, waste management and technology, solidification and disposal

- Services for health institutions, production of radiopharmaceuticals
- Radiation applications, ageing of safety-related cables for NPP, sterilization of medical materials, testing of the reliability of electrical components and chemical stability of materials in radiation environment

The Risø National Laboratory, Denmark

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Abstract: The Risø National Laboratory of Denmark started as a nuclear research centre, under the Atomic Energy Commission in 1955, with research reactors, an accelerator and related facilities. The research component, aimed at the introduction of nuclear power plants in Denmark, was wound up in 1985 with the country deciding to forego nuclear power in its energy planning. From 1993 the centre is under the jurisdiction of the Ministry of Research with three main areas of work: i) research on high international level; ii) train researchers; and iii) provide service to industry. The centre is funded up to 53% by the Danish Government and 47% by contract earnings. Some areas of current research include: i) materials science; ii) optics and sensor systems; iii) plant production and ecology; and iv) systems analysis. The nuclear component of the research centre is related to the operation of the nuclear facilities and for maintaining national expertise in nuclear safety and radiation protection.

Risø's history in brief

The Danish Atomic Energy Commission was created in December 1955 with Niels Bohr as its first chairman. The peninsula Risø at Roskilde Fjord, 40 km from Copenhagen, was chosen as site for the commission's research centre. Construction works were started in 1956 and the official inauguration of the centre took place in June 1958. The first small reactor DR1 went critical already in August 1957, followed by the larger research reactors DR2 in December 1958 and DR3 in January 1960. DR2 was closed in 1975, while DR1 and DR3 are still in operation. In addition to the reactors, Risø has had an electron accelerator, a hot-cell facility, and a treatment plant for radioactive waste in operation for many years. The hot-cell facility was closed in the mid 1990s.

During the first two decades nuclear research in a broad sense dominated the work at Risø, partly preparing for the introduction of nuclear power plants in Denmark. However, more generally oriented research in natural sciences and engineering also played an important role. In 1976, when nuclear power was heavily debated in Denmark, it was politically decided to postpone the decision of introducing nuclear power plants until further studies of reactor safety and disposal of radioactive waste had been carried out. At the same time the Atomic Energy Commission was abolished and in a new law the purpose of Risø was defined more broadly to be energy research in general but still including nuclear energy. In 1985, The Danish Parliament decided that nuclear power should no longer be included in Danish energy planning, and the purpose of Risø was restated to being scientific and technological research centred around energy. Nuclear research should still be included to the extent needed as a basis for operating Risø's nuclear facilities and for maintaining a national expertise in nuclear safety and radiation protection.

In 1990 a major reorganisation took place at Risø. Some departments and areas of research were discontinued while others were initiated. It was defined that Risø's research should mainly be concerned with energy, environment and materials. In 1993, Risø came under the jurisdiction of the newly established Ministry of Research, and from January 1994, Risø entered into its first four-year contract with the ministry. From January 1998, a new four-year contract went into force, which stipulates that Risø shall continue to carry out research on a high international level and will also be evaluated on its ability to service industry and to train new researchers.

The number of employees at Risø reached a maximum in the late 1980s of about 1000. During the 1990s the personnel has amounted to between 899 and 974 man-years per year until 1998 where it was reduced to 863. There has been a steady shift from technical and administrative staff to academic staff during the years, so that now more than half of the staff is academic staff including post docs and Ph.D.-students. In 1998 the annual turnover was about 500 million DKK, of which 53% was government appropriations and 47% was contracts earnings.

The present situation

Risø's transformation from a nuclear research centre to a national laboratory beginning in 1976 has been successful, and Risø has been commended for carrying out this transformation in a timely and efficient manner. Nevertheless, there have been many discussions about Risø's role during the last decade. Today Risø's role is to carry out research within science and technology, providing Danish society with new opportunities for technological development. The research aims at strengthening Danish industry and reducing the adverse impact on the environment of the industrial, energy and agricultural sectors. In addition, Risø maintains the scientific and technical knowledge needed for advising the authorities and the public on nuclear matters. Risø's research is now organised in seven programme areas that can be shortly summarised as follows:

Industrial materials: Development and studies of materials technologies to find economically feasible and safe applications for advanced materials. The activities cover long-range research, design and testing, and are particularly directed towards the energy and industrial sectors both in Denmark and internationally. The key areas of expertise are materials physics, solid state mechanics, electro-chemistry, materials technology, and mechanical design and testing, as well as interdisciplinary combinations of these areas.

New functional materials: The research focuses on the synthesis and structural characterisation of materials, including new polymers, at the atomic, molecular and supramolecular levels. A significant part of the research utilises neutron radiation from the DR3 reactor and X-radiation from the synchrotron facilities in Hamburg and Grenoble. In this connection work is carried out on developing advanced methods, as well as theory and computer simulations. The key areas of expertise are condensed matter physics, structural chemistry, chemical synthesis, and interdisciplinary combinations of these areas.

Optics and sensor systems: The research aims at the understanding of nonlinear processes in optical and fluid dynamic systems as well as the development of diagnostics methodology and information processing that can be applied in research and industry. The foundation is laid for new types of miniaturised optical systems, including systems for image and pattern generation. A new area of research is biomedical optics. Key areas of expertise are physical optics, continuum dynamics, mathematical-numerical methods, and information processing.

Plant production and ecology: The research is primarily directed towards the need for cost-effective plant production with minimal adverse impact on the environment, Besides this, the research helps to alleviate and restrict adverse impact on the environment resulting from energy consumption and industrial production. Key areas of expertise include genetics and genetic engineering, chemistry, ultra-sensitive analyses of trace elements, as well as controlled multi-parameter experiments in the RERAF greenhouse facility. RERAF is Risø's Environmental Risk Assessment Facility, where experiments are carried out in areas such as the interaction between plants and micro-organisms, the development of new plant properties by means of transformation, as well as assessment of risks from spreading genes.

Systems analysis: The objective of the research is to develop and apply methods and models to provide Danish society and international organisations with an improved basis for decision-making concerning technological priorities in society. Key areas of expertise are systems reliability, organisation, informatics, simulation methods, work studies, economics, experimental psychology and technological foresight. The UNEP Collaborating Centre on Energy and the Environment, financed by the UN, Danida and Risø, provides technological-scientific support to the United Nations Environmental Programme through energy and environmental projects in a number of developing countries.

Wind energy and atmospheric processes: The research is concerned with the development of methods for designing, testing and siting wind turbines, determining wind loads and wind resources, as well as methods for determining dispersion of air pollution. The key areas of expertise are boundary layer meteorology, aerodynamics, aero-acoustics, and machine and construction technology, exploiting full-scale field tests and advanced numerical simulation. Risø operates test stations for wind turbines at Risø and in Jutland with the purpose of promoting the use of wind energy in Denmark and abroad through the testing, approval and certification of wind turbines.

Nuclear safety: The research addresses the needs of governmental authorities and others for consultancy on nuclear and radiation matters and the operation of Risø's own nuclear facilities. The research areas include nuclear safety, radiation protection, radioecology, and the development and application of nuclear methods for tracer studies and other applications. Key areas of expertise are reactor physics, radiation protection, radioecology, radiation measurements, dosimetry, dispersion and dose calculations, and contamination physics.

Risø's interaction with the Danish society

In 1997 an international evaluation of Risø was carried out. Among the conclusions were that the overall quality of the science at Risø is very good, but it is an important challenge to Danish society to find more effective ways of utilizing Risø for the benefit of Danish industry and the educational system. Risø's interaction with the Danish society has been extended during recent years and can be viewed as taking place within four areas.

Research: The collaboration with universities and government research institutes entails obligations for both parties and involves the development of more operational and integrated forms of collaboration. For example, Risø and the Technical University of Denmark (DTU) have entered into three agreements under the national strategy on materials research. This implies that a new joint centre for polymer research and two joint programmes, one for materials research on the nanometre and micrometre scales, the other for biomedical optics, have been set up. The agreements cover an exchange of staff, whereby Risø becomes involved in teaching at DTU and DTU becomes involved in Risø's research. As another example, Risø has entered into an agreement with the National Environmental Research Institute (DMU) implying that the activities of the DMU Systems Analysis Department and Risø's research programme Energy Systems Analysis are being integrated into a new Centre for Analysis of the Environment, Economy and Society, whereby the two institutions will co-ordinate their efforts in this area, sharing tasks, finance and management.

Education: Risø has been engaged in education of researchers for many years offering Ph.D.-projects at Risø in co-operation with the universities. This has been intensified during the 1990s where also an increasing number of post docs, many of them from other countries, have received training at Risø. Since 1996, the number of Ph.D.-students and post docs at Risø has exceeded 100 man-years per year. A number of Risø employees have also contributed to the teaching at the universities for many years on an ad hoc basis. It is expected that more Risø staff will be involved in teaching at the universities during the coming years in connection with the extended research co-operation between Risø and the universities. Risø has also been involved in a few Ph.D. and post doc projects in direct co-operation with industrial companies. More projects of this type are expected in the future in connection with an extended interaction between Risø and industry.

Industry: As one of the means of meeting the challenge of increasing the interaction between Risø and the industry, Risø has entered into new projects with industrial companies implying an integrated type of collaboration, similar to that mentioned above for universities and governmental research institutes. A co-operation with Danfoss A/S concerns the development of artificial muscles, while another co-operation with DLF-Trifolium concerns the development of knowledge to make it possible to control the formation of stems and flowers in grasses. Both co-operations receive support from the Danish Research Councils. The joint work with DLF is located in Risø's Plant Biology and Biogeochemistry Department as an independent programme, DLF-Risø Biotechnology, and is managed by a researcher employed at DLF-Trifolium. In 1998 Risø, on its own or jointly with collaboration partners, has applied for eight patents and entered into seven new licensing agreements on the use of patents and know-how.

Governmental authorities: In the nuclear field Risø has a special role as scientific-technical back-up and as adviser for governmental authorities with an interest in nuclear matters. This is particularly the case for the Emergency Management Agency under the Ministry of the Interior and for the National Institute of radiation Hygiene under the Ministry of Health. There is a formal co-operation agreement between Risø and the Emergency Management Agency. In addition, Risø also acts as adviser in other areas, e.g. for the Ministry of Energy and Environment.

International collaboration

Risø has always been strongly involved in international collaboration. The research is carried out in a world-wide co-operation with other research institutes and other partners. The research reactor DR3 is appointed as a European Large-Scale Facility and the neutron beam instruments are intensively utilized by researchers from Risø and from other EU-countries. Risø also participates in the EURATOM research programmes on fusion, fission safety and radiological sciences, and to a larger extent in the EU non-nuclear energy and other programmes. There has been a close co-operation on nuclear safety research (the NKS programme) among the Nordic countries for many years, and in the 1990s the collaboration with East European countries has been extended. Risø collaborates with a number of international organisations, in the nuclear field notably with the EU, IAEA, ICRP and OECD/NEA. Risø operates the UNEP Collaborating Centre on Energy and the Environment, supporting the United Nations Environmental Programme.

Future challenges

In 2000, Risø will work out a new strategy which will form the basis for new contract negotiations with the Ministry of Research in 2001. It may be expected that Risø shall further develop the interaction with industry, the universities and other research institutes, the governmental authorities, and the society in general.

In the nuclear field the main challenges will presumably be to prepare for the eventual decommissioning of Risø's nuclear facilities, and to maintain a national expertise in nuclear matters through transfer of knowledge and skills to the young generation.

The future operation of DR3 will be influenced by the continued need for neutron sources in Europe and how this need can be met. However, in a 10–20 years perspective it is to be foreseen that, with the exception of the Waste Treatment Plant, the nuclear facilities at Risø will all be in some stage of decommissioning. For DR2 and possibly DR1 the decommissioning could even be completed already during the next decade.

As part of the work on a new strategy, the possibilities of new large research facilities at Risø will be discussed. In addition, Risø will take part in international efforts, such as the preparations for a large European Spallation Source.

Nuclear research centres — the Egyptian experiment

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Abstract: The Atomic Energy Authority of Egypt has four research centres located at two sites. Its research reactors are devoted to the production of isotopes, neutron beam experiments, activation analysis and materials research. The accelerators are devoted to the production of short lived isotopes for medical applications and materials R&D. Irradiation technology is used for sterilization of medical supplies and food preservation. High level of expertise in those centres is also useful for other developmental activities in Egypt.

Introduction

AEA was established some forty years ago, to take the lead in research and development in the nuclear field in the country. In 1959, a Van de Graff accelerator and a nuclear physics laboratory were inaugurated. Two years later, the first research reactor (No.19 in the world at that time) went critical. An isotopes production laboratory became available late in1962. AEA had, always, managed to provide its staff with the best available in training and education. Advanced facilities and tools were made available for both basic and R&D areas.

Nowadays, AEA employs slightly more than 1000 capable scientists, who work in the different branches of nuclear sciences and technologies, in the fields of the peaceful uses of nuclear energy. Their work is supported by almost 700 trained technicians. AEA employ also more than 2000 employees for administrative and housekeeping works.

AEA's operations are managed through the following Research Centres:

Inshas Site

- The Nuclear Research Centre
- Waste Management and Hot laboratories Centre

Nasr City Site

- National Irradiation Research And Technology Centre
- National Nuclear Safety and Radiation Protection Centre

Domains of Activities of these centres include: Research and Technological Projects, Nuclear Regulatory and radiation protection, Providing Services to the community, as well as Regional and International Co-operation.

Domains of Research include:

- Materials
- Engineering
- Physics
- Chemistry
- Life Sciences

Applications

Nuclear power applications: reactors, fuels, reactor materials, instruments
Isotopes applications: medicine, industry, agriculture, drilling, etc.

Technologies involved

Nuclear iechnologies

Research reactors
- Production of Radioisotopes
- Materials and Fuel Research and Testing
- Neutron Beam Experiments (and other applications)
- Activation Analysis
- Preparation of Special Materials (Silicon Doping for Production of Microchips)

Accelerators
- Short-lived isotopes
- Materials R&D

Irradiation technologies

- Sterilization (medical supplies)
- Improvements of materials properties (plastics, woods, .etc.)
- Food preservation (agricultural crops, meats)

These applications are supported by a score of well equipped laboratories (chemical, physical), machine shops as well as maintenance services (mechanical, electrical and electronics)

Financing of NRCs Operations

1. Fixed assets
- Governmental budget

2. Operating costs of facilities
(including addition & replacement of equipment)
- Governmental (contracts with universities and other organizations)
- Services to the Industry
- Sales (Isotopes, simple electronic equipment)

3. Salaries
- Government payroll
- Bonus from contracts

Any reduction made by the government, on the annual allocations, would certainly affect NRCs' operations. These centres, therefore, should seek other resources, to secure the continuity of their activities.

Probable roles for nuclear research centres

- Play the role of the consultant.
- Help to introduce new technologies.
- Development of human resources.
- Upgrading of the local industry.

Consultation services
- Preparation of feasibility studies.
- Preparation of technical specifications in connection with advanced technology projects.
- Engineering design review.
- Preparation of projects engineering documents, including QA, QC, safety, operating manuals and calibration of equipment.

(Case studies)

Case 1. Manufacturing of stainless steel tanks for the MPR research reactor

- main pool
- auxiliary pool
- decay tank

Designer:	INVAP S.E. (the Argentinean vendor of the MPR
Manufacturer:	RATOMAG Engineering Co., 10th of Ramadan, Egypt (original activities metallic kitchen furniture)
Owner:	Atomic Energy Authority of Egypt (AEA)
Auditor:	AEA's MPR Project Engineers.

Case 2: Materials development: *aluminum alloy 6061*

Production of special sections (and subsequent heat treatment), to be used for manufacturing MPR Fuel Elements.

Manufacturer:	Aluminum Co. of Egypt.
Consultants:	Institute of Metals Research.
Owner:	AEA
Auditor:	MPR Engineering Group

Case 3: Construction works:

MPR Reactor building

Owner:	AEA
Engineering:	INVAP (with minor participation of AEA)
Contractor:	Kollaly Engineering Co. (Construction of Buildings and Factories)
Auditor:	MPR Engineering Staff

FMPP Fuel Plant

Owner:	AEA

Engineering: INVAP
Contractor: Kollaly
Consultant: MPR
Auditor: MPR

The benefits were**:**

- Qualification of a local contractor for the construction of nuclear facilities.
- Qualification of MPR engineers as consultant, auditor and design reviewer.

Introducing new technologies to the local industry

- Research
- Pilot plants and demonstration facilities
- Transfer of knowledge to the private sector and help it through the process of acquiring the new technology.

***(Case Study*)**

Transfer of technology for production of heavy water

- The KIMA Fertilizers Co., Egypt wanted to add a unit, to their existing plants in Aswan, to produce reactor- grade Heavy Water, of 25 tons annual capacity.
- AECL is the Proprietor of the CECE and CIRCE processes which are most suitable for this case.
- AEA would eventually act as a consultant and/or a mediator
- Scope of AEA Participation: Back-up during contract negotiations.
- Training of KIMA's engineers and operators, as AEA has a CECE Demo Plant, which is under commissioning now, (20 kg/a capacity)
- Maintenance and services.

Manpower development

Training

- To train and qualify new engineers and technicians for new processes.
- Special classroom courses.
- Field training (NRC's available facilities).

Licensing

For operation and maintenance for personnel and facilities dealing with advanced technologies (nuclear or irradiation), whether belonging to the government or the private sector.

Upgrading of national Industry

- Nuclear Technologies need materials of special specifications or services of certain quality. The local industry might be incapable of satisfying those needs.

- NRCs could help to qualify the local industry, through training of personnel and introducing and enforcing QA & QC concepts to the industry programs. This would certainly lead to quality improvement.
- Tools are training, codes and standards, etc.

CONCLUSIONS

Nuclear Research Centres are unique specialized institutions. They utilize capital equipment (research reactors, accelerators, irradiators, as well as sophisticated analytical tools). They are complementary to Universities and should not be repetition to them. In fact, they are capable of bridging universities with industry and community. The benefits from the NRCs should be maximized and their role in developing the community should be appreciated.

Nuclear research centres in the 21st century: The French perspective

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Abstract. In France the reactor technology is mature and R&D needs for reactors are small. However, there are substantial R&D needs in the electro-nuclear field. These include optimization of operation of nuclear power plants and the associated factories and to have a long term vision for the nuclear technologies. The State continues to be a major provider of resources for the long term strategic objectives. However, lack of resources has resulted in shutting down of some large facilities and it is becoming difficult to refurbish some large experimental tools. The possibility of earning resources through solving complex problems beyond the nuclear field is, therefore, under exploration. Nuclear research centres are also looking into new advanced technologies (energy, micro electronics, materials, bio-technology) and for development of partnership with other public research organisations. The issue of preservation of expertise is being addressed by development of networks between the European centres working in the same field. Cost and risk sharing of nuclear R&D is being pursued by collaboration with countries outside Europe, namely the USAA, Japan and China. Public perception of nuclear energy is being enhanced by opening CEA centres to the public.

Some key elements at the beginning of the 21st century

- Development of networks between research organizations, universities and the industry
- Strengthening international co-operation
- Better use of fundamental research to promote innovative applied research
- Increased use of physical modeling and numerical simulation
- Keep the nuclear option wide open to prepare future energy policy decisions in a changing geopolitical context
- Stimulating R&D with active international co-operation

Past and present situation of nuclear research centres

R&D programmes and the related finances, manpower and infrastructure

Evolution of activities with growing maturity of nuclear technologies

- Decrease of the industrial need for R&D on reactors but a still substantial global need in France for R&D in the Electro-nuclear field
- to optimize the operation of power plants and factories
- to keep the nuclear option open for 2010/2030
- to keep a long term vision on the benefits of nuclear technologies for a long lasting energy policy
- Reinforcement of programmes aimed at other objectives than the nuclear ones within the framework of the energy policy of the government: alternative energies and rational use of energy
- Gathering French potential in nuclear sciences: tightening the links between the CEA and the CNRS

- Active participation in the policy of promoting innovation and the transfer of non-nuclear technologies to the industry, by placing these actions, as often as possible, within the framework of the MENRT technological research networks

Strengths and limitations

- Public resources and manpower generally maintained (significant backing of the State needed for all the long term strategic objectives, less financed by the industry)
  - Decrease (-20%) of income from nuclear industrial partners
  - Finding additional financial backing through new partners (non-nuclear and nuclear)
  - Development of partnerships between French and foreign laboratories
- Ability to solve complex problems beyond the nuclear field (potential of diversification of the activities while remaining within the framework of the missions and expertise of the organization) thanks to the competencies, the multi-discipline nature of the research, the modeling abilities, the specific testing means, the experience acquired from large projects, the co-operation with research and industrial partners
- Maintaining investments and rationalization (on the European level) of large experimental means:
- Difficulties specific to large facilities : shutdown at the end of the programme

(BETHSY in Grenoble), increasing difficulty to renew programs (MASURCA since the shutdown of Superphénix)

- Refurbishing large experimental tools presently in use .for a national decentralization strategy (JHR, successor of Siloe and Osiris in Cadarache, Atalante for the back end of the cycle in Marcoule)
- European strategy for large equipment (synchrotron radiation, accelerators, sources of spallation neutrons for physics and for technological irradiations)

Challenges faced by nuclear research centres

New directions

- New energy technologies: Promotion of innovation and reinforcement of technology transfers to the industry and the SMEs.
- Development of partnerships with other public research organizations (CNRS, INSERM…), with universities (>30 agreements signed), with the industry
  - Reinforcement of international co-operation in Europe and beyond
- Improved use of fundamental research for a more innovative applied research : « Nuclear Sciences » for the Electro-nuclear field, and « Sciences and Basic Techniques » for the development of non-nuclear technologies
  - Increased use of physical modeling and numerical simulation
- Opening of CEA centres to inform the public

Examples of successful orientation

- New technologies for energy, micro-electronics, materials, bio-technologies

- Technology transfer : Technical platforms and Centres for technological resources, Structures for multi-partner incubation, EMERTEC venture funding

Preservation of expertise

- Keeping or reinforcing the co-operation between the nuclear countries of the European Union (nuclear research themes, student and professor exchange programs) Opening the INSTN courses on nuclear engineering to Europe, as well as other specialized courses

- Creation of Centres of competencies through the development of networks between European centres working in the same field (by taking advantage of the EU common research centre (CCR))

- Promoting the transfer of experience and technologies in the nuclear field to the non-nuclear field (prevention, risk management…)

Interaction of nuclear research centres with public

- Opening of CEA centres example : Cadarache centre

Collaboration and co-operation

Civilian nuclear field:

- Cost and risk sharing of nuclear R&D: Active and « strategic » co-operation with other countries in the European Union, Japan and Russia. Reinforcing co-operation with the USAA (renewal of the agreement with US-DOE) and with China

- Adding R&D co-operation to the existing industrial co-operation (Framatome in China, Cogema in Japan)

- Co-operation themes

- Tightening co-operation between EU countries to maintain the level of nuclear expertise in Europe and prevent France from being isolated

- Active participation to the nuclear FWP (fission + fusion)

- Contribution to improving the safety of nuclear power plants in Eastern Europe

- Assistance to new programmes in developing countries

Fundamental research and applied technologies

- Particle physics
- Astrophysics
- Climatology
- Radiobiology, medical imaging

Technology transfer

- 90 contracts within the framework of the 4th FWP

- Agreement with Fraun hofer for the creation of a Franco-German research group on GERAILF lasers

- Development of technology transfers on the European level : opening of offices representing the CEA in Milan, Munich, and Stockholm.

Possible IAEA role

- Promote exchange of information and co-operation between nuclear countries
- Promote harmonization of national approaches and common practices (calogenes, desalination…)

Past and present situation of nuclear research at Forschungszentrum Karlsruhe

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Abstract. The case of Forschungszentrum Karlsruhe is presented which had to transform from a centre devoted to nuclear power R&D to one in which this activity is allocated only 20% of the resources. A large number of operating nuclear power reactors coupled with the Government decision to phase out nuclear power is causing serious concerns regarding the availability of human resources for meeting the long term needs of nuclear facilities. The Energy Division of the research centre currently focuses mainly on safety research and on nuclear fusion. Another Division of the centre has nuclear facility decommissioning as one of the programmes. Independent research in areas of essential need for nuclear facilities must be carried out to maintain know how.

Introduction

The Project Nuclear Safety Research at the Forschungszentrum Karlsruhe co-ordinates nuclear fission research at this research centre, and I will review the situation of nuclear fission research at the Karlsruhe research centre, which I think reflects fairly well the general situation in Germany. I will have a wide look-back into the history of nuclear research, then discuss the present situation and finally say a few words on what we believe are the needs for the future.

Historical perspective

Karlsruhe started in 1956 as a foundation of the Society for Construction and Operation of Nuclear Reactor. The goal was the design and construction of a reactor of German origin, the research reactor FR2, following the famous speech of President Eisenhower in Geneva. This Society had a contribution of 30% Federal Government, 20% local State Government and 50% industry. In 1957 construction was initiated in a forest north of Karlsruhe, which is in the south-west of Germany. This early start was possible because some preparatory work had been done earlier by a group of Professor Wirtz who co-operated already with Otto Hahn in the 40s. In 1959 a Society for Nuclear Research was founded, which was to promote the construction and operation of research and development facilities at Karlsruhe. In this Society there was 75% Government and 25% local state government contribution. FR2 went critical in 1961. Some work on breeder reactors was initiated in 1957 but research activities formally started in 1962. The project “Fast Breeder” was funded with strong international co-operation — there was contribution from EURATOM (40%) and co-operation at international level (France, Belgium, Netherlands). This period in the 60s and up to the end of the 60s represented a rather strong development programme in Karlsruhe. Around 1960 there were 1000 people working at Karlsruhe, in 1962 2000 and by the end of the 60s there were 3000 people working there. There were facilities like STARK, Hot Cells, cyclotron, and other critical facilities like SUAK and SNEAK. In 1969 there was strong international co-operation, a new project for the USAage of actinides and safeguards, SpFK, was also started in this area. In 1968 the decision was taken for construction of a prototype fast reactor in Germany. The fast breeder project took a very significant part — up to 50% — of the research area in Karlsruhe. In 1968 the decision for the construction of a prototype, the SNR 300, was taken in a consortium between Germany, the Netherlands and Belgium. Also a fuel reprocessing facility started to come into operation.

In the 70s some public opposition rose in Germany and this led to new activities, especially concerned with nuclear safety. The project "nuclear safety" was founded which was famous for such programmes like CORA and BETA. CORA was a study of fuel melt-down in severe accidents, BETA was melt concrete interaction. Also a reactor outside Karlsruhe, the hot steam reactor, was converted to an accident simulation facility. A fast test reactor, KNK, went critical in 1972. The prototype fast breeder construction started in 1973.

A reprocessing project was started in 1974. Also in the mid-70ies we had new management in Karlsruhe, the first generation was replaced by the second generation of directors and this also entailed reorganization of the major research areas. Thrust was given to secure fuel cycle, also already at this time decommissioning of nuclear installations, and safety of nuclear facilities. Another division was fundamental research. 1974 is marked by the start of the CABRI project, where also Karlsruhe was heavily involved by developing instrumentation and also participating in the experiments ongoing in Cadarache in France. In 1977 we had a fast breeder start-up at the Karlsruhe research site, the compact sodium-cooled reactor KNK II, so this was still a period of good activities.

In the 80s the situation was somehow reversed, the breeder project did not advance as it was originally supposed. There was the shut-down of the research reactor FR2, we had a period of change, new research activities, shift of budgets, nuclear fission research which in the 70s was allocated about 80% of funds in Karlsruhe, had only 30% by the end of the 80s. There were new tasks like environment (15%), new technologies, key technologies — nuclear fusion took up some part (20%) of it — and several research reactors were shut down during that period. After some delay the construction of the prototype reactor SNR 300 was complete and in 1985 some pre-nuclear tests were started. Also work on the design of a large European fast reactor project was started at this time on a European level, where Karlsruhe was heavily involved.

In 1986 it was decided in Karlsruhe to close the project "nuclear safety", this was in fact the same year when Chernobyl happened, showing that in spite of large R&D, nuclear safety was not really resolved. This caused some sensitization of the German public. Decommissioning of nuclear facilities started in 1987. In 1989 the project of "nuclear safety research" was founded by merging the remaining activities of the fast breeder project and the nuclear safety project. 1989 marks the period of feasibility studies for reactors with high safety criteria. In fact it was investigated whether a reactor could be constructed in a way that it could withstand even severe accidents without far reaching consequences for the environment. In principle, the answer was "yes", this could be done. In fact such safety requests are in the meantime included in the German atomic law at least for future reactors. On the other hand the industry withdrew from the nuclear reprocessing option in 1989 in Germany and this also meant that a project for fuel reprocessing had to be terminated and the pilot reprocessing plant at Karlsruhe, WAK, had to be closed.

In 1989/90 there was the unification of Germany which meant the third reorientation of the scientific landscape. There was also a research centre in Eastern Germany. It meant reduced budget and certain discussions of the roles and goals of large research centres. In 1990, the PHDR project for safety investigations had to be terminated and in 1991, the decision came to abandon the prototype fast reactor SNR 300. There was an attempt to keep the breeder option open in the frame of European Fast Reactor development. In 1993 finally the Government decision came to abandon all breeder activities in Germany. This meant also that the breeder activities in Karlsruhe had to be abandoned.

At this time the participation in safety concept development for the European pressurized water reactors started. The European pressurized water reactor, which is a common development of French and German industries, aims at designing a reactor of having very high safety and which can replace the present-day reactors. In keeping with the shift in emphasis of research, the nuclear research centre Karlsruhe was renamed to research centre Karlsruhe in 1995.

In 1997 some activities in the field of accelerator-driven fission systems were started at Karlsruhe.

Current situation

In the Forschungszentrum Karlsruhe there are now four main areas. These are: i) Division of Environment which deals with topics like low-pollutant or low waste processes, as well as conversion of energy and matter; ii) Division of Energy, iii) Division of Key Technologies with topics like micro-systems, medical technologies and Nano technologies, and; iv) Division of Fundamental Research dealing with particle/astrophysics and matter at extremely high pressures and temperatures.

Figure 1 shows the budget change during the past 15 to 20 years. Nuclear fission has gone down from 70% to less than 20%, fusion is around 20% if we include super-conductivity activities, environment activities have significantly increased (25% now) and also key technologies (25%). Fundamental research is at a level of 10%.

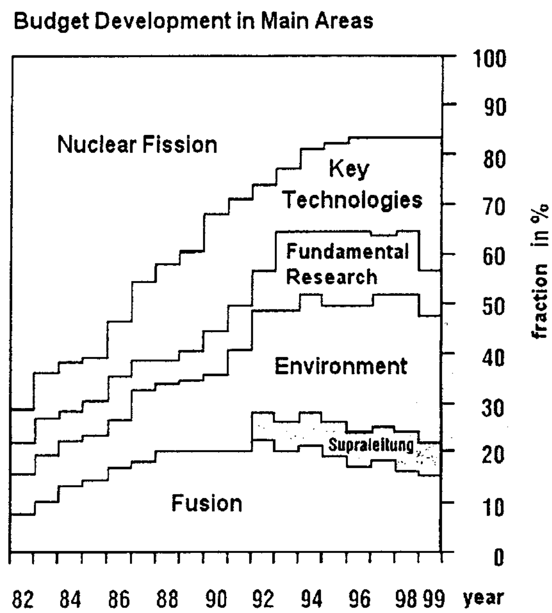

Figure 1.

At the Energy Division of the research centre, there are essentially three nuclear activities which are: i) a project on nuclear fusion which is organized around ITER development (blanket questions, materials, plasma heating, tritium technology); ii) the project "Nuclear Safety Research", essentially 60% of it covers severe accident research for water reactors (European pressurized water reactor). This is oriented around concept development with topics of accident phenomena which could jeopardize the containment integrity, steam explosion, hydrogen issue, ex-vessel melt behaviour, source term and consequences. A general topic is in-vessel accident progression in order to get initial conditions for the other studies like melt concrete interaction and cooling of melts in order to carry out core catcher development. The other topics in the project nuclear safety research are actinide transmutation, the CAPRA project for core design where actinides and fission products could be burnt. More recent activities are at accelerator driven systems, design studies, nuclear data evaluations, materials corrosion studies, and we are currently setting up a technological loop for Pb-Bi technology (KALLA). Very recently there is a new activity for design of a light water reactor cooled by supercritical water, the HPLWR; and iii) Institute for Nuclear Waste Disposal specially concerned with vitrification of fission products and studies of geochemical aspects for waste disposal addressing deep storage questions.

Another Division outside the Energy Division is concerned with decommissioning of nuclear facilities. Activities to transfer five reactors and one reprocessing plant either into safe containment or to complete removal are in progress. The Research Reactor FR2 has in the meantime been modified to a museum. We have decommissioned the HDR hot steam reactor at Karlstein, and a reactor at Niedereichbach, and at Karlsruhe, the KNK, the compact sodium cooled facility is decommissioned and also the multi-purpose research reactor and reprocessing pilot plant.

Outlook

As you know, the present Federal German Government has decided to phase out nuclear energy. Also the public opinion is not in favour of the nuclear option. Also problematic is the opening of the electricity market, which means less funding by utilities. But nevertheless we have to accept that nuclear power is significantly contributing and will continue to do so for at least 10 or 20 years and if one considers decommissioning of those plants, maybe even more. By law the Federal Government is responsible for the safety of reactors and disposal of waste and we also want to participate on an international level in the nuclear development. Therefore, it is absolutely necessary that the safety of nuclear reactors must be maintained during the remaining operating time. The know-how must be maintained in licensing and expert organisations — here we face a difficult problem of age structure of the people. At the moment not many young people are coming into research. We need independent research — independent from industries — and we also want to transfer our know-how on an international level. So the immediate needs, we believe, are maintenance of the present research budget, we need the maintenance of expert know-how, concentration and co-ordination of the tasks and here the remaining research centres will have to get together under a roof organization.

Nuclear research centres — their evolution in the Indian context

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Abstract. In a developing country, the role of the nuclear research centres (NRC) is quite large as it involves research, development, demonstration and deployment. The Bhabha Atomic Research Centre (BARC), the mother institution for all nuclear activities in India, has played this role for more than 40 years. With the successful deployment, the subsequent growth and management, both in the power and non-power sectors, is carried out by public sector enterprises. BARC continues to provide R&D support for improving performance and safety, technologies for repair and refurbishment, plant life management and evolutionary changes in the plant design. It has the responsibility of managing the backend of the fuel cycle. BARC has also been the nucleus for new research centres devoted to the development of fast reactors, accelerators and lasers. National NRCs, which provide exciting R&D opportunities with future orientation, provide assurance of availability of requisite skills and expertise while at the same time working for the futuristic objectives of the country.

Introduction

Nuclear research centres (NRCs) have played a very important role in the development demonstration and deployment of electricity as well as non-electricity applications of nuclear energy. **In the early years of the development of nuclear energy, the NRCs in almost all the countries were built around research reactors.** We in India also followed the same model. Bhabha Atomic Research Centre (BARC), the first NRC in India, located in Mumbai, was set up around the research reactors APSARA[1] and CIRUS[2] and over the years, one more research reactor[3] and critical facilities have been added. This research centre is the mother institution of all other research centres as well as the nuclear power programme in India. Also the programme for applications of radioisotopes was launched in India based on R&D done at BARC. In the initial years, trained personnel for manning the nuclear power programme, both for the design and the operation, came from the research reactors at BARC. Now that we have a well-established power programme, research reactors are functioning more as workhorses for the production of radioisotopes and as platform for basic and applied research involving neutrons. The demand for radioisotopes is continuously increasing and to meet this increasing demand, an additional research reactor for isotope production is considered necessary. There are also ideas for some innovative research facilities around the new reactor, which our research community has proposed. We will come back to this again later.

The next NRC viz. Indira Gandhi Centre for Advanced Research (IGCAR) located at Kalpakkam on the east coast, was also set up around a research reactor (fast breeder test reactor) and is now the centre for pursuing research related to fast reactors. The fast breeder test reactor (FBTR) is working at this centre since 1985 and has fulfilled all the technology objectives assigned to it. The unique mixed carbide fuel, which is used in the FBTR was developed at BARC and has already seen a burn-up level of more than 49 000 MWd/tonne.

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[1] It is a swimming pool rector and attained criticality in 1956.

[2].It is a 40 MWt reactor and attained first criticality in 1960. It has natural uranium fuel, heavy water moderator and light water coolant.

[3].The reactor DHRUVA, a 100 MWt research reactor, attained first criticality in 1985. It has natural uranium fuel, and heavy water coolant and moderator.

Experience gained in setting up and operating this reactor has given us the confidence to embark on the programme of setting up 500 MW(e) Prototype Fast Breeder Reactors (PFBR) and the construction work for the first unit is likely to commence in the year 2001–2002. The design and technology development for the PFBR has been done at IGCAR in co-operation with Indian industry.

Besides BARC and IGCAR, we have other research centres in India. They were set up comparatively recently and keeping in view the needs of the future, have been set up around accelerators. Variable Energy Cyclotron Centre (VECC) located in Calcutta was set up to meet the research needs in physics and is now building a super-conducting cyclotron. Centre for advanced technology (CAT) located at Indore conducts research in the area of lasers and accelerators particularly synchrotrons. Institute for Plasma Research (IPR) located at Ahmedabad is spearheading fusion research.

Evolution of nuclear research centres

The profile of research and development programme being pursued in a NRC has to keep changing with the evolution of the overall nuclear programme in the country. To cite from Indian experience, in the early years of the evolution of the programme involving setting up of pressurised heavy water reactors (PHWRs), in addition to R&D on reactor systems and components and process development for the fuel cycle and the heavy water plants, BARC provided support for the manufacture of complex equipment, construction, acceptance testing and calibration of equipment and components manufactured for the first time by Indian industry or in-house facilities, and plant operation. Now when the programme is well developed, many of these activities are being supported by industry. On the other hand newer activities involving R&D focused on technologies related to repair and refurbishment[4] had to be taken up at BARC to take care of emerging needs of the operating power reactors. Plant life management has now become a major programme at BARC[5]. This kind of applied work requires a lot of specific data to be generated and we did this. We have now gained adequate experience in this area as well and because of technical assistance provided by BARC, Nuclear Power Corporation of India is in a position to meet all the problems that arise during operation of a nuclear power reactor[6] and as a result power reactors are operating at high capacity factors. Having reached a degree of maturity in the PHWR programme the focus has once again shifted and we are now working on new reactor systems, particularly The advanced heavy water reactor (AHWR)[7]. This reactor aims to utilise vast thorium reserves available in India and incorporates several passive safety features. With regard to safety features, it would exceed current international expectations and we expect it to become a forerunner of similar systems, which may be developed by us as well as other countries. To verify some of the design features, thermosyphon studies have been done on specially built experimental facilities in BARC. Further a low to medium pressure experimental facility is being set up at Indian Institute of Technology, Bombay, Mumbai. engineering development

[4] Rupani, B.B. and Sinha, R.K. “Improvement of lifetime availability through design, inspection, repair and replacement of coolant channels of Indian Pressurized Heavy Water Reactors”, IAEA-TECDOC-1054, November 1998.

[5] Sinha, R.K. and Kakodkar, Anil, “Management of Ageing of Pressure Tubes of Pressurised Heavy Water Reactors”, IAEA Specialists Meeting on Technology for Life Time Management of Nuclear Power Plants, Tokyo, Japan, 1994.

[6] Chaturvedi, V.K. and Sisodia, D.K., “Challenges in Maintenance and Rehabilitation of PHWR Type Reactors”, Nuclear Power in the 21st Century — Challenges and Opportunities, Mumbai, April 1999.

[7] Anil Kakodkar, “Energy from Atom: 21st century R&D Perspectives in Indian Context”, XIIth International Congress & Exhibition on Research & Development, New Delhi, January 1999.

and detailed engineering of this reactor is progressing well and we hope to be ready to launch its construction in a few years. Development efforts in the fuel cycle area have to match the needs of emerging reactor programme. This in fact has been the case with activities at BARC.

There is considerable difference in the approach which a country like India has to follow vis-a-vis the approach, which a country in the North may follow. In the industrialised countries, many activities, which NRCs have to carry out in the developing countries, are done by the industry. This is dependent on the level of development of high-tech infrastructure and the size of the programme. Industry would like to take up a programme purely on commercial considerations. Favourable conditions for industry involvement arise with the growth and sustenance of the programme. For developing countries it takes some time for such conditions to arise. NRCs provide a vital support to deployment of Nuclear Power till such time.

In case of any slowdown in the nuclear programme as is being witnessed in many industrialised countries, industry would be forced to redeploy trained personnel and facilities for other more lucrative activities. Moreover, it is unlikely that younger people will get into activities perceived to be declining. A complex technology like nuclear, demands continuity to maintain a high level of skills needed for safe and reliable operation spanning several decades and can ill afford disruptions in available skills dictated by market forces. To expect continuity from private industry based on purely altruistic considerations is expecting too much. One may remember that a number of facilities exist in the OECD countries, where 24% of electricity was supplied by nuclear power plants in the year 1998. These facilities are going to be there for another 40 to 50 years.[8] In case of life extension of nuclear power plants, the first application for which has already been moved in the USA, this period can be longer. This implies that to ensure safe operation of nuclear plants, whose life span is much longer than the working life span of individuals, it is necessary to induct and train young personnel on a continuing basis. This does not seem to be happening in the developed world. Its consequences can be serious. **Under such circumstances national NRCs, which promise exciting R&D opportunities with future orientation, provide assurance of availability of requisite skills and expertise while at the same time working on the futuristic objectives for the country.**

To come back to the Indian scene, we are quite bullish about nuclear energy in India and therefore have a continuing training programme at the Training School being run at BARC since 1957. More than 6000 students have graduated from our training school and we have plans to start one more training school at CAT, Indore to meet the demands in certain specific areas. We also have a tie up with Indian Institute of Technology, Kanpur, for training young graduates in nuclear engineering and technology for eventual absorption in the Department of Atomic Energy. We are in the process of formulating more schemes to attract young graduates to work in nuclear areas.

These personnel are needed to man ongoing research activities as well as to work on emerging areas. We have strong programmes in development of waste management technologies, electronics and instrumentation, robotics and remote handling, applications of radiation and radioisotopes, accelerator-based technologies and development of new materials. We would also like to pursue many emerging areas. Thus the work profile of the research centres would evolve as per the requirements of national programme and the available skill level in the Indian industry.

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[8] See figure 13, "Nuclear Energy — the future climate" The Royal Academy of Engineering and The Royal Society, June 1999.

Nuclear R&D — emerging areas

R&D activities could be with a short term or long term focus, Private sector, driven by commercial considerations, is more likely to concentrate resources towards areas where assured returns are expected quickly. Looking at this issue from a different perspective, one may say that in the case of nuclear power as is the case with any other technology, R&D focus is needed both towards evolutionary as well as revolutionary ideas. We should remember that science and technology have progressed to the present stage both because of evolutionary as well as revolutionary ideas and as we move into the next millennium, we must keep all our options open and that would call for continued emphasis on national NRCs.

Research needs of the nuclear industry have been listed by many experts[9] and we would like to go through various issues involved. On a short term basis one has to work towards improving the performance and safety of existing reactors. This has to be done with proper cost-benefit analysis. This would include adaptation of the front-line developments in information technology, better techniques for preventive maintenance to reduce overall man-rem expenditure, increase in automation to minimise the consequences of operator error, optimised techniques for component replacement and safety inspection so as to reduce plant outage time and so on. Next group of activities relate to evolutionary changes in the plant design, such as increasing use of passive systems and this is an area where there will be difference in approach in developed and developing countries. In developed countries, private industry is pursuing such activities, while in developing countries this has to be done by NRCs.

From a long term point of view, it is necessary to find technology solutions in all areas, which are presently appearing as barriers to rapid growth in nuclear power. Low capital cost, simple operator friendly reactors, systems with greater public confidence with respect to safety and long term waste issues and breeder technologies could be some of the drivers for newer technology options for nuclear power. It is also necessary that such technology options are appropriate to the conditions prevailing in developing countries. NRCs in developing countries can effectively meet these objectives.

As indicated earlier, at BARC we are working on evolving the design of AHWR so as to exploit our vast thorium reserves. We would also like to pursue emerging areas such as accelerator driven systems (ADS) and would like to develop expertise in setting up ALWRs. The first twin units of ALWRs will be set up at Kudankulam on the east coast with technical co-operation of the Russian Federation. On a long term basis, we would like to indigenise light water technology and this calls for a lot of work to be done by a NRC. As mentioned earlier, demand for radioisotopes in India is growing and very soon there will be requirement for a new research reactor for producing high specific activity Ir-192, Mo-99 (to generate Tc-99m) and Co-60 sources for use in radiography cameras, irradiators, brachytheraphy and teletherapy units. There is a large demand for many units, which is yet to be fulfilled. Production of these isotopes and some others like Re-188 call for a high-flux reactor. We intend combining the needs of the research community and isotope production in the new high flux reactor.

In the developed countries, very often while R&D is done in the NRCs or the universities, its deployment is done by the private industry as the technical skills are available and there is a

[9] For example see comment by John Taylor in "An Appropriate Role for Nuclear Energy in Asia's Power Sector" by the Atlantic Council, December 1997.

strong motivation to gain leadership through introduction of new technology. However, in case of developing countries NRCs have to play a bigger role, they have to do not only R&D, but what one may say RD^3 i.e. research, Development, Demonstration and Deployment. This further enhances the need for research centres. **To sum up, as for as Indian scene is concerned and this is true perhaps for all developing countries, there is a continued need for nuclear research centres. And in our considered view for R&D in emerging areas, NRCs are needed in developed countries as well.**

Linkages with academia, industry & society

We would like to share our experience about running a research centre. First and foremost, there must be a large presence of young persons. This is possible, if we have a continuous intake of young graduates. We do it through our Training School. Additionally one can have young population in the form of students working for research degrees and this requires an organic linkage with universities. In this regard, one may go a step further and co-locate a university level institute and a nuclear research centre. In addition, it is necessary to create mechanisms to fund research in the university system on topics of interest to nuclear energy and this should be pursued in collaborative mode, where a part of the work is done in the university and a part in the research centre. This provides many benefits, inputs in the form of young students who work on research so sponsored, expertise of the university faculty, training of young manpower who may be available for working in nuclear areas after graduation and enrichment of the education system of the country. We also have strong linkages with agricultural universities in the country. This collaboration has enabled us to develop 22 improved varieties of seeds (9 of pulses, 8 of groundnut, 2 of mustard, 1 each of rice and jute) using nuclear techniques.

In addition to universities, links with industry as well as society are also essential. In our experience, such links upgrade the skills available with the industry, which in turn feeds back and helps to accelerate the nuclear programme[10]. There are many areas, where we have helped Indian industry and it includes simple techniques like radiography to sophisticated technologies like SCADA (Supervisory control and data acquisition system), Gamma scanning of Process Equipment, Study of silt movement in Ports and Harbours using Tracer Techniques etc. We have adopted all possible means for transfer of technologies including training of personnel from industry by conducting specialized courses and others.

Collaboration in areas of complimentary strengths among research and development centres on the basis of equitable partnership enables a cost-effective approach to meeting common objectives. While several countries have implemented such strategies with success, there is a greater need to involve developing countries in such collaborative links. A greater linkage among developing countries may well enable evolution of technologies more appropriate to the developing world. **The IAEA could consider creating mechanisms to promote such co-operation with equal access to its Member States.**

Concluding remarks

To sum up nuclear research centres are necessary to ensure continuity of knowledge and skills, to address the needs of national nuclear programme and to pursue work in emerging areas of long term interest. This need exists both in electricity as well as in non-electricity applications of nuclear energy. In developing countries, NRCs have an additional role of

[10] Grover, R.B., “Technology Transfer and Management by the DAE”, Nuclear India, Sept-Oct 1999.

demonstration and deployment of technologies in the society. The IAEA, Governments and Industry have to ensure that an established technology like nuclear power, which has proven itself, plays a more effective role in carrying forward the development process to enable an equitable quality of life for the entire humanity. Nuclear research centres are important elements in this development process.

Challenges faced by nuclear research centres in Indonesia

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Abstract. Nuclear research centres in Indonesia are mainly owned and operated by the National Nuclear Energy Agency, covering basically various research and development facilities for non-energy and energy related activities. The research and development activities cover a broad spectrum of basic, applied, and developmental research involving nuclear science and technology in supporting various fields ranging from basic human needs, e.g. food and health; natural resources and nuclear & environmental safety; as well as industry. Recent economic crisis, triggered by monetary turmoil, has dictated the IAEA to face new challenges and to give more efforts on the application of the so called "instant technology" i.e. the technology which has been developed and is ready for implementation, especially on food and health, to be better utilized to overcome various problems in the society. Various short and medium term programmes on the application of isotopes, radiation, and nuclear techniques for non-energy related activities have emerged in accord with these efforts. In this regard, besides the intensification of the instant technology implementation on food and health, the nuclear research and development on food plant mutation, fertilizers, radio-vaccines, production of meat and milk, production processes of various radiopharmaceuticals, and radioisotopes as well as radiation processing related to agro-industry have to be intensified using the available laboratories processing facilities. The possibility of the construction of irradiators for post harvesting processes in some provinces is being studied, while the designing and manufacturing of various prototypes of devices, equipment, and instruments for nuclear techniques in health and industry are continued. Considering the wide applications of accelerators for non-energy and energy related research and development, construction of accelerator-based laboratories is being studied. In energy related research the feasibility of the introduction of the nuclear power plants is under investigation taking into account various important changes due to new realities. Therefore, the safety and fuel cycle aspects, especially the long term program on the back-end fuel cycle, utilizing the existing facilities is also maintained. The construction of a laboratory for carrying out research and development on radio-ecology and marine environmental studies is being planned to support the radioactive waste management for the future nuclear power plants. Considering the need to maintain the energy related research and development and the need for clean water, the study on the utilization of a high power research reactor for generating process heat, hot vapour, and producing clean water as well as electricity is being carried out. The possibility of the construction of this research reactor is being studied. As a developing country, Indonesia needs to co-operate with other countries to support her nuclear research and development programme in various fields due to the fact that she has to overcome her chronic challenges that are perhaps also faced by other countries, i.e. to have a better understanding, perception, appreciation, and support from decision makers, social leaders, scholars, and the whole community nationally and internationally on the importance of peaceful uses of nuclear science and technology.

Introduction

The nuclear research centres in Indonesia are mostly own and operated by a governmental research and development institute namely the National Nuclear Energy Agency (BATAN, Badan Tenaga Nuklir Nasional, Act no 10, 1997), formerly known as the National Atomic Energy Agency of Indonesia (Act no 31, 1964). As stipulated in the Act 10, 1997 about nuclear energy, BATAN is a non-commercial governmental institute having the task of nuclear research and development as the promoting body with no more function of regulatory body. Since the application of nuclear science and technology is utilized by various institutes, e.g. universities, hospitals, industries either state own or private, the nuclear research and development is also carried out, to a lesser extent, by universities and very little by private industries. In most cases, however, they do their nuclear research and development together with BATAN employing the BATAN's nuclear research centres.

The research and development done by BATAN covers mainly nuclear science and technology in support of energy and non-energy related activities covering basic human needs; development of natural and energy resources as well as nuclear and environmental safety; and development of industries. To be able to carry out these research and development appropriately, BATAN has also to have activities in software, hardware, orgaware and human resource development as well as socio-cultural to have the support from the society.

Having approximately 4000 personnel, 90% of which are technical personnel i.e. scientists, engineers, and technicians, BATAN is relatively well equipped with various research and development facilities, e.g. three research reactors of 100 kW, 2 MW and 30 MW suitable for education, research and development, and production of radioisotopes. These reactors are complimentary and equipped with many beam tubes for spectrometry, isotope production, radiography, etc. Various capsules, rigs, and in-pile loops, as well as irradiation facilities, storage pool, hot cells, and pneumatic, dry and wet radioactive sample transfer facilities are also available in these reactors to be used for research and development of fuels, materials, and radioisotope production. Various out of pile loops for engineering and safety experiments, thermohydraulics, corrosion and component test, together with cold mechanical laboratory and computational laboratory are available in the engineering and safety installation. Complete set of post irradiation examination of fuels, reactor components and materials can be carried out at radiometallurgical installation consisting of hot cells equipped with various analytical instruments at the hot laboratory, complete physico-chemical and nuclear based method analytical instruments at the medium activity laboratory and general analytical equipment at cold laboratory. Relatively complete research and development facilities relating to fuel cycle, except for enrichment, are also available at various installations starting of with exploration of radioactive minerals, mining, processing, conversion, experimental fuel element manufacturing facilities, up to radioactive waste treatment and management except for deep repository. A fabrication plant for research reactor fuel elements is also available. An installation consisting various equipment and instruments for electro-mechanical component fabrication, instrumentation and control devices, and glass blowing is also available. Two complete installations for radioisotope and radiopharmaceuticals production are available adjacent to the 2 MW and 30 MW research reactors, while a radiochemistry laboratory is available adjacent to the 100 kW research reactor. Various irradiators, e.g. gamma cells (^{60}Co), and accelerators namely electron beam machines, neutron generator, ion implantor, cyclotron are available for various research and development activities and radioisotope production. Various laboratories for applied research in industries, agriculture, health, and environment, e.g. radiation processing, hydrology, radiochemistry, radiation chemistry, physics, chemistry, radiobiology and biology, environmental monitoring, materials, electronics, computers as well as libraries, workshops, and a centre for education and training are also available. In 1996 the production facilities, i.e. for fabricating research reactor fuel elements, and for processing the radioisotopes and radiopharmaceuticals as well as the electro-mechanical workshop are transferred to be PT BATAN Teknologi, a state owned company.

New realities and program reorientation

Ever since the second quarter of the year 1997, economic crisis has taken place in Indonesia triggered by monetary turmoil. The high economic growth that Indonesia had experienced for about thirty years came abruptly to an end about 30 months ago. The industries having the raw materials imported and or somehow dependent on offshore supplies/input have seriously suffered, the economic growth has decreased sharply. In 1998 the economic growth was -13.1%, while the growth in 1999 is expected to be slightly negative with the inflation rate of 15–20%. Indonesia shall strive to achieve positive growth again beginning in the year 2000. Resources based industries, especially agro-industries, due to the fact that have no significant dependency on import, have however been in a better position and able to grow positively. Nevertheless, Indonesia faces the more pronounce problems on basic human needs, i.e. supply of foods, partly due to long dry season caused by El Nino last year, and also health as a result of the decrease of the people wealth due to unemployment. The unemployment has increases sharply reaching 17.1% of the workforce [1].

The present economic crisis has had a significant negative impact on the nuclear research and development in Indonesia. Foremost is due to the budget cut being experienced by BATAN, in conformity with the austerity program being pursued by the Government. Secondly due to the collapse of Indonesian currency (rupiah) value especially against hard foreign currencies. Despite the economic crisis, nuclear facilities such as irradiators (isotopes, reactors, and accelerators), laboratories with various measuring instruments, and production facilities for radioisotopes & radiopharmaceuticals and fuel elements (PT Batan Teknologi's, state own company, facilities) remain operational and functional to support nuclear research and development as well as production activities. BATAN is undertaking a reorientation of some of its activities to address and to assist the concerns relating to the social safety net program and the empowerment of technology based co-operatives and small & medium scale industries. It is apparent that BATAN's research and development on basic human needs become more important and should become the first priority to carry out in short future as the immediate program, while the dissemination of the technologies previously developed and ready to implement as the results of this research and development, namely instant technologies, to the society should be intensified. While the growth of BATAN's personnel is negative to become less than 4000, the function and the activities are increased. The organizational structure is rearranged (President Decree no 197, 1998) to suit the new challenges by installing 4 chairman's deputies and trimming the structure but having complete tasks of research and development up to the dissemination of new technologies and techniques (R&D products, i.e. goods and services) to the society. As the Indonesian economy improves hopefully not in the far future then BATAN will be able to take up other activities closer related to the industrial sector. These will constitute the medium term program such as the application of accelerators for new materials development in industry and the application of particle beams in biotechnological research. Application of accelerators in medicine needs special attention, since the prevalence of new cancer patients in Indonesia is between 0.8 to 1 per-mill per year or ~ 200 000 new patients annually. New facilities for high efficacy and precision radiotherapy are therefore needed at the turn of the century. As the medium term program BATAN also intends to utilize the reactor neutron for the services of humanity especially in the field of health, i.e. neutron capture therapy for cancers. For the long term program, BATAN shall continue the preparations for the eventuality of the introduction of nuclear power plants in Indonesia. Studies, have been undertaken lately, on the feasibility of the construction of a nuclear power plant (NPP) have now been hampered by the economic crisis, thus BATAN is now concentrating the efforts in the direction of strengthening the bases for nuclear power planning and implementation. In the meantime BATAN has made considerable investments in manpower development in anticipation of the introduction of the nuclear power. While it will be up to the new government to decide on the nuclear power program, BATAN feels that it is justified in pursuing the course as it has been done in the past. BATAN shall continue to maintain the manpower and even to continue to upgrade their capabilities. Therefore the aims of BATAN long term program, among others, are optimal utilization of research reactors and related facilities for the benefit of both the energy and non-energy sectors; the development of capability in nuclear fuel technology in support of a future nuclear industry; the realization of a long term national energy plan including the nuclear option; and the establishment and achievement of a reliable and secure nuclear safety system [2].

Immediate programme responding to current needs

The instant technology in food covers 6 varieties (^{60}Co radiation induced mutants namely Atomita 1, 2, 3, 4, and Situgintung, as well as a mutant of crossing Cilosari) of rice, 3 varieties (^{60}Co radiation induced mutants namely Tengger, Muria, and Meratus) of soybean, 1 variety (^{60}Co radiation induced mutant namely Camar) of mungbean, and also food supplements for cattle to increase the production of meat and milk, as well as 2 kinds of radiovaccine for cocksidiosis of poultry. The production of the radiovaccines has been done by state own company. While the instant technology in health covers the production processes of various radioisotopes and radiopharmaceuticals and manufacturing of diagnosis equipment using nuclear techniques, i.e. X ray machine and renographs. Most of the production of these radioisotopes and radiopharmaceuticals, together with the production of radioisotopes for industry have been done also by state own company. Table 1. shows the radioisotopes and Table 2. shows the radiopharmaceuticals that have been produced by the company.

Other instant technologies that have been utilized by private companies for many years are the radiation processing for sterilization of food, spices, and medical products as well as irradiation of latex for condom and gloves. While the radiovaccines, radioisotopes, and radiopharmaceuticals are sold by the state-own companies, some X ray machines and renograph manufactured by BATAN have been granted to some hospitals. Technological packages, developed by BATAN, have been introduced to individual farmers and cooperatives to increase rice, meat, and milk production. The implementation of these programs commencing in 1998 in the provinces of West Java, Central Java, and West Nusa Tenggara, with field guidance of BATAN's personnel, have been very successful and met expectations. Therefore, these packages consisting of Cilosari rice variety for rice production and food supplement using Urea Multi-nutrient Molasses Blocks (UMMB) for increasing meat and milk production are further introduced this year in the provinces of Bengkulu (Sumatra), South Sulawesi, and North Sulawesi. The implementation of these programs is managed through tripartite co-operation, namely local province government, local universities, and BATAN involving industries, co-operatives, and or ultimate beneficiaries. This co-operation is to be enhanced to cover 10 provinces this year in line with the new acts recently put into force stipulating a greater autonomy for local government.

As mentioned earlier, BATAN immediate programme has had to be redesigned and tailored to Indonesia most urgent needs, namely to be aimed at addressing basic human needs and providing social safety nets. In this regard, BATAN shall strive to continue those previous program relevant and pertinent with those aims in the area of food, agriculture, and livestock production; health care and medicine; and in industrial process applications. The use of radiation to obtain improved varieties of rice, and beans; to prolong the self-lives of food and commodities, as well as medicines and medical herbs; and to improve the characteristics of materials utilizing ^{60}Co sources and electron beam machines will be continued and as far as possible to be enhanced. BATAN immediate nuclear research and development program covers also the production process of radioisotopes and radiopharmaceuticals utilizing research reactors and cyclotron. Table 3. shows the radioisotopes and radiopharmaceuticals being prepared by BATAN.

The radioisotopes and radiopharmaceuticals produced by PT BATAN Teknologi and BATAN have been used by couple of hundred industries and 17 hospitals in Indonesia.

Table 1. Radioisotopes Produced by PT BATAN Teknologi (using neutrons from reactors)

No.	Radioisotope	Nuclear Reaction	Applications
1.	^{99}Mo solutions	^{235}U fission or ^{98}Mo(n , γ)	Parent nuclide for ^{99m}Tc generators
2.	^{192}Ir industrial sources	^{191}Ir(n , γ)	Non destructive test
3.	^{32}P solutions	^{32}S(n , p)	Therapy of polycystemia vera, tracers or labeling in agriculture experiments
4.	^{198}Au solutions	^{197}Au(n , γ)	Sedimentation and hydrology investigation
5.	^{131}I solutions	^{131}Te(n , γ), β decay	Various investigations and compound labeling

Table 2. Radiopharmaceuticals produced by PT BATAN Teknologi

No.	Radiopharmaceutical	Application	Specification/Stability
1.	^{99m}Tc generator	Investigation of morphology and function of human organs; combined with radiopharmaceutical kits	Very stable, expire 10 days after calibration date. Sterile, non-pyrogenic; 20 mCi-1 Ci
2.	Kits:		
	DTPA	Brain and GFR (kidneys) studies	Non radioactive, freeze-dried, sterile, non-pyrogenic, stable 6–12 months
	MDP & HEDSPA	Bone investigation	Ditto
	HIDA	Hepatobiliary system investigation	Ditto
		Blood pool studies	
	HAS MAA	Lungs perfusion studies	Ditto
	PHYTATE/TSC	RES studies	Ditto
	TSPC	Visualization of the lymphatic gland	Ditto
			Ditto
3.	(^{131}I)-NaI capsules	Thyroid function studies	Stable, very specific; 25,5 mCi
	(^{131}I)-NaI solutions	Hyperthyroid and thyroid carcinoma therapy	Very effective radiotheraphy
	(^{131}I)-Hippuran inj.	Investigation of kidneys	Stable, very specific
	(^{131}I)-MIBG inj.	Investigation and therapy of neuroblastoma and pheochromocytoma	Stable, very specific and effective

Medium term programme enhancing responses

Some of the medium term programme cover the continuation of the nuclear research and development on insect control and studies of artificial as well as natural fertilizers. Mutation breeding and radiation processing of horticulture covering various fruits, vegetables, ornamental plants and studies of radiation processes for agro-industrial wastes and improvement of materials for industry as well as production processes of radiovaccines, radioisotopes, and radiopharmaceuticals are to be ones of the nuclear research and development in the medium term. Developmental research for the construction of irradiators for post harvest process of food, spices, and horticulture for North Sumatra and North Sulawesi provinces are also in the medium term program. As mentioned earlier, new facilities for high efficacy and precision radiotherapy, e.g. brachytherapy, accelerator, and neutron capture for cancer therapy utilizing reactor neutron are also envisaged in the program. While in the diagnosis developmental research, the manufacturing of portable renograph and gamma camera will be the program.

In the field of accelerator, it is worth noting that BATAN has a rather long record of modest developmental efforts with some results. BATAN has been interested in this machine due to its wide range application and multidisciplinary subjects that can trigger various opportunity of development in the future[6–9]. Activities on the development and application of particle

Table 3. Radioisotopes and radiopharmaceuticals being prepared by BATAN

No.	Item	Application	
	^{201}Tl-chloride inj	Heart blood perfusion studies	Already available, sterile, sensitive and stable
	MAG_3 kit	Glomerulus filtration studies	1999 production
	MIBI kit	Heart blood perfusion studies	1999 production
	Hepatitis C RIA kit	Hepatitis C diagnosis	1999 test
	AFP-IRMA kit	Soft tissue tumours diagnosis	1999 test
	HM-PAO kit	Brain blood perfusion studies	1999 clinical trials
	^{153}Sm-EDTMP	Palliative therapy of bone cancer metastases	1999 clinical trials
	^{192}Ir brachytherapy	Various tumours therapy	2000 test
	CEA IRMA kit	Various tumours diagnosis	2000 clinical trials
	^{153}Sm-particulates	Rheumatoid arthritis therapy	2000 clinical trials

accelerators in Indonesia have been carried out on a modest scale since 1979. Some 10 MeV electron linear accelerators have been operated by hospitals for medical treatment and an electron beam machine is operated by a tyre manufacturer, as well as 5 accelerators have been acquired or developed by BATAN, i.e. 200 keV ion accelerator for ion implantation, 150 keV ion accelerator for neutron generator, 300 keV and 2 MeV electron accelerators for electron beam processing, and 20 MeV cyclotron for radioisotope production. The BATAN's first two accelerators are of Cockcroft-Walton type, designed, constructed, and installed at the Research and Development Centre for Advanced Technology (RDCAT), formerly known as the Yogyakarta nuclear research centre by BATAN scientists and engineers as part of their exercise to acquire knowledge and skill in accelerator technology. The 300 keV and 2 MeV electron beam machines installed at the Research and Development Centre for Isotope and Radiation Technology (RDCIRT), formerly known as the Centre for Application of Isotope and radiation as well as the cyclotron installed at the Development Centre for Radioisotopes and Radiopharmaceuticals (DCRR), formerly known as the Radioisotope Production Centre were purchased commercially. The ion implantation accelerator at RDCAT consists of a Penning ion source, a Cockcroft-Walton high voltage generator with a maximum of 200 kV, an acceleration tube system, a mass separator system, a beam sweeping system, a vacuum system, and a target chamber. A maximum beam current of 100 mA is obtained for Ar ions, 200 mA for P, B, and C ions, and 600 mA for N ions. The current research and development activities utilizing this accelerator at RDCAT are on the techniques of implantation into semiconductor materials with the emphasis on [10]:

1. the study of dopant behaviour in implanted semiconductors
2. the determination of the range distribution of dopant species, lattice disorder, location of dopant species on substitutional and interstitial sites in the lattice
3. the study of ion implantation into II-VI and IV-VI semiconductors for solar cells or infrared detectors and
4. the ion implantation technique with the emphasis on:
   - implantation into metals to modify the mechanical properties of metal surfaces, surface hardness, corrosion resistance, friction coefficient, fatigue behaviour and adhesive properties
   - implantation into optical materials: research and development of light guides by alteration of the refractive index.

The neutron generator at RDCAT consists of a RF ion source, a Cockcroft-Walton high voltage generator with a maximum voltage of 150 kV, an acceleration tube system, a beam focusing system, a vacuum system, a target and cooling system. A maximum deuteron beam current of 2.5 mA is obtained. The current research and development activities are emphasized on:

1. biological and environmental research, e.g. the determination of protein contents in food, nitrogen and phosphor contents in fertilizers, and quantitative analyses of elements in aerosol pollution
2. nuclear physics research, e.g. the acquisition of neutron activation cross-section data around 14 MeV, especially for calculations on radiation damage, nuclear transmutation, and induced activity.

The electron beam machines at RDCIRT are currently utilized primarily [11]]:

1. as a pilot-scale demonstration plant for radiation curing of surface coating technology
2. for training course, demonstration as well as for studying both technical and economic aspect of cross-linking of wires and cables
3. to increase awareness of the industries on the potential applications of electron radiation technology including its benefits
4. to promote radiation as a means of rubber vulcanization, curing of surface coatings and cross-linking of wires and cables.

The cyclotron at the DCRR has six beam tubes with a switching magnet, two beam tubes are utilized for ^{67}Ga and ^{201}Tl production while the others are for research activities, e.g. thin layer activation for industrial investigations.

To enhance the participation in the national development, BATAN is currently planning to establish accelerator-based laboratories at RDCAT. The establishment and operation of the laboratories are expected to provide significant contributions in:[10]]

1. solving various scientific-technical problems, primarily those related to human health and medicine, industrial techniques, environmental care and biotechnology
2. developing and acquiring a wide spectrum of modern technologies, such as those related to ion sources, particle acceleration techniques, beam handling and diagnostic, magnet technology, vacuum techniques, detector technologies, nuclear electronics, and data acquisition as well as processing techniques
3. developing and upgrading of human resources in various branches of nuclear science and technology, in particular in collaboration with local universities and foreign institutions.

The envisaged laboratories are planned to have an accelerator system, equipped with several experimental stations and supporting facilities. Form the user point of view the laboratories may be divided into two areas, namely the low energy and the medium energy areas.

The low energy area is foreseen to accommodate a low energy ion accelerator and an electron accelerator. The choice of the accelerator type could be made among the three available types, i.e. the electrostatic, RFQ (radio-frequency quadrupole), or cyclic (e.g. cyclotron). Optimization will be made with respect to the ion types (light, medium, and heavy), achievable beam current, beam phase space quality and time structure. It is envisaged that the low energy accelerator may be used not only as a stand-alone machine to serve several experimental and application facilities, but should also be able to serve as an injector into a higher (medium) energy machine for further beam acceleration and handling. The various different beams shall be utilized among others in the following fields:

1. industrial application, e.g. ion implantation techniques for semiconductor device development and modifying mechanical properties of the material surfaces to achieve special effects, as well as implantation into optical materials
2. biotechnology, e.g. genetic mutation induced by particle beams for new mutants of plants
3. health and medicine, primarily for diagnosis and therapeutic purposes
4. environmental care, primarily as an analytical tool in the identification of various types of pollutants in various samples.

The medium energy area is to accommodate intermediate energy accelerator, e.g. synchrotron, emitting light ion beams with medium energy (200–300 MeV/nucleon) equipped with scientific facilities among others for the following activities:

1. health/medical research and therapy
2. application oriented as well as fundamental research
3. development of special techniques and analytical methods.

Planning and promotional activities are currently in progress. In an attempt to optimize the benefits-costs ratio, careful considerations based among others upon user requirements shall be given to the selection process to obtain the most suitable type of accelerators among those commercially available.

Long term programme preserving the expertise and continuing the preparation of nuclear power plant introduction

For the long term program BATAN shall continue the preparations for the eventuality of the introduction of nuclear power in Indonesia. Studies, research and development in support of the NPP introduction, and the pre-project activities have been done and briefly described in the previous papers [12,13,14,15] which basically comprises:

1. optimal utilization of research reactors and related facilities for the benefit of both the energy and non-energy nuclear research and development activities
2. the development of capability in nuclear fuel technology in support of a future nuclear industry as well as the development of a long term program on the back-end fuel cycle
3. the establishment and achievement of a reliable and secure nuclear safety system
4. the realization of a long term national energy plan which includes the nuclear option.

Due to the new realities faced by Indonesia recently, the study being done is taking into account the new inputs. In the mean time BATAN also is concentrating the efforts in the direction of strengthening the bases for nuclear power planning and implementation. Two-year program starting in 1998 has covered:

1. environmental impact analysis and site data collection
2. geo-technical studies for foundation design
3. severe accident analysis
4. support for decision making which will look into system and method for democratic decision making process for NPP implementation. BATAN will also expand and intensify the activities in public information and public acceptance program.

In the meantime BATAN is also interested in the radio-ecology and marine environmental study starting of with the candidate sites of the NPP in support of among others the radioactive waste management including the long term back-end fuel cycle of the future NPP. A program on the construction of a laboratory for carrying out this radio-ecology and marine environmental research and development is being planned. To maintain the BATAN's manpower involving in this nuclear energy program and even to continue to upgrade their capabilities, while there is also a need to have clean water supply, the study on the utilization of a high power research reactor (e.g. high temperature reactor type) for generating electricity and producing clean water is being pursued. The possibility of the construction of this research reactor at the candidate sites of the NPP in Muria peninsula is also being studied.

Chronic challenges to overcome

As a developing country Indonesia has limited budget to allocate for her research and development activities. The research and development activities have been considered to be less important that they have been at the bottom on the list of priority. The proportion of the government budget allocation for research and development has been therefore very much less than the ones in developed countries. Although to a certain extent it can be understood if the budget proportion is less than the ones of developed countries but too much less is giving rise to the difficulty to gain results of significant impact to the society. BATAN as a governmental institute with the task of doing research and development in nuclear science and technology faces even more limitation on the budget granted since various misperception, misleading information and unbalanced understanding are common in the society, such as:

1. Nuclear research and development have no direct commercial value, it is wasting money and is not an auspicious investment
2. Nuclear technological push is much less important than market pull, and is not worth-while to do it now
3. Trading is much more important than doing nuclear research and development since it is more profit making
4. Nuclear, radiation, and radioactive substances are dangerous, uncontrolled, and harmful leading to catastrophe
5. Misleading information and understanding about the application of nuclear techniques, nuclear power plants, nuclear fuels, and the nuclear weapon, the safety and acceptable risk of nuclear activities including nuclear reactors.

In short, BATAN has to face public acceptance problems. It is indeed important and imperative to win the mind and the heart of decision makers, social leaders, scholars, and public as a whole community. Although BATAN has been adequately granted with budget for maintaining the safety but it has been insufficient for doing proper research and development to produce significant impact. Having a better perception, understanding and appreciation are indispensable giving rise to more conducive condition, e.g. more budget granted, for carrying out more fruitful research and development in the peaceful uses of nuclear science and technology. Sufficient budget allocation certainly will improve the motivation of the human ware since it gives more opportunity to maintain and utilize the hardware, software and technoware better leading to more effective research and development activities, more out-put, more out-come and more impact on the society. BATAN has long been doing, sometime together with partners, public communication via mass-media, seminars, symposiums, workshops, dialogues, exhibition, even traditional performances, e.g. puppet shadow play to have better public acceptance by disseminating simplified but credible information about nuclear science and technology, their applications and peaceful uses. Similarly, BATAN has also been doing the communication with the decision makers, social leaders, scholars, and universities. The effort can surely be done more effectively and efficiently in the future if it is better conducted together with partners nationally as well as internationally. This is now even more imperative since much more misleading information about nuclear has been spread globally by anti-nuclear groups.

Conclusion

Ever since 1997 the economic crisis has dictated BATAN to face new challenges due to new realities. Responding to new realities BATAN has reoriented its programs, i.e. the immediate program responding to basic human needs for food and health, the medium term program enhancing responses to basic human needs and industries, and the long term program preserving the expertise and continuing the preparation of nuclear power plant introduction.

BATAN has also restructured its organization in order to be able to intensify the dissemination of its instant technologies, especially in the immediate program to participate in the basic human needs. So far the dissemination of the instant technologies has been successful through the implementation of tripartite co-operations. In line with the new acts recently put into force to grant more autonomy for local government, the tripartite co-operations, which have given rise to greater beneficial impact on the society, are to be expanded. With the expectation that the economic crisis can be overcome in the near future, BATAN hope that the medium term and the long term programs can be implemented to enhance, preserve, and continue improving BATAN's role in the society.

To overcome the chronic challenges, e.g. insufficient budget and public acceptance problem, BATAN has done various methods of public communication to disseminate simplified but credible information about nuclear science and technology, their applications and peaceful uses. BATAN appeals to the decision makers, social leaders, scholars, and public for having better appreciation about nuclear research and development. BATAN also appeals to the nuclear community for conducting co-operation to enhance public acceptance nationally and internationally.

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Nuclear research centres in the Islamic Republic of Iran

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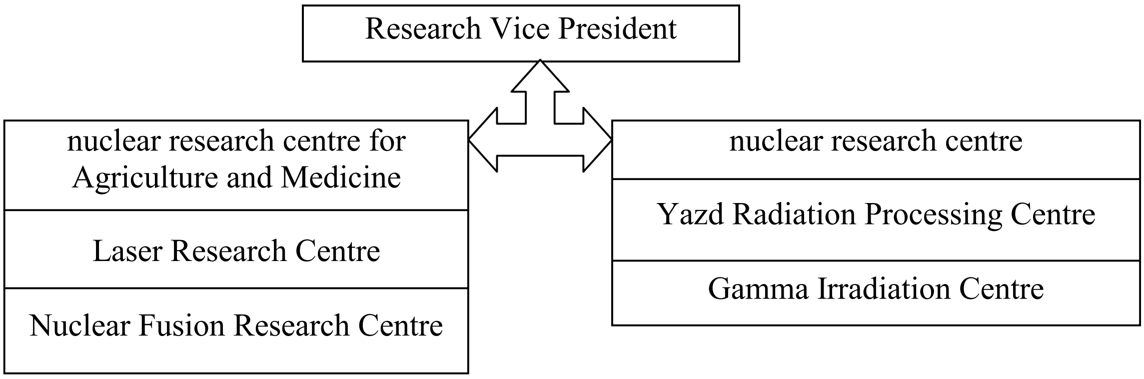
Abstract. The Islamic Republic of Iran has a number of research centres devoted to various facets of nuclear energy. A reactor and a cyclotron have been successful producing radioisotopes for use in medicine, industry and agriculture. The use of gamma radiation and electron beams for radiation sterilization and radiation processing is widely practised. One centre is specifically devoted to fusion research and another for laser development. The important role played by IAEA in promoting applications of radioisotopes and radiation in the Islamic Republic of Iran is highlighted.

Past and present situation of nuclear research centres in the Islamic Republic of Iran

The infrastructure under the research vice president:



R&D programmes and the related finances, manpower and infrastructure.

Nuclear research centre (NRC)

The nuclear research centre has a five Megawatt swimming pool type reactor and has taken up a program for the production of short-live radioisotopes which were developed in 1981. Initially the purpose of this program was to deliver services to the isotope users in nuclear medical centres, producers of radiopharmaceutical kits and radioimmunoassay kits, as prime objectives of NRC/AEOL, for medical diagnostics and therapy.

This centre is also working on the production of high specific activity of radioisotopes used in brachytherapy and industries. These projects have been supported by the technical assistance of the IAEA since many years ago.

Nuclear Material Department

- Radio-metallurgy studies.
- Nuclear and Biological Ceramics.

- Production of materials for dosimetry such as LiF and CaSO4 as Thermo-luminiscence Detectors.
- Evaluation of pre and post irradiated specimens of critical structural materials of PWR reactors.
- Evaluation of PWR components and radiation damage and failure analysis of power reactor structural materials.
- Studying crystalline structure o ceramic materials.

Gamma irradiation centre (GIC)

- Following activities is the summary of what have been carried out at GIC over the past few years up to date
- Determining the specific dose and microbial QC for disinfecting and sterilising the disposable medical
- and hygienic products, as well as herbal drugs, spices, nuts, and packed food materials.
- Co-operation with food industry on as many as food products as possible.
- Studying the effects of irradiation on indo-toxins.
- Studying the effects o irradiation in antibiotic sterilisation.
- Studying the effects of irradiation on polymeric materials.
- Studying the possibility of sterilising polymeric materials.
- Rendering services to the laboratories inside and outside of the AEOI.
- Analysing the wheat proteins with the method of SDS-Electrophoresis.
- Research in determining the micro-organisms of dates.
- Studying the effects of irradiation on herbal drugs and their colours.
- Design and construction of different dosimeters for irradiating system Dosimetry IR-136.
- Design and construction of ferric standard chemical dosimeters for Gamma cell irradiating system calibration.

Laser research centre (LRC)

The most important tasks at LRC are design and construction of various lasers development of related technologies such as optics, coating, glass blowing, establishing production lines of lasers and the related parts and manpower development.

Yazd Radiation Processing Centre (YRPC)

The installed electron accelerator at YRPC has the capability of emitting 5 and 10 MeV electron beams. Following is the summary of activities carried out over the past few years and some of the plans for the near future at YRPC.

- Irradiation of packaging materials.
- Food irradiation.
- Irradiation of glass.
- Irradiation of disposable medical products.
- Quality improvement of polymers.
- Production of Heat-Shrinkable Tubes and wrapping materials.
- Production of Head-Resistance Pipes.

Nuclear Fusion research centre (NFRC)

AEOI has been co-operating with the Kurchatov Institute of the Russian Federation since 1992. One of the outcomes of this co-operation has been the construction of Damavanc Tokomak for the purpose of fusion research. Presently joint research programs are being carried out with various universities incorporating postgraduate students working towards M.Sc. and PhD. degrees at NFRC. The design and construction of Plasma Nitriding system has already been completed. This system has many research and industrial applications.

Nuclear research centre for Agriculture and Medicine (NRCAM)

- Various radioisotopes such as Ga-67, TI-201, Kr-81m, In-111, and FDG for diagnostic purposes in medicine have been produced at the Cyclotron Department over the past few years. The scientists at this department are currently working on production of Iodine-123, and palladium-103 for prognostic purposes.

- Beside the researches done in radioisotope productions some other research programs such as nuclear-reaction-cross-section studies in the field of nuclear physics and beam-resolution-improvement-design as well as beam-eminence-measurements in the field of Beam Optics have been carried out by the PhD. students at the R&D division.

- Through applying the nuclear techniques in agriculture, noticeable accomplishments in quality and quantity of products have been achieved at the Nuclear Agriculture Research Department. For instance the Plant Breeding Group is in applied mutation through the aid of physical mutagen as a breeding technique to increase the genetic variety in different agronomic crops. Fixation of a desired mutated trait is pursued afterwards. So far mutation breeding on crops such as wheat, barley, rice, cotton, soy beans, sesames, and green beans have produced desirable traits such as early maturity, lodging resistance, shattering resistance, resistance to different biotic and abiotic stresses, and finally yield enhancements at this department. The Soil and Water Management & Crop Nutrition Group have optimised the ever more efficient ways of using water, fertilizers, natural resources, and soil fertility through utilising the applied nuclear techniques.

- The Food Irradiation and Pest Control Group has been aiming towards identifying food pests and eradicating them through the different developmental stages off growth by irradiation. This group has studied the γ-irradiation effect on ten important pests of stored-cereals at different stages of their growth. Survey of sunn pest (Eurygaster integriceb) migration with the use of P-32 and Zn-65 to determine their population distribution, winter's habitual, and starting the new method of male insect sterilization technique to control rice stem borer.

- The Animal Husbandry Group has been focusing their activities towards nuclear techniques in diagnosis, prognosis, prophylaxis, controlling animal diseases, genetic improvements for better breeds, determination of the digestion coefficient as well as measuring the nutrients in animal feeds, hygienic states of animal feeds, and reproduction improvement of live stocks.

Currently, the scientists at this department are carrying some researches to substitute composites for metals in many structural applications.

Strength and limitations

Strength:

- Having sufficient well-trainable manpower to be trained in any desirable scientific and professional fields.
- Having the society's support for implementing any project under the peaceful applications of nuclear techniques.
- Our past experience shows that the trained personnel have often been able to transfer the subjects in which they had been trained.
- The government has been supporting the main portion of the expenses on almost every project under the peaceful applications of nuclear techniques so far.

Limitations:

- We have usually had difficulties in receiving spare parts needed for maintaining or repairing the equipment at our facilitated centres.
- The private organisations in the Islamic Republic of Iran have not got accustomed to financially support the AEOI towards implementing its new ideas. Even though they may be the very primary beneficiaries of the new techniques implemented which would help them to improve quality of their products.

Challenges faced by NRCs

New directions

We have basically done fundamental and scientific researches in the past. However, we are shifting emphasis towards applied research in the fields of Medicine, Industry and Agriculture.

Examples of successful orientation

Establishing the nuclear research centre for Agriculture and Medicine (NRCAM) could be counted as a successful example in changing the direction towards more of an applied research. The Secondary Standard Dosimetry Laboratory (SSDL) at NRCAM is counted as the national centre for accurate measurements of X and γ radiation fields as well as dose measurements in the Islamic Republic of Iran. This centre has been providing calibration services both in therapy and protection levels.

Preservation of expertise

Considering the new direction taken towards the applied researches at AEOI, we feel the ever more lack and need for training expertise in different areas of the applied researches which we have very few of them at AEOI.

The technical co-operation of the IAEA has accelerated and enlarged these productions and in particular has provided the access to the application and utilisation of nuclear energy in the field of nuclear medicine and industries in the Islamic Republic of Iran. The transferring of these technologies by the IAEA's technical co-operation has promoted a tangible socio-economic impact in our country program frameworks.

Interaction of NRCs with their environment

Social and economic sector

The nuclear centres have always been worrying the society's minds due the word "nuclear". However, this mentality is changing ever since the peaceful applications of nuclear techniques in industry, medicine and agriculture have been implemented and eye witnessed by the people of our society.

Academia

About 50 PhD. and more than twice as many M.Sc. students are currently working through out the nuclear centres at AEOI. Practically all of them are working on some interesting applied research projects. Basically in the third world countries such as ours the universities are very dependent on the existing nuclear centres to pursue their researches in the related nuclear fields.

Public

The NRCs have vast relations with nuclear medical centres, cancer institutes, therapeutically clinics, different industries, universities, and research centres throughout the country. Currently more than 65 nuclear medical centres in the Islamic Republic of Iran are receiving some type of radiopharmaceuticals from our centres. Prior to distribution to any of the nuclear medical centres in The Islamic Republic of Iran, the quality control of these productions is carefully investigated according to the IAEA regulations.

The end users of our products are quite satisfied with quality of our productions and the on time delivery of the products. Gladly, we have a very close collaboration and scientific relation with the doctors in the referred hospitals.

Our productions are used nearly by 5000 patients in the country every day. We have established a very close relation with the doctors in the field and the public in effect.

Collaboration and co-operation

North-south and south-south

For production of the radiopharmaceuticals, kits, and radioactive tracers we normally supply our essential materials from some European countries. Unfortunately, in most cases "end user statement" is needed. Though it is very time consuming, we prepare and send them the statements since the European suppliers are required to ask for such a thing according to their "Export license". Our orders are mostly chemical, biochemical, biological materials for synthesis, and some formulation for the production of radiopharmaceuticals and kits which will be used for diagnostics and prognostic purposes in patients who are suffering from a disease. In this respect the North-South relation seems too weak and we believe that the IAEA can co-operate in some cases by fund in-trust procedure and supply the necessary materials for the projects. In some cases our centres are obliged to supply and purchase the materials they need from a free market twice as much as the actual price, or more, which is economically reasonable neither for the hospitals nor for the patients.

Since the above materials should be spec-pure and reliable to be synthesised for injection to the patients, the South-South collaboration in this particular case cannot be practical and efficient. However, in transferring the technology, expertise, and training of personnel is currently very effective in south-south collaboration and co-operation. We believe and we are sure, that the IAEA can and would play an important role to implement the projects.

IAEA role

The technical co-operation of IAEA has potential economic advantages for implementation of any project. The IAEA attempts to answer the needs by delivering the necessary materials, spare parts, equipment, and in particular expert missions for duration of one to three months. The essential mission tasks would be to install the equipment, carry out teaching and training programs on the theory and practice of the project. In this regard the IAEA plays an important role for the implementation of any project related to the development and practical applications of the Atomic energy for peaceful uses throughout the world.

Other issues considered relevant

We would like to thank the IAEA for its assistance and collaboration in arranging expert missions, training our personnel, and providing the necessary equipment and instruments. We hope this co-operation will be continued until the objectives or the “TC Projects” are accomplished. Today, we are deeply indebted to the technical co-operation department for their collaboration that has considerably helped our national development in nuclear medicine and industries. We are mostly benefited by bye IAEA’s expert training of our personnel and supply and delivery of some of the up to date equipment.

Japan Atomic Energy Research Institute in the 21st century

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Abstract. Major nuclear research institutes in Japan are the Japan Atomic Energy Research Institute (JAERI), Nuclear Cycle Development Institute (JNC), National Research Institute of Radiological Science (NIRS), and the Institute of Physical and Chemical Research (RIKEN). In the 50s and 60s JAERI concentrated on the introduction of nuclear technology from overseas. Energy security issues led to the development of a strong nuclear power programme in the next two decades resulting in Japan having 50 light water cooled nuclear power plants in operation. Japan also worked on other reactor concepts. The current emphasis of JAERI is on advanced reactors and nuclear fusion. Its budget of 270 million US$ supports five research establishments. JAERI has strong collaboration with industry and university system on nuclear and other advanced research topics (neutron science, photon science). In many areas Japan has strong international links. JAERI has also been transferring know-how on radioisotope and radiation applications to the developing countries particularly through IAEA-RCA mechanisms.

Introduction

Major nuclear research institutes in Japan were established in the late 50s, when Japan embarked upon research and development into the use of nuclear energy for peaceful purposes after US President Eisenhower's Speech at the United Nation on Atoms for Peace. These are the Japan Atomic Energy Research Institute (1956), the Atomic Fuel Corporation (1956, reorganized to Power Reactor and Nuclear Fuel Development Corporation in 1967), the National Research Institute of Radiological Science (1957), and the Institute of Physical and Chemical Research (1958).

The above four institutes have been under the jurisdiction of the Science and Technology Agency (STA) of the Japanese Government which is responsible for, among others, planning, formulation and promotion of policies on the utilization of atomic energy in consultation with the Atomic Energy Commission (AEC). AEC decides on the long term programme for Research, development and utilization of Nuclear Energy to meet the requirements and needs of the Japanese Government and society.

The promotion of research and development in nuclear related fields with active international co-operation, as well as proper introduction of advanced technologies from foreign countries, has greatly contributed to the enhancement of the Japan's technological level in these fields. In the course of the progress in research and development in Japan, these research organizations have been engaged in a variety of research and development activities in their respective fields.

The Japan Atomic Energy Research Institute (JAERI) has promoted diverse research and development, e.g. safety of nuclear facilities, high temperature engineering, nuclear fusion, radiation applications. It has established basic studies related to these activities, along with the development of fundamental technologies. JAERI has also made available its large research facilities such as accelerators, research reactors and material test reactors to outside researchers.

The key role of the Japan Nuclear Cycle Development Institute (JNC), which was renamed from Power Reactor and Nuclear Fuel Development Corporation (PNC) in October 1998, is to develop a wide range of technologies on, light water reactors (LWR), spent fuel management, conversion of Mixed Oxide (MOX) fuel, and the development of fast breeder reactor (FBR).

The National Institute of Radiological Sciences (NIRS) carries out researches related to radiology such as prevention of radiation harm to people and medical application of radiation including cancer treatment. NIRS applies a considerable portion of its budget to utilization of the Heavy-Ion Accelerator for Medical Applications (HIMAC) which is in service to treat various types of cancer.

In the Institute of Physical and Chemical Research (RIKEN), which carries out research and development on a wide range of scientific fields, nuclear research forms one part of research activities. While RIKEN is undertaking joint researches based on overseas research facilities in basic nuclear science like muon science, RIKEN has started to construct the RI beam factory which will exploit new science and technology for RI utilization. A major portion of the nuclear research funds in RIKEN goes to the 8 Gev Super Photon Ring which was constructed jointly with JAERI.

The budget of the Japanese Government for nuclear energy R&D in JFY 1999 is 347 billion yen (approx. US$ 3.3 billion). About 43% of its budget is allocated to JNC, whereas 34% is allocated to JAERI. Thus, from viewpoints of financial resources for R&D as well as scope and variety of research activities, JAERI has played a major role in research and development of nuclear energy in Japan.

General description of JAERI

Trends and priorities of research in relation to the Government policy

Since its establishment in 1956, JAERI has endeavored to fulfill its role as a core research organization in the nuclear field by engaging in advanced research and development activities. Guidelines for nuclear energy research in Japan have been given in the long term program formulated by AEC, which outlines the Government policy in the nuclear field. The policy is based on the principles of peaceful use, safety first, democratic management, independency, public disclosure of results and international contribution. AEC has revised the long term program approximately every 5 years to meet scientific, technological and social needs of the times.

1950s and 60s

In this period, the intention of the Government was to introduce technology which had been developed overseas so that Japanese research could catch up with the rest of the world. The highest priority was the development of facilities, such as research reactors, radiation facilities, and basic research facilities. The largest portion of the budget was supplied by the Government. Despite low funding for reactors other than light water reactors, research activities ranged widely from fission to fusion, including waste management.

1970s and 80s

Energy security has led to the promotion of nuclear energy development, and to the construction of nuclear power plants. By the end of this period, about 50 nuclear power plants had been put into operation, including the advanced thermal reactor, "FUGEN". Safety research was the first priority for nuclear power plants. Nuclear research programs were expanded to the fields of radiation utilization, computer application, new concepts for nuclear reactors, the fuel cycle, and high temperature gas cooled reactors to meet the various requirements from the Government.

1990s

The long term program was revised by the AEC in 1994 to form the guidelines for nuclear research and development into the next century. This program recognizes the fact that the understanding and co-operation of the Japanese public and of the international community are indispensable for the smooth promotion of nuclear energy.

At present, JAERI's research and development aims at the further improvement of the reliability and safety of light water reactors as well as the increase in the choice of energy systems through the R&D of advanced reactors, nuclear fusion reactors, and so on. In addition to these research and developments, JAERI has recently begun advanced research which would lead to the overall development of science and technology in such fields as neutron science, science of the photon and synchrotron radiation, research on the utilization of radiation, environmental science, high grade calculation science, advanced basic research, and so on.

Current status of JAERI

JAERI's budget:

27 billion yen for the fiscal year(FY) 1999 A major portion (89%) of the budget comes from the STA and 5% of the budget from private sectors. The total operating budget escalated during the 1980s but has become relatively stable in recent years.

Number of employees:

2347 as of FY 1999. This consists of; 1105 researchers (47%), 844 engineers + technicians (36%) and 398 administrative staff (17%) The total number of employees escalated during the 1960s and since 1980, has decreased at a rate of 1% per year.

Number of research establishments: 5

Tokai-Establishment: 1071 employees as of FY 1998, consisting of 459 researchers (43%), 499 engineers + technicians (47%) ,and 113 administrative staff (11%).Activities: A wide range of research and development has been carried out using various test facilities including research reactors, safety research facilities, and accelerators. Basic research and technology fulfill the establishment's role as a comprehensive research centre in JAERI.

Oarai-Establishment: 318 employees, consisting of 154 researchers (48%), 131 engineers + technicians (42%),and 33 administrative staff (10%) activities: The development of fuel and materials for nuclear reactors is carried out using the Japan Material Test Reactor (JMTR). The high temperature Test Reactor (HTTR) reached first criticality in November 1998 to meet the necessity of diversification of the use of nuclear heat and high temperature technology.

Takasaki Radiation Chemistry-Establishment: 141 employees consisting of 78 researchers (55%), 27 engineers + technicians (19%), and 36 administrative staff (26%). Activities: radiation applications are conducted using the large Co-60 irradiation facilities and accelerators for electrons and ions. Many useful results have been obtained in the field of environmental conservation and upgrading of polymers.

Naka Fusion Research Establishment: 321 employees, consisting of 241 researchers (75%), 55 engineers + technicians (17%),and 25 administrative staff (8%). Activities: Experiment with a large Tokamak device (JT-60) is in progress for plasma physics. Related technologies have also been developed for a fusion reactor. Engineering design activities (EDA) for the International Thermonuclear Experimental Reactor (ITER) are being carried out for the next stage of fusion reactor.

Kansai Research Establishment: 96 employees, consisting of 79 researchers (82%), 5 engineers + technicians (5%), and12 administrative staff (13%). Activities: advanced photon sources (Spring-8) have been developed and their application to X ray lasers, 3D microscope ultra fine machining and medical diagnostics/treatment are being promoted. The development of ultra short pulsed lasers with high peak power and innovative applications in various fields will be carried out.

Mutu Establishment: 36 employees, consisting of two researchers (6%), 24 engineers + technicians (66%), and 10 administrative staff (28%). Activities: Storage of the reactor room from the decommissioned nuclear ship MUTU. Marine environmental research has been started.

New situations surrounding JAERI

Governmental reform

In the Government reorganization which is to be enforced at the beginning of the year 2001. The STA and the Ministry of Education will be combined into a new Ministry of Education and Science. Under the new ministry, JAERI will be expected to continue its current research activities as Japan's core research organization in both nuclear and advanced scientific research. Most of the present research activities are planned to continue into the 21st century. However, the jurisdiction over nuclear activities related to commercial power reactors will be transferred from the STA to new Ministry of Economy and Industry. This would entail changes in and abolishment of certain research subjects, reorganization and reshuffling of personnel, concentration of research resources on priority matters, etc., in accordance with the Government's reorganization.

Preservation of expertise

JAERI has always played a major role in nurturing a highly skilled and knowledgeable workforce in the field of nuclear research in Japan through the integration of young scientists and engineers in its nuclear research programs. At the outset of nuclear research in Japan, industries and other governmental organizations recruited their specialized staff from JAERI.

JAERI's ample facilities such as research reactors, accelerators and associated staff attract various researchers of universities and industries. Early on, JAERI's collaboration with other organizations was restricted to the nuclear field. With the diversification of research and development in JAERI, however, collaboration has been gradually extended to advanced sciences.

Collaboration with universities and industries helps JAERI maintain high scientific level. Now JAERI is attempting to recruit young scientists from universities and industry to meet the diversification of research subjects.

New relationship with industry

In the past years, major projects in nuclear research have been conducted by government sponsored institutes such as JAERI primarily as national projects. However, nowadays, the various nuclear power industries and utilities have already accumulated experience and technology in the utilization of nuclear energy. It is expected, therefore, that those industries and utilities will be capable of resolving on their own technical problems in the practical application of nuclear energy.

It can be foreseen that diversification of nuclear research will occur at nuclear research institutes. As mentioned above, JAERI has already diversified its activities even into such non-nuclear basic research as neutron science and advanced photon science.

Advanced technology and science which may have potentialities for commercial application will be transferred to the private sector for industrial application. The purification of ventilated air by electron beam irradiation is a typical example of technology which has been transferred to industry. JAERI researchers have developed an elimination technology for the effective removal of toxic volatile organic compounds from wastewater and exhaust gas.

International collaboration

International collaboration is highly emphasized in such projects as nuclear fusion, fast reactor and large accelerator development because they are too big for one country to maintain in the current world trend of slowing down of nuclear activities in developed countries. The role of international organizations will become more and more important in international collaboration.

JAERI will construct a facility for high-grade environmental analysis, " Clean Chemical analysis laboratory", through which Japan will positively contribute to fulfill its international roles with regard to strengthening safeguards in (93 + 2) plan. Chemical analysis of radioactive nuclide in the atmosphere in the form of super-microscopic substance will be improved to meet the requirements of Comprehensive Test Ban Treaty (CTBT).

JAERI will continue to promote international collaboration in the field of radiation utilization with Asian countries through RCA projects and also bilateral agreements.

Accident at nuclear fuel conversion facility at Tokai-Mura

On 30 September 1999 at 10:35 local time, a criticality accident occurred in the fuel conversion building at the uranium conversion facility of JCO Company Limited, Tokai-mura, Ibaraki, Japan. Uranium solution with an enrichment level of 18.8% uranium-235 and a mass exceeding several times the pre-specified limit was fed into a precipitation tank, resulting in a contravention of the legally approved criticality control. The outcome was that three workers were exposed to dangerous levels of radiation and several staff working in the facility and the public in the surrounding area were exposed to radiation, 161 people living within 350 m or so from the facility were evacuated, and some 310 000 people were advised to stay indoors as a precautionary measure.

An extensive investigation was carried out, of the following:

a) the facilities, including the design, managerial organization and operation,
b) regulatory control, including licensing and inspection,
c) emergency preparedness and response, including new laws and modifications to existing laws for nuclear accidents in the government,
d) medical care of the three workers suffering from radiation sickness and of the neighboring public,
e) the accident itself, including a detailed description of the procedures which were carried out at the time,
f) the safety network in the local community.

Government activities in connection with this accident were supported by JAERI because of its accumulated expertise in handling nuclear accidents. Research and development in nuclear field cannot be continued without the acceptance of the general public and the local governments. JAERI, together with other nuclear related organizations, is expected to make efforts to ameliorate the present situation and recuperate public acceptance.

Projections for the future

New situations described above will promote diversification of research subjects and expansion of collaboration with both universities and industries as well as with international organizations. However, no major drastic changes are foreseen in the tasks JAERI will undertake in the near future. The main categories of current research and development will be continued are:

1) Energy research:

- Improvements in the reliability and safety of light water reactors for long life fuel and cladding material and aging evaluation on main reactor components will be investigated in the field of nuclear safety research.

- High temperature gas technology and utilization of nuclear heat, and also high temperature advanced technology will be examined during the HTTR power up test in the field of high temperature gas cooled reactors.

- In fusion research, extensive research on plasma physics and fusion technology will be done through the activities of JT-60 and ITER. engineering design activities (EDA) of the ITER project will play a key role in fusion research for the next century.

- Light water reactors with a new design which will feature a high breeding ratio. Liwithwia compact reactor core, could be one candidate reactor for the next generation.

2) Advanced scientific research:

- A systematic approach using combination of neutrons, ions, electrons, photons, and laser beams will accelerate basic research in physics, chemistry and material science.

- In the field of the neutron science, technologies for nuclear transmutation with high-power proton linac will be developed for R&D of material science.

- Radiation application will be expanded in biotechnology and environmental conservation through the development of environment-friendly organic compounds. Basic research and related technologies for Table-Top-Terawatt laser, X ray laser in photon science and Spring-8 in synchrotron radiation will be continued.

Research and development will continue in JAERI in line with the long term program in which the role of the Government sponsored research institutes are clearly defined to enhance the system for promotion of nuclear research and development. It is emphasized that exploring new possible uses of nuclear energy to meet diverse needs is an important area of research to be pursued by the government sponsored institutes. Other important areas are education of young students and training of engineers, and public acceptance. Currently the long term program is under review, and a new version of the long term program is expected to be finalized at the dawn of the 21st century.

Korea Atomic Energy Research Institute (KAERI) in the 21st century

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Abstract. KAERI (Korea Atomic Energy Research Institute), a national nuclear research institute in the Republic of Korea, celebrated its fortieth anniversary last April. It has played a key role in the Korean nuclear history such that it:

- initiated and promoted the peaceful uses of nuclear energy in the Republic of Korea;
- maintained nuclear expertise on whole spectrum of nuclear field through conducting nuclear R&D programs, operating nuclear research facilities, and training and educating specialized nuclear personnel;
- founded a cornerstone of Korean nuclear industry by participating in the establishment of a nuclear engineering company and a nuclear fuel company and localizing nuclear fuel and reactor technology ; and
- contributed to nuclear safety regulation by incubating a specialized nuclear regulatory body.

Recently, to concentrate on nuclear R&D on advanced technology, KAERI went through management reform such as:

- the transfer of nuclear engineering divisions responsible for NSSS design and nuclear fuel design to nuclear industry in 1996 ; and
- the downsizing of manpower in 1998.

Currently KAERI is in the challenging stage in terms of its missions and manpower. In the coming 21st century, KAERI is required to maintain the current R&D momentum and also to conduct priority-based research requiring concentrated effort.

Past history

Founding stage (60s)

1. AERI (Atomic Energy Research Institute), the initial body of KAERI, was established in 1959 as one of governmental bodies under the Ministry of Nuclear Energy. Its initial missions were:
   - to educate and train specialized nuclear personnel;
   - to promote the application of radiation and radioisotopes;
   - to perform nuclear basic research; and
   - to develop indigenous expertise in nuclear science and technology.

2. Priority was given to the establishment of nuclear infrastructure such as nuclear basic research, application of radiation and radioisotopes, construction of nuclear R&D facilities and training of manpower.

3. The first research reactor, TRIGA-MARK II (100 kW), began its operation at AERI in 1962. The second research reactor, TRIGA-MARK III (2 MW), began its operation at AERI in 1972.

4. To further application of radiation and radioisotopes, Radiological Research Institute (RRI) became independent from AERI in 1963 and so did Radiation Research Institute in Agriculture (RRIA) in 1966.

Exploring stage (70s)

5. In 1973, the Korean government restructured the national nuclear research system. KAERI was reborn as a government-affiliated nuclear research institute, merging AERI, RRI and RRIA.

6. Priority was shifted to nuclear power and nuclear fuel cycle technology development including researches on nuclear safety and nuclear materials in parallel with the construction of the first NPP in the Republic of Korea.

7. KNFDI (the Republic of Korea Nuclear Fuel Development Institute) was established in 1976 to devote special effort for nuclear fuel cycle. A pilot scale nuclear fuel fabrication facility was completed at KNFDI in 1978, which accelerated fundamental R&D on nuclear fuel manufacturing technology.

Enlarging stage (80s)

8. KAERI was reshaped with merging KNFDI in 1980 and moving from Seoul to its current site in Daeduk Science Town in 1984.

9. Priority was shifted to self-reliance of nuclear fuel and nuclear reactor technology along with the rapid growth of nuclear power in the Republic of Korea.

10. For the self-reliance of nuclear power technology, the Korean government assigned technological responsibilities for design, manufacturing, construction and maintenance of NPPs to several specialized organizations. The rationale for the division of responsibilities was to maximize the utilization of national resources such as high-level manpower, technical capability, facilities, etc.

11. KAERI was given the responsibility for design of NSSS and nuclear fuels for both PWR and CANDU in consideration that it possessed nuclear specialized personnel suitable for digesting those technology compared to other organizations in the Republic of Korea.

12. The active participation of R&D personnel in nuclear power projects was one of key factors which brought the success of the localization of CANDU fuel, PWR fuel and NSSS design.

13. Along the localization effort, KAERI's manpower doubled in 1989 compared to that in 1981 and its budget increased about eight times in 1989 compared to that in 1981.

14. KINS (the Republic of Korea Institute of Nuclear Safety) was separated from KAERI and became an independent organization

15. KAERI established NEMAC (Nuclear Environment Management Centre) as its affiliate, which took the responsibility of managing radioactive waste and spent fuel management.

Challenging stage (90s)

16. In 1992, the Korean government launched the mid and Long term nuclear R&D program covering from 1992 to 2001 to advance nuclear technology to the level of nuclear advanced countries, which streamlined KAERI's R&D projects.

17. Priority was shifted to large-scale nuclear R&D projects on nuclear advanced systems such as SMART (System-integrated Modular advanced Reactor), KALIMER (Korean Advanced Liquid Metal Reactor), DUPIC (Direct use of spent PWR fuel in CANDU), etc.

18. A multi-purpose research reactor, HANARO (high-flux advanced neutron application reactor, 30 MW), began its operation in 1995.

19. According to the Government's decision to restructure nuclear industry in the Republic of Korea, KAERI transferred its nuclear engineering functions (NSSS design, nuclear fuel design and manufacturing, radioactive waste management) including related technologies and personnel to nuclear industry in 1996. The rationale of the transfer was that the nuclear industry became mature enough to take over the functions and KAERI would concentrate its effort to nuclear R&D.

20. At the same time, the Korean government established nuclear R&D fund, which would secure financial resources for national nuclear R&D and is calculated based on a fixed monetary rate of on1.20(about 1.0.1) per kWh of electricity produced annually with nuclear power. KAERI is a major beneficiary of the fund.

21. The second phase of the mid and long term nuclear R&D program covering from 1997 to 2006 began in 1997, reflecting the changing national and international nuclear circumstances.

22. KAERI, like other research institutes in the Republic of Korea, went through hard downsizing of its manpower due to the Korean economic crisis in 1998.

Present situation and challenges

Missions

23. KAERI restructured its missions in 1996 to concentrate its effort to nuclear R&D. Its current missions are as follows: to carry out integrated nuclear R&D such as
    - nuclear basic research,
    - nuclear safety research,
    - advanced reactor technology development,
    - advanced fuel development,
    - back-end fuel cycle research,
    - research reactor utilization,
    - radiation and radioisotope application; and
    - other subsidiary missions such as support for national nuclear control (safeguards, export control), training of specialized nuclear personnel, and national nuclear policy research.

24. These missions are expected to be continued in the new century considering the Korean government's positive and active position on nuclear energy.

R&D areas

25. The current R&D areas of KAERI cover almost whole spectrum of nuclear field such as nuclear reactor, nuclear fuel cycle, radioactive waste management, nuclear safety, radiation/radioisotope applications, radiation protection, and safeguards/physical protection.

26. Maintaining whole spectrum would be one of KAERI's strengths and also one of its weaknesses. KAERI could maintain broader nuclear expertise but might not reach deeper level of expertise. KAERI needs to be more streamlined and specialized in some areas not all.

27. The concentration of KAERI's effort to the self-reliance of nuclear power technology had resulted in relatively little concern on researches on the application of radiation and radioisotopes and on hardware-oriented R&D's. These areas would get relevant concerns in the new century.

Manpower

28. KAERI's manpower dropped to 1000, half of that in 1996, due to the transfer of nuclear engineering functions in 1996 and the downsizing in 1998. The split of nuclear expertise could impact KAERI'S R&D for the time being until KAERI gets back its momentum.

29. KAERI's manpower structure is another challenge. KAERI is forty years old, hence the manpower structure looks like a diamond skewed upward. There are very few under 30. It is difficult to maintain a sound manpower structure under the Korean culture.

30. Furthermore, the young generation's interest on nuclear field is declining, like in other countries, considering the fact that the number of students in nuclear engineering departments in the Republic of Korea is decreasing. This could be a big barrier to the recruitment of manpower in the future.

R&D facilities

31. KAERI maintains fairly well established R&D facilities such as HANARO (a multi-purpose research reactor, 30 MW), PIEF (Post-Irradiation Examination Facility), IMEF (Irradiated material Examination Facility), etc. They are in full utilization now and are expected to be so in the new century.

Financial resources

32. KAERI's financial resources come from the Government and from nuclear R&D fund established in 1996. The 1999 budget of KAERI except affiliated organizations records US$ 137 million.

33. The current financial status of KAERI is relatively stable, while having some uncertainty due to the restructuring of electricity industry in the Republic of Korea expected to occur in the near future.

Other issues

34. After the transfer of nuclear engineering functions to nuclear industry, it became more important for KAERI to keep close ties with the nuclear industry for maximizing the utilization of nuclear resources.

35. Public acceptance on nuclear energy is a key issue in the Republic of Korea like in other countries. Therefore, KAERI is making effort to keep sincere and close relationship with the local society, public media, NGOs, etc.

International co-operation

36. KAERI puts great importance to international nuclear co-operation with international organizations and various nuclear research centres in the world.

37. International nuclear co-operation is believed to be a viable way to overcome challenges most nuclear research centres in the world are facing. Many developing countries are in needs of nuclear technology and infrastructure, which nuclear research centres in the developed countries in concern have maintained.

International collaboration on research reactors

38. Research reactors are necessary for various purposes such as nuclear fuel and material irradiation testing, radioisotope production, neutron beam research, neutron activation research, neutron transmutation doping, manpower training, etc. There are and will be much needs for research reactors and their related technologies over the world, especially in developing countries. Usually building a research reactor has been the first step for introducing nuclear energy in a country. Nuclear specialized personnel have been first raised through research reactors.

39. However, the reality seems to be far from fulfilling the needs. The total number of research reactors over the world has been decreased to about two thirds of the peak number in around 1975. About two thirds of the reactors are over 30 years old, and more than 80% are over 20 years old. Generally the construction of new reactors becomes harder due to the tighter regulation and the poorer public acceptance in advanced countries. Developing countries lack of financial resources and technology to build research reactors.

40. Therefore, the first viable way to meet the needs for research reactors would be to maximize the utilization of the existing research reactors over the world. The important point here is to match the possible demand and the possible supply. Many developing countries are in needs of nuclear technology and infrastructure while many nuclear research centres in developed countries are suffering lack of demand.

International Nuclear University

41. The expected growing need of nuclear energy in the coming future requires relevant human resources and knowledge. However, we are experiencing the declination of nuclear personnel over the world, especially of the younger generation's interest on nuclear field. We should take preparations to meet for the nuclear future.

42. In this respect, the establishment of a human resources development mechanism, so called "International Nuclear University (INU)", would be a viable option, which could help fill the gap expected in the new nuclear age.

43. INU would provide professional education and training in the nuclear field with emphasis on global and interdisciplinary perspectives and hence offer professional staffs and younger generation broader opportunities and motivation to acquire and improve their knowledge on nuclear field.

44. INU would organize a world network of nuclear related departments and specialized training centres of Member States so as to fully utilize their facilities and human resources. Professional staff of the IAEA and Member States, either actively in service or retired, could be a source of faculties and advisors for INU.

45. KAERI, with the IAEA, is willing to take a leading role of elaborating and realizing the concept of INU.

Interaction of NRCs with their environment — KAERI's experience

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Abstract. Main players in KAERI's environment are the Government, nuclear industry (essentially nuclear power related), Academic community and the public. The Board of Trustees of KAERI has members from three important ministries of the Government and this Board formulates the nuclear R&D programme. The current programme plan covers a period of 1996–2006. The Korean nuclear industry has grown out of the core groups within KAERI. Until 1996, certain key areas in the design of nuclear steam supply system, nuclear fuel and nuclear waste management were still a part of KAERI responsibilities. However, with the growth of the nuclear power programme to 14 GW(e) (16 reactors), and more reactors under construction and plan, a decision has been taken to shift these activities to the industry, along with the personnel (600). The Government has also decided to secure financial resources for R&D by a contribution of 0.1 cents/kw•h from the nuclear utilities to a fund. In 1998 this fund collected 90 million US$ and 75% was made available to KAERI. So there is a very strong linkage between the Government, KAERI and the nuclear industry. With the academic community, KAERI takes post-graduate and post doctoral research students, gives R&D projects to the universities and has joint projects in some areas like fusion research. With public, KAERI has followed the policy of openness. It has made specific efforts to convey more easily understood benefits of radioisotopes and radiation. Also, communication is quite often targeted at specific groups rather than public at large. This policy has helped in the public acceptance of nuclear power which provided 41% of the electricity in 1998.

Introduction

The environment of nuclear research centres means what surrounds and affects them in everyday life. Without the environment like air or water for human beings, nuclear research centres can't exist. Therefore, it is vital for nuclear research centres to interact well with and adapt themselves to their environment.

KAERI celebrated its fortieth anniversary last April. During the forty years, KAERI has had lots of successful and sometimes painful interactions with its environment as described in the discussion paper already distributed to you for this meeting. During the 60s and 70s, KAERI remained rather in a primitive stage doing basic researches and radioisotope applications. During the 80s, KAERI could make a breakthrough by actively involving in nuclear power technology development. Without it, KAERI could not have survived.

I think KAERI's experience is worth of sharing with you. I hope my presentation would help our discussions in this meeting to be more fruitful.

First, I'll shortly describe the environment which surrounds KAERI, and then I'll talk about its interaction with the environment: namely, the government, nuclear industry, academia, and the public. Finally, I'll conclude with my views and lessons from KAERI's experience.

KAERI's environment

In general, KAERI's environment could be divided into four categories.

The first category is the government. Ministry of Science and Technology (MOST), Ministry of Commerce, Industry and Energy (MOCIE), and Ministry of Foreign Affairs and Trade (MOFAT), and Ministry of Planning and Budget (MPB) are major bodies related to nuclear field in the Korean government.

The second category is nuclear industry. The only one utility in the Republic of Korea, Korea Electric Power Company (KEPCO), and several companies such as Korea Power Engineering Company (KOPEC), Korea Nuclear Fuel Company (KNFC), and Korea Heavy Industries and Construction Company (HANJUNG), are major players in the Korean nuclear industry. KOPEC and KNFC are daughter companies of KEPCO.

The third category is academia such as universities and other research institutes. There are six universities operating a nuclear engineering department.

The fourth category is the public such as new media, non-governmental organizations, local society, etc.

Interaction with the government

The government is a key environment of KAERI. KAERI was established by the government in 1959 and is under the auspice of the government. Government officers for MOST, MOCIE and MPB serve as members of KAERI’s board of trustees.

By nature, the government is a KAERI’s major customer. Most of KAERI’s R&D projects are based on the mid and long term nuclear R&D program, which was launched by the Korean government in 1992 and is now on its second phase covering from 1997 to 2006. The program streamlined KAERI’s R&D projects and KAERI’s priority was shifted to large-scale nuclear R&D projects on nuclear advanced systems.

The Korean government established nuclear R&D fund in 1996 to secure financial resources for national nuclear R&D. The fund is calculated based on a fixed monetary rate of about 0.1 cents per kWh of electricity produced annually with nuclear power. The total amount of the fund contributed in 1998 was about 90 million US dollars. KAERI is a major beneficiary of the fund.

On the other hand, KAERI supports the government for establishing and implementing its nuclear policies through nuclear policy studies. Technology Centre for Nuclear Control (TCNC) of KAERI supports national nuclear control such as safeguards, nuclear export control, and physical protection of nuclear materials.

Interaction with nuclear industry

KAERI has been maintaining a close relationship with nuclear industry in the Republic of Korea.

First, KAERI was deeply involved in the establishment of the Korean nuclear industry. In 1975, KAERI established a daughter company, Korea Atomic and Barns & Roe (KABAR), the original body of current KOPEC. Also, in 1982, KAERI established another daughter company, KNFC, responsible for manufacturing locally needed nuclear fuels. These two companies later became independent from KAERI and became daughter companies of KEPCO.

Second, KAERI played a major role for the self-reliance of nuclear power technology such as CANDU fuel design and manufacturing, nuclear steam supply system (NSSS) design and PWR fuel design. To concentrate on nuclear R&D, KAERI transferred related technology and personnel to nuclear industry in 1996. I'll talk about this in more detail later.

Third, KEPCO contributes to nuclear R&D fund, as I already explained, at the rate of 0.1 cents per kWh of electricity generated by nuclear power. KAERI is using more than three quarters of the fund.

Fourth, KAERI provides R&D services for nuclear industry, especially for KEPCO. KAERI receives R&D projects from nuclear industry to solve field-specific problems.

Nuclear power programme in the Republic of Korea

Since the first commercial operation of Kori Unit 1 in 1978, the Korean nuclear power program has grown very fast. Currently, twelve PWRs and four CANDUs are in operation. The nuclear installed capacity shares 28.9% (14 GW(e)) of the total installed capacity and 41.7% (90 TW•h) of the total electricity generation in 1998.

Four units of PWR are under construction and additional ten units will be constructed by 2015. In addition, the Republic of Korea is going to construct two PWRs in North Korea under the Korean Peninsula Energy Development Organization (KEDO) framework. At the same time two units will be decommissioned by 2015. This means there will be a total of 30 operational units in the Korean Peninsula in 2015.

Nuclear power development in the Republic of Korea

Chronologically, nuclear power technology development in the Republic of Korea from the 1970s to the present can be divided into three phases.

Phase one was characterized as a turn-key base contract. The Republic of Korea's first three units, each of 600 MW(e) class, were constructed on a turn-key base by foreign vendors in the 1970s; two Westinghouse PWRs and one AECL CANDUs. It was natural to have turn-key plants for a country having no experience, no capability, no qualified manpower, and not enough financial resources.

In phase two, the Republic of Korea's next six units, each having 950 MW(e) capacity, were constructed on so-called a component approach. In this phase, the utility was in charge of project management, and the plant design and manufacture of the primary system was performed under contract by foreign suppliers. By expanding the participation of domestic industry, the government aimed to expedite our capabilities and progress to a self-supporting position in nuclear power technology.

Phase three was characterized as the self-reliance of nuclear power technology starting from Yonggwang units 3&4. Combustion Engineering (CE) of the USA was selected to supply nuclear steam supply system hardware. For effective technical self-reliance, a joint system design concept was introduced between KAERI and CE, where both organizations share 50–

50 manpower participation in the NSSS design and engineering work. This provided KAERI with the maximum opportunity in gaining real nuclear power project experience with guaranteed quality, schedule commitment and cost control measures.

Through participation in joint design and R&D efforts in parallel the technical self-reliance, the Republic of Korea developed Korea Standard Nuclear Power Plant (KSNP) concept. In the Ulchin units 3&4 projects, 1000 MW(e) level PWR reactor plants, the first standard design concept was established in which the primary system and the main components were adapted from those of Yonggwang units 3&4. KSNP is being applied to the construction of Yonggwang 5&6 and Ulchin 5&6 and can be replicated as many times as is required to provide a stable, adequate, economical and reliable electric power supply. Also, KSNP will be applied to the first commercial nuclear power plant in North Korea.

Currently, the development of Korea Next Generation Reactor (KNGR), of which the first unit is planned to be constructed by 2010, is in progress. Its capacity is 1400 MW(e).

Nuclear power technology self-reliance

For the self-reliance of nuclear power technology, the Korean government assigned technological responsibilities for design, manufacturing, construction and maintenance of nuclear power plants to several specialized organizations to maximize the utilization of national resources such as high-level manpower, technical capability, facilities, etc.

Responsibilities were given to KEPCO for project management; to KAERI for the design of NSSS and nuclear fuels for PWR and CANDU; to KOPEC for architectural engineering work, mainly for the balance of plant (BOP) except NSSS; to HANJUNG for component design and manufacturing of reactor vessels and turbine-generators; and to KNFC for manufacturing of all the locally needed PWR fuel based on KAERI's design.

The rationale for KAERI, a nuclear research institute, to take a key responsibility of nuclear power technology self-reliance was that at that time there were more nuclear specialized personnel capable of digesting those technologies at KAERI compared to other organizations in the Republic of Korea. Also KAERI was considered to be more proper organization to recruit Korean nuclear scientists and engineers abroad. The active participation of R&D personnel in nuclear power projects was one of key factors which brought the success of the self-reliance of nuclear power technology in the Republic of Korea.

Transfer of nuclear power technology

After successfully completing the responsibilities assigned to it, KAERI, according to the Government's decision to restructure nuclear industry, transferred its nuclear engineering functions including related technologies and personnel to nuclear industry in 1996: NSSS design to KOPEC, nuclear fuel design and manufacturing to KNFC, and nuclear waste management to KEPCO. Over 600 persons at KAERI moved to respective companies.

The rationale of the transfer was that the nuclear industry became mature enough to take over the functions and KAERI would concentrate its effort to nuclear R&D.

On the other hand, the transfer could be a painful experience for KAERI with respect to related personnel, who were forced to move from a research institute to a industrial company.

However, the transfer was assessed inevitable to enhance the international competitiveness of the Korean nuclear industry.

Interaction with Academia

Academia could be a knowledge and manpower source for nuclear research centres. Academia having strong knowledge bases and excellent students could and should be able to help nuclear research centres to be more competitive.

In this regard, first, KAERI subcontracts parts of its R&D projects to universities. There are many professors specialized in nuclear field in universities. Therefore, it is requested to fully utilize their expertise and integrate their work focusing on specialized areas. Through subcontracts to universities, KAERI could organize small works of individuals in universities in a larger context.

Second, KAERI carries out joint R&D projects with universities and other research institutes in national perspectives, which brings more competitiveness to KAERI. For example, research on nuclear fusion is being jointly performed by several institutes including KAERI.

Third, many professors in nuclear engineering departments involve in the review and evaluation of KAERI's R&D projects. Also many professors involved in the establishment of the mid and long term nuclear R&D program, which is the backbone of KAERI's R&D projects.

Fourth, KAERI exchanges personnel with universities. Many graduate and post-doctoral students are working at KAERI for their thesis and experience. Some senior researchers at KAERI are serving adjunct professors in several universities.

Interaction with the public

In the Republic of Korea, during the 70's, the public used to be favorable to nuclear energy. That's why the government could implement the nations nuclear power program without any significant difficulties. But the recent changes in the socio-political climate in the Republic of Korea influenced change of the public perception. Beginning from the 90s, practically from 1988 when new government formed after almost 30 years of military regime, there were significant indications of the change of the public's attitude towards the industrialization including nuclear power programs.

The failure of nuclear waste disposal site selection in 1990, for which KAERI was responsible at that time, is a typical example.

From KAERI's experience with the public in the Republic of Korea, I can draw some general lessons on public acceptance strategies.

First, openness is a key. KAERI, like other nuclear-related organizations in the Republic of Korea, maintains the principle of openness to the public. KAERI provides site tours for students, local residents, etc. Almost 10 000 people have visited the KAERI site in 1999. The department of public information of KAERI provides news media with necessary information. Second, "low-profile" communication strategies focusing on specific target groups seem to be more effective than "high-profile" strategies targeting the general public at large.

Third, "go and meet" strategy was one of the rewarding approaches, to go out from office, ivory towers, laboratories, and plants to meet the target groups wherever and whenever necessary.
Fourth, "Proact rather than React" strategy is recommended. We have to carefully study what will be possible arguments by the anti-nuclear activists and prepare measures in advance.

Along with these strategies it is important to give the public a positive image of nuclear energy. Applications of radiation and radioisotopes and health care could be good examples. KAERI is putting much effort to the development of radioisotope application technology and the advancement of nuclear medicine through its affiliate, Korea Cancer Centre Hospital (KCCH).

KAERI participates in national public acceptance activities such as the establishment of Organization for Korea Atomic Energy Awareness (OKAEA).

KAERI also supports pro-nuclear non-governmental organizations. One typical example is Women Interested In Nuclear (WIIN), which was established in 1995. Currently WIIN operates 16 local branches and has more than 10 000 members.

Conclusion

In conclusion, I'd like to make four comments.

First, it is vital for nuclear research centres to interact well with and adapt themselves to their environment. KAERI has adapted itself to the changes in the environment, especially as the nuclear industry become mature.

Second, nuclear research centres in developing countries could play a key role for establishing and promoting their nuclear industry considering the cases of KAERI's involvement in the Korean nuclear industry. Involvement of nuclear research centres on nuclear industry is quite natural considering the limit of nuclear technology and specialized personnel and will be more successful. Also this will help nuclear research centres to survive and have a break-through.

Third, close relationship of nuclear research centres with industry and academia helps themselves to maintain their competitiveness and financial stability.

Fourth, special attention to the public is necessary also for nuclear research centres with growing importance of public acceptance for nuclear energy.

I'd like to end my presentation emphasizing that we all together should prepare for nuclear renaissance in the near future.

Making R&D at MINT relevant to national development

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Abstract. This paper attempts to identify issues facing nuclear research centres by tracing the development of the Malaysian Institute for Nuclear Technology Research (MINT). Approaches taken to arrive at the strategies in the areas of research and technology development, co-operation and technology transfer, and commercialization are highlighted. Interspersed in that review are some of the issues that are then collated in the Issues section.

Introduction

Nuclear power, which is generally regarded as the mainstay of the peaceful applications of nuclear science and technology, is the last option in the Malaysian national energy policy. As such, Malaysia currently has no nuclear power program.

This situation does not disadvantage MINT, which was established with nuclear power program as one of the considerations, for that enables it to concentrate in non-power applications of the technology that spans all major socio-economic sectors (agriculture, industry, manufacturing, medicine, environment, etc.). Success in these areas of application could swing the generally negative public perception on nuclear technology towards one that would be more supportive of it so that future introduction of nuclear power program, if and when the need arise, would not be faced with great misunderstandings and oppositions.

MINT was established in September 1972 as Tun Ismail Atomic Research Centre (PUSPATI). In June 1983 it was renamed Nuclear Energy Unit (UTN) following its placement under the Prime Minister's Department. In October 1990 it was retransferred to the Ministry of Science, Technology and the Environment and in August 1994 it adopted its current name. The change of name to MINT better reflects the technology-orientation of the Institute. In addition it should also be noted that nuclear energy or atomic power is after all a subset of nuclear technology.

These changes, taking place at about a decade intervals, reflect "virtual milestones" or stages in the development of the organization. During the formation stage in the 70s to early 80s the site of the complex was acquired, buildings and facilities erected, and the core staffs recruited and trained. In fact the 1 MW TRIGA Mark II research reactor went into criticality in June1982. The next stage is the capacity building stage during which several research support facilities were set up and put into operation; among the early ones are those related to the utilization of the research reactor such as NAA and radioisotope production.

In 1994, at a strategic plan workshop, the upper and senior management staffs formulated MINT's mission, viz. "to enhance national development and economic competitiveness through excellence in nuclear and related technology." The workshop also formulated MINT's vision, objectives, and strategic thrusts that are all compiled into a book entitled "MINT Corporate Plan 2000." The mission statement clearly identifies the purpose of MINT's existence, its stakeholders, and the explicit recognition that nuclear technology can contribute to national development. It also recognizes the fact that other, related, technology should also be considered to bring all to bear. The workshop indeed set the tone for further development of the Institute.

In November 1995 a new organization structure was put into effect that placed all MINT activities into three major programs, viz. corporate, Research and technology development (R&TD), and business operation program. Each program is like a piece of a jigsaw puzzle, individually it means little, but reveals the continuum of technology transfer process from development to the market place when assembled. The corporate program provides the overall support (administrative, information, finance, international affairs), the R&TD program conducts research and technology development as well as provides technical services, and the business operation program is the gateway to the end-users.

As a further step in moving ahead, MINT is working towards elevating its status to a statutory body that would enable it to form technology companies or joint-venture business operation with the private sectors. With that status, some of the constraints that hinder efficient technology transfer can be overcome.

Research and technology development

Management

To better utilize existing capabilities all research projects are now clustered into several project groups under six divisions. The approach of grouping researchers based on methodology or expertise, which worked well during the capacity building stage, was abandoned. This expertise is now directed or used in projects that focus on a specific area. For example, capability in mutation breeding, soil-plant relationship, pesticide residue analysis, etc. are used to implement projects in the Fruit Industry project groups of the Agrotechnology & Biosciences Division.

This arrangement smoothen interactions between the various expertise and capabilities needed at various stages of project implementation especially since most projects are multidisciplinary in nature. Also, it contributes towards enhancing the synergies between projects and minimizes the occurrences of “orphan” projects; thus contributing to the attainment of project critical mass in any particular focus area.

To support the structure a three-dimensional matrix management system is adopted. The axes of the matrix are the division (in which administrative matters pertaining to the division are handled), project groups (in which research activities are taking place), and the service groups (in which technical services are rendered to both internal and external “customers”). This arrangement also optimizes resource utilizations by enabling them to be used efficiently across several projects. We believe that this approach will be continued in the years to come as a way of maximizing the use of limited resources.

R&D orientation

MINT adopts a stand that all research must be mission-oriented, meaning that it must serve useful ends, not merely for the sake of knowledge. Research needs to solve real problems or create opportunities in the medium term. In line with this stand, all research project proposals are reviewed to ascertain among others that end-users are identified, adequate infrastructure to support and sustain the project is available, duplication is avoided, and the project objectives support the overall objectives of the relevant project group.

The question of whether R&D should be market or demand-driven or technology push in orientation is settled with the view that both are appropriate. Demand-driven research is externally motivated whereas technology push is normally internally generated. The latter has its own merit in that it opens up possibilities in generating new processes, services, and products or improving existing ones whereas the former rests partly on the premise that the market knows what is available or demandable.

Research funding

The main funding sources for R&TD at MINT are the Intensification of Research in Priority Areas (IRPA) fund, development budget under the government's five-year development program, MINT's own trust fund, and other sources.

The IRPA fund was introduced by the government in 1986 in the move towards elevating the role of S&T in line with the approach of achieving growth through productivity enhancement or productivity-driven growth. Thirty-three research institutes and other public agencies, including universities, are eligible to bid for this funding. Currently, over 20 research projects at MINT are funded by IRPA.

The development budget is for financing capital equipment, infrastructures, and maintenance activities that are to be implemented in that five-year planning period. We are now in the fourth year of the Seventh Malaysia Plan. Buildings and facilities for physical sciences, commercial tissue culture, polymer-plastic industrial laboratories, and biomaterial laboratories are among the development projects now in progress.

In 1986 MINT set-up a trust fund for depositing revenues generated from services rendered to clients in both the public and private sectors. In addition to financing activities related to the rendering of these services the fund is also available for research, especially for technology re-investment that would contribute to the enhancement of the quality of services.

Other sources of fund include research contracts, MOUs, and other government S&T-related funds such as the Industrial Grant Scheme (IGS), Commercialization of R&D fund (CRDF), and Technology Acquisition Fund (TAF) that are managed by a government technology venture capital company, the Malaysian Technology Development Corporation (MTDC). However, the MTDC-managed funds are opened only to the private sector for projects that are jointly implemented with a research institute. Together with private companies, MINT is now conducting a project on thermal oxidation plant under the IGS, a project on cross-linking of wire and cable under the CRDF in addition to a research contract on surface curing; and MOUs on tracer applications and other areas.

Due to the varying scope of coverage of the funds, most of MINT's projects are therefore multiply funded. For the same reason MINT regards the IAEA TC and other regional co-operation program such as the RCA as highly essential especially for the provision of expertise, technology, and human resource development. Funding management of some projects at MINT, therefore, includes co-ordinating the channeling of these sources at various stages and for various aspects of implementation of the projects.

Overall, it can be concluded that the improved stature of and support for S&T at national level provides the kind of environment conducive to further growth of nuclear science and technology in the country.

Co-operation and technology transfer

Mechanism

The mechanisms for technology transfer and co-operation practiced by MINT include MOU, project agreement, research contract, licensing, and service contract.

The MOU is an agreement between parties to the MOU to co-operate in areas of mutual interest. The areas of co-operation, modes of implementation, costs, and ownership of intellectual property rights (IPR) that may arise from the co-operation are detailed out in project agreements that become part of the MOU. research contract, as the name suggests, is an agreement by MINT as a research contractor to undertake research works required by the contractee. Whereas in MOUs the project costs are shared and IPR are jointly owned between the parties, in research contracts project costs are fully borne by the contractee that also has full ownership of any IPR that may result.

Licensing and service contract are commercial arrangements with the private sectors. In licensing a private company is given the right to commercialize technology that was developed at MINT in return of a fee. Our experience in this arrangement, however, was not encouraging. Service contract on the other hand is a contractual obligation between MINT and a client for MINT to provide technical services to the client at an agreed cost. This arrangement is mostly used in sterilization and irradiation services using the MINT’s gamma irradiation plant, Sinagama.

Needless to mention that seminars, conferences, workshops, and training courses continue to be regular events that are held every year as mechanisms for technology diffusion, promotion, and awareness.

Programme and activities

To date MINT has close to twenty active MOUs with various parties, including with almost all of the major universities in the country, covering diverse areas. In the agriculture sector mutation breeding and mass propagation of ornamental plants with a private nursery and study of rice agro-ecosystem with an agriculture development authority (MADA) are now on-going. In radiation processing a joint project to study the use of EB for flue gas treatment with the research arm of a utility company is now on-going. In the environment sector tracer technology is the central methods used in a MOU with a power utility company to investigate sedimentation problem at its cooling water intake pipe. There are other MOUs, but the above typified their scope and coverage.

The MINT-MADA co-operation resulted in the publication of a 255-page reference book entitled “Rice Agro-ecosystem of the Muda Irrigation Scheme, Malaysia” in 1998. In the same year another book entitled “Research Highlights on the use of induced mutations for Plant Improvement in Malaysia” was also published. Books on “Case Studies on Tracer Applications in Malaysia” and “Food Irradiation” are scheduled for publication next year. In promoting knowledge and awareness of the technology MINT, together with other government agencies, private sectors, and NGOs hosted international conferences on nuclear technology-related areas for the past three years. The latest was the 7th International Conference on Radiation Curing or RadTech Asia ’99 and RadTech Asia Expo ‘99 that were held in August 1999.

To further enhance technology transfer and collaboration MINT designated its second complex at Dengkil as the MINT Technology Park (MTP). The Park, officiated by the Prime Minister in January 1999, provides the necessary infrastructure and support for joint technology development and commercialization efforts with private companies, including the site for demonstration or semi-commercial pilot plants.

Pilot plants

If the process of technology transfer for other technology areas is having difficulties, then for nuclear technology the difficulties are even more. First there is public acceptance issue, and then there is the unfamiliarity with the technology issue.

In addition, it takes real demonstration of the technical and economic feasibility of technology for the private sector to be convinced of it. In that manner, the private sector can assess the risk involved in venturing into such operation and adopt appropriate strategy to minimize risk and maximize profits. It is with this in mind that MINT goes the extra length of constructing and operating plants of semi-commercial capability. One such plant is the gamma irradiation plant, Sinagama. The plant obtained the ISO 9002 certification in 1992 in addition to EN 46002 certification and the USAFDA current Good Manufacturing Practice. Based on the success of this plant, a private company set-up a similar facility in 1994. Recently agreement was reached between MINT and another private company to jointly set-up Sinagama-2 next to the existing plant.

We believe the RVNRL, EB cross-linking plant, and others will in future replicate this success.

Commercialization

Commercialization inevitably means dealing with the private sector whose culture, work practice, goals, and requirements very much different from those of nuclear research institutes. To commercialize the technology therefore, it is usually the research institutes that need to make the adjustments that would accommodate as far as possible those requirements.

MINT started offering nuclear technology to external users in 1986 for a nominal fee. Among the first service is NAA. Today MINT has ten technical service groups ranging from personnel monitoring, equipment calibration, industrial plant assessment, irradiation, to human resource development. Each group has one or more specific technical services area. They are offered either as service contract, consultancy, fieldwork, or training. The proceeds from this activity grow every year as also the number of customers. Statistics shows that on an average 76% of the annual revenue was generated from services rendered to the private sector and the remainder from the public sector.

Of more significance than the amount of revenue collected, however, is the creation of a new, “nuclear” market which was not there before. This activity, nonetheless, will become more important with the government policy of requiring industrial research institutes to generate revenue of up to 60% of its annual operating budget by the year 2000. Turning MINT into a statutory body thus is a strategy both for facilitating technology transfer as well as generating revenue in the process.

Some of the steps taken to improve MINT’s services as well as to gain confidence of the private sector include having a client charter, a credit policy, IPR, and quality accreditation of key facilities. Twelve laboratories have been identified for ISO Guide 25 accreditation; three are now at advanced stage of the accreditation process. With respect to IPR six patent applications have been filed and one product trademark registration is being processed. The client charter states MINT's obligations in dealing with the services it rendered. In fact for several years government agencies are required to have a client charter in a move by the government to further improve public sector administration and management practices.

The issues

The main issue in the author's opinion is making nuclear research institutes relevant to national development. Other issues (human resource, technology transfer, sustainability, etc.) are just corollaries. Commercialization of research results is seen to be one of the main criteria for relevance. To commercialize, the technology must have added value. In order to have the technology commercialized or adopted by end-users, the issues of organizational sustainability, further R&D, human resource, competing and alternative technology, technological development, market sophistication, peculiarity of the technology, among others will arise; and they are not mutually exclusive.

One of the ways by which MINT brings nuclear technology to the market is by direct provision of the service by our own personnel. More often than not the person is also the "developer" of the technology or technique. This is so since the customers have no capability to undertake the work by themselves. Thus the person ends up implementing the whole range of the task, from "developing" the technique to applying it. The long term implication of such an approach is stagnation in technology development since the personnel, often times qualified to undertake further development work, will not be able to do so. Thus some technological sophistication should exist in the private sector so as to be able to absorb the technology to eventually be able to handle the work. The market too needs to have some level of sophistication in order to find nuclear technology applications useful.

Some of the advantages offered by nuclear technology such as processing speed actually work towards its disadvantages in small market volume. It can be said that in this case the technology arrives before its time. Successful applications of radiation processing using electron beam machine (EBM) for example depends heavily on the availability of the machine. The capital cost is considered high to most companies, especially SMEs, and the efficiency too high for the volume available. Usually it is the newly set-up SMEs that are more responsive to using new technology since the more established companies may find it expensive to change their existing methods or to retrofit existing systems. In addition, specialized teams for maintenance and operation are required. Since EBM is such an indispensable component of this process it is a prime candidate for further development of a more compact and low-cost machine.

From MINT's experience the process of introducing a technology to the market including creating the market from technology "development" takes about a decade. This duration will become shorter with experience and the presence of market demand. An issue, however, is sustainability of the capability when compared against interest among students on S&T related subjects.

Since nuclear technology is a tool to be applied in every sector where it can be useful, an in-depth knowledge of the sector in which it is to be applied need to be developed by its practitioner or promoter. To apply nuclear technology solutions in the petrochemical industry for example, the personnel must have some knowledge of petrochemical plant layout, working principles, safety procedures, alternative methods, etc. To develop this knowledge some exposure and active interactions has to be provided to the personnel. There are a host of other issues, but with careful analysis and strategy they can be overcome.

Conclusion

Technology by itself cannot sell. There are other factors beyond technology that contribute towards the creation of the necessity to have it. Some of these include the PESTEL factors (political, economic, social or situational, technology, environment, and legislation). Some of the PESTEL factors can be controlled or initiated from within MINT; others are outside its jurisdiction or capability. Nevertheless by always be aware of these factors nuclear technology can be made relevant and nuclear technology solutions sought after.

Challenges faced by NRCs

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Abstract. The Mexican Nuclear Research Institute (ININ) played an important role in setting up of nuclear power plants (two) and development of fuel technology. However, with no current plans for expansion of this programme, the Institute is looking mainly into multi-cycle fuel management and life extension issues. The Institute focuses on programmes related to radioisotope and radiation applications and on the use of nuclear technologies for non-nuclear applications. The ININ is the major provider of radioisotopes for medical uses. It also promotes and uses nuclear analytical techniques for addressing a variety of problems. In non-nuclear areas some R&D examples include: the use of thermal plasma for hazardous waste incineration, biodegradation of polymers and development of separation techniques for treating industrial effluents. For preservation of knowledge, the Institute has instituted PhD. programmes in materials science, medical physics and nuclear science in collaboration with a university.

Introduction

Like many other nuclear centres around the world the Mexican Nuclear Research Institute was created in the sixties. Its initial mission to carry out scientific research and technological development in the area of nuclear sciences and their applications still stands, however some of the initial research is now well established as applied technologies carried out by commercial companies.

One of the main objectives for the creation of NRC´s was to provide support for the nuclear industry especially in the design, construction and operation of nuclear power plants. In the 60´s and 70´s there was a large increase in nuclear power plants. However, in the 80´s and 90´s the construction of new plants declined worldwide with the exception of a few countries.

The reduction of the construction of nuclear power plants, their ageing and the new openings for nuclear and radiation applications in other fields has modified the mission of many NRC´s.

New directions

Most of the NRC´s have started to widen their scope in nuclear and related applications and will continue to do so in the next century.

Nuclear power

The NRC´s will direct their efforts in two principal areas: to improve the current operation of the existing nuclear power plants making them safer, reducing their environmental impact, and extending their life cycle and to design and construct prototypes of the next generation of nuclear power reactors. These reactors will be smaller, safer, simpler and more compact than the current ones. With regard to the nuclear fuel cycle, studies will be carried out to improve the performance of the current nuclear fuel and also to design new fuel formulas using other materials such as thorium and plutonium.

Nuclear and radiation applications.

Medical: The production of new radioisotopes with improved characteristics such as half life, different types and energies, chemical compatibility together with new production processes is required in medical applications for the diagnostics and treatment of illnesses.

Food irradiation: The banning of the use of certain chemicals to destroy plagues in fresh fruits and the need to eliminate bacteria from fresh products such as poultry and meat will result in the increased use of irradiation as an alternative. Studies will have to be conducted to determine the efficiency of the method and also work on the standard irradiation protocols. At the same time new and more efficient irradiation facilities based on radioactive sources or accelerators will have to be conceived and designed.

Environmental studies: The use of nuclear and related techniques such as neutron activation analysis (NAA), particle induced X ray emission (PIXE), X ray diffraction and fluorescence etc. are unique in the study of pollutants in air, water and soil. With the development of more advanced equipment and analysis software the use of these techniques in environmental studies will be substantially increased.

Other areas of increase in nuclear and radioactive applications are in archaeology, to study ancient objects, materials sciences, to investigate composition of new materials, biology, to understand the effects of radiation in human cells, radiochemistry, to study the chemistry of actinides and lanthanides, etc.

Plasma technology and fusion

Plasma technology has undergone a rapid development in the last few years and will continue to do so in the XXI century. This technology offers marked advantages when compared with other technologies, it can be successfully applied to improve the physical and mechanical properties of materials and also it can be applied to the destruction of hazardous waste. Fusion studies will also be continued in the future, but they should be carried out at very specialized centres, as these investigations require large facilities, sophisticated equipment and groups of experts in the fields.

Materials sciences

In the field of new materials, emphasis will be directed to the characterization and synthesis of new carbon and carbon-nitrogen compounds which with their increase in hardness will have immediate applications. Molecular manipulation or nanotechnology will also be applied in the creation of new materials with improved physical properties. New materials can be first conceived and designed through computer simulation and modeling. Once the formula is known it can be recreated experimentally in the laboratory.

Examples of successful orientation

Computer modeling and simulation

The computer models used originally for modeling and simulating a nuclear accident for predictions of the transport of radioactive gases and particles have served as basis to simulate dispersion of environmental pollutants. Models of contamination transport in the atmosphere of Mexico city have been created using the same principles as the ones used to simulate a nuclear accident.

Natural materials

Natural materials such as zeolites and clays have been studied because they possess retention properties for radioactive compounds and can be applied for the treatment of radioactive waste, the same technology was reoriented to study the treatment of industrial wastewater which can contain herbicides, chemicals an heavy metals amongst other pollutants. Currently there is a project underway to study the effectiveness of using these materials treated chemically in the retention of oil products in wastewater from oil refineries.

Nuclear fuel technology

The Mexican nuclear research centre (ININ) designed and constructed a prototype nuclear fuel plant which produced some fuel assemblies which are currently used in one of the reactors of the Mexican Power Plant of Laguna Verde. The plant fulfilled its objectives and now the technology and expertise is being applied to industrial problems in special welding, non-destructive testing of materials, calibration of instruments and quality control systems.

Preservation of expertise

The ININ has an active programme to update its expertise by promoting technical visits to other laboratories, participating in national and international conferences and symposia and by encouraging and supporting postgraduate studies in universities with renowned prestige. Three years ago the ININ initiated three PhD programs in materials sciences, medical physics and nuclear sciences with a local university with the aim of increasing the academic qualifications of its staff and also to form new scientists in these fields. The ININ also actively participate; in the IAEA regional program ARCAL and send its scientists to research visits and conferences and also send its engineers and technicians to training courses organized by the IAEA.

Future programme

The principal areas of research where the ININ will be focusing in the XXI century are:

Radiation studies

The use of radiation to sterilize biological tissues which can be used in humans shows a great deal of potential. Already our Institute has started a project to create the first bank tissue bank in Mexico.

Studies of protection mechanisms for genetic damage caused by some types of radiation using selected bacteria strains as test vehicles will be carried out in order to understand the radiation damage and the repair mechanisms.

Mexico, being located in a seismic and volcanic region is preoccupied as to how to predict earthquakes. Measurements of radioisotopes such as radon which emanates from rocks can help to understand the evolution of earthquakes and volcanoes.

The hydrogen system as a future alternative source of energy needs to be studied, its presents two technological problems: finding an alternative method for its production and how to store it.

Reactor physics and engineering

Some very important issues have to be addressed for the current nuclear reactors used electricity production: the nuclear fuel cycle and reactor materials. The optimization of the nuclear fuel through multi-cycle fuel management, the use of alternative fuel composition such as oxide fuel or thorium and the management of radioactive products present great challenges. The life extension of the current nuclear power plants depends largely on their of the structural materials. Therefore, the understanding of the behaviour of such materials under operating conditions is very important.

Nuclear analytical techniques

Nuclear techniques such as neutron activation analysis, particle induced X ray emission and other related techniques usually require the use of large installations such as nuclear research reactors or particle accelerators, therefore, the analysis of materials with these techniques is only possible in a nuclear research centre.

Neutron activation analysis
This technique which has been around for more than 25 years is still unique and most suitable for many applications where it is necessary to analyze the elemental composition with the detection limit of less than parts per million. Improvements considered for the future are based on the prompt neutron activation analysis using a cold neutron source.

Particle induced X ray emission PIXE
PIXE was normally performed only in big accelerators such as the Tandem from ININ. However, smaller and more compact accelerators are now available. The ININ has just installed a Tandetron accelerator with a PIXE line which will be used to characterize many different types of materials.

Environmental applications

The thermal plasma technique is been successfully applied for the destruction of hazardous waste such as biological waste contaminated in hospitals. The ININ has designed and constructed a prototype thermal plasma reactor which at temperatures of more than 3000 ºC can practically disintegrate waste, transforming it into non-hazardous substances without releasing poisonous gases to the atmosphere. The next step is to scale it to a commercial plant.

The biodegradation of styrene used to manufacture polystyrene foam is another area of interest at ININ. The waste generated by this polymer causes liver or urinary track cancer. Using bacteria that feeds from this material in a bio-filter can solve this problem.

Environmental pollutants in air, water and soil have to be well understood. Techniques such as PIXE, neutron activation analysis, X ray diffraction, X ray fluorescence are current techniques used for determining the elemental composition of pollutants and with the use of electron microscopy it is possible to determine their morphology.

The use of natural materials such as zeolites and clays can be considered as an alternative for the elimination of radioactive waste materials in liquids or pollutants in industrial wastewaters.

Numerical modeling has also been used to study particle dispersion and to simulate the transport of pollutants through different media.

Materials

Nanotechnology is the materials technology of the future, with this technology it is possible to design and create new materials, for example the creation of materials through carbon and carbon-nitrogen compounds with greater hardness than diamonds. Metallic matrix materials with ceramic reinforcement particles also present great advantages over other materials for their weight, resistance to abrasion and high temperatures.

Microwave plasma and low energy ion beams can be used to prepare extra hard coatings, insulators, semiconductors and thin films which can be used in the field of optics and microelectronics.

The irradiation of materials with the purpose of improving their mechanical characteristics needs also to be studied.

The ININ recently created an electron microscopic laboratory with the installation of three modern microscopes where morphologic, topographic and characterization of materials can be performed.

Computer modeling and simulation

For studies of nuclear physics reactions, fluid dynamics, stellar evolution, non-linear dynamics neural networks and image processing, advanced computer sciences have to be applied.

Numerical simulation is capable of reproducing experiments creating virtual laboratories where all the parameters involved in a natural phenomena can be modified at will.

Metrology

Being the only nuclear centre in Mexico the ININ has the responsibility of keeping and maintaining the national reference standard for ionizing radiation. In this laboratory instruments for measuring radiation are calibrated and serviced and personal dosimeters are measured.

Nuclear medicine

The ININ is the major provider in Mexico of radioisotopes for medical uses. The main radioisotopes supplied are technetium and iodine. Another radioisotope being studied as a palliative against cancer pain is samarium.

The development of new techniques for medical imaging such as tomography and new treatments of illnesses using radiation therapy will go hand in hand with the development of new radioisotopes and radiation detectors.

Moroccan experience in nuclear sciences and technology: Present status

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Abstract. The applications of nuclear technology started in Morocco in the early sixties and were developed particularly in the sectors of Agriculture, Education and Medicine. In the early seventies, these applications were extended to other important sectors such as Industry using gauges and NDT techniques, Mines and Hydrology. But a lack of sufficient and adequate infrastructure has limited the development of these applications. Further more, as Morocco relies totally on foreign imports to meet its energy needs, the option of nuclear power generation started to be considered seriously. This was the initiator of a real national reflection on an integrated program for all peaceful applications of nuclear energy which led to the progressive constitution of an institutional and regulatory frame. In this context, the National Center for Nuclear energy, Sciences and Techniques (CNESTEN), which is a public institution, was created in 1986. Its current programme and future are described in the paper.

Introduction

This paper presents the Moroccan experience in the field of nuclear science and technology. A modest experience in comparison with the large and valuable experiences of advanced countries in this field, but it is nonetheless ambitious.

The rapid development of a number of social and economic sectors such as Medicine, Agriculture, environment, and so on … requires the input of new technologies. Morocco has always believed in the significant contribution that nuclear science and technology can make to meet the needs of development of these sectors. Such techniques have proved their efficiency in many countries with advanced programmes in this field. The many co-operation programmes, within the framework of the IAEA and the bilateral contexts, from which Morocco benefited since many years, take all their significance in this respect.

An integrated programme of peaceful applications of nuclear energy was launched with the creation of a National Centre for Nuclear Energy, Science and Techniques (CNESTEN) in 1986 and its current and future role are discussed below.

Current programmes at CNESTEN

The main missions assigned to CNESTEN are as follows:

- Promotion of nuclear energy applications in various social and economic sectors,
- Development of national technological capacity for the future introduction of nuclear power,
- Technical assistance to the national authorities for the safe use of nuclear energy activities in the country.

Within the scope of these missions and after having identified the national needs in the field of peaceful applications of nuclear energy, CNESTEN has defined a set of strategic objectives which constitute the reference frame of its activities for the short and medium terms as follows:

- To be the leading operator in nuclear and para-nuclear research and development in the country,
- to be the principal adviser to the Government on nuclear technology matters,
- to advise the authorities on nuclear security matters and manage, on their behalf, the radioactive waste generated at the national level,
- to host the main scientific and technological nuclear information centre,
- to be the reference centre in ionising radiation metrology,
- to promote nuclear techniques within the frame of multidisciplinary studies,
- to be the national competence pole in nuclear instrumentation,
- and finally, to be the main centre for development and supply of radioactive products for applications in medicine and biology.

To achieve these objectives, CNESTEN needed scientific and technological infrastructure and qualified staff. Therefore, since its creation, CNESTEN has given a high priority to the development of its human resources and expertise in selected areas of the field of nuclear science and technology. Today, CNESTEN has a total staff of about 200 people. This number will reach about 300 in the next three years.

Currently, various activities concerning development of research, services, training, and so on, are being carried out by CNESTEN in many sectors such as medicine, biology, industry, environment, hydrology and so on. The major programmes that are being developed are as follows:

Nuclear medicine and radiochemical applications:

- Development and production of radionuclides and radiopharmaceuticals for therapeutic and diagnostics purposes;
- Molecular biology applications

Industrial applications:

- Development of quality control systems (gauges),
- industrial units process optimization (tracers),
- research on NDT methods

Environment and water resources:

- The assessment and transfer of radionuclides in marine environment,
- the study of marine pollution,
- the contribution to sustainable water management and climate changes

Energy:

- Feasibility studies of NPP
- Small and medium power reactors (desalination, electricity generation)

Nuclear and radiological safety:

- Radiation protection,
- Radiological and nuclear safety analysis and impact studies of nuclear facilities and installations
- Radioactive waste management
- Environmental radiological monitoring

These programmes are developed in a partnership frame with universities and public and private operators from different sectors.

Today, a number of national networks, have been established dealing with specific themes:

- Soil and water
- Industrial applications
- Nuclear techniques and environment
- Nuclear physics and instrumentation
- High energy physics
- Reactor technology and engineering
- Irradiation technology
- Biotechnology
- Non destructive testing

The international co-operation particularly the IAEA has played an important role in the development of our programmes. On a bilateral level, CNESTEN has established numerous co-operation relations with many nuclear research centres (NRCs) in different countries. At the current stage of development, the available infrastructure is no longer able to meet the growing needs of the different social and economic sectors in terms of nuclear applications.

The construction of the first Moroccan NRC, the works of which have started last year, will allow to fulfill these needs in terms of scientific research, radioisotope production, nuclear technology services as well as in terms of expertise. The centre is located in the vicinity of the capital city, Rabat, and it will be operational by the end of year 2001.

The main buildings of this research centre are:

- The reactor building: equipped with a 2 MW Triga Mark II reactor, will be used for the production of some isotopes and activation analysis. Lateral beams will be equipped for neutron radiography, neutron diffraction and prompt Gamma neutron activation.
- A laboratory for production of in vivo and in vitro radiopharmaceuticals as well as for molecular biology applications.
- A laboratory for nuclear analytical techniques equipped for elemental and radiometric analysis as well as light stable isotopes ratios determination.
- A laboratory for nuclear instrumentation and industrial applications.
- A laboratory for radiation protection and environmental monitoring.
- Waste treatment and disposal activities.
- A training centre.
- Workshops and necessary support installations: administration, canteen, etc.

CNESTEN is also interested in the installation of a multi-purpose industrial irradiator. An economic and technical feasibility study is being implemented. Preliminary results have shown that there is an urgent need for such an installation in Morocco, the objective of CNESTEN is to realize the first unit in order to enable the private sector to take over.

This NRC will constitute the major scientific and technological infrastructure of the country in this field and will undoubtedly contribute to the development of scientific research in the nuclear field for the benefit of the social and economic sectors.

Future role of CNESTEN

The realization of this NRC will constitute an essential step toward a future potential power programme. It will maintain the nuclear power option open. The main challenges that will be focusing CNESTEN in a very near future are to meet the growing needs of the National Social and Economic Sectors but also to ensure the sustainability of the NRC in terms of scientific and technological productions as well as in terms of human and financial resources.

In conclusion, the Moroccan experience in the nuclear field is dominated by the will to stick closely to the multiform development phase that the country is undergoing. It is intended to be useful, pragmatic and ultimately at the service of the efforts made for the promotion of a national sustainable development.

Nuclear research centres in Pakistan: Status and prospects

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Abstract. Nuclear research centres (NRCs) played an important role in the introduction of nuclear techniques in their respective countries. These centres are now faced with changes in public and government attitudes, pressures from anti-nuclear groups, competition from non-nuclear technologies, budget cuts and privatization, etc. These NRCs are still making useful contribution in the field of science and technology but need to change their strategy to operate under these pressures. The Pakistan Institute of Nuclear Science and Technology (PINSTECH) has a record of 34 years of successful operation. Salient features and achievements of this Institute are presented as a model for a research centre in a developing country. The elements that are contributed for the success are described. The IAEA and other cooperative agencies can help to overcome the negative factors posed to these NRCs.

Introduction

Nuclear research centres have played an important role for the introduction, development and application of nuclear techniques for almost half a century. Since their establishment in the 50s and 60s, these cents have provided valuable R&D support which has been applied not only for nuclear technology but also several aspects of conventional techniques. During this period the nuclear research centres had to survive through various challenges in the shape of economic, political, commercial, regulatory and environmental concerns. However, their continued operation critically depends on their ability to meet current scientific demands and undertake new technical challenge. The present meeting of the IAEA provides a valuable forum for reviewing the past achievements and outlining plan to meet the future needs of NRCs.

In Pakistan, the development and introduction of nuclear technology has been entrusted to the Pakistan Atomic Energy Commission (PAEC). In order to meet this responsibility, the PAEC established several research centres, distributed all over the country. These centres are conducting basic and applied research in various disciplines including, physical sciences, Agriculture, Medicine, Mineral development, environmental studies. Most of the research centres focus on problems specific to the area or the region and can be regarded as 'mono-discipline' research centres. The present meeting aims to address the future needs of 'multi-disciplinary' research centre. Traditionally, such a centre must have an operational nuclear research reactor as one of research facilities. In this context it will be appropriate to review the status and future plans for the Pakistan Institute of Nuclear operating this fine nuclear research centre in Pakistan. In doing so, I will present a brief Science and Technology (PINSTECH), which is the premier multidisciplinary nuclear PINSTECH was established in early 60s.

I would like to share with you our experience of description of the Institute, its organization, facilities, R&D work and perception of the future. I hope to leave with you an impression that PINSTECH can be considered as a role model for a nuclear research centre in a developing country.

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Research and development experience at PINSTECH

The establishment of PINSTECH was planned in the early 60s. Construction of Phase-I started in 1963 and the first major facility, 5 MW research reactor went critical in December 1965. Since then PINSTECH has continued to expand and change.

Objectives of establishing PINSTECH

The goals for establishing PINSTECH can be broadly described as:

- Undertaking research in various nuclear fields to gain knowledge and experience;
- Providing guidance and leadership in the technological development for the peaceful application of nuclear energy;
- Providing radioisotopes and radio-pharmaceuticals to meet the need of nuclear medical centres, industry research institutes;
- Developing human resources to meet the strict standards for working as professionals in nuclear fields;
- Developing know-how and technology for the production of sophisticated equipment and nuclear materials, etc.;
- In general, provides an environment for developing science and technology in the country, including non-nuclear fields;

A brief description of PINSTECH

The PINSTECH is located in the south-east corner of Islamabad. It consists of a large rectangular block comprising various laboratories and a research reactor. The construction of the Institute proceeded in two stages: in the first stage, the reactor building and ancillary facilities were completed and in the second, various laboratories, workshops, library and auditorium were built. The first phase was completed in December 1965 when the reactor started operation and the second in 1974. Subsequent expansion comprised additional, separate buildings built according to needs and resources. These included the second research reactor, waste management and disposal facilities and a training centre.

Organisation

The operation of PINSTECH is managed by its Director General who is responsible to implement the programmes as decided by the PAEC. Within the Institute, work is distributed among various Divisions; each having specific assignments and allocation of resources. It is interesting to point out that PINSTECH started in 1966 with only four Divisions. It has now grown to have 14 Divisions. The Divisions, which have primary task for the R&D, are nuclear physics, nuclear chemistry, nuclear materials, nuclear engineering, radioisotopes applications, applied physics, applied chemistry, radiation physics and health physics. Some have mainly a supportive role. These are Electronics, Computer, Scientific Information and General Services Divisions. In addition to this there are separate Divisions for Administration, finance, programme co-ordination.

The manpower development facilities are continuously being upgraded. Presently, a separate institute, Pakistan Institute of Engineering and Applied Sciences (PIEAS), is functioning on the same campus and provides training. PIEAS also carries out basic and applied R&D. The PIEAS will soon get ‘degree awarding’ status. There are separate laboratories on the campus which undertake micro-seismic studies and R&D in optics and lasers. Changes and improvements in the PINSTECH organisation are a matter of routine. New institutes, laboratories are created, while those, which have fulfilled their purpose, are closed. Major changes are made to meet technical and functional requirements.

R&D facilities, programmes

PINSTECH is equipped with some of the most advanced research facilities and has a wide range of sophisticated tools and equipment. It is managed by highly qualified and skilled scientists and engineers. With the passage of time research facilities are upgraded and new ones added to achieve the objectives for its establishment. These facilities are shared with other establishments of the PAEC and other organisations and educational institutions in the country. Major facilities are briefly given in Table 1:

Table 1. Major facilities

1. **RESEARCH REACTORS**
   - PARR-1 (10 MW)
   - PARR-2 (30 kW)
2. **ELECTRON MICROSCOPES**
   - Scanning Electron Microscope
   - Transmission Electron Microscope
3. **ACCELERATORS**
   - Neutron Generator (14 MeV)
   - Charged particle (250 keV)
4. **RADIOISOTOPE PRODUCTION FACILITIES**
   - Production Cell for Isotopes for Medical, Agriculture and Industrial Uses
   - Radiopharmaceutical Kit Production
5. **COMPUTER STATIONS**
   - Central Computer Network
   - Sparc Station 2 & Super Sparc Station 20
6. **SCIENTIFIC INFORMATION FACILITIES**
   - INIS and other Scientific Networks
   - Library with Scientific Books, Scientific Journals, Reports, etc.
   - Printing Press

There are several research groups at the Institute who are engaged in the study of basic physical phenomena and nuclear reaction characteristics. The neutron diffraction technique has been extensively used for investigating crystal structures. A harmonious blend of pure and applied basic research has been achieved in the field of solid state nuclear track detectors (SSNTD). The research on SSNTD at PINSTECH has played a pioneering role in the development and practical applications of these detectors.

The chemistry programme around the reactor includes neutron activation analysis, nuclear and radiation chemistry and radioisotope production. Neutron activation analysis is used for accurate and precise determination of rare earth elements, impurities in high purity uranium compounds and nuclear fuel materials. These measurements are necessary for the quality assurance of the fuel.

Research reactors

A pool type research reactor, which was established in 1965, has been upgraded for operation at 10 MW with several improvements. The modifications done to the reactor includes Replacement of the entire Instrumentation and Control with the locally designed instrumentation, lining of various pools with stainless steel, increasing the power level from 5 to 10 MW and conversion of the reactor core from high to low enriched uranium fuel.

The second research reactor at PINSTECH is a tank-in-pool type reactor with a nominal power of 30 kW. This reactor was installed in 1991 and is mainly used for a neutron activation analysis and training.

Table 2. Characteristics of research reactors at PINSTECH

	PARR-1	**PARR-2**
Reactor type	Pool	Tank in pool
Reactor power	10 MW_t	30 kW_t
Fuel	U3Si2-Al	U-Al Alloy
Enrichment,% U235	19.99	90
Control rod	Ag-In-Cd, 5	Cd, single rod
Cooling	Forced, 900 m^3/h	Natural convection
Reflector	Graphite, H_2O	Beryllium, H_2O
Maximum neutron flux	1.5×10^{14} n/cm^2-s	10^{12} n/cm^2-s
Criticality date	December1965	November 1991
Critical loading, U235	4.1 kg	,1kg
Operation core loading	5.75	<1 kg

Analytical facilities

PINSTECH is equipped with a variety of analytical tools, and has manpower conversant with advanced, powerful instrumental techniques. Separation and pre-concentration procedures have been developed for a variety of elements. These are applied in radiochemistry and waste management. Services are available for analysis of biological, environmental, geological and industrial samples, alloys, etc. Following analytical facilities are available at PINSTECH

- Mass spectrometer
- Mossbauer spectrometer
- Neutron spectrometer
- Gamma spectrometer
- Atomic absorption spectrophotometers
- X ray fluorescence spectrometers
- X ray diffraction spectrometers
- ICP-optical emission spectrometer
- Atomic emission spectrograph
- Chromatography (HPL)
- Chromatography (GAS)

Production of radioisotopes and radiopharmaceuticals

PINSTECH has been producing a variety of short lived isotopes for use in agriculture, industry and hydrology. Facilities also exist for the conversion of radioisotopes into suitably labeled compounds and radiopharmaceuticals for direct use in nuclear medical centres and other hospitals. PINSTECH scientists were involved in the investigation of several problems of national importance using radioisotope tracer techniques. These include seepage from dams and canals, detection of leaks in underground water network of Shalimar garden, identification of damaged tube in a heat exchanger of national refinery, etc. In radiation technology, the know-how developed at PINSTECH was used to set up a commercial plant for sterilization of medical products at Lahore. Some of the radioactive products and cold kits produced at PINSTECH are given in Table 3

Table 3. Radioactive products and cold kits

PRODUCTS	**APPLICATIONS**
Sodium Iodide (^{131}I)	Diagnosis & Treatment of Thyroid Diseases
Sodium Phosphate (^{32}P)	Localization of Brain Tumor
Chromic Phosphate (^{32}P)	Cancer Treatment
Sodium Chromate (^{51}Cr)	Red cell labelling
Chromic Chloride (^{51}Cr)	Determination of Protein Loss
Chromium-EDTA (^{51}Cr)	GFR studies
^{99}Mo — ^{99m}Tc Generator	Labellin with Pharmaceuticals
Gold Colloid (^{198}Au)	Liver Cancer
COLD KITS	**APPLICATIONS**
MIBI	Heart Perfusion
DTPA	Kidney & Brain Imaging
MDP	Bone Imaging
Sn-Colloid	Liver Imaging
DISIDA	Hepatobiliary studies
DMSA	Kidney Imaging
Ca, Heptagluconate	Kidney & Brain
MAG_3	Renal Function
ECD	Brain Perfusion
Pyrophosphate	MUGA studies

Radiation and radioisotopes applications

Radiation and isotopes are used to investigate various industrial processes, e.g. flow rate measurement, residence time measurement, measurement of mixing/blending time, leak detection in heat exchangers/pipelines, etc. A group of experts provides advisory and technical services in this area. A variety of non-destructive techniques have been mastered and industry is encouraged to use these techniques for improvement of their products.

The application of nuclear technique in hydrology is a new concept. Several types of hydrological problems has been resolved including identification of ground water origin and determination of the air flow, velocity and direction.

Fuel fabrication

In 1974, the development of indigenous technology for the supply of fuel for the Karachi Nuclear Power Plant (KANUPP)was initiated, by the production of reactor grade UO_2 and the manufacture of prototype fuel at PINSTECH. The R&D experience at PINSTECH was applied to set up a commercial scale plant which now provides the entire supply of fuel for KANUPP. Zirconium used for cladding of UO_2 fuel pellets must be free of Hafnium, which occurs with it in the mineral. For this purpose a pilot plant was locally designed, fabricated and commissioned. Metallurgical laboratories have been set up for developing alloys for special application in nuclear as well as non-nuclear fields.

Quality control

To ensure the quality of materials, the institute has developed a comprehensive quality assurance programme, for the analysis and testing of materials. A number of highly sensitive techniques such as neutron activation analysis, atomic absorption spectrometry, X ray fluorescence, inductively coupled plasma and emission spectrography have been set up to check the chemical purity of materials used in reactor technology. Mechanical properties and stress analysis of materials are also carried out. Excellent facilities exist for fabricating specialized equipment like printing circuit boards and for repair and maintenance of a wide variety of electronic instruments in use at the Institute. Computers, both dedicated and general purpose, have been installed for experimental and theoretical work.

A network terminal provides easier access to the main computer facility. Assistance is also provided to other centres of PAEC as well as universities and other organizations in repair and maintenance of electronic and computer based equipment.

Environmental studies

Environmental pollution is a worldwide problem affecting the air, land and water resources. PINSTECH is using various nuclear techniques for environmental studies. And has carried out measurement for trace and toxic element at Islamabad. Modern equipment is available to carry out this work and for conducting R&D in this area.

Materials development

Development of material needed for the nuclear power programme and industry has been one of the most useful programme at PINSTECH. R&D activity has been pursued for the development of reactor fuel, structure materials, alloys, ceramics and for heat treatment mechanical and corrosion testing, material characterization. Sophisticated metallurgical laboratories are carrying out R&D activities for the preparation of alloys. The laboratories are well equipped for mechanical testing, phase/texture analysis, corrosion studies, stress corrosion cracking and fatigue testing. These techniques have provided tremendous support for the operation of KANUPP, PARR 1, CHASNUPP and other projects of the PAEC.

Health and safety

The importance of health physics, radiation protection and safety is increasing day by day and is an important factor in receiving public confidence and support. The basic principal of health physics and radiation protection of a programme is to minimise and the keep the radiation exposure to the workers, public and environment as Low as Reasonably Achievable

(ALARA). Constant surveillance and strict adherence to the procedures has given PINSTECH a clean record of safety and radiation protection. The Health Physics Division not only provides the radiation protection service but undertakes R&D programmes and is managing a secondary standard dosimetry laboratory.

Scientific and technical services

Computer oriented facilities were introduced at PINSTECH at a very early stage. Currently the Computer Division is providing all kinds of services to the entire community of scientists at PINSTECH. This includes hardware and software support, maintenance of computerized machines, operation of LAN, etc.

PINSTECH posses an excellent collection of scientific and technological literature. The library specializes in the field of nuclear and related sciences. The Scientific Information Division is the national centre for co-ordination of INIS activities. These facilities are shared with other establishments of PAEC and organizations in the country.

National and international collaboration

PINSTECH has developed an affective and working research collaboration with various advanced laboratories in Europe, and USA as well as with the International Atomic Energy Agency (IAEA). Scientists and Engineers from PINSTECH have been regularly invited to the advisory meetings of IAEA, and some have worked as technical experts to other countries. As a result of its quality of research the Institute has been awarded a number of IAEA research contracts and research grants from European agencies. Scientists and engineers from PINSTECH have made important contributions in research and have won international recognition in their fields. To keep the scientific community of the country abreast with the latest developments in science and technology PINSTECH has successfully organized a number of conferences both at the national and International level. One of these "The Nathiagali Summer College in Physics and Contemporary Needs" is the only International Conference in the sub-continent to be held regularly for the last 20 years. Nationally, PINSTECH has helped Pakistan industry in adopting the latest nuclear techniques for improvement in quality

The research potential at PINSTECH has been utilised for the benefit of several organizations like PIA, WAPDA, PAF, Department of Irrigation, Hydrocarbon Institute, Department of Archaeology, etc. Scientists at PINSTECH help universities in teaching and research. Universities, lacking basic facilities have benefit from close collaboration with PINSTECH. The Government of Pakistan has been kind enough to recognize the high quality of work carried out at PINSTECH by conferring high civil awards and prizes to some of its scientists. The Pakistan Academy of Sciences and other international academies and organizations have also appreciated the work carried out by PINSTECH scientists by making them life members and awarding gold medals to them.

Major achievements

PINSTECH have shouldered diverse responsibilities in the field of nuclear technology and have accepted many difficult challenges. PINSTECH has made a crucial contribution towards the fabrication of fuel for KANUPP and for the production of zirconium metal for use as cladding material for the reactor fuel. The production of radioisotopes and radiopharmaceuticals for use in the nuclear medical centres and for other applications has been a unique facility in the country. Another major achievement has been the complete replacement of instrumentation and control of PARR-1, through local efforts in design, fabrication and installation. The conversion of the core from HEU to LEU and upgrading power from 5 to 10 MW was undertaken and completed with local efforts. The Institute has also played a vital role in providing trained technical manpower for various specialised programmes of the PAEC.

Future programme

PINSTECH has played a key roll in the national development, contributing trained and talented manpower for various programmes. This will be continued and improved. The programmes concerning reactor physics, nuclear engineering and development of materials will be upgraded.

The collaboration with industry, universities other S&T organizations will be enhanced. This policy aims at making the maximum use of the human and material resources available at PINSTECH.

At the international level, co-operation at bilateral and regional levels will be encouraged. The work with the IAEA has a very good track record. This will be continued, strengthened.

Discussion

I have described salient features of 34 years of PINSTECH operation. It can be said that PINSTECH has progressed steadily, and continues to improve, to fulfill its mandate. The key to this success is the *well defined programme*, its *ability to adapt to changing needs* and *qualified, dedicated staff*. This has been adequately supported *by positive public attitude* and *support by the Government*.

The public interest in various programmes of PAEC remains highly positive. This can be attributed to the tremendous contribution, which the PAEC has made for introducing various nuclear techniques. The list is long and covers nuclear power, agriculture, medicine, quality control, non-destructive testing, industry, etc. In almost all cases necessary R&D or analytical services were developed at, or provided by, PINSTECH. Some basic research is undertaken but the primary goal is to acquire and maintain scientific competence. All this has been very helpful for securing adequate allocation of resources.

The research reactor, PARR-1, at PINSTECH is 34 years old. During this period its operation has been flawless and the safety record is excellent, thanks to a very dedicated operation team. It has gone through constant upgrading and modifications and, therefore, this reactor has no signs of ageing or safety degradation.

PINSTECH did have its share of problems. These are mainly the un-availability of manpower, need for more funds and pressures to generate revenue from its products and services. The manpower needs are met by recruitment but there is a constant brain drain to other PAEC projects, private sector and, in some cases, opportunities abroad. Somehow, a reasonable balance has been reached. The causes of shrinking budget are inflation and constant slide against the hard currency. Thus the effective allocation is reducing, even though the government funding is maintained at more or less reasonable level. This problem is tackled by increasing the indigenous production of scientific equipment, and spares and thus reducing foreign spending.

The generation of external revenue is not succeeding much as contrary to the industrialized countries the clients do not have much funds and in many cases pay only in gratitude and thanks. This is happily accepted and PINSTECH strives to make as many clients as possible.

Global perspective

According to the IAEA research reactors database there are 291 operational reactors in 58 countries. This includes 39 developing countries. In general, a nuclear research centre is established around the reactor facility. The NRC may have more than one reactor on one campus. The problems, which are being faced, are mainly the anti-nuclear feelings, changing government attitudes, reduced funding, giving up basic research in favour of applied research, safety and security upgrades. These problems are real but not all NRCs face all of these at the same time. In this context the NRCs may be considered in three broad categories, each having more or less common problems and solutions.

The first category is the NRCs, which are located in the industrialized countries. These NRCs have to survive in the face of competition from other research centres, technologies and economic, environmental issues, etc. In general they have technology, resources and capability to resolve their problems.

In the second category we may consider the NRCs in the developing countries which have programmes for nuclear power. The nuclear power programme requires substantial technical support for which the NRCs play a useful role. The investment needed for operating the NRC is a very small fraction of the investment committed for the nuclear power programme. Thus in this case, the NRCs can manage to continue to operate and serve several purposes in addition to the nuclear power programmes.

In the third category, the NRCs belonging to the developing countries which do not have an active nuclear power programme. In this case they have to justify their utility every time they need to improve or upgrade the facilities. The budgets are very tight and manpower gets frustrated, as they do not find the career in this field to be much rewarding. In such cases, the research reactor is generally of very low power level and therefore the operation and management cost is only nominal. Such centres may exist for several years providing only radiation measurement and health physics service.

Collaboration and co-operation

The problems faced by NRCs are real but are differ from one facility to the other. It may not be feasible to suggest a ‘generic’ programme to satisfy every situation. To this end cooperative efforts must be promoted based on technical, economic and political compatibility. The co-operation can be in the form of using facilities at one centre by the scientists of another centre, expert advice or training. Such efforts are possible as bilateral, multilateral or regional agreements. The major problem in introducing such programmes is the unavailability of budgets to cover the travel costs of experts and trainees. In general, the host governments are able to provide local hospitality, including accommodation but not the travel costs which require foreign exchange expenditure. The IAEA can play a useful role by supporting such programmes, even if at a very small level. Another aspect of the co-operation can be transfer of equipment from one centre to another on free of cost basis. Such situations arise when a facility is upgraded or shutdown and the equipment can be utilized at some other place, which is still operating in the same or lower level.

Conclusion

A nuclear research centre is a general-purpose laboratory facility, which supports multidisciplinary research and development programmes. It is a vital links with nuclear technology but the results of R&D benefit several sectors. In the case of developing countries, a nuclear research centre may be a place, which has the highest technical expertise and equipment within the country. These centres will be needed for decades to support the nuclear and non-nuclear technology. Such centres may be regarded as national assets and merit support

In order to survive in the case of competition, the NRCs must have:

- Well defined goals, which must be realistic and consistent to ensure results;
- A reasonable balance should be established between fundamental and applied research to maintain scientific competence;
- The R&D programmes should have good commercial potential and oriented towards the customers;
- The organizational structure and management policies must be clear and acceptable;
- Long term budget commitments must be ensured.

ACKNOWLEDGEMENT

I would like to express my appreciation to the IAEA for organizing this meeting in which very important issues concerning the NRCs are discussed. The fact that such a large number of experienced managers of NRCs are present here is a manifest of the interest in this area. I hope such meetings will continue until the objectives are achieved.

Personally I would like to thank the IAEA for the support which has enabled me to attend this meeting.

Nuclear research centres' co-operation and the IAEA's role

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Abstract. Russian nuclear science and technology developed as per the "Eastern School". Similar development in OECD countries followed a "Western School" but both schools have slowed down due to objective and subjective reasons. Economic crisis has been the main weakening element in Russia and COMECON Member States. In spite of that the ten nuclear science and technology centres in Russia have more than 100 000 scientists and engineers. The IAEA programme for the immediate future includes co-ordination of some key activities in nuclear science and technology. However, issues like disarmament, non-proliferation, advanced reactor concept are other areas of possible international co-operation in which the IAEA could play an important role.

Introduction

Development of nuclear science and technology is, at the present time, not as rapid as it was in the recent past. It is known that the main research in nuclear science and technology in the past was conducted at the same extent on a broad line by two schools: "Eastern", which included the former USSR and countries that closely co-operated with it, and "Western" — mainly in OECD countries. Research and the accumulated scope of knowledge and technologies of both schools were developed in general in the same direction, but differed in some cases by the original approaches to the solution of the investigated problems, applied standards and regulatory basis. Today, the rate of development of nuclear science and technology of both schools has slowed down because of objective and subjective reasons that considerably vary.

As far as Russia is concerned it is mainly due to the disintegration of the USASR and the breakup of economic, scientific and technical relations between COMECON Member States and CIS, as well as of complex economic situation during the last ten years.

As far as the developed Western countries are concerned, it is due to the slowdown of rate of growth of NPP construction and, in some countries, even due to attempts to phase out nuclear power because of several reasons — objective as well as subjective:

1. Low cost of organic fuel
2. Accelerated shift to use of gas for electric power production
3. Reduction of electric power demand
4. Ongoing privatization process in the energy sector of the industrially developed countries.

Challenges

nuclear science and technology faced the following negative consequences because of the developments listed above:
1. Considerable decrease in financing research in this field
2. Quantitative reduction of the attention to the power development strategy, etc.

Despite predictable reduction of NPP share in the world electric power production, absolute NPP capacity will rise up to 2010 and will be 500 GW (against 345 GW for the time being).

This growth will be determined mainly by NPP construction in the countries of South East Asia (China, possibly Indonesia, Japan, the Philippines and South Korea).

There are several strategic reasons that indicate the perspective of future nuclear power development, e.g. global climate change related to the increase of greenhouse gas discharges. It is hardly possible to achieve the reduction of CO_2 discharge to the recommended level without serious involvement of NPP in electricity production.

In addition to the general problems of nuclear power, a number of other issues appeared recently the solution of which is impossible without the development and implementation of key programmes, such as:

1. Global safety of the entire nuclear cycle that includes nuclear disarmament and non-proliferation of nuclear weapons
2. New aspects of the environmental problems covering radioactive waste management, and restoration of territories from radionuclide contamination
3. Industrial scale application of nuclear radiation
4. Nuclear medicine and radiopharmacy.

Nuclear research centres

The implementation of these key programmes forms the basis for long term utilization of nuclear science/technology centres. Almost all of these problems are covered by programmes conducted in Russian research centres. Under the auspices of MINATOM more than ten RCs are working. Six of such large centres are in 'scientific cities':

- SAROV, VNIIEF
- SNEZHINSK, VNIITF
- OBNINSK, IPPE
- DMITROVOGRAD, RIAR
- PROTVINO, IPHE
- TROITSK, TRINNITI

Several similar research centres (RC) are working in Moscow (Kurchatov Institute, NIKIET, Bochvar Institute, Gidropress, etc.). More than one hundred thousand scientists and engineers are working in these centres. Ten years ago the number of their staff was at least twice higher. In spite of that, the main problem for the RC, as mentioned before, is funding. In the past some of them were deeply involved in the Soviet nuclear armament programme. Such programmes have been reduced several fold since that time. At present they have to re-orient their activities to civil areas. In many cases they are doing so successfully due to international co-operation programmes. The existing problems, taking into account their complexity and variety, can be successfully solved only by sharing the effort between the nuclear centres, i.e. through close co-operation.

Role of the IAEA

It is difficult to underestimate the role of IAEA in this process. The IAEA is the most competent organization in the field of nuclear energy that protects the interests of 131 Member States in this area and, thus, should take the role of initiator and co-ordinator of such co-operation.

Some of the key scientific and technological tasks have already been included in a number of IAEA programmes such as MP1, MP2 and MP3. The process of charting the strategies, priorities and objectives of the major programmes has been guided by recent reviews of the activities of MP1 by the Senior Experts Group and PPAS Committee and of MP3 by the PPAS review, and has also taken stock of new realities and challenges, in particular with regard to the present and future generations of NPPs that deal with the problems of fuel cycle and radioactive waste and defining the role of nuclear energy for sustainable energy development and climate protection.

However, new challenges include the development of new reactor concepts, with enhanced nuclear safety and proliferation resistance, in which the IAEA can co-ordinate the efforts of the nuclear research centres engaged in this work. The IAEA may also be asked by its Member States to have a role in nuclear disarmament

We would believe that it is necessary for efficient use of the nuclear centre capabilities to assess their unique scientific bases and identify leaders among them and, in particular, research areas. This would help in the more effective use of capabilities of the scientific and technological bases of each centre. Taking into account the up to date level of communication system development, the distance between the centres should not be an obstacle for beneficial co-operation.

From our point of view it is worth to consider the issue of periodic call (for example, once in two years) for a meeting of nuclear centre managers under the auspices of the IAEA to resolve possible problems that may arise while moving in this direction.

Evolution of the Atomic Energy Corporation of South Africa

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Abstract. In order to understand the AEC in its present form and its strategic positioning for the next century, it is essential that cognisance be taken of its evolution over the past 40 years and, in particular, also the external forces which triggered major strategic re-orientation actions in the past. These resulted in a fundamentally downsized organization (by about 80%) which will in the new millennium be judged on its ability to make nuclear technology available for the needs of a developing country, discharge the nuclear liabilities of the past and commercially exploit its technology base to contribute to national economic growth. The Corporation has a strong programme in isotope applications and nuclear waste management. For the future it is looking forward to develop a Pebble Bed Modular Reactor for safe nuclear energy production.

Historical overview

The Atomic Energy Board (AEB) was established in 1959 with the following aims:

- Development and refinement of South Africa's nuclear raw materials
- Promotion of nuclear power
- Development and utilization of nuclear technology in industry, medicine, agriculture and for research
- Basic research in support of the above.

Phase 1 (1960–mid seventies)

In the execution of the above objectives the following main facilities and programmes were established at Pelindaba and focused on during the sixties and early seventies.

SAFARI-1 research reactor (20 MW pool type)

Research programmes included nuclear and solid state physics and chemical applications (radioanalytical and radioisotope production technology) which lead to the establishment of a capability and facilities for the local supply of certain radioisotopes.

Van de Graaff accelerator (3 MeV)

Nuclear physics and PIXE as well as other nuclear analytical techniques.

Physical metallurgy

Studies in uranium and other compounds, inert glove box facility.

Extraction metallurgy programme

Development of uranium processing technology.

Radiation applications

Radiation chemistry and radiation polymerization and sterilzation applications, food irradiation. Industrial scale irradiator was established.

Life sciences applications programme

Focus was on the diagnostic use of radioisotopes on fundamental level.

Reactor development programme

The group, which initially focused on a unique sodium cooled natural UO_2. fueled reactor concept, later turned to PWR technology and established strong capabilities in reactor physics, reactor design and engineering and nuclear instrumentation.

Uranium enrichment

Development was focused on South African developed vortex tube technology which resulted in the establishment of a pilot plant and the Uranium Enrichment Corporation (UCOR) in 1970.

Nuclear fusion research

A South African designed and built Tokamak facility (major radius 0.52 m, aspect ratio 2.17) was commissioned during this period.

Theoretical physics

A strong group of theoretical physicists was formed at Pelindaba during this phase.

Nuclear geology

The group specialised in the selection of sites for PWRs and nuclear waste disposal and the estimation of South Africa's uranium.

Nuclear waste programme

Process facilities for nuclear waste and a waste disposal site at Pelindaba were established.

Licensing group

This was established as part of the AEB's activities in this period. It later became independent of the AEB (1987) with the establishment of the Council for Nuclear Safety.

Phase 2 (mid seventies to end of eighties)

The nuclear programme entered a more applied and strategically focused phase following a government decision in the mid seventies on the local production of nuclear fuel for the new Koeberg Nuclear Power Station (KNPS) consisting of 2 × 980 MW(e) French design PWRs. The activities of most of the existing staff, and additional appointees, were redirected to the industrialization of the vortex tube uranium enrichment process and the establishment of the

1200 t U/a conversion, 300 t SW/a enrichment and 100 t U/a fuel fabrication plants for the production of PWR fuel as well as a hot cell complex and facilities for the post irradiation examination of PWR fuel. A fuel fabrication facility for the production of MTR fuel with HEU (45% enriched) obtained from the pilot enrichment plant was also established during this phase. The AEB and UCOR merged to become part of the newly established Atomic Energy Corporation (AEC) in 1982 in a first step towards rationalization. In 1986 the Vaalputs waste disposal facility was established and licensed for the disposal of low and intermediate waste.

The above activities resulted in the establishment of strong technological capabilities in inter-alia the areas of gas dynamics, UF_6, and U metal production and analytical technology, UF_6 chemistry and technology, turbo compressor technology, high precision manufacturing, surface science and technology, HF and F_2 technology, isotope separation and cascade calculations. It also led to the development of an extensive capability and experience in radiological and other safety matters associated with U, UF_6, HEU, F_2 and HF, a broad range of other radioisotopes, hot cell and glove box operations.

The production plants were all commissioned successfully. MTR fuel has been produced in South Africa since 1982 and the first PWR fuel elements were delivered to the KNPS in 1986. A research programme on molecular laser isotope separation (MLIS) uranium enrichment was also initiated during this period, but was terminated in 1997.

The commercialization phase (1990 onwards)

By the early nineties it became evident that, due to the political normalization in South Africa, fuel for the KNPS would in future be available from international sources and that the small scale strategic plants in South Africa would not be economically viable entities in the new circumstances. This coincided with a world wide decline in the growth of nuclear generation and extensive over capacities for nuclear fuel production. Furthermore, the electricity utility, ESKOM, abandoned its earlier plans for a large scale PWR based nuclear power programme of up to 10 units by 1995. That, together with a drastic reduction in financial support from government led to a decision to phase out uneconomic production operations including the conversion, enrichment and fuel fabrication plants and to seek other commercial applications for the AEC's extensive technology base.

It was eventually decided that future commercial programmes should be based on the AEC's core competencies of radiation applications and fluorination technology where the organization was regarded as internationally competitive. The identification of the AEC's core competencies resulted from an exercise aimed at the introduction of a firmer application of technology management principles and was achieved through an audit of the organization's capabilities along the lines of the Prahalad-Hamel model. These actions resulted in the loss of more than 80% of the AEC's personnel, many of which were in the highly skilled category, and the associated technologies.

Present situation

Groups and programmes

The organization has since evolved into two main focus areas, namely a group dealing with commercially directed activities and another group is responsible for institutional activities such as the operation of the research reactor, site and waste management and the development and maintenance of specialist nuclear technologies. The two groups have now been separated organizationally, thus allowing full ring fencing.

Commercial group

This group focuses on:

- Chemical products
  - production plants utilizing fluorination technology to produce products like HF, F_2, SF_6, WF_6, CF_4, c-C_4F_8, ClF_3 and to perform surface fluorination of polymers
  - development work on the beneficiation of zircon by fluorination technology and on production technology for NF_3 and other fluorinated electronic gases.

- Radiation products
  - medical and industrial isotopes (^{99}Mo, mainly for export, ^{99m}Tc-generators, labeling kits, ^{131}I, ^{32}P, etc.)
  - nuclear based instrumentation, for example a coal ash monitor
  - NTD silicon.

Irradiations are done by the institutional group of the AEC which operates the SAFARI-1 reactor and which also provides technical support and development of new products in the radiation field on contract.

- Technology systems

Products include specialised fabrication and unique welding capabilities, project management as well as dust filtration, fluid dynamic services and gas membrane separation filters.

Total revenue earned from the sales of commercial products and services within these 3 groups amounted to approximately USD 21 million in 1999, with more than 40% of sales arising from exports to more than 30 foreign countries.

The commercial group presently still receives state support of approximately USD 7.5 million for development work. This will be phased out over the next 2 years after which all development work will be funded from business income. Business ventures are mostly undertaken in conjunction with the private sector in order to obtain capital and access to markets.

Institutional group

This group consists of groups in the following areas:

- Nuclear technology which operates the SAFARI-1 reactor and maintains specialist groups in the fields of reactor and radiation theory, radioanalysis, radiochemistry and radiopharmaceuticals, nuclear instrumentation, beam line application (neutron diffraction and radiography), accelerator applications and MTR fuel fabrication.

- Nuclear fuel technology which is engaged in the establishment of a fuel fabrication facility for the South African Pebble Bed Modular Reactor (PBMR) project.

- Nuclear liabilities management which is responsible for nuclear and chemical waste management, D&D of former nuclear plants and associated facilities, operation of the nuclear waste site at Pelindaba and also the national waste site at Vaalputs in the Northern Cape Province.

- Facilities management which is responsible for management of the Pelindaba site, including buildings and services. Rental of buildings and the provision of services is managed on a contract basis to internal clients, joint venture groups and also some external clients. The successful recruitment of almost 40 external clients is presently making useful contribution to better utilization of the Pelindaba facilities along the principles of an informal technology park.

- Risk management is responsible for the maintenance of the site license and the provision of SHE services and control of the site.

- Quality, engineering and safeguards group (non-proliferation management).

Finance, personnel and infrastructure

The AEC's budget contribution from government was reduced by more than 80% in real terms over the last ten years. Personnel numbers declined by about 80% over this period.

Figures for the present financial year are as follows:

USD (million)	
Corporate turnover	80.5
Total sales	42.0
Government grant (activities)	30.2
Corporate allocation to business activities:	7.9
Corporate allocation to institutional activities:	17.0
Corporate overhead:	5.8
R&D expenditure	
Commercial group:	8.3
Institutional group	6.0
Personnel (staff on contract included)	
Total AEC	1580
Commercial group	605
Institutional group	825
Corporate overhead	150

Strengths and limitations w.r.t. R&D and new products

Strengths

- Well established and competitive technology base, facilities and personnel in the fields of radiation applications and fluorination technology.

- Demonstrated ability to industrialize new developments, i.e. the total innovation cycle and the creation of new profitable business through, inter alia, international joint venture agreements with organizations such as IRE, Studsvik, BOC and Air Products.

- Close co-operation between institutional group and radiation application business on the same site enables the limited retention of critical know-how which would otherwise not be affordable by any of the groups.

- Control over the whole production cycle, from the SAFARI-1 reactor (including an HEU inventory) and hot cell complex to waste disposal, provides an international competitive advantage for radiation applications.

- Close co-operation with and support from IAEA Technical Co-operation fund and African Regional Co-operative Agreement (AFRA) projects. Leading role in AFRA projects.

- Strategy aimed at the optimal utilization of the Pelindaba site and infrastructure creates a favourable climate for new project developments.

Limitations

- Financial constraints result in cutback of R&D programmes and loss of expertise as well as the ageing of equipment and lack of investment in new facilities.

- Activities of the institutional group will in future be limited to nuclear matters, by a parliamentary act, without the scope for diversifying into other areas as was done by many nuclear institutes elsewhere in the world.

- The nuclear power programme in South Africa has thus far been small with limited technology supporting requirements. This may change if ESKOM's PBMR project proceed as planned.

- Lack of rapid decision making by government on the formation of international alliance ventures.

- Lack of a national nuclear waste policy.

- Large funding requirements for discharging the nuclear liability of past activities.

Challenges

New directions

New directions for future development (excluding the non-nuclear part of commercial work) should be sought in the following areas:

- Planning for the eventual replacement of the SAFARI-1 reactor and associated programme with facilities of promising commercial potential to justify investment, but also of sufficient scope to serve as basis for a broader research programme which will maintain a wide range of expertise, also for the execution of the AEC's institutional role of industrial and academic support as well as technical capacity building and its role in the IAEA/AFRA.

- Improving nuclear waste management technologies and techniques for estimating and discharging nuclear liabilities, including the establishment of a deep disposal facility for HLW.

- Further development work on fuel and neutronic calculational methodologies for the South African PBMR programme.

Examples of successful re-orientation

- **Commercialisation of SAFARI-1 reactor**

Greater commercial application of the SAFARI-1 reactor and its associated technology base was identified as one of the main areas for the broader commercialisation programme. The termination of the South African weapons programme as well as the nuclear fuel programme freed the HEU inventory and a modern hot cell complex, used for post irradiation examination of PWR fuel, for application in the commercial programme, mainly for radioisotope production and NTD silicon irradiations. In the process, the hot cell complex was transformed into a fully commercial isotope production facility. The AEC now supplies approximately 10% of the world's fission ^{99}Mo. The net income from total radioisotope and irradiation sales will cover 53% of SAFARI-1's operational cost in this financial year. The aim is to increase this figure to at least 75% in future. The contribution from commercial sales reduces the cost of the reactor and the maintenance of supportive technologies to an affordable level for the State, thus probably ensuring the future use of the reactor and several nuclear capabilities (reactor and radiation theory, radiochemical processing technology, etc.) for the science and technology community in South Africa and its role in AFRA.

- **Fluorination technology**

The AEC's extensive capability and infrastructure in HF and fluorine technology provided another competitive business platform for the commercial programme. A significant investment was, however, required to expand it beyond the familiar inorganic compounds to also include fluoro-organic compounds. The present product portfolio is largely for the export market and is generally produced in conjunction with international joint venture partners. Total expected sales of fluorochemicals for the financial year are approximately USD 11 million.

- **Vortex tube commercialization**

The vortex tube technology developed in South Africa for the enrichment of uranium was commercialised successfully for dust separation applications in industrial processes, helicopters and other vehicles. Products are presently sold in 10 countries around the world earning more than 50% of total revenue in this field.

Preservation of expertise

The drastic downscaling of the AEC resulted in a rapid loss in expertise during the nineties. This became a cause of major concern and led to the above mentioned exercise in defining the organisation's core competencies and the supporting technologies required to maintain those competencies. For the radiation application core competence, for example, products and services such as radioisotopes, waste processing, irradiation services, radiological safety, some beam line application, radioanalysis, etc. were identified as essential. This approach provided some vision and guidance on technologies which were to be retained.

Requirements of the commercial programme and the associated income saved several areas of expertise which otherwise would have been lost to South Africa. The threat of losing expertise is still there and it is clear that a strong commercial programme will also in future be essential for the preservation of expertise also for many institutional applications. The SAFARI-1 reactor would, inter alia, not be affordable without a significant income from product sales.

In an attempt to preserve expertise for the country, the theoretical physics and the life sciences application groups were transferred to 2 universities some ten years ago. The termination of the MLIS programme led to the loss of approximately 200 highly skilled staff. Some specialists from this programme are presently being transferred to a national laser centre which was created by government to retain some expertise after the closure of the programme.

Interaction with the environment

Industry sector

The establishment of the AEC's commercial programme necessitated much closer links with the South African and international industrial sector, particularly in view of the strategy of commercialising technologies through joint venture arrangements with industry to gain access to capital and markets. In doing so the AEC, for example, enabled industry to join new business ventures in the fields of fluorinated chemicals and radioisotopes production.

Apart from new business, the AEC is also closely involved in supporting industry with specialist knowledge and technology. Examples include the development of an online coal ash monitor for the coal mining industry, beneficiation of minerals, provision of radioanalytical services, specialist radiological support to the mining sector in dealing with radioactive waste and the establishment of a fuel fabrication facility for the PBMR project.

Academia

Presently the AEC interacts with 14 universities and technikons in fields such as the provision of SAFARI-1 and Van de Graaff beam line facilities for neutron diffraction studies of materials, joint training courses in reactor and radiation physics and studies of radionuclides in the environment. Co-operation with foreign academic institutions includes radio-pharmaceutical development, study of nuclide migration in the geosphere, fast neutron generation techniques and reactor physics software development.

AEC facilities are also utilised by several educational institutions for graduate and undergraduate practicals. The AEC recently had a major role in the establishment of a post graduate MSc course in radiation science and technology at the North-West University, one of the country's previously disadvantaged universities, and AEC staff are still involved in theoretical and practical training of the course.

Social contribution and public interaction

The AEC's extensive facilities for experiential training has been transformed into a national centre for training, specifically aimed at the training of young artisans and technicians from previously disadvantaged communities. Some 250 students were trained last year. The centre is presently managed by a trust which receives good financial support from external sources.

Scientists from the AEC are also involved, on a voluntary basis, in the presentation of special Saturday classes in science and mathematics for children from previously disadvantaged groups.

A monthly discussion group with the AEC's neighbouring communities was established a few years ago. The meetings are aimed at informing the community on safety matters, including full reporting on any incidents, environmental impact of existing and planned activities and the provision of a forum for open discussion with the community. There has been a noticeable improvement in the AEC's relationship with our neighbours since the establishment of the discussion forum. Similar discussions are held with the community in the sparsely populated region of the Vaalputs waste disposal site.

International obligations and relations

Obligations under the Nuclear Non-Proliferation Treaty such as reporting on the As national counterpart to the IAEA, the AEC is responsible for fulfilling several national material balance and advice to government on export control measures.

The AEC is also represented on IAEA advisory groups such as the Standing Advisory Group on Technical Assistance and Co-operation, the Standing Advisory Group on Safeguards Implementation, the International Consultative Group on Food Irradiation, the Joint IAEA/NEA Uranium Working Group and the Waste Technical Advisory Committee. It is also a member of the Zangger Committee and the Nuclear Suppliers Group.

The AEC and several South African institutions are fulfilling a leading role in AFRA with a current involvement in 13 projects. Some examples include the conditioning and storage of spent radium sources, dam leakage detection and auditing of radiotherapy and nuclear medicine facilities. The AEC is developing a borehole disposal concept for radioactive sources, mainly of medical origin, under the AFRA programme and acted as technology gatekeepers for food irradiation and research reactor utilisation.

Several initiatives were recently undertaken in South Africa under the IAEA Technical Co-operation programme. Some of these include the establishment of a centre for training in radiological protection, neonatal screening for metabolic disorders at a hospital and the eradication of fruit fly with the sterile insect technique.

A large number of delegates have attended AFRA and IAEA workshops and meetings in South Africa in the recent past. In addition, a total of 67 fellows are in training in South Africa, with a further 34 being processed for placement.

South Africa is actively involved in the Comprehensive Test Ban Treaty monitoring network to supply seismic data, analyses from the Pelindaba radionuclide laboratory, noble gas monitoring information and the establishment of a nuclide monitoring station on Marion Island.

Thailand ’s nuclear research centre

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Abstract. The office of Atomic Energy for Peace, Thailand, is charged with three main tasks, namely, Nuclear Energy development Plan, Utilization of Nuclear Based technology Plan and Science and technology Plan. Its activities are centred around the research reactor TRR-1/M1. The main areas of contribution include improvement in agricultural production, nuclear medicine and nuclear oncology, health care and nutrition, increasing industrial productivity and efficiency and, development of cadre competent in nuclear science and technology. The office also has the responsibility of ensuring nuclear safety, radiation safety and nuclear waste management. The office has started a new project in 1997 under which a 10 MWt research reactor, an isotope production facility and a waste processing and storage facility would be set up by General Atomic of USA. OAEP has a strong linkage with the IAEA and has been an active participant in RCA programmes. In the future OAEP will enhance its present capabilities in the use of radioisotopes and radiation and look into the possibility of using nuclear energy as an alternative energy resource.

Introduction

Development of nuclear technology in Thailand could be traced back to the proposal for an 'Atoms for Peace' programme by the US Government in 1953. A national committee was then established to pursue the study and deliberation on atomic energy for proper moves into the atomic age. The first Thai legal instrument concerning nuclear energy, the Atomic Energy for Peace Act, B.E.2504 was enacted and became effective on 26 April 1961. By virtue of this law, the Office of Atomic Energy for Peace (OAEP) came into being as the centralized office governs the work on the utilization of the nuclear based technology in all field including the responsibility on radiation protection, radioactive waste management and nuclear safety. The first Thai research reactor was installed and brought to its initial criticality in 27 October 1962, which was an important milestone in the history of the development of nuclear technology in Thailand.

Since then, the application of nuclear techniques has been gradually increasing. At present, nuclear technology are quite well known by most of Thai scientists, academicians, medical doctors, industrial men, etc. The principal usage of the nuclear technology is those in the medical treatment and diagnosis, scientific research work, agriculture and industry. The prospect for using nuclear energy as a resource for electricity was also introduced since 1974, but it has not been implemented yet.

Past and present situation of NRCs

OAEP, the national nuclear research centre of Thailand, is a governmental institution under the Ministry of Science, Technology and Environment (MOSTE). The principal responsibilities of OAEP are; serving as a competent authority in conformity with the Atomic Energy for Peace Act, B.E. 2504 (1961); acting as an intermediary co-ordinating with in the country and foreign organizations; conducting activities relevant to the atomic energy for peaceful uses; and undertaking study, research and development of nuclear technology as well as maintaining and operating the reactor for the national research.

The reactor building was established in June 1960 and the reactor was completely commissioned in June 1962.The reactor was manufactured by the Curtis Wright Company, USA, and was officially named "the Thai Research Reactor-1 (TRR-1)". It went critical for the first time on 27 October 1962 and has been applied as a principal equipment for nuclear technology study and research, training, and isotope production for the country use, ever since. Later, the OAEP modified and upgraded the reactor by changing the reactor core into TRIGA Mark III Type of General Atomics, USA. and renamed it "the Thai Research Reactor-1 Modification 1(TRR-1/M1)". The TRR-1/M1 has been mainly used for study, research and isotope production until now.

The TRR-1/M1 situates on the Vibhavadi Rangsit Road, Chatuchak district, about 8 kilometers from the Bangkok International Airport. Over the past decade, OAEP is the centrepiece for conducting the research and development programme in Thailand. But due to the limited office area causes difficulty in expanding the projected researches and studies.

The second research reactor project, has been initiated in 1991. The suitable site for such reactor has been selected and developed, since 1993. The site is located at the Ongkharak District in Nakornnayok Province, about 70 km. from Bangkok. The Ongkharak Nuclear research centre Project was started on 26 June 1997. The contract for the turnkey delivery of the three facilities, the Reactor Island (RI), the Isotope Production Facilities (IPF), and the Waste Processing and Storage Facilities (WPSF), was signed by OAEP with General Atomics (GA) of USA. The Electrowatt Engineering Ltd. (EWE) of Switzerland served as the consultant of OAEP for this ambitious project. The centerpiece of the Reactor Island is a multipurpose, pool-type TRIGA reactor having a steady-state thermal power output rating of 10 MW. The reactor uses low-enriched uranium (LEU) fuel having a U-235 enrichment of about 19.7 wt.%, is cooled and moderated by light water, and reflected by heavy water (D_2O) and beryllium. At the time of this report, the basic design of all facilities has been technically accepted. It is expected that the detail design documents will be submitted for subsequently approval in due time.

At present, OAEP consist of 11 divisions, organized into three groups according to the major task as follow:

Administration and conferences

- Office of the Secretary

Nuclear and radiation safety

- Health Physics Division
- Radiation Measurement Division
- Waste Management Division
- Nuclear Facility Regulatory Center

Promotion of nuclear energy application

- Reactor Operations Division
- Isotope production Division
- Electronic Instrumentation Division
- Physics Division

- Chemistry Division
- Biological Sciences Division

R&D programmes

OAEP has been conducting many R&D activities by using the TRR1/1M research reactor and some other related facilities. The fields of work include:

- Applied nuclear physics
- Nuclear chemistry
- Radiation technology
- Radiation health and safety, waste Management
- Isotope production
- Engineering and industrial application
- Biological sciences, food and agriculture
- Environment and natural resources
- Rare earth production and utilization

In addition, OAEP has been also involved in rendering services on various subjects namely:

- nuclear-based analytical services (special emphasis on medium and heavy element)
- carbon dating
- radiation measurements, including fallout monitors
- health physics services
- waste management and decontamination services (low and medium level)
- gamma irradiation services (for research and project development only)
- nucleonic equipment maintenance
- industrial radiography services (with capability for in-plant / in-field inspection)
- distribution of radioisotopes
- tracer techniques application
- consulting services in peaceful application of radioisotopes and radiation technology.

Manpower, finances and infrastructure

In 1999, the total number of OAEP's employees, is about 500, divided into technical staff of 250, the remaining are administrative officers and supporting staff.

Since OAEP is a governmental organization, the financial support for all activity is from the government. The budget for the year 199 is totally US$ 46 million and can be divided into three main task namely, nuclear energy development plan; utilization of nuclear based technology plan; and science and technology development plan.

At OAEP, the divisional structure is observed only to an extent of compliance with civil services normal practices. But, in order to attain maximum and efficient utilization of a very limited resource of well-trained manpower, OAEP encourages its personnel to work in team rather than keeping strictly to the routine work assigned to their respective divisions. Apart from carrying out routine divisional work, most medium and senior-level scientists and engineer are normally assigned to joint R and D projects, in which more than one division within OAEP and one or more organization outside OAEP participate.

Strengths and limitations

As a governmental institution, OAEP is expected to conduct activity on nuclear aspect to render the service to the publics and society as a whole. Research and development work of any subject can be performed subjected to the interest of OAEP scientists and engineer. But in reality, there is a limitation of human resources in the organization. Knowledgeable people capable to conduct the R&D are rare. Since there is no formal education course on nuclear in under-graduate level. The budget for conducting the R&D is also a problem. Researchers could do only the small projects in a small group of a few people. Big project for investigation of more important problem is rarely the case.

The vision for R&D in nuclear science and technology has been set but not fully implemented.

Challenges faced by NRCs

New directions

Due to past experiences with some of the success and failure on conducting R&D in nuclear, a plan for a new direction was purposed:

- *Organization:* the promotion of peaceful uses of nuclear energy should be separated from the regulation authority i.e. the Thailand Atomic Energy Research Institute as a publics governmental organization was purposed.

- *Planning:* the comprehensive nuclear energy utilization plan will be purposed including the vision for the new organization–to be:.

- To expand the applications of nuclear technology to medical, agricultural, and industrial areas.

- To study the application of nuclear energy as an alternative resources of energy.

- To secure nuclear safety and radiation safety

- *Co-ordination:* establishing R&D work as a joint research programs with other organizations and institutions.

Interaction of NRCs with their environment

Social and economic sector

The Thai government has devised various instruments and development infrastructure to support research and development of science and technology for benefits of the general populace. The key emphases have been those contributing to development of agricultural produce, improved public health and welfare, and industrial productions. Contributions of science and technology have been increasingly essential to present quality of life of Thai society as globalization prevails and economic turmoil continues.

Among other science disciplines, nuclear science has been recognized to be an important extension of the basic sciences from which number of advance technologies are developed and utilized for peaceful purposes. In the past 37 years, there have been substantial progresses made on peaceful and safe utilization of atomic energy in various Thai research institutions including OAEP. Their main contributions have been in areas of education and training, and for agricultural produce development and treatments, nuclear medicine and nuclear oncology, health care and nutrition, and increasing industrial productivity and efficiency. The important association to the contributions, apart from tangible economic and social benefit, has been a national asset of a cadre of competent personnel in nuclear science and technology community where successful future development are assured. Furthermore, their expertise has been internationally recognized and contributing to regional peace and development as well.

Such progresses are assured by only with sufficient safety measures. Enforcing of radiation and nuclear safety measures has been a major commitment to the public of the safety inspectors and safety officers at OAEP and the Department of Medical Science. It has been clearly successful, as there has been no record of any nuclear accident in Thailand since 1962. It has also been well recognized among users of the technology that the inspectors and officers have always been attentive, careful, and decisive on radiation and nuclear safety implementation to maintain public safety standard.

Academia

OAEP has a good relationship with the Universities in Thailand, both in Bangkok and in the provinces. Some R and D programs are worked jointly among various institutions and the NRC. The scientists and engineer from OAEP are invited to be the lectures and co-supervisor in many thesis and special problems for the student in many graduate schools.

Public

To achieve the public understanding or acceptance on nuclear energy, efforts had been made through activities of public information and public understanding. OAEP keeps on conducting many technical training courses, seminars, workshops, conferences, exhibitions and etc. for many target groups such as, university lecturers, school teachers, scientists, engineers and general public. Up to now, it seems that achievement of public acceptance is satisfactory in certain level only for some target groups of higher education. It is still unsatisfactory for the general public and few targets group especially the non-governmental organization that opposes nuclear.

Collaboration and co-operation

IAEA role

OAEP recognized IAEA role for providing assistance on various R&D programme in many sector, via the channel of Technical co-operative program, and RCA. Thailand has participated in many project activities generating social and economic benefits as well as welfare to the people in the country. Subjects for the on going activities are as follows:

- Radiation protection infrastructure
- Thematic health care program
- Agriculture-related projects

- Industry and environment-related projects
- Energy and research reactor-related projects.

Conclusion

OAEP is a centralized office, governs the work on the utilization of the nuclear-based technology in all field including the responsibility on nuclear safety, radiation protection and radioactive waste management and nuclear safety. OAEP, by its statutory functions, is a nuclear research centre of Thailand, undertaking research and development in nuclear science and technology including the operation of the national research reactor. At the same time, it acts as a regulatory organization, performing regulatory roles pursuant to the Thai Atomic Energy for Peace Act.

For the 21st century, it is expected that nuclear energy will play a major role as an alternative energy resource as well as the high technology tool in various sectors namely, medicine, agriculture and industry. R&D in nuclear field will be increase and enlarge substantially, to meet the demand of the technology. NRCs will still be a good place for commence the development and maintain the high standard of technology, subjected to the well-established plan.

Some thoughts from the United Kingdom

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Abstract. The UK Atomic Energy Authority has three research centres and many industrial enterprises. However, there is a general decline/stagnation of activities with only one research reactor for civilian use and no growth in the nuclear power sector. The United Kingdom may soon face the shortage of personnel in the essential field like health physics, radiation protection and safety management. Also there is a concern about anti-nuclear culture which is growing roots. British Nuclear Fuels Limited is trying to address some of these problems by opening a visitor centre in Sellafield and a centre of excellence in radiochemistry in one of the universities. International collaboration among nuclear research centres would be very valuable for optimizing the use of research reactors, training of nuclear engineers, decommissioning and handling other related issues.

Introduction

Before I begin, I would like to tell you of an event which happened last week. Our Department of Nuclear Science & Technology of the Royal Navy finally decommissioned our nuclear reactor JASON, at its historic site in the Royal Naval College, Greenwich. This was the reactor sited in the historic building, parts that date back to King Henry VIII, in the 16th century. Last week we signed it off as a nuclear site. Our Department is charged with the education of Naval Officers manning the UK nuclear submarine fleet, and the supporting personnel. We had already moved our staff and facilities down to HMS SULTAN, near Portsmouth last year. This is the largest mechanical engineering training establishment in the UK, where we now have the centre of all UK naval nuclear training and education. We teach all aspects of nuclear power and safety from designing and building to disposal, and we have an active research group looking into all aspects of submarine propulsion and nuclear safety.

But I was going to talk about the UK. I don’t really want to go into too much detail on specific nuclear research centres. The UKAEA and its offshoots BNFL, the AEA at Harwell, Risley and Winfrith, the National Nuclear Corporation and Nycomed (formerly Amersham) are major organizations, with the NRPB & Magnox Electric. I mention DRPS, the Defence Radiological Protection Service. This was formerly a Defence Establishment but in the wave of privatizations that swept the UK this unit is now open for civilian business as well.

Likewise, I am sure some of you will know the major university nuclear research centres I should mention that our Department comes under the accreditation of the University of Surrey.

Problem faced

I would summarize the problems we have in the UK, in nuclear research, and show how we are attempting to solve them. I see this as an aspect of our meeting here. With my background in education, I will largely stay in this area but the problems equally affect the commercial world.

Finally — I would like to pose some questions to which the meeting might suggest answers, which must have a collaborative component.
One problem is the closure of nuclear research reactors in the last ten years. We only have four left, one for civilian use and three for defence.

Other problems include a stagnant nuclear power industry — which affects the recruitment of new trained staff, via the Masters or PhD route. Also it is not only at PhD level. One young graduate student told me that he didn't want to go into the nuclear industry, if all you did in your career was decommission old plants. He saw no fun and accomplishment in that.

Our staff, academics and trainers, are getting older as are the facilities we work with. There's not many people coming along behind — there was a ten-fold drop in nuclear academic numbers between the great days of the 60's to the 90s[(1)]. With this decline, undergraduate nuclear courses have cut back.

And with the approaching shortfall in suitably qualified personnel, especially those in areas of health physics, radiation protection and safety management, we may soon not have enough to go around. And remember there is that time lag — if we inspire a young keen school student today — it will be 8 to 10 years before he is into mainstream practice, in teaching, operations or research.

Some possible approaches

So what's to be done about it? Universities are not standing still of course: They are looking outwards. For an example, I can show you a profile of the current research at the University of Birmingham — a range of studies and international links.

For numbers, some are doing very well: The Physics Department at Surrey University, where we have strong links, has some 30 research students, 10 research fellows and 10 academic staff — a very thriving group devoted to nuclear research and many of the students are not from the UK.

Are there any new initiatives?

As the major player in the UK, British Nuclear Fuels have recognized the beginnings of the problem and are actively looking into ways of pushing the academic sector. They have established a centre of excellence in radiochemistry at the University of Manchester. £2M over 5 years will fund a Professor, academic staff and PhD students. They currently sponsor 30 other PhD students per year and are now looking much more closely at these students as prospective employees of the company.

Of course there is still the anti-nuclear culture to contend with, and general apathy to science in general. BNFL established their very successful Visitors centre at Sellafield to try to put across the nuclear vision to the public and more especially to school children. If we can get them, they are the prospective science graduates of the future.

BNFL have also established the Westlakes Research Institute, a research and consultancy company set up in the Lake District to study environmental science, biotechnology and genetics. I was personally pleased when one of my own PhD students joined the Company to do radio nuclide environmental modeling.

Finally, the Company is planning a new technology centre at Sellafield. Although not really part of my academic summary, it should be mentioned here.
On a larger platform, NAILS, the Nuclear Academic Industry Liaison Society, an offshoot of the British Industry Nuclear Forum, now meets regularly, to exchange ideas between the universities and industry.

These may not solve all the problems, but they will surely help.

Some questions to nuclear research centres

So, after this very brief resume, I mentioned I had some questions. My colleagues set them for me to ask you here in the context of planning for the 21st century. We haven't the answers but the questions might be useful points for long term consideration and collaboration.
In these nuclear research centres:

- Do we need research reactors?
- How many research reactors does a country need?
- What research is being done on low power reactors?
- Can a nuclear research centre survive without a reactor?
- Have other countries created *shared* centres of excellence?
- How are other countries planning to provide courses to produce the next generation of nuclear engineers?
- How are other centres approaching commercial realities?
- How are other centres involved with industry?
- How are other centres approaching the planning for decommissioning?

Are there answers yet? The 21st century is less than three weeks away. To conclude the problems are there — I think the solutions must be found both internally and with external collaboration.

We must get more students into science and more specifically — into the nuclear world.

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Argonne National Laboratory:
An example of a US nuclear research centre

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Abstract. The nuclear era was ushered in 1942 with the demonstration of a sustained nuclear chain reaction in Chicago Pile 1 facility. The USA then set up five large national multi disciplinary laboratories for developing nuclear technology for civilian use and three national laboratories for military applications. Reactor development, including prototype construction, was the main focus of the Argonne National Laboratory. More than 100 power reactors operating in the USA have benefited from R&D in the national laboratories. However, currently the support for nuclear power has waned. With the end of the cold war there has also been a need to change the mission of laboratories involved in military applications. For all laboratories of the Department of Energy (DOE) the mission, which was clearly focused earlier on high risk, high payoff long term R&D has now become quite diffused with a number of near term programmes. Cost and mission considerations have resulted in shutting down of many large facilities as well as auxiliary facilities. Erosion of infrastructure has also resulted in reduced opportunities for research which means dwindling of interest in nuclear science and engineering among the younger generation. The current focus of nuclear R&D in the DOE laboratories is on plant life extension, deactivation and decommissioning, spent fuel management and waste management. Advanced aspects include space nuclear applications and nuclear fusion R&D. At the Argonne National Laboratory, major initiatives for the future would be in the areas of science, energy, environment and non-proliferation technologies. International collaboration would be useful mechanisms to achieve cost effective solutions for major developmental areas. These include reactor operation and safety, repositories for high level nuclear waste, reactor system decommissioning, large projects like a nuclear fusion reactor and advanced power reactors. The IAEA could have a positive role in these collaborative programmes.

Background

The nuclear age was ushered in on December 2, 1942 under the stands of the Stagg Field at the University of Chicago. Enrico Fermi and his team of scientists produced the first sustained nuclear chain reaction on the CP-1 (Chicago Pile 1) facility. Shortly thereafter, a duplicate of this pile — the CP-2- was constructed at a site roughly 50 km from the university at the initial location of what was to become Argonne National Laboratory (Argonne). Argonne was formally inaugurated in 1946 with the basic mission of developing nuclear technology for civilian use. Subsequently, a number of other national laboratories were established. Three laboratories — Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory (LLNL) — were aimed primarily at the development, testing, and maintenance of nuclear weapons. The other laboratories — Oak Ridge National Laboratory (ORNL), Brookhaven National Laboratory (BNL), Idaho National Engineering and Environmental Laboratory (INEEL), and Pacific Northwest National Laboratory (PNNL) — were multi-purpose laboratories like Argonne with part of their mission dedicated to the development of nuclear technology and its civilian applications. Taken as a whole, the USA. multi-purpose laboratories fit the definition of a nuclear Research Center (NRC) posed by the organizers of the Workshop.

Changing conditions have altered the missions of these national laboratories drastically. With the end of the cold war, the defense missions of the three weapons laboratories have been modified and each of them has increased the civilian nuclear component in its R&D portfolio. For the original multi-purpose laboratories, the missions have also been altered in response to the changing conditions in the nuclear power field. In this paper, I will focus on Argonne National Laboratory as an example of a US NRC. I have spent my professional career at Argonne and can speak authoritatively on it. Challenges and opportunities faced by Argonne are typical of the USA multi-purpose laboratories and their discussion addresses the basic question of the evolution of the nuclear research centres, which is the topic of this workshop.

The early focus of Argonne was the development of civilian nuclear power systems. The EBR-I reactor (CP-3) at the Argonne-West site in Idaho was one of the early successes. This NaK cooled HEU fueled system was the first nuclear system to produce electric power. The early heavy water cooled and moderated reactor (CP-5) was also developed at Argonne, as was the first boiling water reactor (EBWR). In fact, for virtually every class of reactors in use, the early work up to and including prototype construction was performed at Argonne, the main exceptions being the gas-cooled reactor and the molten salt reactor. The early work involved development of methods needed for the design of reactors. This included measurement and evaluation of nuclear data, development of reactor physics and thermal hydraulics methods, control system theories and equipment, sensors, materials, etc. In addition, organizations were assembled to work on supporting areas — health effects of nuclear radiation, chemistry, physics, etc.

Challenges faced

In the fifty years since the start of the nuclear era, conditions in the USA have changed significantly. The support for nuclear power has waned and the support to nuclear R&D from the USA Congress has been reduced. The reasons for the decline in support for nuclear power have been well chronicled — the early optimism about the economics and operational advantage of nuclear power proved to be too hopeful. A few nuclear accidents have raised serious questions in the minds of the public and decision-makers on relying on nuclear power as a major energy option. The current plentiful availability of fossil energy (particularly natural gas) in the USA further reduced the basis for political support to nuclear R&D. The expectation for increased interest in nuclear power in the wake of the Kyoto accord and general concern for global warning has not materialized so far. In part, this is because of inherent uncertainties in global warning estimation; in addition, it is difficult to get pubic and political attention for very long term problems. The upshot of all of these events is that support for nuclear R&D has declined dramatically.

As a natural consequence of reduced support, the missions of the multi-purpose national laboratories have become increasingly diffuse, as illustrated by the funding distribution shown in Figure 1. The earlier focus on high risk, high payoff R&D, which was the basic purpose in the formation of the national laboratories, has now shifted toward nearer term developmental activities. This near term work has often proved to be unsuited to the existing cultures of the national laboratories.

Cost and mission considerations have resulted in the shutdown of numerous DOE research and test facilities including several at Argonne such as the EBR-II facility, the TREAT reactor, and several zero power critical facilities. Several university reactors have also recently been permanently shutdown while others are facing difficulty in meeting operational expenses. Within the USA national laboratory system the only test reactors still operating are the Advanced Test Reactor (ATR) at INEEL, the HIFR facility at ORNL, and the ACRR facility at SNL. It is ironic that the only reactor facility at Argonne, which in early days boasted of a number of major facilities, is a small TRIGA reactor (the NRAD) at Argonne - West used for neutron radiography. The chance for the construction of a new nuclear test facility in the foreseeable future is slim at best. The Advance Neutron Source (ANS) facility planned to be constructed at ORNL was cancelled because of the projected cost overruns. The current plan is to construct the Spallation Neutron Source (SNS) at ORNL to provide the neutrons for science research; this is an accelerator based neutron source. The story is alarmingly similar for the auxiliary nuclear facilities needed for R&D — hot cells, glove boxes, etc.

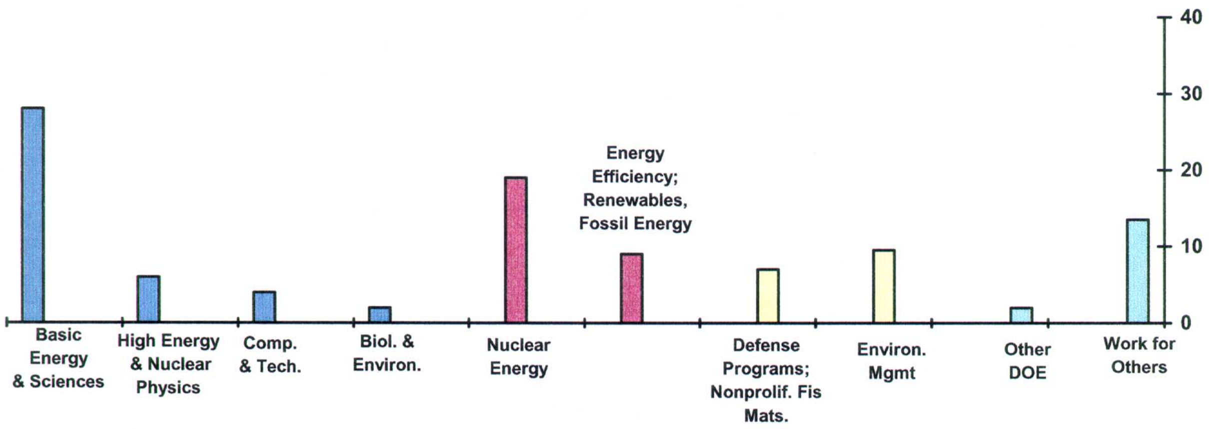

Figure 1. Argonne FY 1999 funding levels (% of lab total).

The eroding infrastructure has been the subject of much discussion within the USA Department of Energy (USDOE). There is concern about safety and the costs of dismantlement and disposal of many of the contaminated facilities; replacement is generally far from decision makers' thought. Concomitant with the mission defocusing and infrastructure erosion if the major fact of reduced opportunities for research personnel. This leads to increasing frustration and reduced morale among the very bright people that generally populate the national laboratories. In addition, it reduces the influx of new people that is so essential to adding new ideas and enthusiasm to any organization. The reduced opportunities in the nuclear field are well known, the result is reduced interest in nuclear engineering among students and reduced enrolment in the field. A majority of the nuclear engineering Departments in US universities have had to merge with other engineering departments and have lost their independent identities.

All of the above add up to formidable challenges to the future maintenance of the "nuclear research centres" as defined by the IAEA. For those of us who believe in a nuclear future — one in which nuclear energy is a part of a national optimum mix of energy sources used to power the human enterprise for a long time to come — it is time to consider seriously the steps necessary to stabilize the situation and if possible turn it around soon. This workshop is certainly very timely in this regard.

What is needed is the development of relevant, sustainable long term missions for the nuclear segments of the multi-purpose national laboratories. These missions need to be defensible in public and political debates and thus supportable by the government. Such missions would provide stability to the enterprise, maintain expertise for the future, and aid in the transfer of expertise to new entrants to the field.

Current programs

All of the USA multipurpose national laboratories now have broad-based R&D portfolios comprising nuclear technologies, basic sciences, environmental management, non-nuclear energy technology, national security, and industrial support components. The relative breakdown of these components varies from laboratory to laboratory. Even the defense laboratories (LANL, SNL, LLNL) have had major programs in the other areas included in their program portfolios. This is I keeping with the continued diffusing the missions of most of laboratories. A feature of the science programs in the laboratories is the operation of large user facilities (e.g. the advanced photon source at Argonne)

National laboratories pursue the following R&D programs within the nuclear area:
– Nuclear waste management
– Spent fuel management
– Reactor systems D&D
– Plant life extension
– Nuclear non-proliferation
– Nuclear regulatory support
– space nuclear applications
– Next generation nuclear plant concepts
– Nuclear fusion R&D
– Industrial support R&D

Some of these existing major programs are described briefly below.

1. *Spent fuel management:* Electrometallurgical technology is being utilized to condition spent fuel from the EBR-II reactor (sodium bonded metal fuel in preparation for disposal. The technology has been demonstrated with a number of driver fuel elements processed and several blanket elements processed to date. It appears that this method could be utilized for other fuels as well.

2. *Reactor systems D&D:* The safe and cost effective deactivation and decommissioning (D&D) of nuclear reactor facilities that have reached their end-of-life is a very significant challenge in the nuclear system life-cycle. At Argonne a number of research and test reactors had been designed, constructed, and operated over the years. Essentially all of them have been shutdown now. Argonne has embarked on a program of developing, testing, and applying methods for safe and cost effective D&D. We have decommissioned four test reactor systems at the Argonne-East site, and have demonstrated a large number of advanced technologies for D&D. The methods and procedures developed are being utilized in the remaining D&D work at the Argonne facilities, throughout the USADOE complex, and elsewhere in the USA government (e.g. NASA). We also interact with the USA nuclear utilities to assist the owners in their D&D efforts. We developed and presented a significant training course in D&D to US and international participants (this included an IAEA group in 1998).

3. *Nuclear non-proliferation*: Like several other national laboratories Argonne has a significant program on development of technologies and procedures to reduce the risks of widespread development of weapons of mass destruction and diffusion of associated technology. Argonne's main activities are in the areas of sensor systems development, proliferation vulnerability analyses of various aspects of the nuclear fuel cycle, development and utilization of databases and analysis tools for nuclear materials control, and the Reduced Enrichment Research and Test Reactor (RERTR) program. The RERTR program has developed high density fuel with low enrichment uranium (<20% fissile enrichment) that can be used to enable research reactors to utilize LEU instead of HEU with little, if any, loss of performance. Over thirty-five reactors worldwide have been converted to date and several more are planned. Recently a joint program in this area is being negotiated with Russia.

4. *Isotope Production:* Several national laboratories (INEEL, ORNL, SNL) are involved in the production of radioisotopes for medical and other use. Argonne's primary contribution this area is the development and demonstration of methods for the utilization of LEU targets to produce the Mo^{99} isotope.

5. *Space nuclear applications:* Several longer term space missions (manned Mars landing, probes to the distant planets, etc.) will likely require nuclear fission devices for power and propulsion. Along with several other laboratories, Argonne has used its proved advanced nuclear reactor development capabilities to work o several concepts and on technologies to support this endeavor.

6. *Nuclear fusion:* The core competencies developed in the course of the fission reactor programs (e.g. liquid metal technologies, materials science, activation evaluation, etc.) have been applied to the fusion power development program. Argonne scientists have worked in these areas collaboratively with US and international colleagues for several decades in areas that include blanket and materials development.

7. *Industrial Support:* A number of Argonne's core competencies are being applied to help US industry in various ways to become more efficient and cost competitive. Example of technologies being applied are sensor systems, modeling capabilities, laser technologies, materials technologies, and environmental technologies.

8. *Electrochemical energy system development:* There is a major program at Argonne dedicated to the development and testing of electrochemical energy system (batteries and fuel cells) for use in the industrial and transportation sectors.

Argonne's major initiatives for future work are shown below:

Science

- Rare isotope accelerator
- Fourth generation light source
- Strategic computing
- Second target ast SNS
- Accelerated protein studies
- Combinatorial materials S&T
- Nanoscience

Energy

- Nuclear technology R&D
- Transportation technologies
- Ag-biotech for chemical products

Environment

- Environmental nuclear technologies
- S&T for environmental Stewardship
- Remote Treatment Facility at ANL-W
- Synchrotron environmental science

National security

- Arms control and non-proliferation technologies

Strengths and limitations

A major strength of the USA national laboratories in general is the concentration of a large number of extremely capable technical people, many of whom have demonstrated skills in producing solutions to complex scientific and engineering problems. The expertise in laboratories such as Argonne is multidisciplinary. This is a major resource that can be used to tackle significant technical problems that face the nation, all of which require the utilization of multidisciplinary skills, working as a team. A second major strength of the laboratories is the availability of several billion dollars worth of capital equipment and instrumentation, much of which are one of a kind and cannot be reproduced without considerable expense. This combination of intellectual and physical assets coupled with the demonstrated capability of using them to solve large complex technical problems positions the laboratories well to tackle problems of national significance in the future.

The large and expensive infrastructure, however, is difficult to maintain and is expensive to keep in good operating condition. since the major support for all the laboratories comes from the government, support from the annual budgeting process from the USA congress becomes a major issue. With declining public and political support for nuclear power, funding for nuclear infrastructure has been neither consistent nor totally adequate.

The other major complication with the national laboratories is that is has proven to be quite difficult to make large changes in R&D directions because of the large inertia of the system. Attempts at privatization of pieces of the laboratory systems have not been very successful up to this point.

Interactions with industry and academia

The interactions of the nuclear energy R&D segment of the national laboratories with the outside world are shaped by several factors. the considerable fossil energy sources available in the USA coupled with the disappointing economic performance of some of the nuclear power plants have reduced industry support for nuclear energy. The two major nuclear accidents in nuclear power plants have shaken public confidence in the technology. Finally the continuing debate of the high level waste repository at Yucca Mountain has created a negative impression. It is fair to say that overall public support is mixed, and the USA Congress does not fund much new R&D on nuclear systems.

An additional concern in the USA is created by the deregulation of the power industry. This is resulting in a massive re-evaluation of the economic bases for operating power plants and has been responsible for the premature shutdown of a number of nuclear power plants. Several other plants have been sold, some at incredibly low prices. While there are clearly conditions in the deregulated energy industry where nuclear plants would thrive, new construction will almost certainly be aimed at the more quickly constructed lower cost systems (such as natural gas burners). In this environment the interactions of the industry with the nuclear laboratories is limited to areas such as plant life extension, advanced sensors for monitoring and control, and D&D.

A consequence of the reduced activity in the nuclear field is reduced educational activity in the field in Universities. There are, thus, reduced interactions with academic institutions and reduced opportunities for graduating students to join the laboratories. As was mentioned earlier, this reduces the very necessary influx of new ideas and enthusiasm into the laboratories.

Collaborations

The nuclear world has to be considered as connected. Incidents in nuclear facilities in one part of the world are communicated to all areas instantaneously and affect the operations and thinking in real time as the incidents unfold. The recent criticality incident in Japan is a case in point. It is essential that international nuclear programs stay linked in order to benefit from individual experiences and in order to jointly anticipate potential problems and make the necessary moves to diffuse them. The other major reason to increase collaborations is that the cost of the development of a number of nuclear ventures and applications is every large and outside the capability of most nations to support individually. It would be prudent and cost-effective to share the development expense and risk amongst nations. It would also allow the inclusion of a large variety of view points and ideas into these major developments.

There are several areas in which international collaborations are very appropriate. In several of these areas, some collaborations are already underway as discussed below.

International repositories for high level nuclear waste

The question of repositories for the long term and safe storage of high-level nuclear waste has moved to centre stage in the nuclear scenario. Several countries (including the USA) have very large programmes for repository development. These include assessment of potential sites, construction of suitable waste repository structures, experimentation on migration of radionuclide, and addressing a host of legal and political questions. Most nations with small nuclear programs cannot afford the huge cost of repository development and their small needs do not justify such expenditures and effort. This has led to the development of the concept of international high-level waste repositories. There are several proposals for such repositories currently under consideration. The idea is not free from problems. Significant incentives have to be presented to the nation within which the repository is located. Consideration must be given to the expectation of long term political and social stability of the host nation and their indefinite acceptance of strict safeguards regimes. Finally, the possibility has to be considered that international waste repositories could undermine viable national repository programmes. In any case, this is an area of major significance to the sustainability of nuclear technology and is suitable for international collaboration.

Reactor safety/operations

This is an area in which significant collaborations are occurring already, some under IAEA sponsorship. Since the avoidance of nuclear accidents anywhere in the world is of paramount importance, every effort should be made to disseminate operations information and safety experiences to reactor operations worldwide.

Reactor systems decommissioning

As nuclear reactor systems age, there is a growing need for the development and utilization of methods for either refurbishment and life extension or the safe and cost effective D&D of reactor facilities. This area represents a very large activity, estimated to cost about 1 trillion US dollars worldwide over the next five decades. Several nations, including the USA, have successfully decommissioned a number of reactor facilities — research, test and power systems. A set of technologies has been developed and continues to be developed to perform various facets of D&D efficiently. The experience and technologies developed can be utilized worldwide to complete the final phase of the first generation of reactor systems. It is our belief that this needs to be done safely and cost effectively for the next generations of nuclear systems also.

Large nuclear applications

International collaborations are also very desirable for large nuclear projects. There has been long term collaboration on the development of fusion energy, and this continues to this day, despite the recent decision by the USA to withdraw from the ITER project. The use of fission systems for space exploration and exploitation is an area that could provide exciting opportunities for collaboration in the 21st century. The design of advanced nuclear power systems that incorporate features of inherent safety, proliferation resistance, reduced waste, and ease of decommissioning could be another area in which international collaborations could pay rich dividends.

There are a number of mechanisms by which such international collaborations could be effected. The IAEA provides a number of opportunities for such activities. There are also a number of bilateral and multilateral agreements through which collaborations are performed. In this regard, special reference must be made of the Nuclear Energy Research Initiative (NERI) project, recently started by the Office of Nuclear Energy in the USADOE to address the key issues affecting the future of nuclear energy. There is a strong impetus in that initiative to seek and utilize international collaboration.

Other considerations

By way of summary, a few significant points should be emphasized. First, we simply cannot afford to have another major nuclear accident anywhere in the world. Such an accident would cause a major loss of credibility from which it would be nearly impossible to recover. The recent criticality incident in JNC in Tokai Japan, while not a very major accident, certainly caused considerable consternation around the globe. A reactor accident of the Chernobyl scale could be disastrous. What is needed is an international repository of operational data and rapid dissemination of operational and safety information to all operators. Safety support should be made available to all reactor operations personnel.

We must do out utmost to prevent a nuclear proliferation incident triggered by a sub-national group. It is essential to safeguard all nuclear materials and control the export of technologies and the movement of experts to minimize the threat of terrorist groups acquiring and utilizing nuclear explosives. International agreements on appropriate safeguards regimes, such as the IAEA safeguards programs, are needed. There is a fertile area of development and utilization of advanced sensor systems that are on-line and continuous and supported by modern signal processing and intelligent software in this area that needs to be considered. NRCs possess critical expertise for finding solutions in these areas.

Finally, the issues related to the safe and economic solution to the problems of the back end of the nuclear fuel cycle needs to be tackled effectively if there is to be any real hope of sustained utilization of the nuclear option worldwide.

Conclusion

In an era of uncertainly in nuclear energy programs, government supported nuclear research centres must adapt their missions to ensure that they tackle problems of current significance. It will be critical to be multidisciplinary, to generate economic value, and to apply nuclear competencies to current problems. Addressing problems in nuclear safety, D&D, nuclear waste management, nonproliferation, isotope production are a few examples of current needs in the nuclear arena. Argonne's original mission, to develop nuclear reactor technology, was a critical need for the USA in 1946. It would be wise to recognize that this mission was a special instance of a more general one — to apply unique human and physical capital to long term, high risk technology development in response to society's needs. International collaboration will enhance our collective chances for success as we move into the 21st century.

A proposed new mechanism for research and development co-operation

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Abstract. Scientists in developing countries sometimes lack knowledge of recent developments, co-operation with advanced countries, and government appreciation of the importance and quality of their work. The present IAEA mechanisms like CRPs and TC projects are very helpful but do not fully meet R&D co-operation needs of these scientists. A new complementary mechanism of co-operation among the Member States is proposed that would utilize IAEA services through a suitable agreement. The IAEA could help to evaluate joint R&D proposals, to provide an example legal agreement, to monitor progress, to disseminate the results, and, in some cases, to administer joint funds. This new mechanism would be similar to ITER, but on a smaller scale, and applicable to all fields of nuclear R&D.

Introduction

Research and development (R&D) programmes in some developing countries have problems keeping abreast of progress, arranging for co-operation with advanced laboratories, and obtaining recognition by their governments of the importance and quality of their work. These problems could be alleviated by international co-operation. The IAEA is the most appropriate organisation to facilitate international co-operation in nuclear technology R&D, because it has:

- a mandate to promote peaceful uses of nuclear energy
- a global scope of its operations
- an experienced staff
- many TC projects all over the world
- access to experts in all fields of nuclear technology
- prestige
- a tradition of fostering international co-operation.

The International Thermonuclear Experimental Reactor (ITER) engineering design activity (1992–2001) is an example of a successful collaboration that is being done under the auspices of the IAEA. The IAEA provides:

- Assistance with meetings
- Liaison office in Vienna
- Publication of reports and documents
- Monthly newsletter
- Administration of the ITER Joint Fund.

It may be possible for the IAEA to facilitate some smaller nuclear R&D collaborations, in many fields of nuclear technology, that are similar to ITER, with a modest cost to the IAEA.
Scientists from several developing Member States have told the IAEA that the existing Co-ordinated Research Project (CRP) mechanism does not meet all their needs to facilitate international co-operation. The present CRPs

- require significant IAEA funding, so the number of CRPs is limited
- have narrow foci, so many worthwhile topics cannot be covered

- have a long lead time for initiation (2–3 years)
- require a minimum of 5 participants
- do not provide a legal framework for multinational collaborations.

Therefore, a new co-operation mechanism is desirable, to complement the existing CRP mechanism.

The proposed new mechanism

A new research and development co-operation mechanism was proposed by Dr. Adolfo Rodrigo (Argentina), discussed by the International Fusion Research Council (1995–1996), refined by an Advisory Group Meeting (1996, ARG, BRA, CPR, CZR, EGY, IND, IRA, ISR, KOR, PAK, POL), revised by a consultant meeting (1997), sent out for comment (1997–98), broadened to be applicable to many topic areas (1998), discussed within the IAEA (1998–1999), and discussed at the meeting on "nuclear research centres in the 21st century" (1999).

In the proposed new R&D co-operation mechanism, the scientists would:

- contact each other.
- draft a proposal for R&D co-operation, with funding by the organizations submitting the proposal
- submit the proposal to the IAEA via their governments.

Then the IAEA would:

- supervise peer review & selection of proposals
- provide an example legal agreement to the interested Member States
- monitor the R&D projects
- publish and disseminate the project reports to the user communities
- help with fund transfers, if required.

The contracting parties could be government laboratories, R&D institutions, universities, or private entities approved by the governments. The responsibility for defining the proposals would lie with the participants. The scientific responsibilities, funding responsibilities, and legal issues, such as intellectual property rights, would be agreed at the time of submitting the proposals. The IAEA would provide an example legal agreement to assist the Member States in this process, and it could call upon its Member States and experts to share their experience in developing such arrangements. There are precedents for successful cooperative nuclear-related R&D projects, such as the International Thermonuclear Experimental Reactor (ITER) Protocols and the International Energy Agency (Paris) Implementing Agreements. In those cases where fund transfers are needed but difficult to arrange directly between the governments, the IAEA could help with administration of joint funds, as it does for ITER.
This proposed new mechanism differs from the present CRPs in several important ways, as described in Table 1. The funding would come from Member States, rather than from the IAEA Regular Budget.

The benefits of this new R&D co-operation mechanism to *advanced* Member States would be

- Additional manpower, knowledge, and financial resources.

- Contact with research done in developing countries
- Contact with bright young scientists and engineers from developing countries.

Table 1. Comparison of proposed R&D co-operation mechanism with CRPs

	CRP	**R&D Co-operation Mechanism**
Initiation	IAEA	Member State scientists
Participants	5–15	any number
Project duration	~3 years	any duration
Funding source	IAEA budget	participating countries
Meetings	paid by IAEA	no cost to IAEA
Contracts	paid by IAEA	no cost to IAEA
Project selection	Research Contracts Committee	Peer review by external experts and IAEA Technical Staff
Legal framework	NACA contracts & agreements	Example legal form plus advice from IAEA and interested Member States
Cost to IAEA	~200 k$	low

The benefits to *developing* Member States would be

- Co-operation with advanced laboratories and with each other
- Knowledge of recent developments
- Reduced costs
- Improved R&D capabilities
- Advice from other countries and from the IAEA on how to organize international collaborations
- Assurance to governments that the research is important and of good quality.

Example project

To illustrate one possible realization of this proposed new R&D co-operation mechanism, a fictitious example project is described in Table 2.

This new co-operation mechanism could be used in many nuclear R&D fields, such as:

utilization of research reactors
utilization of particle accelerators
environmental monitoring
food and agriculture

human health
water supply
nuclear safety
fuel cycle & decommissioning
waste management
nuclear fusion energy
humanitarian demining
synchrotron radiation
spallation neutron sources.

Some issues of concern are:

1. What would be the costs to the IAEA? (As presently envisioned, the IAEA costs would be mainly staff time for the services provided. In the future additional services could be provided by the IAEA, if extra budgetary funding were available.)
2. To what extent would intellectual property rights issues interfere with collaboration?
3. Would governments of developing countries be willing to fund R&D collaborations?

Table 2. Hypothetical example R&D co-operation project

Scenario	Scientists in Brazil, China, India, and the Republic of Korea need to develop high heat flux materials. They want to use materials test facilities in Russia and the USA to test their experimental tiles. They contact scientists in those countries and agree to collaborate. Then they write a proposal to the IAEA for initiation of an RDCP project.
Selection	The IAEA organizes a peer review and the proposal is selected for implementation.
Implementation	The IAEA provides an example legal contract and free advice. The 6 Member States modify the contract to suit their specific needs and sign it. Russia and the USA open their facilities for free use by visitors. Brazil, China, India, and the Republic of Korea provide the tiles and pay the expenses of their scientists. (In this case, no fund transfers from one country to another are required.)
Benefits	Russia and the USA benefit from participation in the research and knowledge of the results. Brazil, China, India, and the Republic of Korea benefit from use of the high heat flux test facilities. All benefit from the IAEA evaluation, example contract, monitoring, and dissemination of the results; and from the concomitant assurance to governments of the importance and quality of the R&D.

Demonstration of high-level waste disposal technologies in an underground research laboratory

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Abstract. A number of nuclear research centres in different countries are investigating the issue of underground disposal of high level. The paper proposes that a collaborative programme be launched, under the IAEA auspices, to find solutions to various facets of this issue.

Scope

Underground research laboratories for geologic disposal of high-level radioactive wastes already exist in some countries (Belgium, Canada, Germany, Sweden, Switzerland) and are planned in others (Finland, France). In the USA an Exploratory Studies Facility for exploring the suitability of a site has been constructed at Yucca Mountain, Nevada, and a geologic repository for disposal of long-lived transuranium contaminated waste is in operation at the Waste Isolation Pilot Plant (WIPP) in New Mexico. These facilities offer a unique opportunity for collaborative research on technologies for the disposal of high-level and long lived radioactive wastes among nuclear research centres (NRCs). One or more collaborative projects is proposed in which researchers from different NRCs would jointly plan and implement key experiments to demonstrate technologies or answer important scientific questions related to safe long term isolation of high-level and long-lived wastes.

Duration

Initially, a period of five years is envisioned from initial planning to completion, for one project in one facility. However, several projects in parallel in URLs in different geologic media, with a series of sequential experiments and demonstrations can be envisioned.

Venue

Discussions have already been held regarding work in the URLs in Mol, Belgium (clay) and Canada (granite), and the WIPP repository in the USA (salt). It is likely organizations in other locations may be interested in participating, were a collaborative project established.

IAEA role

The IAEA would provide the Secretariat for the collaborative project(s). Its resources would be available to organise meetings to plan projects, report on progress and present final results. The IAEA could provide for publication of the results. Through the frameworks of its co-ordinated research programmes it could provide grants to support research participation by developing Member States. Within the framework of its Technical Co-operation Programme, it could sponsor fellowships, scientific visits and training for scientists in developing Member States to be involved in the research.

Benefits/expected outcome

Increased public confidence that geologic disposal of high-level and/or long-lived waste is feasible and safe.

Answers to specific scientific questions that were identified by the scientific teams that would advance the scientific understanding of geologic disposal.

Transfer of technology for geologic disposal from industrialised Member States having these facilities to developing Member States.

Reduced costs in participating Member States' national programmes resulting from cost sharing among participants.

A series of high-quality publications on the results of the collaborations that would enhance world-wide technology transfer on geologic disposal.

Knowledge that would improve the designs of the national repositories that will finally be built.

A framework for international co-operation that could eventually lead to development of multi-national repositories.

Partitioning and transmutation of radionuclides

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Abstract. Many countries with large nuclear power programme are pursuing programmes for transmitting long lived radioisotopes in high level waste, particularly actinides, into short lived radioisotopes so that the viability of disposal sites has to be ensured only for a few hundred years. The possible role of the IAEA in this area is highlighted in the paper.

Introduction

Different programs in many countries are working on the transmutation of long-lived radioactive waste.

In **France** the CEA **CEN of Cadarache** is working on research programs (since 1991) in collaboration with the European Union, PSI in Switzerland, ITU and FZK in Germany, ECN in the Netherlands. The Spin Project is for Separation Incineration. Research reactors are PHENIX, OSIRIS, HFR in Petten, and in the future RJH in Cadarache.

In the USA, Congress has directed the Department of Energy to carry out a study of the Accelerator Transmutation of Waste Management (ATW) and to prepare , before the end of the fiscal year 1999 a roadmap for its development. The ATW is already defined by **LANL** as a three "building blocks", including a linear accelerator, a sub-critical nuclear assembly to convert the spallation reactions into an intense neutron flux and a chemical process for treating nuclear waste.

In **Japan**, **JAERI** and **CRIEPI** are promoting research and development of transmutation system that combines a minor actinide fuelled subcritical reactor with a high-intensity proton accelerator.

In the **Russian Federation**, some reflections are done by **IPPE** to optimise the closed nuclear fuel cycle including transmutation of minor actinides and the fast neutron systems is pointed out to be better actinide transmuters than thermal ones.

It is considered as an institutional requirement for countries which has developed an important capacity in nuclear energy production to reduce the volume and radiotoxicity of nuclear wastes. For that purpose R&D on Transmutation was or is being initiated in these countries or are under to be initiated, using available research reactors or developing new "reactors".

IAEA role

The IAEA may have a role in promoting co-operation between the national projects on the subject of transmutation through programmes on the development of the new reactors or accelerators that could be used in this field.

To summarise, the IAEA may have collaboration with NRCs on:

- Chemical separation processes
- Management of the actinides after separation:
- transportation, preparation of experimental elements for transmutation, ….
- Different ways to produce transmutation for different actinides:
- neutronic capture, fission, spallation,
- kind of transmuters to perform experiments on transmutation
- fast breeders, water reactors or hybrid reactors chemical separation process, or acceleration driven systems (ADS)

International collaboration between nuclear research centres and the role of research reactors

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Abstract. A research reactor is a core facility in many nuclear research centres (NRCs) of Member States and it is logical that it should be the focus of any international collaboration between such centres. There are several large and sophisticated research reactors in operation in both developed and developing Member States, such as Belgium, China, Egypt, France, Hungary, Indonesia, India, Japan, ROK, Netherlands, South Africa and the USA. There are also several new, large reactors under construction or being planned such as those in Australia, Canada, China, France, Germany, and Thailand. It is felt that the utilization of these reactors can be enhanced by international co-operation to achieve common goals in research and applications.

Current IAEA activities

In order for new proposals and plans to be put into context, it is important to know what the IAEA is currently doing to facilitate international collaboration and co-operation among research reactor owners and operators. Therefore, current work is listed below with some brief notes.

- *IAEA-wide strategic plan for research reactors.* The development of an IAEA-wide strategic plan for research reactor activities is in the program for 2001, starting with an advisory group meeting (AGM).

- *Strategic utilization plans for each research reactor facility.* Each research reactor is being encouraged to develop a facility strategic plan for sustainable utilization. One regional workshop has been held on such plans, with an AGM on the topic scheduled for September 2000. The existence of an active plan may become a prerequisite for IAEA utilization assistance in the future. International collaboration will need to be part of the plan, if appropriate for a specific facility.

- *Increased Research Reactor Database (RRDB) availability and usefulness.* Since July 1999 the RRDB has been accessible via the Internet. The utilization data is being greatly expanded with the current questionnaire. Both of these facilitate the sharing of knowledge about who is doing what, which in turn makes communication and co-operation possible.

- *Availability of regional and world research reactor list servers.* The IAEA has just in the past month developed such list servers. There are currently about 600 subscribers to the list servers and they are beginning to be actively used for communication between research reactor operators, owners and users. Such a tool greatly facilitates international collaboration.

- *Common research reactor calendar.* A common calendar of events is now available and is being maintained as a service to Member States to further assist in international co-operation. It provides a single source of all known meetings relating to research reactors.

- *Experts meeting on sharing of resources.* This regional meeting is already on the schedule for March 2001. It is specifically on the topic of international collaboration between research reactors in the Asia and Pacific region.

- *International research reactor symposia.* The most recent symposium on research reactor utilization, safety and management was held in September 1999 and the CD-ROM of proceedings is expected early in 2000. Such meetings are convened every few years by the IAEA specifically for the purpose of international communication and co-operation.

- *Topical technical committee meetings (TCM).* These are held routinely with the same aims as the broad symposia, but focused on a specific topic. The last TCM was in June 1999 on the current status of boron neutron capture therapy (BNCT). This was very well attended and contributed greatly to the transfer of knowledge from those facilities currently involved and those wanting to start BNCT programmes.

- *Active participation in non-IAEA international research reactor meetings.* In the past year, IAEA staff members have made presentations at the Asian Symposium on Research Reactors (ASRR), the Organization of Test, Research, and Training Reactors (TRTR), and the International Group on Research Reactors (IGORR). Such participation ensures that there is a common message being communicated among all research reactor facilities.

New initiatives

Despite all of these activities, it is felt that international collaboration can be still further enhanced under the auspices of the IAEA. Part of the purpose of this meeting is to discuss how best this can be done. The advice of the participants is requested in this regard. Perhaps discussion of some of the following questions may help in providing direction to the IAEA.

- *In what regions, or for what topics is further collaboration desirable?*
- *Should the IAEA convene an international (as opposed to regional) TCM on sharing of research reactor resources?*
- *Should the IAEA attempt to 'broker' bi- and multi-lateral agreements with respect to research reactor utilization? If so, what are the legal issues of such an attempt?*
- *How can problematic issues relating to commercial reactor use and international co-operation be best resolved?*
- *How can the IAEA foster sustainable collaboration in ways which do not require significant additional funds?*

International R&D project on high performance LWR

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Abstract. The paper gives an outline of international collaboration which could facilitate the development of a high performance LWR, cooled by supercritical steam, having thermal efficiency of 44% as against 34% for the present generation LWRs.

Background

Light water reactors can make a significant and increasing contribution to future energy needs, and to greenhouse gas reduction, if they can compete economically with fossil alternatives, and if current plants continue to achieve a very high level of safety. LWR technology must continue to progress and develop to assure this economic competitiveness while meeting strict safety objectives.

Current LWRs achieve a thermal efficiency of about 34% by providing steam at temperatures in the 285–290°C range to steam turbines. There is a potential for LWRs to achieve improved economics and efficiency by operating thermodynamically in the supercritical regime, similar to current advanced fossil fired plants. In such a high performance LWR (HPLWR) concept, the water exits the reactor core as a high density steam without change of phase at a pressure above 22 MPa and temperatures above 370°C. Thermal efficiencies of 44% are projected with simplified plant design.

At present, 7 European partners [Forschungszentrum Karlsruhe (Germany), Commissariat a l'Energie Atomique (France), Technical Research Centre VTT (Finland), KFKI Atomic Energy Research Institute (Hungary), Siemens AG Power Generation (Germany), Electricite' de France (France), Paul Scherrer Institute (Switzerland)] and the University of Tokyo (Japan) are beginning a co-operative effort to assess the merit and economic feasibility of the HPLWR.

Objective and scope

The objective and scope of the *international R&D project on the HPLWR under the aegis of the IAEA* would be, sequentially, to:

- support the current international assessment of the merit and economic feasibility of the HPLWR being carried out by research centres, industry and a university.
- identify the key R&D needs [e.g. in fields such as high temperature materials, nuclear data, core physics, thermal-hydraulics, reactor safety, …], and identify research institutes with capabilities for conducting the necessary R&D
- provide a forum for multi-year co-operative research (CRPs) on the identified R&D needs
- provide a forum for planning of an international project to design, license, construct and test a small scale prototype HPLWR.

International R&D project on development of coated particle fuel for innovative reactors

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Abstract. The paper presents an outline for an international collaborative project of coated particle fuel development for innovative reactors. Specific issues include identification of R&D needs and the Member State facilities for meeting the needs followed by development and demonstration of technology.

Background

Considerable experience has been accumulated over the past half century in the production and testing of coated particle fuel material, mainly with regard to high temperature gas cooled reactor technology development. While full core operating experience with coated particle fuels has been limited to HTGRs, small scale testing and studies related to application of coated particle fuels in other reactors has also been conducted. Most of the coated particle experience has been with pyrocarbon and silicon carbide coatings, but other materials have also been investigated on a smaller scale. The production of large quantities of high quality coated particle fuel, capable of retaining fission products over a wide range operating and accident conditions, as well as for disposal of spent fuel, has been conclusively demonstrated for particles with combined pyrocarbon and silicon carbide coatings (referred to as a TRISO particle). While coated particle fuel is an integral element of HTGR technology, there is potential application of the concept for other technologies, especially given the possibility of use of a broader range of coating materials.

Development of coated particle fuel requires the integration of a number of technological capabilities, including:

- Fuel kernel production — Sol-gel and other processes used to economically produce small spherical particles of fuel material require detailed knowledge of materials, process chemistry and engineering
- Coating — Fluidised bed particle coating requires knowledge of potential coating materials, carrier gases, active gases, nozzle and coater geometries, optimum temperatures, flow rates, etc.
- Supporting processes — Heat treatment, rejection of defects, product sampling, inspection methods, and other supporting processes are necessary for attaining high product quality
- Irradiation testing — irradiation testing for both normal operation and power transient simulation is necessary as an integral part of process development to improve product performance and to demonstrate attained product integrity
- Post-irradiation testing — Post-irradiation testing (e.g. temperature transients) provides additional data for process improvement and product integrity demonstration
- Post-irradiation examination — Provides additional understanding of failure mechanisms and detailed information on the condition of the fuel particles after service

Objective and scope

The initial objectives would be to:

- Develop an inventory of existing facilities within participating nuclear research centres capable of performing technology development in the areas listed above
- Identify additional new facility and capability needs, and practical interfaces among elements of process development and demonstration
- Establish a co-operative project utilising existing and new facilities among participating nuclear research centres, with clearly identified roles, responsibilities and interfaces.

The scope would include all of the technological capabilities necessary to develop proven new materials and advanced coated particle fuels for use in a range of innovative reactor designs.

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