CHOOSING THE NUCLEAR POWER OPTION: FACTORS TO BE CONSIDERED

CHOOSING THE NUCLEAR POWER OPTION: FACTORS TO BE CONSIDERED

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
BANGLADESH
BELARUS
BELGIUM
BOLIVIA
BOSNIA AND HERZEGOVINA
BRAZIL
BULGARIA
CAMBODIA
CAMEROON
CANADA
CHILE
CHINA
COLOMBIA
COSTA RICA
COTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
LATVIA
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Printed by the IAEA in Austria
January 1998
STI/PUB/1050

CHOOSING
THE NUCLEAR POWER OPTION:
FACTORS TO BE CONSIDERED

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1998

VIC Library Cataloguing in Publication Data

Choosing the nuclear power option : factors to be considered. — Vienna : International Atomic Energy Agency, 1998.

p. ; 24 cm.

STI/PUB/1050

ISBN 92–0–104197–7

Includes bibliographical references.

1. Nuclear energy—Government policy. 2. Nuclear power plants—Safety measures. 3. Nuclear energy—Law and legislation. 4. Radioactive waste disposal. I. International Atomic Energy Agency.

VICL 97–00179

Foreword

Projections of world electricity consumption indicate a need for a significant expansion of the present generating capacity. In view of the importance of saving energy and improving the efficiency of its use, it is considered that nuclear power will emerge as a compelling option with a significant role to play in meeting the future world electricity demand.

The activities of the IAEA in the field of nuclear power and its fuel cycle are being defined by the need to respond to new challenges for nuclear power development. Increasing global energy requirements coupled with environmental concerns arising from a large scale expansion in the use of fossil fuel resources as well as their rapid depletion are factors likely to influence future energy policies in IAEA Member States.

A need was expressed by Member States for guidance on policy issues to be addressed by decision makers considering the introduction of nuclear power programmes. This publication has been prepared by the IAEA, on the basis of past experience with nuclear power programmes in Member States and the current realities of the world nuclear regime, to provide information on political, governmental, economic, financial, technical and safety issues associated with planning and implementing a nuclear power programme. It highlights the main areas in which policies must be developed as well as the roles and responsibilities of the government, the plant owner and the national industry. For those interested in examining some of the issues in more depth, a list of related IAEA publications is provided in the bibliography. It is hoped that this guide will serve a useful purpose in assisting decision makers and governments in Member States considering the introduction of nuclear power programmes.

The technical information and relevant source material for this publication were provided by staff members of the IAEA and reviewed by a group of senior experts. Appreciation is expressed to all those who participated in the preparation of the guide for their valuable contributions and also to Member States for their generous support in providing experts to assist the IAEA in this work.

Particular mention should be made of the IAEA's Robert Skjöldebrand, a major contributor to the preparation of this publication, who on 6 February 1996 unexpectedly passed away in Wollongong, Australia, at the age of 65.

The IAEA officers responsible for the accomplishment of this work were A.D. Boothroyd and B. Gueorguiev of the Division of Nuclear Power. Gratitude is also expressed to K.V. Mahadeva Rao and S. Flitton for their overall review of the text.

Contents

1. Introduction

"We are ready to cooperate among ourselves so that the use of nuclear energy is conducted all over the world consistently with fundamental principles of nuclear safety. Further, we are committed to measures which will enable nuclear power, already a significant contributor to electricity supply in those countries choosing to exploit it, to continue in the next century to play an important role in meeting future world energy demand consistent with the goal of sustainable development agreed at the Rio Conference in 1992."
(Moscow Summit Declaration, 20 April 1996) [1]

The IAEA has published a large number of guides on the planning and development of nuclear power programmes, especially in developing countries. Until now, the policy[1] issues which have to be considered for a nuclear power programme have not been directly addressed together in one publication, partly because of the connection seen with national political questions. However, while it is clear that policy decisions will be influenced by political considerations, nevertheless it is possible to discuss the policy issues without prejudging the political aspects which will be important in decision making.

In planning and developing a nuclear power programme, policies will have to be formulated and decided at different stages and at different levels by the government and its organizations, by the utility and by other organizations in industry, research and education, each within its sphere of interest and influence. It is the purpose of this guide to highlight areas where policy decisions will be needed, the options which are available, what they mean and the contexts in which they should be considered. The publication is thus aimed not only at decision makers but also at those individuals in different organizations who help to prepare policy decisions. There will be many who will have no technical knowledge of nuclear power and some technical issues will therefore be explained in simple terms. The background discussion in Section 2 is not likely to include any new information for nuclear power specialists but is intended for non-experts who must be aware of the facts, uncertainties and options available in preparing and taking policy decisions.

The approach taken is to discuss policy issues which should be considered in establishing a nuclear power programme. This should be particularly helpful for countries proposing to introduce a nuclear power programme and, at the same time, should be useful for countries with established programmes when reviewing their

[1] The word 'policy' is here used in the sense given in The Concise Oxford Dictionary (9th edn, 1995): "a course or principle of action adopted or proposed by a government, party, business, or individual etc." The word is often translated into the equivalent of 'politics' but, as an example, the French expression 'ligne de conduite' would be closer to the sense of the English word as used in this publication.

policy framework. This guide does not discuss whether a country should or should not launch a nuclear power programme, but focuses on the issues of a policy nature which must be considered in choosing the nuclear power option.

The primary use of nuclear power is now for electricity production. As with any heat source it can also have other uses, such as district heating or desalination, but this guide chiefly considers its use to generate electricity, especially as electricity supply is seen as a critical factor for a country in meeting development targets, in particular for the industrial sector. The same considerations would in most cases apply in similar ways to other applications of nuclear power plants.

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

When deciding on the expansion of the electricity generating system, the government and the utility would have to carry out comprehensive assessments of all the options available. The reasons for choosing a specific option will differ from country to country, depending on local and regional energy resources, technological capabilities, availability of finance and qualified personnel, environmental considerations and the country's overall energy policy.

It will be assumed here that in a country which is considering the nuclear option there exists a plan for the whole energy system and, in particular, the electricity supply system, based on an overall optimization, that includes not only a supply mix of different energy sources (such as coal, oil, gas and hydropower) but also possibilities for conservation and efficiency improvements. The planning process should be based on economic optimization over a period of at least two decades.

A government and its authorities considering the introduction of a nuclear power programme will know about the assistance that the IAEA can provide through its Technical Co-operation Programme in helping to shape policy and make policy decisions credible to a broader public as well as internationally. This the IAEA can do mainly by providing:

- Specialized training;
- Planning tools which are widely acknowledged and approved by lending banks;
- Expert services to review the basis for policy decisions and help in formulating the laws and regulations which could result from these decisions;
- Expert teams to review the functioning of, for example, regulatory bodies, the adequacy of the regulations and standards and how they are being applied, and the general level of safety achieved.

When formulating a policy for a nuclear power programme, a number of issues must be addressed. These include:

— The economic competitiveness of the programme and how the programme is to be financed;
— The safety aspects to be considered in the licensing of the plant and the development of a safety culture;
— The need for trained personnel and how the training is to be provided;
— The need to gain public and political acceptance, which requires that attention be paid to such matters as the management of severe accidents, spent fuel management, waste disposal, decommissioning and non-proliferation of nuclear weapons.

Nuclear power plants are capital intensive and have a long operating life. A nuclear power programme should thus be viewed within a medium to long term electricity supply strategy (i.e. over two to three decades). In this respect the current trend in many countries towards basing nuclear power construction on private sector finance, with its emphasis on short term returns on investment, means that governments may need to play a significant role in ensuring that national longer term strategic objectives are met.

2. Nuclear Power: Status and Prospects

2.1. STATUS OF NUCLEAR POWER

Well designed, constructed and operated nuclear power plants have proved to be a reliable, environmentally acceptable and safe source of electrical energy. In 1996, 442 nuclear power reactors[2] operating in over thirty countries provided about 17% of the world's electricity (Fig. 1) and the total operating experience amounted to about 8135 reactor-years [2]. Of those countries with operating nuclear power plants, about half depended on these plants for 25% or more of their electricity production (Fig. 1 and Table I). There were 36 power reactors under construction in 14 countries, one of which was constructing its first nuclear power plant. According to statistics of the IAEA and of the World Energy Council (WEC), over the past 10–15 years nuclear power plants in operation have shown steadily improving performance levels and demonstrated their economic competitiveness with alternative generating sources.

[2] A power reactor with its generating equipment is called a 'unit'. Several such units may be located on the same site to form a nuclear power 'plant'.

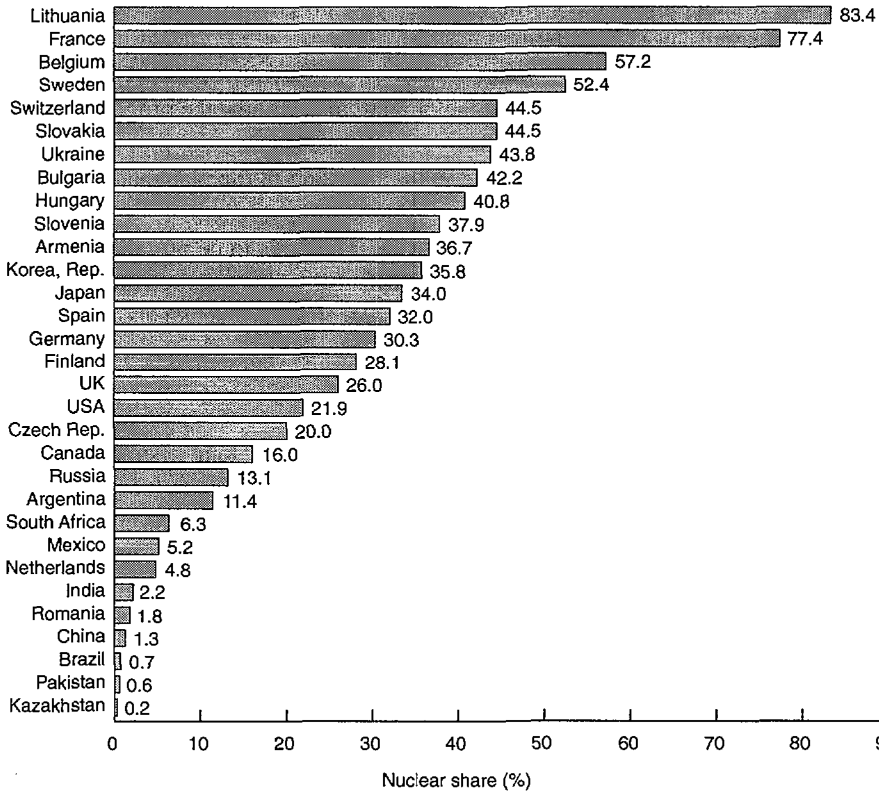

FIG. 1. Nuclear share of electricity production in 1996. In Taiwan, China, 29.07% of the total electricity was supplied by nuclear power.

The safety of nuclear power generation has been enhanced, both through improved designs in newer reactors and through improvements in operating reactors, as shown by reviews and statistics of national and international organizations, including the Institute of Nuclear Power Operations (INPO) in the United States of America, the World Association of Nuclear Operators (WANO), the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA). There have been two major accidents: at Three Mile Island Unit 2 in the USA in 1979 and at Chernobyl Unit 4 in the former USSR in 1986. The Chernobyl accident resulted in widespread contamination. Otherwise there have been few incidents involving releases of radioactivity from operating reactors and the amount released in each event was sufficiently low that there were no public health effects.

TABLE I. NUCLEAR POWER REACTORS IN OPERATION AND UNDER CONSTRUCTION (31 DECEMBER 1996)

	Reactors in operation		Reactors under construction		Nuclear electricity supplied in 1996		Total operating experience to 31 Dec. 1996	
	Number of units	Total MW(e)	Number of units	Total MW(e)	TW(e)·h	Percentage of total	Years	Months
Argentina	2	935	1	692	6.92	11.43	36	7
Armenia	1	376			2.10	36.72	29	4
Belgium	7	5 712			41.40	57.18	142	7
Brazil	1	626	1	1 245	2.29	0.74	14	9
Bulgaria	6	3 538			18.08	42.24	89	1
Canada	21	14 902			87.52	15.97	369	9
China	3	2 167	2	1 200	13.62	1.27	11	5
Czech Rep.	4	1 648	2	1 824	12.85	20.00	42	8
Finland	4	2 355			18.68	28.13	71	4
France	57	59 948	3	4 355	378.20	77.36	935	3
Germany	20	22 282			152.80	30.29	530	7
Hungary	4	1 729			14.18	40.76	46	2
India	10	1 695	4	808	7.42	2.21	139	1
Iran, Islam. Rep.			2	2 146			0	0
Japan	53	42 369	2	2 111	298.20	33.99	756	1
Kazakhstan	1	70			0.09	0.15	23	6
Korea, Rep.	11	9 120	5	3 870	70.33	35.77	111	10
Lithuania	2	2 370			12.67	83.44	22	6
Mexico	2	1 308			7.88	5.19	9	11
Netherlands	2	504			3.90	4.79	51	9
Pakistan	1	125	1	300	0.31	0.56	25	3
Romania	1	650	1	650	0.91	1.75	0	6
Russia	29	19 843	4	3 375	108.82	13.10	555	6
Slovakia	4	1 632	4	1 552	11.26	44.53	65	5
Slovenia	1	632			4.36	37.87	15	3
South Africa	2	1 842			11.76	6.33	24	3
Spain	9	7 207			53.80	31.97	156	2
Sweden	12	10 040			71.40	52.38	231	2
Switzerland	5	3 077			23.72	44.45	108	10
Ukraine	16	13 765	4	3 800	79.58	43.76	190	2
UK	35	12 928			85.90	26.04	1 098	4
USA	110	100 685			674.78	21.92	2 138	7
Total	442	350 964	36	27 928	2 312.06		8 135	8

Note: The totals include data for Taiwan, China, where at the end of 1996 there were six units with a total capacity of 4884 MW(e) in operation. The six units generated 36.33 TW(e)·h in 1996, representing 29.07% of the total electricity generated there. A total operating experience of 92 years 1 month had been gained.

The majority of the operating nuclear power reactors are light water reactors (LWRs), in which the light water acts as both coolant (by removing the heat from the reactor core) and moderator (by reducing the energy of the fast neutrons produced in the fission reaction). LWRs use either pressurized water (PWRs), of which there were 253 units in operation at the end of 1996, including 47 PWRs of Soviet design (WWERs), or boiling water (BWRs: 94 units in operation). By far the most operating experience has been accumulated with LWRs (5405 reactor-years). There were also 34 pressurized heavy water reactors (PHWRs) in operation at the end of 1996.

The majority of the plants under construction are large LWRs (24 units at the end of 1996) with a generating capacity of about 1000 MW(e). The next largest type is the PHWR, of which there are nine units being built: five are in the 600–700 MW(e) range and four units in India are each 220 MW(e) in size.

Large nuclear power plants are available from well known suppliers in Canada, France, Germany, Japan, Russia, Sweden, the United Kingdom and the USA. Standardized designs which could be built on a wide variety of sites are available. The suppliers can generally refer to a long experience of providing high quality and up to date technology with a high level of reliability. China is supplying a 300 MW(e) plant for export. The Republic of Korea is also in a position to supply plants for export. Because new orders have been rare or non-existent in western industrialized countries, several suppliers in those countries have had to cut back design and construction capabilities and to specialize more in providing support to existing plant operation and maintenance. New plant suppliers are likely to appear in the next five to ten years in developing countries which have growing domestic orders and also have accumulated experience. A new supply situation may thus develop which will call for careful consideration of potential suppliers when any new nuclear power programme is started.

Most of the current plants are in a capacity range which is relatively large for many developing countries but there is interest among some of the plant manufacturers in performing research and development work on small and medium power reactors (SMPRs) below 600 MW(e), which could be better suited not only to situations in developing countries but also to meeting generally lower rates of increase in electricity demand. Some new designs are emerging both for SMPRs and for large reactor sizes. They all draw upon proven systems and equipment which are performing well in currently operating plants.

2.2. PROSPECTS FOR NUCLEAR POWER

In the countries of North America and western Europe, the capacity to generate electricity is generally adequate to meet current and foreseeable demand at least until 2000, as a result of past investment in power plants, a tendency towards saturation in the use of electricity and low population growth. Construction of nuclear and coal fired power plants is generally at a standstill, but there has been increased investment in gas generation in some of these countries. When new generating capacity is needed in these countries, nuclear power will be an option for meeting this demand. To use the option will, however, require that there be sufficient public knowledge and public and political acceptance of the following:

- —The need for more generating capacity and the benefits that electricity can bring;
- —The continued economic viability of nuclear power, which should improve if all environmental protection costs are charged to all electricity generating plants;
- —The safety of nuclear power plants, which is being improved so that no more serious accidents should occur, with new plants being designed and built to meet stricter and easily understandable safety criteria;
- —The existence of acceptable solutions for management and disposal of radioactive wastes;
- —The environmental benefits of nuclear power;
- —Legal liability issues, on which international agreement is required;
- —The non-proliferation regime, which can provide assurances on the peaceful use of nuclear materials.

Most of these issues concern policy to some extent, but it is symptomatic of the current situation that governments in many countries do not feel any obligation to proceed quickly on these matters when there is no urgent need to order new plants.

Russia and eastern European countries are now generally confirming their need for and commitment to nuclear power but are severely constrained by lack of financial resources not only for expanding their nuclear power programmes but also for improving the safety of existing plants. The Pacific Rim region of East and Southeast Asia, on the other hand, is experiencing rapid economic growth and needs large scale additions to generating capacities. There are large and rapidly expanding nuclear power programmes in Japan and the Republic of Korea. China has launched a programme which is expected to expand rapidly and Indonesia is considering the nuclear option. In southern Asia, India has a significant programme, but constraints on domestic production due to a paucity of financial resources and weaknesses in the national electric grid system infrastructure limit its growth rate. Other developing countries have small programmes with up to three nuclear power reactors and uncertain or no plans for future expansion. These include Argentina, Brazil, Cuba, the Islamic Republic of Iran, Mexico, Pakistan and South Africa.

In 1996 the IAEA published [3] projections for the development of nuclear power up to 2015 based on low and high estimates of nuclear generating capacity. In the low estimates, the current barriers to nuclear power development were assumed to prevail in most countries during the next two decades:

— Low economic and electricity demand growth rates in OECD countries;
— Public opposition to nuclear power, leading to policy decisions not to consider the nuclear option in spite of its competitive costs and potential contribution to reducing environmental impacts from electricity generation;
— Institutional and financing issues preventing the implementation of previously planned nuclear programmes, in particular in countries in transition and in developing countries;
— Inadequate mechanisms for nuclear technology transfer and nuclear project funding in developing countries.

The high estimates reflected a moderate revival of nuclear power development that could result in particular from a more comprehensive comparative assessment of the different options for electricity generation, integrating economic, social, health and environmental aspects. They were based on a review of national nuclear power programmes, including an assessment of technical and economic feasibility. It was assumed that some policy measures would be taken to facilitate the implementation of these programmes, such as strengthening of international co-operation, enhanced technology adaptation and transfer, and establishment of innovative funding mechanisms.

The 'high case' showed an increase in capacity of almost 50% over 1995, most of it occurring in East Asia (Fig. 2(a)). The 'low case' showed a stabilization of the installed capacity, the increase in the Pacific Rim countries being balanced by retirement of plants in North America and western Europe (Fig. 2(b)). Thus in both cases no rapid expansion of world nuclear power capacity is expected in the next ten years. The development of nuclear power after 2015 will depend on its economic competitiveness and on public and political acceptance of the nuclear power option, including increased recognition of its environmental benefits.

2.3. SPECIAL CHARACTERISTICS OF NUCLEAR POWER PLANTS

In nuclear power plants the primary energy form is heat from the fission of atoms of uranium-235 (^{235}U). The heat is used to produce steam under high pressure and the steam drives a turbine generator, which generates electricity. The plant is connected to the national electric power generation and distribution systems.

In the operation of a nuclear power plant, fission in the fuel elements will result in the creation of radioactive products. Moreover, materials in the reactor core and the coolant are bombarded by neutrons released during fission and nuclei which absorb neutrons will become radioactive. It is therefore necessary to take measures to contain the radioactivity to prevent it from causing harm either to the operating staff or to the public. Radioactive fission products in the fuel elements also give off heat, and even after it has been shut down a nuclear power reactor has to be cooled continuously, although at a much lower rate than when it was in operation.

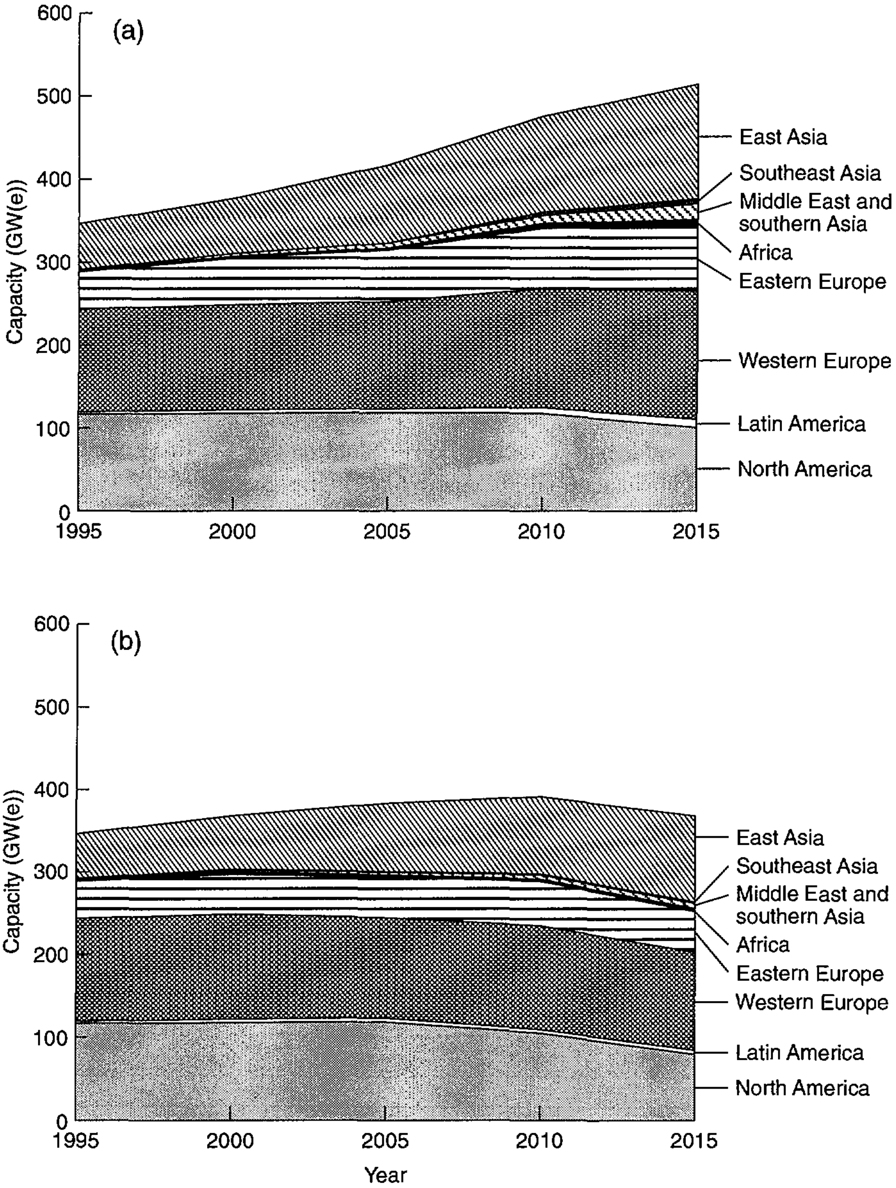

FIG. 2. IAEA projections for the development of nuclear power up to the year 2015: (a) high case, (b) low case [3].

Plutonium is created in the fuel elements during reactor operation. Some of it will be consumed in the fission process and provide a significant contribution to the energy produced by the fuel. The rest of the plutonium will remain with the uranium and fission products in the spent fuel. Natural uranium and low enriched uranium, the fuel materials used for PHWRs and LWRs, respectively, cannot be made into weapons, but plutonium can. The plutonium from spent nuclear power reactor fuel is, for technical reasons, not a very desirable material for making weapons, but it is important to ensure that all of it is accounted for and properly safeguarded. Control of the production of nuclear materials that could be used for nuclear weapons, including the generation of plutonium, is one of the main reasons for the non-proliferation regime that now covers the international transfer of nuclear technology, equipment and materials (Section 7.3).

Nuclear power plants have high initial investment costs but low fuel costs. In this respect they resemble hydropower plants, which often are very capital intensive. Fossil fuelled power plants can have lower construction costs. A coal fired power plant is cheaper to build than a nuclear power plant, and a gas fired plant can be cheaper in some circumstances, but they both have higher fuel costs.

2.4. ECONOMICS OF NUCLEAR POWER

As mentioned above, nuclear power plants have high initial investment costs but low fuel costs. A nuclear power plant unit with 1000 MW(e) capacity will cost of

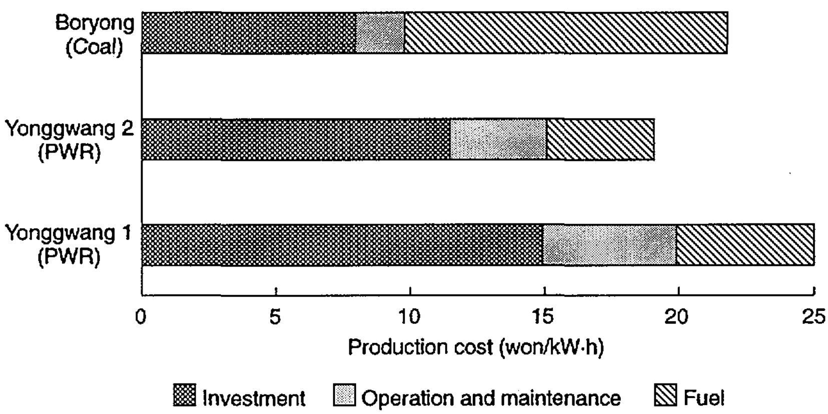

FIG. 3. Comparison of production costs for recent coal fired and nuclear power plants in the Republic of Korea (US $1 = 1051 won as of 23 November 1997).

the order of US $2000 million to build, or about twice the amount for a coal fired plant without flue gas cleaning (to remove sulphur dioxide and nitrogen oxides). Figure 3 gives a comparison of production costs per kilowatt-hour for recent coal fired and nuclear power plants in the Republic of Korea. It shows the importance of the capital cost but also the advantage of constructing a second, standardized unit at the same site. The figure also demonstrates that it is important for operation and maintenance costs, which have shown an increasing trend in recent years, for example in the USA, to be kept low. With recent developments in many countries to introduce competition into electricity markets, the costs of fuel and of operation and maintenance for nuclear power plants will have to be kept lower than the corresponding costs for fossil fuelled plants to remain competitive without jeopardizing plant safety in any way.

Because of the importance of capital costs in nuclear power, the financing of a nuclear power programme is sensitive to inflation. Financing schemes and the related issue of supply contracts are therefore essential considerations. Three types of supply contract have been commonly used in the past: turnkey, split package and multiple package. In recent years, two new supply mechanisms have been used for fossil fuelled power plants: build–own–operate (BOO) and build–operate–transfer (BOT). All these supply contract options are dealt with in Section 8.8.

In the overall context, there are economic benefits from a nuclear power programme that go beyond the mere comparison of electricity costs between alternatives. The potential benefits of nuclear power include a certain buffering against escalating fossil fuel prices, which therefore helps to maintain the long term stability of electricity prices. An important consideration in many developing countries has been the influence of a national nuclear power programme in increasing the technological level of the country and enhancing the global competitiveness of the domestic industry. The participation of the domestic industry could help to speed up a nuclear power programme. On the other hand, certain additional costs are directly related to the introduction of nuclear power in a country, such as the cost of establishing a regulatory infrastructure. It would be desirable if these costs could be distributed over a number of plants. All these considerations lead to the conclusion that it is necessary to plan a nuclear power programme which is large enough to enable costs to be spread in order to yield potential benefits.

3. Nuclear Safety and Radiation Protection

3.1. NUCLEAR SAFETY

A nuclear power plant is allowed to operate if and only if adequate measures to prevent accidents are in place. Nevertheless, if an accident does occur, it is necessary to be able to manage the accident to limit its escalation and, at the same time, to

Box 1

PUBLICATIONS OF THE IAEA NUCLEAR SAFETY STANDARDS (NUSS) PROGRAMME

The Safety of Nuclear Installations (Safety Fundamentals) [4]

Code on the Safety of Nuclear Power Plants: Governmental Organization [5]
(with 7 Safety Guides)

Code on the Safety of Nuclear Power Plants: Siting [6]
(with 12 Safety Guides)

Code on the Safety of Nuclear Power Plants: Design [7]
(with 15 Safety Guides)

Code on the Safety of Nuclear Power Plants: Operation [8]
(with 12 Safety Guides)

Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations [9]
(Code with 14 Safety Guides)

mitigate the consequences, particularly with regard to the release of radioactive materials, so as to reduce the potential exposure of the public and of plant personnel. Therefore the low probability of accidents with potentially severe consequences has to be demonstrated through safety assessments, safety research, sound design with suitable materials, high quality construction, good operating practices and procedures, proper staff selection and training, etc. Appropriate reviews and assessments have to be carried out by the regulatory body. If the demonstration fails, then plant operation will not be licensed or the operating licence will be withdrawn. Because of this there is a need for a nuclear safety culture (Section 3.1.3) to be established in all countries which operate nuclear power plants and to be codified in laws, regulations and standards for nuclear safety. Many IAEA Member States have already shown their commitment to this idea by consenting to be bound by the Convention on Nuclear Safety, which entered into force in October 1996.

To provide support at the international level, the IAEA has published fundamental safety concepts as well as Codes and Safety Guides as part of its Nuclear Safety Standards (NUSS) programme (Box 1). There are thus clear rules for defining responsibilities and technical measures to attain high levels of safety. It is of basic importance that only one organization, the owner/operator, has primary responsibility for the safety of a plant. As a prerequisite for obtaining an operating licence the owner/operator has to accept this responsibility, which cannot be shared either with the plant designer or constructor or with the authority which regulates safety in the country (Section 7.1.1).

3.1.1. Defence in Depth

For all technical safety measures there is a general strategy of 'defence in depth'. This means that if anything goes wrong there is always a backup to protect against the consequences of an accident. A publication of the International Nuclear Safety Advisory Group (INSAG) entitled *Basic Safety Principles for Nuclear Power Plants* [10] discusses the need for a defence in depth concept centred on several levels of protection, including successive barriers to prevent the release of radioactive materials to the environment. The objectives are:

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

INSAG has further developed the requirements for a defence in depth strategy in a more recent publication [11]. In this strategy, accident prevention is the first priority. However, if preventive measures fail, mitigation measures, in particular the use of a well designed confinement system, have the potential to provide additional protection of the public and the environment. A containment building, which remains leaktight even with high pressure inside, is an essential barrier to contain radioactivity released from a reactor in an accident.

Defence in depth is generally structured in five levels (Box 2). Should one level of protection fail, the subsequent level comes into play. The objective of the first level of protection is the prevention of abnormal operation and system failures. If the first level of protection fails, abnormal operation is controlled or failures are detected by the second level of protection. Should the second level fail, the third level ensures that safety functions are further performed by activating specific safety systems and other safety features. Should the third level fail, the fourth level prevents accident progression through the containment so as to prevent or mitigate severe accident conditions with external releases of radioactive materials. The last objective (fifth level of protection) is the mitigation, by the off-site emergency response, of the radiological consequences of significant external releases.

Box 2

LEVELS OF DEFENCE IN DEPTH

Level 1: Prevention of abnormal operation and system failures

Essential: Conservative design and high quality in construction and operation, including in particular well trained operators.

Level 2: Control of abnormal operation and system failures

Essential: Control, limiting and protection systems and other surveillance features.

Level 3: Control of accidents within the design basis

Essential: Engineered safety features and accident procedures.

Level 4: Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents

Essential: Containment building, complementary measures and on-site accident management procedures.

Level 5: Mitigation of radiological consequences of significant releases of radioactive materials

Essential: Off-site emergency response procedures, such as evacuation plans.

For the confinement of radioactive materials from an accident at level 4, the containment building is of greatest importance. This building withstands pressure and has strict design specifications. There are several measures to further protect the containment building, such as cooling systems, hydrogen catalytic burners to prevent hydrogen explosions, and internal barriers to stop any object accidentally thrown out from rotating equipment or an explosion. The confinement at level 4 should protect against accidents even more severe than the design basis accidents, i.e. those accommodated by the design of the plant. INSAG foresees that, for new power reactors, the containment function should be further strengthened to ensure the confinement of radioactive materials under all circumstances. This would mean that off-site emergency measures, including evacuation, would hardly be needed, but INSAG considers that they should nonetheless be maintained.

3.1.2. Quality Assurance

The importance of achieving the highest levels of quality in all stages of a nuclear power project, from site selection through design, construction and commissioning of the plant to operation and decommissioning, is indicated by the fact that quality assurance (QA) is one of the five main topics of the Codes and Safety Guides issued in the IAEA's NUSS programme (Box 1). Quality assurance is defined as: "all those planned and systematic actions necessary to provide adequate confidence that an item or service will satisfy given requirements for quality" [9].

The recently revised NUSS Code and Safety Guides on QA [9] put greater emphasis on the essential responsibility of everyone concerned to achieve their performance objectives. The QA programme will then be effective when the managers, those performing the work and those assessing the work all contribute to quality in a concerted and cost effective manner. These concepts can be summarized in the following three levels of responsibility:

(1) Management is responsible and accountable for all aspects of quality of performance, including planning, organization, direction, control and support.
(2) The line unit is responsible and accountable for achieving quality of performance so as to ensure safety and reliability.
(3) The assessment unit evaluates the effectiveness of the management and line units in carrying out their responsibilities to achieve quality of performance, and identifies and ensures removal of barriers which may hinder the ability of the plant organization to function effectively in carrying out its responsibilities.

The IAEA approach to QA expects quality of performance at the highest level and encompasses all managerial, working and assessing activities. The quality of performance concerns all areas in the nuclear project and therefore safety, reliability and economics are positively influenced. The overriding principle is that safety shall not be compromised for reasons of production or economics, or for any other reason.

3.1.3. Safety Culture

The QA approach has to be part of an all-embracing safety culture, a concept which can be described as inculcating in all personnel, from the plant management to the maintenance workers, a pervasive safety consciousness, a commitment to excellence and personal accountability [12]. Of course, it is fundamental that safety be paramount and have priority over energy production. A safety culture, governing the

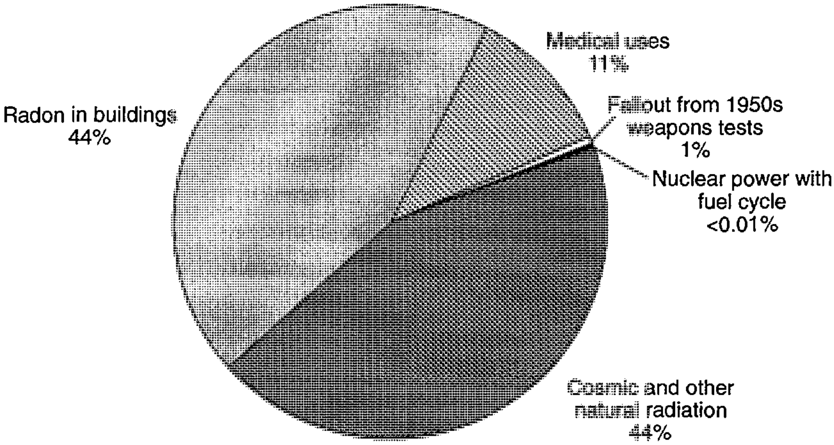

FIG. 4. Average non-occupational radiation doses to the world population.

actions of all individuals and organizations concerned and based on attitudes as well as on organizational structures, should be embedded in every nuclear power programme.

3.2. RADIATION PROTECTION

3.2.1. Health Effects of Radiation Exposure

Ionizing radiation and radioactive substances are natural and permanent features of the environment, and low level radiation is part of our surroundings. Figure 4 shows the average percentage exposure of the world population to all sources of radiation except those to which radiation workers are exposed. Exposure to radiation has an associated health risk but, as we are always exposed to radiation, this risk can only be constrained, not entirely eliminated. Through the use of nuclear reactors for power production as well as for research, the amounts of radioactive materials available for medical and industrial use, but also requiring control, have been greatly increased. Very strict radiation protection standards have been formulated and experience has shown that risks can be kept under control.

Radiation and its effects on health have been studied by expert bodies for over half a century and more is known today about risks from radiation than about those from practically any other physical or chemical agent in the environment. The effects of large doses of radiation on human health are well understood and such doses are clearly hazardous. There is a source of information about the effects of high radiation doses in the epidemiological studies that continue to be performed on the survivors of the atomic bombings of Hiroshima and Nagasaki in 1945. In addition, studies have been made or are being made on health effects in people exposed for medical purposes and in large numbers of radiation workers who have received known doses.

Radiation exposure can induce 'deterministic' and 'stochastic' effects on human health. Deterministic effects, such as nausea, reddening of the skin or more acute syndromes, will occur if the dose exceeds a threshold level. They will be evident within days after the exposure. Stochastic effects are those for which the magnitude of the effect is not related to the dose but the probability of its induction is taken to be proportional to the additional dose, i.e. the amount by which the dose exceeds that due to the natural background radiation. The major stochastic effect is the induction of cancer, which, as shown by the Hiroshima and Nagasaki survivors, can occur a long time (5–50 years) after the exposure. It is assumed that this can occur independent of the actual dose level, i.e. the likelihood of one cancer occurring is the same whether 1000 persons each receive one dose unit or 100 people each receive 10 units. It is further assumed that there is no threshold for this stochastic effect, i.e. there is no dose level, however low, which does not have the possibility of inducing a stochastic effect. This is called the 'linear hypothesis'. The assumption is used as a conservative basis for setting radiation protection norms.

3.2.2. Radiation Protection Standards

The International Commission on Radiological Protection (ICRP) has, since 1929, worked on the establishment of scientific principles for radiation protection. The basic recommendations of the ICRP are kept under continuous review to take into account all information which becomes available. The stochastic effects, i.e. the risk of cancer induction, determine the protection norms for occupational exposure as well as exposure of the public. The ICRP in 1990 issued new recommendations, based on the most recent re-evaluation of the doses to the atomic bomb survivors, corresponding to a reduction of earlier recommended dose limits. The *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (BSS), issued by the IAEA in co-operation with the Food and Agriculture Organization of the United Nations (FAO), the International Labour Organisation (ILO), the OECD/NEA, the Pan American Health Organization (PAHO) and the World Health Organization (WHO), constitute a translation of the ICRP recommendations into practical standards of radiation protection for the public and radiation workers. The BSS have been updated several times in response to changed ICRP recommendations, most recently in 1996 [13]. The severity of these standards is indicated by the fact that the limits for additional doses to the general public now fall within the rather large range of levels of natural background radiation found in different parts of the world.

There are, of course, other agents which can cause cancers but in no other case do there exist protection standards which are scientifically as well founded and strict as for ionizing radiation. For these agents it is normal for a threshold level to be assumed, i.e. a particular concentration in air, water, etc., below which there is no detrimental effect.

It is virtually certain that some radiation exposures will result from the operation of nuclear installations and that their magnitudes will be predictable, albeit with some degree of uncertainty; such exposures are termed 'normal exposures'. Normal exposures are controlled by restriction of the doses delivered. The primary means of controlling additional, unplanned exposures consist of good plant design, operating procedures and monitoring programmes, trained personnel and strong management. This control is verified by the independent regulatory authority.

Radiation exposures encompass the exposures of workers pursuing their occupations (occupational exposures) and those of members of the public who may be affected by the operation of a nuclear installation (public exposures). Experience from well managed nuclear power plants shows that occupational and public exposures have been kept to a fraction of the annual dose limits stipulated by safety standards.

4. Nuclear Fuel Cycle

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

4.1. FRONT END

The acquisition by a country of its first nuclear power plant will involve a major degree of dependence on external suppliers, with associated commitments to non-proliferation and international co-operation. The power plant is usually provided initially with fuel for one to four years of operation but it will have to be supplied with fuel over its lifetime of 40 or more years. The fundamental choice of fuel form is made when the type of power plant is decided upon:

- Heavy water moderated reactors (PHWRs) can be fuelled with natural uranium (which contains about 0.7% ^{235}U and 99.3% ^{238}U) and have a fairly simple fuel cycle.
- Light water moderated reactors (LWRs) require either low enriched uranium, containing about 3–4% ^{235}U, or a mixture of uranium and plutonium oxides (MOX).

A desire for assured fuel supplies over a reactor lifetime of 40 or more years will lead to consideration of whether a domestic fuel supply and fuel production technology should be established to guarantee the continued operation of the power plant at all times. With the exception of enrichment, the front end process technologies are available for transfer, usually on commercial terms through a licensing agreement. It is even possible to develop these technologies domestically but this would require a major effort in process development and testing of the product in a test reactor, particularly in the case of fuel fabrication.

Fuel fabrication for PHWRs is simpler than for LWRs so the technology may be easier to acquire at an early stage of a nuclear power programme. However, this should only be considered in terms of whether this particular technology transfer is desired, since LWR fuel is commercially available from so many suppliers that security of supply is not a real issue.

The counter-argument to establishment of domestic front end fuel cycle services is that it is hardly economical at present. It is normally cheaper and can be just as reliable to use the international market for fuel supplies.

Uranium has become so cheap that some uranium mines have had to close. Currently, the global production capacity is equivalent to only about half of the demand and power reactor owners have been drawing on inventories procured in the past. However, mining operations in several countries, including Australia, Canada and Namibia, could be expanded easily to meet demand if necessary. In addition, low enriched uranium, diluted from the high enriched uranium from disarmament operations, could become available on the market in the near future. Any prospective buyer with good non-proliferation standing would have no difficulty in obtaining supplies both on the spot market and under long term uranium supply contracts. Furthermore, as a result of these large scale industrial operations, prices are likely to be lower than could be obtained domestically by most countries.

The enrichment process is very complex and costly and is not available for transfer, nor can it be established domestically without major effort. Enrichment services are, however, normally available for any prospective buyer with good non-proliferation standing. Services for conversion of uranium to the chemical forms required for enrichment are also widely available and competitively priced. Thus, in all aspects of the front end of the fuel cycle, security of supply should not be a serious concern to policy makers if the country's non-proliferation standing is good.

In spite of the economic arguments against establishing front end fuel cycle services domestically, several countries have nevertheless taken a decision to do this. The reasons given have been that the nuclear power programme was growing to a sufficient size and that it was desirable to establish complete domestic capabilities in this sector.

4.2. BACK END

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

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

As regards spent fuel from LWRs there are different opinions on whether to reprocess or not. The uranium in the spent fuel has approximately the natural content of ^{235}U and there is about 1% plutonium. If reprocessed, the plutonium and uranium could, in other proportions, be used for fabrication of MOX fuel. Authorities in several countries consider that the 50% additional utilization of uranium which is obtained through the recycle of MOX fuel gives an additional energy independence and some have argued that this justifies reprocessing. The economic advantages of reprocessing and recycling are marginal at present but could be more clearly justified if uranium prices increased. Other considerations, such as the use of plutonium by burning it in reactors instead of disposing of it and the more suitable form of the remaining HLW, could encourage reprocessing.

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

Reprocessing technology is not available for transfer internationally even though details were first published in 1955. A large nuclear power programme of more than 30 000 MW(e) would be needed for economic justification of a commercial reprocessing plant. Fast breeder reactors (FBRs) would require reprocessing of the fuel but at present there is interest in breeder development in only three countries (France, Japan and Russia), the main problem being that an FBR has a higher capital cost than an LWR of the same size.

The reason why supplier countries do not agree to the transfer of enrichment or reprocessing technologies is that both technologies could lend themselves to production of materials (high enriched uranium and plutonium, respectively) that are directly usable for manufacturing nuclear weapons.

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

The objection often raised about the direct disposal option is that it is difficult to conceive that one would dispose of an energy resource (plutonium in the spent fuel) in an irretrievable manner, and that disposal sites could therefore become plutonium mines in the future. Because of the characteristics of reactor grade plutonium it is very unlikely that it would be retrieved for weapons grade plutonium and in any case spent fuel would be safeguarded indefinitely after disposal. In addition, the credibility of deciding on this option will depend on how much is done to prepare for the spent fuel disposal.

The third option, chosen by many countries, of deferring the back end decision is the cheapest as it would permit deferral of decisions on HLW disposal technology and siting. It could, however, provide an easy point of attack for opposition movements maintaining that there is a waste problem which has not been solved.

5. Management of Radioactive Waste and Decommissioning of Nuclear Facilities

5.1. WASTE MANAGEMENT AND DISPOSAL

Radioactive waste has become a focus of some environmental concerns in connection with nuclear power. The main feature of wastes from nuclear power plants is that they arise in small quantities, which therefore can be more easily managed and disposed of. Box 3 compares the annual amounts of wastes from nuclear and coal fired power plants for the same electricity production.

Another perspective on the small amounts of wastes produced by nuclear power plants is given by some data from France, where over 75% of all electricity is produced by nuclear reactors. The following amounts of waste products arise annually per capita:

- — 360 kg of domestic wastes;
- — 7300 kg of agricultural wastes;
- — 3000 kg of industrial wastes, of which 100 kg are toxic;
- — 1.4 kg of radioactive wastes, of which 20 g are highly radioactive and only 1 g is long lived, requiring special attention for that reason.

Box 3

ANNUAL OPERATIONAL WASTES FROM 1000 MW(e) PLANTS

LWR plant

Consumes 27 t of low enriched uranium fuel each year.

- 27 t of high level waste; if reprocessed, this gives 3 m^3 or 8 t of waste to be disposed of
- 300 t of intermediate level waste
- 450 t of low level waste

Coal fired plant with best available pollution abatement

Consumes 2.6 million tonnes (Mt) of coal each year.

- 6.5 Mt of CO_2
- 300 000 t of ash
- 20 000 t of SO_2
- 4000 t of NO_x
- 400 t of heavy metals, including mercury, cadmium, lead, arsenic and vanadium

Radioactive wastes are divided into three categories:

(a) Low level waste (LLW) arises from nuclear plants and from applications of radioisotopes in medicine, industry and research, and has to be kept isolated only for a limited period of up to about 200 years.

(b) Intermediate level waste (ILW) consists to a great extent of operational wastes from power plants, such as ion exchange resins, and can usually be treated and disposed of in the same general manner as LLW.

(c) High level waste (HLW) consists of the fission products and plutonium contained in spent fuel elements and has to be kept safely isolated from the environment for very long periods, possibly for hundreds of thousands of years. HLW also generates heat, which can be significant for the first 30–50 years.

Safe waste management involves the application of technology and resources to limit the exposure of the public and workers to ionizing radiation and to protect the environment from the release of radioactivity in accordance with national regulations and internationally agreed standards.

To meet these objectives, the following internationally agreed principles are to be applied [14]:

(1) Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
(2) Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
(3) Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
(4) Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
(5) Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
(6) Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
(7) Generation of radioactive waste shall be kept to the minimum practicable.
(8) Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
(9) The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

A key concept underlying these principles is the 'intergenerational argument', according to which the present generation, which benefits from nuclear electricity production, should not leave waste management problems or costs to future generations.

Further international progress was made in this area when the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management was adopted at a diplomatic conference held at the IAEA Headquarters on 5 September 1997 and opened for signature at the IAEA General Conference on 29 September (see Box 4, Section 10.3). As of 6 October 1997, 23 States had signed the agreement.

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

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

In many countries the different categories of waste can be stored at the plant itself for between five and ten years. Most industrialized countries with nuclear power plants have established special organizations for waste management and disposal to which utilities, hospitals, industries, etc., can send their wastes, usually on a charge basis. Some countries have even set up separate organizations for LLW and HLW. It is common for these organizations to be charged with planning waste management operations outside the waste producing institutions, notably the power plants, including intermediate storage, and performing all preparatory research and investigations for disposal, in addition to the actual waste management operations.

5.1.1. Low and Intermediate Level Wastes

Well before a country considers developing a nuclear power programme, it will have been using radioisotopes and radiation sources in medicine, industry and research and there should therefore be a system in place for management of LLW arising from these uses, involving regulations, approved practices, storage and possibly LLW disposal. Experience from countries which have LLW disposal tends to indicate that establishment of an LLW disposal operation at an early stage to some extent may ease the waste issue, but it has to be borne in mind that any waste disposal siting may involve much the same policy considerations as the siting of a power plant (Section 7.1.1).

Operational radioactive waste from nuclear power plants is often treated (to reduce its volume) and/or conditioned ('immobilized', i.e. converted to a mechanically stable and insoluble form, and then packaged) prior to its disposal. Liquid waste is usually concentrated before immobilization. The volume of solid waste can be reduced by compaction and/or incineration. This area of LLW and ILW management, having been established and proven over the past forty years, is considered to be mature in terms of technology development. As a result, several effective, safe and feasible treatment and conditioning options exist for these types of waste.

Well proven technology is now being used for the disposal of LLW and ILW from nuclear power plant operation. The most common methods for LLW and some ILW involve shallow land burial in concrete lined trenches or disposal in structures on the ground surface. Safe near surface disposal of LLW and ILW has been practised in a number of countries for about thirty years. The rationale behind near surface disposal is that the time for which this type of waste needs to be kept isolated is relatively short (from one hundred to a few hundred years), and thus it is likely that the institutional or administrative control of the disposal site can be ensured during that period. Countries are continuing to rely on a combination of near surface and subsurface facilities for disposal of LLW and ILW, but are placing increased reliance on the use of engineered barriers to isolate the wastes. Some countries, including Sweden, dispose of LLW and ILW at much greater depths either because of a lack of suitable near surface locations or for reasons of national policy.

5.1.2. High Level Waste

Methods for immobilizing HLW are also available. With regard to permanent disposal of HLW, there is broad agreement among scientific organizations around the world that deep geological disposal is a suitable method for permanently isolating radioactive waste from the environment. Much development work has been done to validate the technology and demonstrate feasibility in model facilities.

There are many geologically suitable sites available for repositories for permanent disposal of HLW. However, the issues of public acceptance are considerable. The safety of deep geological disposal is achieved by the use of multiple barriers, including the waste form itself, corrosion resistant canisters, backfilling and sealing materials placed in the excavations, and the geological medium in which the repository is built. Repositories are typically planned to be constructed at a depth of several hundred to one thousand metres in media such as granite or other crystalline rocks, bedded or domed salt formations, argillaceous deposits (e.g. clay or shale) or volcanic deposits (e.g. basalt or welded tuff). Several countries plan to operate deep geological repositories for disposal of their spent fuel and HLW in the next twenty to thirty years.

Not all countries with nuclear power programmes would necessarily have suitable geological formations for disposal of HLW. The problem could be more easily solved through international co-operative ventures for the back end of the fuel cycle, involving intermediate storage of spent fuel, possible reprocessing and MOX fabrication where desirable, and disposal of HLW. However, there is now a general international position that each country should take care of its own radioactive wastes and this will have to be taken into account.

There is currently no final repository for HLW in operation but the technology of multilayered natural and engineered barriers which can be used is well studied. Although there is no urgent need to begin HLW disposal it would be highly desirable if at least one government were to start disposal on a pilot scale to demonstrate confidence in the technical solutions which exist. Sweden plans to do this before 2005.

5.2. DECOMMISSIONING OF NUCLEAR FACILITIES

At the end of its useful life, a nuclear power plant has to be decommissioned. A useful life of 30 years is often referred to but nuclear power plants are usually designed for 40 years of operation. The lifetime could be extended beyond 40 years with suitable management programmes which included control of degradation processes, maintenance, repair and refurbishing and/or replacement of plant components and systems.

There are essentially two options for the process of decommissioning a nuclear power plant:

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

The first option has the benefit of making potentially valuable sites available for other purposes, notably for new power plant units, as early as possible. It would also remove the problem of continuing public concern about whether the reactor remained a threat to public health and safety.

The second option has the benefit of reducing the total radiation dose to decommissioning workers as radioactivity will have decayed substantially in the 30–50 year mothball period. This would also reduce the cost of dismantling, though the saving may be partly or completely offset by the cost of maintenance and surveillance during the mothball period. Technology is available for dismantling radioactive reactors today but new technology may be developed over the next 30–50 years that would allow further reduction of costs and worker exposure.

In both cases, as a result of dismantling some radioactive materials will have to be managed as waste. The fuel will in either case be discharged at an early stage and managed according to the option selected for the back end of the fuel cycle (Section 4.2). The primary circuit will have radioactive components with a fairly rapid decay which can be treated as LLW or ILW, at least after a few years or after decontamination. Some of these components are large but are easy to handle or can be cut into smaller pieces. Only a small part of the plant is radioactive. Most of the plant never becomes radioactive and therefore presents no particular problems for immediate dismantling and possible reuse of the equipment.

Several countries have technical experience in the decommissioning of nuclear facilities as about 10–15 nuclear power plants have been decommissioned and their sites restored for reuse. Most of these plants were small and of early designs. The experience is nevertheless relevant for the future decommissioning of currently operating plants.

In order to decommission a nuclear power plant, three prerequisites must be satisfied:

(1) Well trained personnel with appropriate technical skills,
(2) A licensed storage or disposal facility to accommodate all decommissioning wastes,
(3) A regulatory basis for implementing a given decommissioning project.

The IAEA has published general decommissioning guidelines [15] for research reactors and small facilities but they can, to a great extent, also be applied to large facilities. There is now a need for more specific guidance on the development of decommissioning regulations. IAEA safety standards on decommissioning are therefore being developed as part of the RADWASS programme.

5.3. COSTS AND FINANCING OF WASTE MANAGEMENT AND DECOMMISSIONING

A 1991 study by the International Union of Producers and Distributors of Electrical Energy (UNIPEDE) estimated the overall cost of nuclear waste management (covering disposal of operational and decommissioning wastes and spent fuel or reprocessed waste) to be approximately 2.5–11% of the total cost of electricity generation [16]. The IAEA has also conducted a detailed study of the total costs for managing wastes from nuclear and fossil fuelled power plants and their whole fuel cycles and arrived at similar results, as shown in Figs 5–7 [17]. There is a rather large variability associated with the reference case values shown in Fig. 5. It is still clear that a coal fired plant has a very costly waste management operation in flue gas cleaning and that for nuclear and gas fired plants the costs are of the same order of magnitude. There is no significant difference between the nuclear fuel cycles with and without reprocessing.

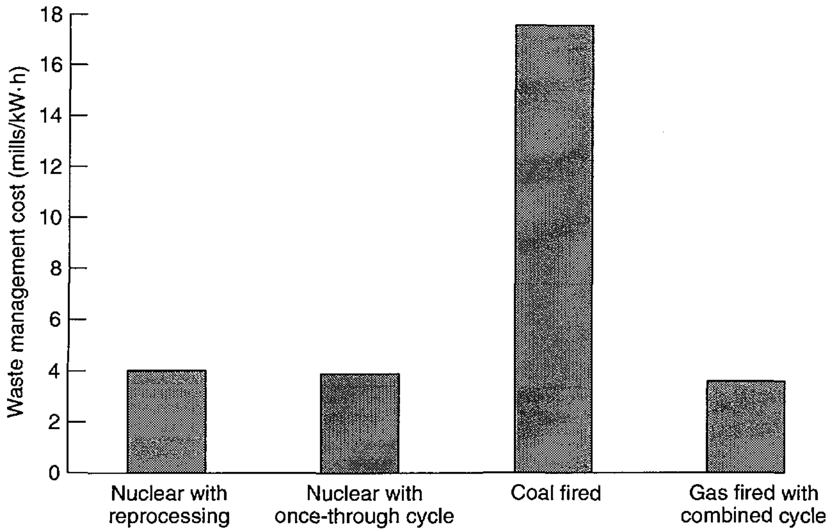

FIG. 5. Levellized waste management costs for various types of power plant (1 mill = US $0.001).

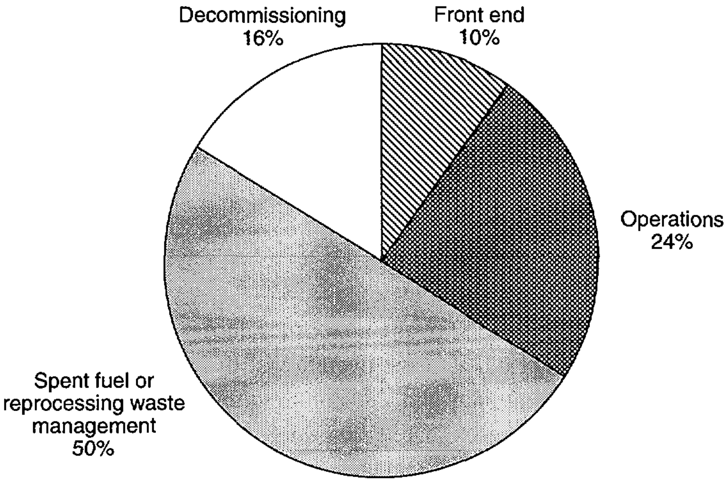

FIG. 6. Waste management costs for a nuclear power plant.

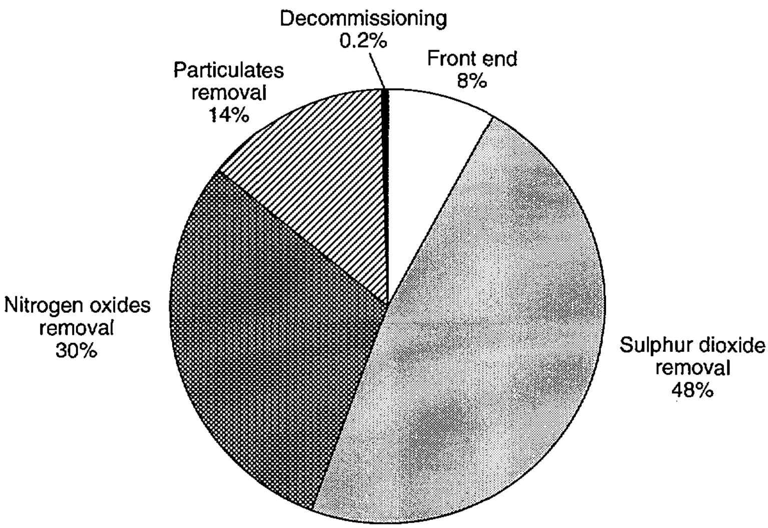

FIG. 7. Waste management costs for a fossil fuelled power plant (coal steam cycle).

Experience of decommissioning of nuclear power plants has shown quite considerable variations in decommissioning costs between plants but a safe estimate would be that a 1% surcharge on the cost of electricity would cover these costs. For the second decommissioning option described above, assuming that decommissioning funds are set aside during a reactor's operating life, interest earned during the mothball period would cover any inflation of costs. Thus this option would cost the current generation less while leaving sufficient funds for the next generation to complete the decommissioning process. The waste generator or utility often pays for the management and/or disposal of radioactive waste even if the actual waste disposal is carried out by a different organization.

There is general agreement in many countries that all future costs for management and disposal of all wastes, including HLW, and decommissioning should be paid for from the receipts of the plant during commercial operation. Several different arrangements have been made, as shown by the following examples:

— In Finland, Spain and Sweden, the government has established a special fund into which the plant owners pay each year (in Finland 1.9–3.3 mills/kW·h, in Sweden 3 mills/kW·h)[3]. The accumulating fund is reserved to pay for waste management, disposal and decommissioning.
— In Belgium and the USA, regulations require the plant owners to establish a fund which after a certain number of years has to amount to a specified sum to pay for decommissioning (in Belgium this is 12% of the initial capital investment).
— In other countries, including Canada, France and Germany, the regulatory requirements are that the plant owner is responsible for decommissioning and must plan this action and have adequate financing available. The utility thus has flexibility in choosing how to invest the fund but must be able to satisfy the regulator that the necessary money will be available when required.

6. Environmental Aspects

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

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

[3] 1 mill = US $0.001.

— Globally, through the contributions of carbon dioxide and methane to the greenhouse effect.

The greenhouse effect and global warming now seem to be the main subject for discussion. However, local effects, with potentially serious health impacts, concern a large number of people in developing countries and are of the highest priority for these countries, whereas the potential for global climate change, caused to the greatest extent by industrialized countries, is regarded as a problem of those countries. Acid rain, the regional effects of which have been so evident across Europe and the northeastern part of North America, is also having an impact within individual developing countries, e.g. in eastern China and parts of India. This will probably change in the future as significant regional effects over the whole of southern and Southeast Asia have been forecast [18]. Local and regional effects are likely to be much more important in shaping energy policies in most developing countries than the concerns for global climate change.

Coal and oil burning is a major source of noxious emissions. Coal now provides about one third of the world's primary energy and this fraction is expected to remain the same over the next thirty years. Several of the large developing countries, notably China and India, plan to expand coal use considerably to meet rising energy demands. Emissions of sulphur dioxide and nitrogen oxides from fossil fuelled power plants can be limited by flue gas cleaning, though at a cost, whereas carbon dioxide emissions can only be limited by reducing fossil fuel use, which could therefore influence the structure of electricity supply systems.

Agreement has been reached on regional treaties to reduce emissions of sulphur dioxide and nitrogen oxides in Europe, and these are having good results. A framework international convention on climate change has existed since 1992 but it contains no quantitative targets for the reduction of carbon dioxide emissions.

Regardless of which environmental goals are set internationally, all countries will probably have to take environmental protection into account in their national energy policies, although the reasons may differ from country to country. It is expected that reduction or at least control of emissions will be incorporated into national goals.

Nuclear power can, of course, play a role in this context as emissions from normal operation are very small. If the electricity now produced by nuclear power plants had been produced by coal fired plants instead, the global carbon dioxide emissions would be 8% higher. In normal operation, nuclear power plants do not emit carbon dioxide, sulphur dioxide or nitrogen oxides, but the production of the concrete and steel used in plant construction and enrichment of the fuel will have caused some fossil fuels to be burnt. In a full energy chain analysis of the alternative ways of producing electricity, which takes into account all energy investments in plant construction and fuel production, nuclear power appears a very attractive option from the point of view of environmental protection (Fig. 8).

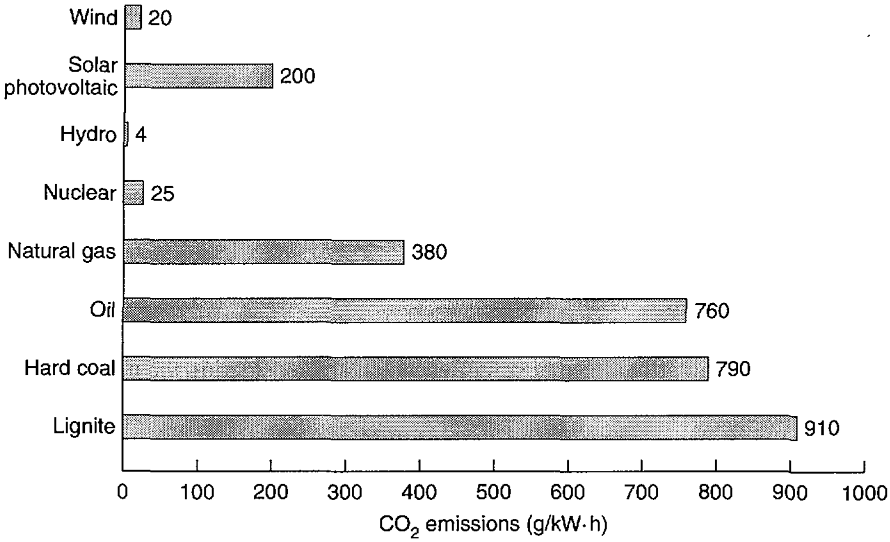

FIG. 8. Full energy chain carbon dioxide emissions produced by different energy sources.

The example of France is often cited as a demonstration of how a nuclear power programme can lead to environmental benefits. In 1974 the French Government decided to launch a major nuclear power programme in order to reduce the national dependence on imported oil. The first plants were connected to the grid in the late 1970s. In 1990 the nuclear plants produced 70% of all electricity in France. Between 1980 and 1990 the total national emissions of carbon dioxide decreased by 23%, those of sulphur dioxide fell by 63% and nitrogen oxide emissions were kept about constant while electricity production increased by 61%. Although the nuclear power programme was established for other reasons the environmental effect has been extraordinary.

There is a trend in industrialized countries towards the internalization of external costs, whereby a producer that freely uses common goods (air or water) for waste disposal is required to pay for their degradation or restoration, the cost of which is passed on to the consumer. As pollution control costs associated with electricity generation are increasingly internalized and passed on, this could lead to some changes in relative generating costs as well as tariff increases and could favour the nuclear power option.

The IAEA has provided computer models for economic optimization of electricity system planning — the Wien Automatic System Planning (WASP) package and subsidiary models — and training in their use for about twenty years. These models are now being routinely used in a large number of developing countries [19–23]. Around 1985 the WASP model was integrated into a comprehensive energy system planning package (Energy and Power Evaluation Program, ENPEP [24]), which includes information about total emissions of pollutants from the power system and additional modules addressing the full energy system. This work has been continued in a multiorganizational project called Databases and Methodologies for Comparative Assessment of Different Energy Sources for Electricity Generation (DECADES). The DECADES project will permit environmental and health costs to be taken into account in the energy system optimization process [25]. Some results are available from this work, notably an information package on costs and emissions for a large number of reference technologies.

The IAEA conducts training courses every year on either WASP or ENPEP. While they are primarily aimed at countries which are considering the nuclear power option they have also been used by a large number of countries for which nuclear power would be feasible only in the distant future.

7. Legal and Regulatory Aspects

The responsibility for the development of all the necessary structures to create, regulate and maintain a nuclear power programme rests with the government and different national organizations and institutions. There are legal requirements at the national level and at the international level which the establishment of a nuclear power programme will entail.

7.1. LEGAL REQUIREMENTS AT THE NATIONAL LEVEL

The responsibility for the safety of nuclear installations and for radiation protection must be defined by law, as must the responsibility of the nuclear power plant operator and the role of the regulatory authority (or authorities where radiation protection and nuclear safety have been allotted to separate regulatory bodies). The responsibilities of the regulatory bodies in establishing regulations, licensing and verifying that requirements are met should be defined and these bodies should be given the necessary resources to carry out these tasks. The standards of the IAEA require that the regulatory authority be clearly separated from the operating organizations. However, in many countries both functions have been vested with the atomic energy authority, but even where this has been the case there is now a clear trend towards ensuring that they are effectively separate.

A legislative and regulatory framework is also usually established for the organization that will take responsibility for waste management and disposal. As with a nuclear power plant operator, this organization will be subject to the regulatory authority or authorities for nuclear safety and radiation protection. A process to ensure that the financing of waste management and disposal and decommissioning operations is properly arranged should be defined by law to ensure that adequate funds will be available when needed.

7.1.1. Nuclear Safety Regulatory Authority

A system for establishing nuclear safety regulations, issuing operating licences and performing inspections to ensure that regulations are met and standards followed is a basic requirement which the government has to meet (Section 3.1). Legislation has to be promulgated to create and empower the nuclear safety regulatory authority. It may seem natural to combine the functions of radiation protection and nuclear safety in one regulatory authority but this has been done in relatively few countries. The reasons are that the radiation protection authority existed before the nuclear safety authority was set up, the specializations of the authorities are quite different and their constituencies would be quite different, with the radiation protection authority having responsibility for surveillance not only of reactors but also of all radioisotope and radiation uses in hospitals, research, industry, etc. The terms of reference of the nuclear safety authority have often included physical protection of nuclear material, safeguards, and national accounting for and control of nuclear materials (Section 7.3).

The regulatory authority must be strictly independent of the operating organization and must have the legal power to do the following:

- To formulate the rules and regulations which the owner/operator must follow;
- To issue licences or permits for siting, construction, commissioning, operation and decommissioning of nuclear power plants;
- To apply surveillance measures to ensure that the rules and regulations are followed by the owner/operator;
- To ensure that the licensee understands its obligations and is competent to fulfil them;
- To exercise law enforcement measures.

The existence of a regulatory authority in no way diminishes the basic responsibility of the owner/operator for the safety of the plant, but should give confidence to the government and the public that the plant is indeed operated safely. The owner/operator cannot even take refuge behind inadequate regulatory safety requirements. It has to lay down its own rules and requirements, which could be stricter than those of the regulatory authority.

The question of enforcement if the regulatory body finds non-compliance with regulations must be considered. The ultimate enforcement action would be withdrawal of the operating licence but other, less drastic measures should also be established for small offences.

An important policy issue will be the basis to be chosen for the national safety regulations. There are essentially three options:

(1) In the past, several countries, when importing their first plant, used the regulations and standards of the supplier country, and the criterion that the plant was 'licensable in the supplier country'. This had an obvious advantage in that the supplier knew in detail exactly which requirements it had to meet. However, this had a significant disadvantage. If a country subsequently purchased a plant from a supplier with a different licensing system it would have the difficult task of reconciling the two systems.
(2) Another approach would be to adopt the IAEA NUSS Codes as a basis and the NUSS Safety Guides as further standards to the extent practicable. The advantage is that the NUSS Codes are well known internationally and suppliers would know which minimum requirements they would have to fulfil. However, the NUSS Codes are fairly schematic and foresee that detailed recommendations would be issued in lower level NUSS documents.
(3) Some countries may choose a more comprehensive system of their own. This should be at least as strict as that laid down in the IAEA NUSS Codes.

The regulatory body will also have to decide which industrial design and manufacturing codes (e.g. pressure vessel codes) are to be used. If the national codes are deemed to be unsatisfactory the question will be which foreign codes to adopt. This decision should be taken only after careful consideration of the options. One key factor will be the codes used by the country's major trading partners.

The national regulations and licensing requirements must be durable, i.e. they must be predictable for the supplier and the plant operator for a reasonable period of time. They should also be transparent and give some assurance to the public that strict safety requirements are in place. Safety regulations are certainly not easy for the public to understand and the regulatory body should therefore make efforts to express an overall safety goal in easily understandable terms.

All organizations concerned with the nuclear power programme must, as a priority, establish and support a safety culture (Section 3.1.3) [12] which makes plant safety a foremost consideration. To strengthen national and international confidence in the intentions of the government to achieve a high level of safety, the country should sign and ratify as early as possible the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Section 10.3). Establishment of a policy to invite IAEA safety reviews, for example by Operational Safety Review Teams (OSARTs) and Assessment of Safety Significant Events Teams (ASSETs), would also serve this purpose.

Experience has shown that it would be useful if government authorities, the regulatory authority and the future plant owner would together develop a policy on how to select and qualify sites for nuclear power plants. It would be beneficial for utilities to identify several potential sites for proposed nuclear and fossil fuelled plants, and keep the options open as long as possible.

It is, of course, important to define which technical criteria should be used for site selection and qualification. The IAEA has issued several NUSS documents which provide guidance on this subject [6]. It is equally important to decide how transparent the site selection and qualification process is to be made, especially as much of the work may well be performed by foreign consultants. A possible way to give added assurance about the adequacy of the process is to call for an IAEA review of it at given stages and publish the results. Such IAEA reviews employ experts from many countries and guarantee neutrality in their findings.

Site approval will also be required from local authorities, which may consider other possible uses of the land, and from environmental authorities. Requirements for environmental impact assessments and land use approval processes are growing in complexity in many countries and will have to be addressed early and with appropriate resources.

Other countries in the vicinity of a proposed nuclear site should be consulted if they are likely to be affected by the plant. The Convention on Nuclear Safety stipulates that other parties to the Convention in the vicinity of a proposed installation be given enough information to enable them to make their own assessment of the likely safety impact in their own territory.

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

7.1.2. Radiation Protection Regulatory Authority

A national system for radiation protection is a precondition for any nuclear activities in a country (Section 3.2). If this does not already exist, the first step would be for the government to introduce appropriate legislation and set up a regulatory authority for radiation protection, giving the authority the necessary powers and establishing regulations and standards to be used. The regulatory authority licenses users of radioactive materials and radiation sources and ensures that regulations are followed. The Convention on Nuclear Safety addresses these issues. The adequacy of the system can be checked by an IAEA Radiation Protection Advisory Team (RAPAT) if the government requests it.

The Basic Safety Standards published by the IAEA (Section 3.2.2) [13] are the only international safety standards available in the area of radiation safety. Therefore, many countries have chosen to accept the BSS in extenso as national standards. The IAEA has a statutory right and obligation to require that the BSS be used in all projects supported by the IAEA in a particular country. A number of countries have their own standards which differ from the BSS in some respects.

Within the radiation protection regime there should be a definition of a policy for handling radiation emergencies. This will be needed not only for nuclear power plants but also to cover accidents with radiation sources, which can have a considerable local impact.

7.2. THIRD PARTY LIABILITY

7.2.1. Background

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

- The international liability regime applies to nuclear installations defined in the Conventions, e.g. civil land based nuclear reactors and reprocessing and storage facilities, as well as to nuclear materials sent from or to such installations.
- Liability is channelled exclusively to the operator of the nuclear installation.
- Liability of the operator is absolute, i.e. the operator is held liable irrespective of fault.
- Liability is limited in amount. Under the Vienna Convention, it may be limited to not less than US $5 million (value in gold on 29 April 1963), but an upper ceiling is not fixed. The Paris Convention sets a maximum liability of 15 million Special Drawing Rights[4] (SDRs); the installation State may provide for a greater or lesser amount (but not below 5 million SDRs) taking into account the availability of insurance coverage. The Brussels Supplementary Convention

[4] The Special Drawing Right, as defined by the International Monetary Fund, is a unit of account calculated on the basis of a 'basket' of currencies of five of the most important trading countries. As of 20 November 1997, an SDR was equivalent to US $1.373.

established additional funding beyond the amount available under the Paris Convention up to a total of 300 million SDRs, consisting of contributions by the installation State and contracting parties.

— Liability is limited in time. Compensation rights are extinguished under the Vienna and Paris Conventions if an action is not brought within ten years from the date of the nuclear incident. Longer periods are permissible if, under the law of the installation State, the liability of the operator is covered by financial security. National law may establish a shorter time limit, but not less than two years (Paris Convention) or three years (Vienna Convention) from the date when the claimant knew or ought to have known of the damage and the operator liable.
— Territorial scope: The Vienna Convention is silent on its territorial scope of application. However, it has been restrictively interpreted to apply only to damage suffered in contracting States and on or over the high seas. The Paris Convention specifically states (Article 2) that it does not apply to damage suffered in non-contracting States. The contracting State of the liable operator may, however, extend in its national legislation the application of the Convention to such damage and incidents.
— The operator must maintain insurance or other financial security for an amount corresponding to the operator's liability. If such security is insufficient, the installation State is obliged to make up the difference up to the limit of this liability.
— Jurisdiction over actions lies exclusively with the courts of the contracting State in whose territory the nuclear incident occurred.
— There will be no discrimination of victims on the grounds of nationality, domicile or residence.

7.2.2. Improvement of International Liability Regime

Following the Chernobyl accident, the IAEA initiated work on all aspects of nuclear liability with a view to improving the basic Conventions and establishing a comprehensive liability regime. In 1988, as a result of joint efforts by the IAEA and OECD/NEA, the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention was adopted, linking the Conventions and combining them into one expanded liability regime. Parties to the Joint Protocol are treated as though they were parties to both Conventions and a choice of law rule is provided to determine which of the two Conventions should apply to the exclusion of the other in respect of the same incident.

In 1990, the IAEA Standing Committee on Liability for Nuclear Damage was established to deal with all aspects of nuclear liability. Following several years of preparatory work, a diplomatic conference held at the IAEA Headquarters in

September 1997 adopted a protocol to amend the Vienna Convention and also adopted a Convention on Supplementary Compensation for Nuclear Damage.

Revision of Vienna Convention. The main improvements include the following:

- —The liability of the operator would be increased to not less than 300 million SDRs and a mechanism introduced to phase in this amount during a limited period of time for those States which may have difficulty in immediately implementing the higher liability figure.
- —The time period following a nuclear incident during which damage claims may be submitted would be extended to thirty years for loss of life and injury and ten years for other damage. National law may fix longer periods if the operator's liability during such periods is covered by financial security.
- —The definition of damage has been revised to address the concept of environmental damage and preventive measures.
- —The Convention would be applied to nuclear damage wherever suffered. However, an exclusion may be made for nuclear damage suffered in a non-contracting State, including its maritime zones, if such a State has a nuclear installation on its territory, or in a maritime zone, and does not afford reciprocal benefits.
- —The jurisdiction clause would be supplemented to provide that in the case of incidents within the exclusive economic zone of a contracting State, jurisdiction over actions concerning nuclear damage shall lie with the courts of that State.

Convention on Supplementary Compensation for Nuclear Damage. The main features include the following:

- —The Convention would operate only between States parties to the Convention.
- —Supplementary compensation would be provided through contributions by States parties in addition to the compensation of at least 300 million SDRs under national legislation implementing the Vienna or Paris Convention or national legislation consistent with the liability provisions in the annex to the new Convention, which are equivalent to those of the above Conventions. A phasing-in mechanism similar to that proposed for the revised Vienna Convention is contemplated.
- —The contributions of a contracting State would be calculated on the basis of its installed nuclear capacity and its United Nations rate of assessment. Contracting parties on the minimum United Nations rate of assessment with no nuclear reactors shall not be required to contribute.
- —Rules would be established regarding the allocation of funds to compensate for nuclear damage suffered in and outside the installation State.

— A jurisdiction clause similar to that proposed for the revised Vienna Convention regarding nuclear incidents occurring in the exclusive economic zone of a contracting State is contemplated.
— The Convention would not affect the rights and obligations of a contracting State under the general rules of public international law.

7.2.3. Operation of Revised Liability Regime

The revised liability regime is intended to operate as follows. National legislation implementing the Vienna and Paris Conventions as well as national legislation consistent with the requirements set out in the annex to the Convention on Supplementary Compensation establishes the rules for operator liability, including the principles of no-fault liability and channelling of liability to the operator of the nuclear installation. It also sets the national compensation amount at not less than 300 million SDRs, to be provided by the operator or by the operator and public funds of the installation State. When the national compensation amount is exhausted, the compensation will be provided from the supplementary fund comprising contributions paid in accordance with a specific formula by States parties to the Convention on Supplementary Compensation. Supplementary funding will be implemented on the basis of the liability rules set out in national legislation. Both new instruments have a phasing-in mechanism that allows a State to join them with interim, lower amounts of liability.

7.3. NON-PROLIFERATION REGIME

Since the first international transfer of nuclear fuel, equipment and technology, assurances of exclusively peaceful use have generally been a condition for supplies under bilateral agreements between a recipient and a supplier State. These agreements generally permitted verification by the authorities of the supplier State. Since the early 1960s, this verification of specific supplies has been in most cases delegated to the IAEA through its safeguards[5] system, a function which had been foreseen in its Statute.

Subsequently, an international non-proliferation regime came into existence. The basis of this regime is the Treaty on the Non-Proliferation of Nuclear Weapons

[5] The word 'safeguards' is commonly used with the meaning of 'safety measures', but in this publication it is exclusively used in the sense of the IAEA's system to verify that nuclear material and equipment are not used for any military purpose.

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

The application of IAEA safeguards requires the State to conclude a standard safeguards agreement with the IAEA which defines in detail the scope and nature of the safeguards. The relevant agreements also specify the rights and obligations of the IAEA and the State. The essential features of the IAEA safeguards system are:

— Requirements for the State to keep control and records of its nuclear material, by means of the State's system for accounting and control (SSAC), and for periodic reports to the IAEA on the amounts and locations of nuclear material;
— Restrictions on movements of nuclear material, which are subject to continuous monitoring;
— Inspections by IAEA inspectors to verify, inter alia, the accuracy of State reports and records.

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

Since the discovery of a clandestine weapons programme in Iraq, measures have been implemented to strengthen the safeguards system, particularly with a view to increasing the capabilities of the system to detect possible undeclared activities and material. This objective is to be achieved through better access to information on States' nuclear activities, to sites and to the most advanced safeguards equipment and techniques, such as digital seals, environmental sampling and remote transmission of data. The IAEA Board of Governors endorsed, in June 1995, the implementation of those measures of the IAEA's safeguards strengthening programme which fell within the existing legal authority under comprehensive safeguards agreements and, in June 1997, approved a model protocol additional to safeguards agreements which, when concluded with a State, will provide complementary authority for the implementation of other measures.

8. Financing of Nuclear Power

8.1. ROLE OF GOVERNMENT

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

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

8.2. *KEY CRITERIA*

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

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

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

8.3. FINANCIAL ANALYSIS

A financial analysis for a nuclear power project would follow a preliminary economic analysis. A financial analysis includes factors such as:

— Capital cost and projected operating and fuel costs
— Projected revenue
— Operating lifetime of plant
— Design and construction period
— Current and projected escalation rates
— Current and projected currency exchange rates
— Rate of return.

There will also be loan specific factors to be included, such as:

— Interest rate and fees (management fee, commitment fee, guarantee fee)
— Frequency of interest payments
— Grace period and repayment period
— Debt cover.

There are three main issues which need special attention when raising finance for a nuclear power project. These are: high investment costs; longer construction times than those of fossil fuelled power plants; and potentially large uncertainties in costs and schedule owing to factors such as regulatory and public intervention and policy and programme changes.

8.4. CAPITAL REQUIREMENTS

As mentioned in Section 2.4, the initial investment cost of a 1000 MW(e) nuclear power plant would be typically around US $2000 million, including the interest during construction. The initial investment could be reduced to a certain extent by choosing a smaller unit of standard design. Another significant issue is the requirement to pay interest (debt servicing) during the long construction period, as during this time there will be no revenue from the sale of electricity. It would be important to check that available credit lines for an individual country are not exceeded.

It is also important to recognize that a nuclear power plant will require higher disbursements in the early years of the project and for a few years after the start of commercial operation during which the cumulative expenditures for building and operating a nuclear power plant are larger than for a fossil fuelled plant. This is a concern in the short term and will be an important consideration for utilities in developing countries deciding whether or not to start a nuclear power programme.

8.5. BASIC FINANCING APPROACHES

The magnitude of the required investment and of the financing constraints underlines the need to explore financing for a nuclear power project from all possible sources, both local and foreign. The local or national financing sources are:

— The investor's own resources, i.e. equity capital and cash flow;
— Private sources as debt capital, i.e. domestic bonds, local bank credits, stand-by facilities for cost increases and prepayments for future services of the project;
— Public sector credits or donations from public entities.

Examples of international financing sources include: public sector export credits; suppliers' credits and financing arrangements through commercial banks guaranteed by export credit guarantee agencies and by multilateral development and financing institutions; bilateral financing sources; and private international markets for commercial loans and international bonds.

Although an increase of the financing flows from multilateral and bilateral lenders would be desirable, especially because of their more favourable amortization conditions, including lower interest rates, in the future additional funds will have to come mainly from private international capital markets, which have been expanding rapidly.

A relatively large proportion of the total investment cost of a nuclear power project in a developing country is normally required in foreign currency in the design, construction and commissioning phases of the project. However, the project, which will generate electricity to be sold to the local economy, will yield its earnings in local currency only. In such a case, both lenders and equity investors that have invested in the project in foreign currency will require firm assurances, in the form of a transfer guarantee by the host government, that their original investment together with interest or dividends can be repaid in a convertible currency.

All lending organizations display extreme prudence in the selection of borrowers. During project appraisal, the lenders' assessment will involve careful scrutiny of various types of risk which may affect the project during both the construction and operation periods. These risks, which are of a technical, commercial, economic and political nature, include: credit and financial risks; legal and regulatory risks; construction risks; operation and market risks; and risks associated with public acceptance and changes in governments and policies.

8.6. LOCAL FINANCING

One of the most difficult problems, which is often underestimated, with regard to financing power projects in many countries is the financing of local costs. As much as possible of the total project costs, but in any event the local portion of these costs, should be financed with domestic funds.

Sound sources of local currency funding for investment in a public utility power project would be funds of the owner/operator, either from equity or from accumulated earnings set aside especially for such a planned investment, government budget and privatization. These sources could be supplemented by credits raised in the domestic capital market. Difficulties in financing local costs arise from shortages of utility and government funds and constraints in local capital markets. A well functioning domestic capital market is particularly important for organizing local financing.

Adequate local financing must be arranged in good time and, in the case of loans, for a reasonable credit period. Electricity tariffs are of special importance in arranging for and repaying loans for nuclear power projects. While social and political considerations may be taken into account in determining tariffs, it is usually thought to be crucial that the overall electricity tariff structure reflect the full electricity generation and distribution costs, which for nuclear power plants include funds for disposal of spent fuel and decommissioning. Tariffs vary between countries and reflect costs which are essential for the economic strength and internal financing capabilities of the utility. Power utilities must show good financial performance to obtain support from financial institutions.

As foreign currency financing of local costs increases the foreign debt burden and carries a significant foreign exchange risk, it is vital for successful project implementation to secure sufficient local financing. Some countries do not allow foreign currency sources to be used for the purpose of local cost payment.

8.7. CONSTRAINTS ON EXPORT FINANCING

Export financing for nuclear power projects in many countries is at present limited primarily to export credits, commercial bank loans and supplier credits. Under the OECD 'Consensus' (i.e. the Arrangement on Guidelines for Officially Supported Export Credits, agreed in 1976, and its Annex on Sector Understanding on Export Credits for Nuclear Power Plants, agreed in 1984), which presents the guidelines, terms and conditions for the financing of nuclear power projects in developing countries, the OECD countries have agreed not to provide tied aid credits, aid loans, grants or any other kind of financing on credit terms that are more favourable than those set out in the OECD Consensus [26].

Specifically, the present terms of the OECD Consensus rule out the use of bilateral soft loans for nuclear power plants but not for other power plants. Because of the high capital cost of nuclear plants, the OECD Consensus allows a 15 year repayment period after plant startup, compared with the normal 10 years for non-nuclear projects. However, this longer repayment period, together with the long construction and loan pay-out periods for nuclear plants, exposes the lenders to increased risks. As a consequence, the OECD Consensus interest rate is 1% higher than for non-nuclear loans. These terms apply to virtually all aspects of new nuclear power projects, including equipment, materials, services, training and commissioning. Official export financing to cover local currency costs and capitalization of interest may not exceed 15% of the total export value from the supplier's country, it being assumed that the export credit agency is willing to finance such costs.

Export credit agencies agree to comply with the OECD Consensus in their own interest. Thus, given the OECD Consensus, it is clear that if foreign sources are available for financing nuclear power projects in developing countries, this financing is likely to be limited and the cost of money is unlikely to be below commercial terms.

8.8. SUPPLY CONTRACT OPTIONS

As mentioned in Section 2.1, there are experienced nuclear power plant industries in eight countries which could export large power plants. Most of them can offer standardized plants which can be built at a variety of sites and they have direct past experience also with exports to developing countries. China is supplying smaller plants with a design based on its 300 MW(e) Qinshan plant. Three types of supply contract have been commonly used in the past: turnkey, split package and multiple package.

The turnkey type of contract refers to the supply of a complete power plant, ready for commercial operation, by one supplier, called the main contractor. A turnkey contract gives the main contractor comprehensive responsibility for completing all parts and all phases of the project to the satisfaction of the client, including the design, engineering, construction, erection, supply, installation, testing and commissioning of the plant, as well as the training of the owner's personnel. The main contractor will also be in charge of the overall project management. The main contractor might be a single company or a group of contractors operating as a consortium with usually one member acting as the sponsor or speaker for the group. The main contractor has to guarantee both its own delivery and services and those of all its subcontractors, foreign and local. Obtaining licences from the national regulatory body should remain the responsibility of the buyer but the main contractor should guarantee that the plant can be licensed and prepare the safety analysis reports.

The essential advantage of this system lies in the fact that one main contractor is held responsible by the buyer for all financial risks during construction. The turnkey approach seems especially advisable when a country has little or no experience with the management of large projects. It has also been used in some countries where such qualifications existed, especially for the procurement of the first plants, but turnkey contracting has generally not been used by experienced organizations in recent years. It seems quite probable that the turnkey type of contract will again be used in industrialized countries if nuclear power programmes are revived, because of both the standardized plant designs now available and the additional security that it offers to the plant owners.

In the split package approach, the overall responsibility for design and construction of the plant is divided among a relatively small number of contractors that manage, design, construct and/or manufacture large, functionally complete portions of the work, such as entire systems or buildings. Each portion is called a package. Under the split package approach interfacing problems may arise which can lead to risks of delays and extra costs to the owner. To overcome this problem, one of the contractors is usually assigned the responsibility for overall system integration and functional design as well as project co-ordination and interfacing.

In the multiple package approach, the owner, either within its own organization or through its architect–engineer, assumes direct responsibility for the design and construction management of the project with a large number of contracts. The multiple package approach may be adopted by a country provided that proven capabilities in full scope project management are available within the country. Bids are invited for the nuclear steam supply system and turbine generator packages, the suppliers are selected and contracts are placed. The owner or the architect–engineer then designs the balance of plant around this equipment, produces a very large part of the safety report, supervises construction and usually also erects the plant. This approach has been favoured as it offers the maximum opportunity to the buyer to select the most suitable plant and to influence the design, but it can result in a tailor-made plant significantly different from a standardized design.

8.8.1. Private Financing

Privatization of an electricity supply industry could facilitate the financing of generating plant. In recent years new supply forms have been used for fossil fuelled power plants: build–operate–transfer (BOT) and build–own–operate (BOO).

The BOT approach and variations on it may represent a viable solution if the primary aim of the country is to obtain the electricity and not to gain other benefits from the introduction of a nuclear power programme. In the BOT approach a number of foreign investors form a consortium, the consortium establishes a joint venture company (JVC) with a local utility and the JVC sells the electricity generated to the utility. The foreign investors procure most of the funds for the project, which are used as follows:

— To build a power plant with foreign engineering expertise;
— To operate the plant under the management of the foreign investors/operator for a certain period until all costs, debt service and equity are recovered by means of the electricity tariff;
— To transfer the ownership of the plant to the country in which it was built.

When a power plant is constructed in a developing country using the BOT approach, there would be advantages in that the foreign capital would not be a governmental debt and the risks would be reduced through the expertise of the JVC. On the other hand, such an arrangement is complex both legally and financially. The BOT approach has been used for fossil fuelled plants but not so far for a nuclear power plant and it seems unlikely that it would be feasible as long as financiers consider nuclear power plants a higher risk than other types of power plant.

An alternative to BOT is the BOO approach, which does not involve the transfer of ownership of the plant to the host country. A BOO plant can, in principle, continue in the hands of the JVC throughout its useful life or up to an earlier date agreed by the host government and the private owner.

9. Public Acceptance and Participation in Decision Making

9.1. PUBLIC ACCEPTANCE OF NUCLEAR POWER

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

— The risk of repetition of a serious reactor accident with consequences like those of the Chernobyl accident,

— The claim that the waste presents a problem that has no solution,
— The alleged close link between civilian nuclear power and nuclear weapons.

There should be no doubt that these arguments have caused fear among the public but, at the same time, it appears that very often the public has been neither well informed nor directly concerned, with side issues sometimes dominating the debate. Experience has shown that the only way to influence public opinion is through a carefully designed long term education programme based on correct, neutral information (Section 9.3). Such a programme requires a major effort but its importance should not be underestimated.

9.2. PUBLIC PARTICIPATION IN DECISION MAKING

With industrial development, governments and parliaments became the guardians of public safety and took the decisions needed to establish new plants and carry through programmes. This led to the creation of local consultation procedures which were to be carried out before decisions could be taken on the siting of new and potentially hazardous industries. Thus in many countries there are legal requirements for local consultation, in the form of a hearing or public inquiry, which apply also to the siting of a nuclear power plant. The hearing is most often consultative and not decisive, even if the public normally has some degree of assurance that the opinions given and the questions asked are taken into account when an authority later makes a decision whether to grant a site licence or not. The basic idea is, of course, that those directly concerned should have a formal opportunity to express their opinion, but a too broad definition of 'directly concerned' has led to special interest groups being present at all hearings and influencing them to the extent that it becomes difficult to create a clear consensus. Such difficulties with local consultations have led some to draw the conclusion that they should be avoided and other, less formal, solutions sought. Nevertheless, under all circumstances it is important that there be a process of local consultation and that it be accessible and transparent.

Because local consultations are increasingly seen as insufficient there are commonly calls for stronger direct participation of the public in decision making on the grounds of protecting the local environment. The new trends are anchored internationally, for example in the 1972 Stockholm Declaration, the 1975 Helsinki Final Act of the Conference on Security and Co-operation in Europe, and the Global Nature Charter of the United Nations General Assembly of 1982. These state an obligation to inform the public, to stress that all categories of the public have a responsibility to contribute to the protection and improvement of the environment, and to make it possible for every person to have the opportunity to participate, individually or with others, in decisions concerning their environment. This has become the main platform for a number of environmental protection organizations when asking for more public participation in decision making, in particular in regard to nuclear power programmes and the siting of individual nuclear facilities.

At the local level the role of politicians in public participation has often been very useful. At this level they have more direct contact with their electorate, see the importance of local issues and can serve as a channel for information to their constituency. This has led some countries (e.g. France, Hungary and Sweden) to establish local information or safety committees which have direct insight into the safety, operation and emergency planning at a plant. In Sweden, where the municipal councils have the power of absolute veto against the establishment of industries that they do not want, a law calls for the setting up of a local nuclear safety committee of municipal politicians which is kept directly informed of all safety related matters at the plant. This committee has to review emergency plans, for example, and inform the local public about them. The experience of these local safety committees has been positive and the model could be emulated elsewhere. It is, of course, not a substitute for direct public participation but it can be useful.

Several countries have constitutional procedures for referendums in which the public decides (Switzerland) or is consulted (e.g. Italy and Sweden). Where a referendum has been held on nuclear power, either directly on the future of a nuclear power programme or as part of a specific issue, the result has generally been detrimental to the nuclear power programme. For example, in Sweden a formal decision was taken by parliament, after a referendum in 1980, to phase out nuclear power production, representing 50% of all electricity generation, entirely by 2010. However, there are recent signs that the decision may be reconsidered.

9.3. PUBLIC INFORMATION AND EDUCATION

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

A basic information strategy implies that the following be defined:

— The goal to be achieved;
— What the message is and who will deliver it, when, where and how;
— The key target audiences;
— The communication tools and resources required;
— The existing assets that can be drawn upon.

Information will have to be collected to demonstrate the precise nature of a planned facility and experience with its forerunners, their economics, and potential community benefits and environmental benefits, as well as costs, risks and regulatory requirements. It is important that this information be — and be seen to be — complete and correct and that it be presented early and in a transparent fashion.

To define to whom the information programme should be addressed, data should be collected about the likely degree of public acceptance in different sectors of society and the extent of existing factual knowledge on the part of local or regional officials, trade unions, politicians, media, doctors, teachers, business and religious leaders and other key opinion formers.

The information strategy should be articulated on at least two levels: the local and the national. Some of the concerns to be addressed may be common to both, while others will be specific to one, particularly as regards the local population in the area of an intended site.

Other aspects that should be considered as part of a co-ordinated information strategy include teaching about energy and electricity in schools, information centres, a strong media relations programme to provide immediate answers to media inquiries and response to media reports, and a separate information programme for legislators and politicians. Information programmes in industrialized countries have included a great number of different tools, such as a grassroots supporters network, a speakers' bureau, brochures, fact sheets, videos and other audiovisual materials, travelling exhibitions and static displays, speeches, articles and media debates. Respected persons of influence and members of other professions and professional institutions acting as opinion formers could make an important contribution to the formulation of public opinion on the acceptability of nuclear power.

Local benefits will accrue from the introduction of a large industrial plant and are likely to increase local support for such a project. Benefits may include added employment opportunities, improved education possibilities and greater local commerce. Local taxes may have to be paid by the plant owner on the value of the production which, in the case of a nuclear power plant, is very large indeed. In some countries governments have decided to give the local municipality special additional benefits if it accepts a nuclear power plant. These benefits may be in the form of reduced local electricity tariffs or social benefits (new schools, hospitals, etc.). The indirect local benefits should be carefully assessed and any policy about additional local benefits should be decided early.

10. National Policies of Importance to Nuclear Power Development

National governments will probably have laid down policies in such sectors as national development (including goals and priorities), energy development (including supply) and international relations. These policies would be of a long term nature and where they are the result of consensus they would not be expected to change with political changes in the country. In some countries energy policy has become an issue of party politics instead of national policy, which has made it difficult to formulate long term energy plans. In these circumstances a nuclear power programme, in particular, has become almost impossible to pursue. Thus nuclear power policy issues cannot be addressed without a consideration of how national policies on energy, development and international relations may influence nuclear power development and operation.

10.1. NATIONAL ENERGY POLICY

A country considering a nuclear power programme would have a national energy plan specifying the objectives for the national energy policy. Some of the possible objectives are discussed below.

(a) *Improved energy independence*
The oil price shocks in 1973 and 1979 led many governments to draw the conclusion that too strong a dependence on one or two imported primary energy forms was undesirable and therefore diversification of energy supply sources became a primary objective. In several countries, including Belgium, France, Japan and the Republic of Korea, nuclear power development was considered the right answer, but in others diversification was sought in coal and natural gas imports from different countries.

(b) *Development of indigenous energy resources*
It is natural that many governments give priority to development of national resources of coal, oil, gas and hydropower as this will give an assurance of supplies at least to some extent. However, if the domestic production is more costly than imported coal or oil, this will influence prices throughout the energy sector of the country.

(c) *Economic optimization of energy and electricity supply*
It is assumed that energy and electricity supply systems should be economically optimized using computer models [19–24]. The planning period should be ten years or longer to make the optimization meaningful. The objectives of security and diversity of supplies could be factored in through appropriate assumptions on future prices of fuel, produced domestically or imported. Policy decisions have to be made on the inclusion of other costs, such as environmental and health costs and infrastructure development costs.

(d) *Stability of electric grid system*
It is necessary to examine the stability of the national electricity grid as it is an important prerequisite for introduction of a nuclear power plant. Necessary measures to minimize any fluctuations of frequency and voltage during normal operation have to be identified and implemented. Thus introduction of nuclear power may indirectly lead to an improvement in the quality of the electricity supply in the country.

(e) *Security of electricity supply*
A secure supply of energy is of crucial importance for development. Electricity supply and the possibilities for industrial development are particularly closely linked. A recent example of success in this respect has been shown by the Republic of Korea, where a secure electricity supply was maintained at reasonable prices in spite of long periods of high increases in demand (13% per year over the 1970s and 10% per year over the 1980s).

(f) *Availability of energy at prices which support general development*
In some countries, including the former centrally planned economies, a policy has been adopted to make energy available at low prices. This can be beneficial to development but if prices are below production costs it will mean that new plants cannot be paid for through revenues and it will be difficult to obtain loans. The World Bank, for example, has made realistic tariffs a condition for loans for new plants.

(g) *Environmental protection*
Fossil fuelled power plants are sources of pollution and they have become an essential factor in considerations of environmental protection, not only at the local level but also regionally and internationally (Section 6). It is becoming increasingly unlikely that any country can avoid taking this into account when setting a national energy policy.

(h) *Privatization of electric utilities*
Many countries, both industrialized and developing, are considering the privatization of government owned utilities in order to make them operate under more commercial conditions. If this limits utilities to seeking funds only in the commercial money markets, with their stronger emphasis on short term returns on investment, it may mean that capital intensive plants will not be favoured by utilities planning without government support. On the other hand, there have been many examples of private utilities, for example in Germany, Japan, Sweden and the USA, which have acquired and operated nuclear plants with little or no government support in financing.

(i) *Opening of competition in electricity market*
In western Europe and North America there is a trend towards policy support of competition in the electricity market, which allows customers to purchase electricity from a generating organization of their choice. The transmission systems then have to serve as 'common carriers' to all generators. This is a clear break from the tradition in which the generating organization has a franchise on an area and has to plan to supply it securely in the future. The new policy could lead to utilities avoiding heavy capital investments and preferring to build cheaper power plants, such as gas fired plants. This concept may be of only academic interest to most developing countries, where one organization is responsible for supply to the whole country, but they will probably see such a development in the future.

(j) *Demand side management*
Demand side management has become an important task for utilities in industrialized countries, where investment in the improved efficiency of use of electrical energy and decreasing demand or shifting demand from peaks can reduce the need for new plants, though shifting demand from peaks may increase the demand for baseload electricity. Demand side management in the past has received less attention in many developing countries. It is desirable that consideration be given at the policy level to ways of achieving effective use of energy. Efficient energy use should be promoted by realistic tariffs as well as by other means such as support for energy saving measures, which may be the least expensive way of making generating capacity available for new uses or minimizing requirements for new capacity. Realistic tariffs should incorporate direct costs, indirect costs, external costs such as those due to environmental and health impacts, and the potential future cost of primary energy.

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

Whichever policies are adopted by a government it is necessary that, in situations of rapidly growing demand, energy policy be durable to permit long term planning. In particular, a nuclear power programme can only be developed if there is long term support for a programme of several nuclear power plants. Even a BOO type contract (Section 8.8.1), based on the assumption that it is only the availability of the electricity which is important, will require some infrastructure development to establish the regulation of nuclear safety and radiation protection. Such development would be justified economically only in the context of a long term programme.

10.2. NATIONAL DEVELOPMENT POLICY

Most countries have a national development plan, which is periodically updated. This plan sets priorities for development and targets for production, education and achievements in various sectors. It provides an important background for the development of electricity generation plans and for any nuclear power programme as it will also give priorities for investments. Countries developing from agricultural to highly industrialized economies would need to decide when it would be appropriate to begin a nuclear power programme. For example, the Republic of Korea embarked on its nuclear power programme right from an early stage of its industrialization.

In the countries of eastern Europe which are making the transition from a centrally planned to a market economy there is generally a need for an initial framework plan on how to structure and start the process of transition, setting out the priorities, targets and mechanisms to be used. If such a plan includes the privatization of electricity generation by nuclear facilities, then certain considerations are in order. Nuclear power may be an important and even essential energy supply source in these countries but safety improvements are necessary in this sector. There is also a need to introduce utility planning mechanisms which respond to the criteria of market economies. Where a government role is maintained in the nuclear power sector, it may be difficult to reconcile the demands from that sector with overall economic policy and the availability of large scale project funding.

10.2.1. Level of National Participation

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

A minimum level of national participation, which would be possible in the case where the government considers that only the availability of electricity is important, would correspond to a BOO type contract with a foreign consortium which would take over from local organizations all responsibility for the design, construction and operation of the plant (Section 8.8.1). Such an arrangement would still require competent national regulatory bodies for radiation protection and nuclear safety and there would still be a national responsibility for site selection and waste management and disposal. Much of the technical expertise for the regulatory organization could conceivably be provided by foreign consultants but as a very minimum the decisions on which safety standards and regulations to use, how to issue licences and how to carry out inspections have to be taken nationally. A key issue would be how the liability of a foreign operator could be defined in a manner that was acceptable to all parties.

A more common approach has been that the first plant is ordered under a turnkey contract and steady progress is then made with subsequent plant orders towards split package and multiple package contracts, each step placing increasing demands on the domestic infrastructures (Section 8.8).

10.2.2. Development of National Infrastructure

A nuclear power programme has often been seen as an opportunity for development of national capabilities, though it is recognized that this places high demands on industry, technology, quality assurance and technical personnel. If a nuclear power programme is to support national development efforts, the infrastructures must be developed in step with these demands. A realistic and well formulated plan for a nuclear power programme and for the development of infrastructures can stimulate a country's general economic and industrial development. If poorly implemented, however, a plan would probably adversely affect the programme schedule and the safety of the nuclear power sector.

Between minimum participation and too ambitious targets there is, at each stage, a desired optimum level of participation which would produce a positive industrial spin-off without jeopardizing the execution of a project. This optimum level must be determined by the decision makers and policy planners, who must take into account the limitations related to the technical and investment capabilities, competitiveness and market size of the national industries, as well as the availability of qualified personnel and of relevant technology and know-how.

The optimum level of national participation will evolve with time and experience as a function of the infrastructures in place. However, it is not infrequent that planners underestimate the time and effort necessary to attain, for example, the required quality of national products. Too frequently the call for maximum participation is emphasized, whereas the real objective should be optimum participation.

National participation in no case should affect quality and there can be no compromise on this, even where national participation is subsidized. It is important that a realistic assessment be made regarding any adverse effect on the cost and time schedule of a project as a result of national participation. If, for reasons of strategy and national policy, certain increases in cost and time schedule are consciously accepted in the initial stages, the overall and long term economics should be kept in view.

When setting targets for national participation, policy makers should consider its evolution together with that of the nuclear power programme. In this context a policy of support to a long term nuclear power programme involving several plants is evidently most important to give local suppliers confidence in achieving an adequate return on their investments.

10.2.3. Participation of National Industry

A progressive growth in the participation of national industry, which may assist in setting targets, includes the following:

(a) As a minimum, local labour and some construction materials are used for non-specialized purposes on-site, especially civil engineering work.
(b) Local contractors take full or partial responsibility for the civil engineering work, possibly including some design work.
(c) Locally manufactured components from existing factories are used for non-critical parts of the balance of plant.
(d) Local manufacturers extend their normal product line to incorporate nuclear designs and standards, possibly under licensing arrangements with foreign suppliers.
(e) Factories are set up to manufacture heavy and specialized nuclear components, possibly under licensing arrangements with foreign suppliers. However, the economic viability of such undertakings would have to be assessed carefully in view of the future domestic market and the availability of such equipment internationally.

This type of plan has been followed, for example, in the Republic of Korea. In step with the increasing participation of national industry there was also a corresponding evolution in the contract form for each successive plant, from turnkey to split package to multiple package, with a corresponding expansion in the capabilities of the owner organization. A national organization now has the overall responsibility in the Republic of Korea for the design of new plants and the country now has a capability to export plants.

In selecting those items and services whose supply is considered to be part of the optimum level of national participation in the project, attention should be focused initially on equipment which presents only moderate technological difficulty and has wider applications than solely to nuclear technology. Such items include the following types:

— Items which are currently manufactured in the country, even if at a lower quality level than needed, and for which a moderate effort may be required to upgrade shop-floor capability and organization;
— Items which already have an internal market whose planned expansion would justify the required investments in view of the expected increase in sales;
— Items which are not critical to the plant construction.

During the preparatory phase of a nuclear power programme, it is important that the local industry be surveyed to identify companies potentially capable of participating in the programme and the requirements and resources for their upgrading and/or expansion. In this connection a policy should be developed to decide how national suppliers are to be accredited, that is, certified as qualified for manufacture of specified equipment. With regard to quality management, the IAEA's NUSS Code and Safety Guides on quality assurance [9] as well as the ISO 9000 standards [27] can be of help.

10.2.4. Development of Human Resources

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

The organizations directly involved in the nuclear power programme, i.e. the plant owner and the regulatory bodies, will need qualified engineers and technicians and will be responsible for providing training for their staff. To achieve the targets set for national participation, local industries and technical support organizations will also require engineers, technicians and other skilled workers. There will be a need for training centres which can provide staff with the necessary hands-on experience. Training programmes should also be established bilaterally with the supplier country and through international programmes, including the IAEA Technical Co-operation Programme.

10.3. POLICY CONCERNING INTERNATIONAL RELATIONS AND DEPENDENCE ON FOREIGN SUPPLIERS

As nuclear power development in a country will rely to a great extent on the use of the international market for plants, fuel, fuel cycle services and technology transfer it will therefore depend on national policy concerning international relations and bilateral assistance. Such policy might exclude or limit the possibility of developing the nuclear power option. For example, a policy that gave priority to national self-sufficiency would make a nuclear power programme unrealistic and limitations in bilateral relations would limit access to the market.

In contrast, a non-limiting national policy on international relations can do much to support nuclear power development. In particular, a strong commitment to non-proliferation as shown by accession to the NPT or one of the regional treaties for prohibition of nuclear weapons is now a condition for free access to the international market (Section 7.3). Accession would also lead to the conclusion of a safeguards agreement with the IAEA on all current and future nuclear activities in the country.

There are also a number of other international conventions, accession to which would facilitate the introduction of a nuclear power programme (Box 4). These conventions came into being through a general desire of many countries to obtain assurances that strict standards for nuclear safety and for physical protection against theft of nuclear materials or sabotage are applied everywhere and that there would be mechanisms for notification and assistance in the case of an accident in any country. This is the reason why many countries that do not have nuclear power plants have also acceded to these conventions.

The dependence of a country on the international market or a bilateral partner for supplies is likely to last for many years into a nuclear power programme, so that the country can obtain spare parts, for instance, if it does not develop its own capabilities in all supply sectors. This will be facilitated by long term bilateral co-operation agreements between supplier and recipient governments, as well as between owner and other organizations and their counterparts abroad, and national policies must support such agreements.

For the plant owner, such counterpart organizations include not only WANO and INPO but also national utility research institutes, such as the Electric Power Research Institute (EPRI) in the USA, and different groups of owners of specific plant types (CANDU Owners Group, BWR Owners Group, Steam Generator Owners Group, etc.) as well as utility driven design groups. Participation in such groups can give direct access to the experience of suppliers and plant operators that is otherwise not available.

10.4. REGIONAL POLICY

Besides policy on international relations, discussed above, policy concerning relations with neighbouring countries within a region is increasing in importance, as shown by the number of regional associations and alliances being formed for various

Box 4

INTERNATIONAL CONVENTIONS

Convention on Early Notification of a Nuclear Accident [28]
Sets up the organizational and communications links with the IAEA and neighbouring countries that would be needed in the event of a nuclear accident.
(In force since 1986.)

Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency [28]
Sets up co-operation links between countries for assistance in the case of an accident.
(In force since 1987.)

Convention on the Physical Protection of Nuclear Material [29]
Obliges parties to make arrangements and follow defined standards for physical protection of nuclear materials and nuclear facilities.
(In force since 1987.)

Convention on Nuclear Safety [30]
Obliges parties to follow fundamental safety principles for nuclear power plants and to report on the implementation of safety measures to a conference to be held periodically.
(In force since 1996.)

Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
Obliges parties to establish a legislative and regulatory framework; provide adequate resources for safety; implement adequate quality assurance, radiation protection and emergency preparedness programmes; take appropriate national measures to ensure the safety of spent fuel and radioactive waste management, including transboundary movement; and report on the measures regularly at peer review meetings.
(Opened for signature on 29 September 1997. Will enter into force 90 days after 25 States, including 15 that have an operational nuclear power plant, ratify the agreement.)

purposes. This applies also in the case of nuclear power programmes as there are many topics in which regional co-operation could yield direct benefits.

(1) *Electric grid integration*
The regional electricity grid integrations in western and eastern Europe and North America have directly benefited participating countries by increasing the security of electricity supply and improving the reliability of supply and economics of operation. There are now also examples of efforts to join grids in other regions, such as Latin America and northern and western Africa. Grid integration will demand co-operative planning of expansion of generation, but planning will be facilitated as a result of the wider experience available. Integration may also permit an increase in the capacity of the largest units to a size greater than what any national grid could accept and this could be very important for nuclear power development.

(2) *Nuclear safety*
Close co-operation in nuclear safety matters between countries in a region can help to give added assurances about the safety of plant operation, for example by providing for immediate access to information about incidents and accidents and co-ordination of emergency plans. It can also give access to specialists and R&D capabilities in other countries to solve safety problems. Several regional co-operation agreements now exist, of which the Nordic nuclear safety co-operation agreement is one good example.

(3) *Environmental issues*
Transboundary effects of pollution such as acid rain are touching more regions of the world (Section 6). Closer co-operation between countries can help in efforts to assess pollution and reduce emissions, as shown by the conventions agreed under the aegis of the United Nations Economic Commission for Europe (ECE), such as the regional treaties to reduce emissions of sulphur dioxide and nitrogen oxides in Europe and the international convention on climate change.

(4) *Sharing of plant services*
If more than one country in a region has nuclear power plants there are obvious advantages in trying to share plant services, such as for plant maintenance and repair and spare parts, where this is feasible.

(5) *General R&D and human resources development*
At a more basic level, if countries of a region combined their R&D capabilities and human resources development programmes, they could each gain tangible benefits and savings in infrastructure development.

(6) *Nuclear fuel cycle*

Early IAEA studies pointed out the advantages that could be obtained from closer regional co-operation in the fuel cycle and its supply services, especially in the back end, dealing with spent reactor fuel [31], but there has been little progress on the concept. In practice, regional co-operation could initially take the form of a joint storage facility for spent fuel; this could later be expanded to reprocessing, as needed, and to HLW management and disposal operations (Section 5.1.2). Such co-operation at joint facilities would not only bring economic benefits but could also give added assurances of non-proliferation and safety in operation and waste disposal. National and international policies have not encouraged such a development but it may become a viable option in the future.

(7) *Non-proliferation assurances*

Regional agreements can give added non-proliferation assurances. Examples are the Tlatelolco and Rarotonga Treaties, mentioned in Section 7.3, and the Argentina–Brazil agreement. The Bangkok Treaty creating a nuclear weapon free zone among the countries belonging to the Association of Southeast Asian Nations (ASEAN), and the Pelindaba Treaty, creating a similar zone in Africa, were opened for signature in 1995 and 1996, respectively, and work is proceeding on an equivalent treaty for the Middle East.

It is not necessary that all parties to a regional co-operation agreement share an interest in nuclear power and its development. For example, there are some agreements involving countries which have sharply divergent views on nuclear power. While Sweden and Finland, for instance, have important nuclear power programmes, Denmark is opposed to nuclear power. This has not prevented good and rewarding co-operation on nuclear safety matters. An important feature of close regional co-operation between countries, such as that between Sweden, Finland and Denmark, is the long history of co-operative associations between those countries. These long associations add assurances of good international agreements.

11. Conclusion

This publication has been prepared for developing countries that may be considering whether to introduce a nuclear power programme. It highlights the areas in which policy decisions would be needed. It has not been the objective to discuss whether a country should select the nuclear option, nor to advise on which policy options to choose. It is in the nature of nuclear policy decisions that they are influenced by other national policies and politics and do not always have the clearly defined technical or economic options which should exist for most of the decisions in the planning process. It is hoped that this publication, by pointing out the areas where policy decisions need to be taken and the options which are available, will assist those who have to prepare the background for such decisions as well as the decision makers themselves.

References

[1] Moscow Nuclear Safety and Security Summit, International Affairs, Moscow (1996).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Reactors in the World, April 1997 Edition, Reference Data Series No. 2, IAEA, Vienna (1997).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Energy, Electricity and Nuclear Power Estimates for the Period up to 2015, July 1996 Edition, Reference Data Series No. 1, IAEA, Vienna (1996).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Installations, Safety Series No. 110, IAEA, Vienna (1993).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Governmental Organization, Safety Series No. 50-C-G (Rev. 1), IAEA, Vienna (1988).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Siting, Safety Series No. 50-C-S (Rev. 1), IAEA, Vienna (1988).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Design, Safety Series No. 50-C-D (Rev. 1), IAEA, Vienna (1988).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Operation, Safety Series No. 50-C-O (Rev. 1), IAEA, Vienna (1988).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations: Code and Safety Guides Q1–Q14, Safety Series No. 50-C/SG-Q, IAEA, Vienna (1996).

[10] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Basic Safety Principles for Nuclear Power Plants, Safety Series No. 75-INSAG-3, IAEA, Vienna (1988).

[11] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Defence in Depth in Nuclear Safety, Safety Series No. 75-INSAG-10, IAEA, Vienna (1996).

[12] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Safety Culture, Safety Series No. 75-INSAG-4, IAEA, Vienna (1991).

[13] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Series No. 111-F, IAEA, Vienna (1995).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning and Management for the Decommissioning of Research Reactors and other Small Nuclear Facilities, Technical Reports Series No. 351, IAEA, Vienna (1993).

[16] INTERNATIONAL UNION OF PRODUCERS AND DISTRIBUTORS OF ELECTRICAL ENERGY, Western European Nuclear Power Waste Management: A Note on its Actual Cost, UNIPEDE, Paris (1991).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Comparison of Waste Management System Costs for Nuclear and other Energy Sources, Technical Reports Series No. 366, IAEA, Vienna (1994).

[18] WORLD ENERGY COUNCIL, INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS, Global Energy Perspectives to 2050 and Beyond, WEC, London (1995).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Model for Analysis of Energy Demand: User's Manual, IAEA-TECDOC-386, Vienna (1986).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Wien Automatic System Planning (WASP) Package: A Computer Code for Power Generating System Expansion Planning, 2 vols, Computer Manual Series No. 8, IAEA, Vienna (1995).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217, IAEA, Vienna (1982).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Expansion Planning for Electrical Generating Systems: A Guidebook, Technical Reports Series No. 241, IAEA, Vienna (1984).

[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Energy and Nuclear Power Planning in Developing Countries, Technical Reports Series No. 245, IAEA, Vienna (1985).

[24] ARGONNE NATIONAL LABORATORY, Energy and Power Evaluation Program (ENPEP): Documentation and User's Manual, ANL/EES-TM-317, Argonne, IL (1987).

[25] BERTEL, E., Electricity, health and the environment: The DECADES project, Int. At. Energy Agency Bull. **37** 2 (1995) 2.

[26] RAY, J.E., The OECD 'Consensus' on Export Credits, OECD, Paris (1986).

[27] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, ISO 9000: International Standards for Quality Management, 2nd edn, ISO, Geneva (1992).

[28] Convention on Early Notification of a Nuclear Accident and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Legal Series No. 14, IAEA, Vienna (1987).

[29] Convention on the Physical Protection of Nuclear Material, Legal Series No. 12, IAEA, Vienna (1982).

[30] Convention on Nuclear Safety, Legal Series No. 16, IAEA, Vienna (1994).

[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Regional Nuclear Fuel Cycle Centres, IAEA, Vienna (1977).

Bibliography

Economic Assessment and Environmental Aspects

ARGONNE NATIONAL LABORATORY, Energy and Power Evaluation Program (ENPEP), Documentation and User's Manual, ANL/EES-TM-317, Argonne, IL (1987).

BERTEL, E., Electricity, health and the environment: The DECADES project, Int. At. Energy Agency Bull. **37** 2 (1995) 2.

Electricity and the Environment (Senior Expert Symposium, Helsinki, 1991): Executive Summary; Key Issues Papers; Proceedings; Background Papers (IAEA-TECDOC-624), IAEA, Vienna (1991).

Electricity, Health and the Environment: Comparative Assessment in Support of Decision Making (Proc. Symp. Stockholm, 1995), IAEA, Vienna (1996).

INTERNATIONAL ATOMIC ENERGY AGENCY (Vienna)

Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217 (1982).

Expansion Planning for Electrical Generating Systems: A Guidebook, Technical Reports Series No. 241 (1984).

Energy and Nuclear Power Planning in Developing Countries, Technical Reports Series No. 245 (1985).

Model for Analysis of Energy Demand: User's Manual, IAEA-TECDOC-386 (1986).

Wien Automatic System Planning (WASP) Package: A Computer Code for Power Generating System Expansion Planning, 2 vols, Computer Manual Series No. 8 (1995).

WORLD ENERGY COUNCIL, INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS, Global Energy Perspectives to 2050 and Beyond, WEC, London (1995).

Nuclear Power Status and Costs

INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear and Conventional Baseload Electricity Generation Cost Experience, IAEA-TECDOC-701, Vienna (1993).

— Nuclear Power Reactors in the World, April 1997 Edition, Reference Data Series No. 2, IAEA, Vienna (1997).

OECD NUCLEAR ENERGY AGENCY, Nuclear Fuel Cycle Costs, NEA, Paris (1994).

OECD NUCLEAR ENERGY AGENCY, OECD INTERNATIONAL ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL UNION OF PRODUCERS AND DISTRIBUTORS OF ELECTRICAL ENERGY, Projected Costs of Generating Electricity, NEA, Paris (1993).

Financing of Nuclear Power Projects in Developing Countries

INTERNATIONAL ATOMIC ENERGY AGENCY, Costs and Financing of Nuclear Power Programmes in Developing Countries, IAEA-TECDOC-378, Vienna (1986).

— Financing of Nuclear Power Projects in Developing Countries, IAEA-TECDOC-610, Vienna (1991).

— Financing Arrangements for Nuclear Power Projects in Developing Countries: A Reference Book, Technical Reports Series No. 353, IAEA, Vienna (1993).

National Participation and Technology Transfer

INTERNATIONAL ATOMIC ENERGY AGENCY (Vienna)

Technical Evaluation of Bids for Nuclear Power Plants: A Guidebook, Technical Reports Series No. 204 (1981).

Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants: A Guidebook, Technical Reports Series No. 224 (1983).

Economic Evaluation of Bids for Nuclear Power Plants: A Guidebook, 1986 Edition, Technical Reports Series No. 269 (1986).

Bid Invitation Specifications for Nuclear Power Plants: A Guidebook, Technical Reports Series No. 275 (1987).

Nuclear Power Project Management: A Guidebook, Technical Reports Series No. 279 (1988).

Developing Industrial Infrastructures to Support a Programme of Nuclear Power: A Guidebook, Technical Reports Series No. 281 (1988).

Guidebook on Training to Establish and Maintain the Qualification and Competence of Nuclear Power Plant Operations Personnel, IAEA-TECDOC-525 (1989).

Non-Proliferation and Safeguards

Communications received from certain Member States regarding Guidelines for the Export of Nuclear Material, Equipment and Technology, INFCIRC/254/Rev. 1/Pt. 1, INFCIRC/254/Rev. 1/Pt. 2, IAEA, Vienna (1992).

Communications received from Members regarding the Export of Nuclear Material and of certain Categories of Equipment and other Material, INFCIRC/209/Rev. 1 (1990), INFCIRC/209/Rev. 1/Mod. 1, IAEA, Vienna (1992).

INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards: Guidelines for States' Systems of Accounting for and Control of Nuclear Materials, IAEA Safeguards Information Series No. IAEA/SG/INF/2, Vienna (1980).

— IAEA Safeguards: Glossary, 1987 Edition, IAEA Safeguards Information Series No. IAEA/SG/INF/1 (Rev. 1), Vienna (1987).

Statement on Full-Scope Safeguards adopted by the Adherents to the Nuclear Supplier Guidelines, INFCIRC/405, IAEA, Vienna (1992).

The Agency's Safeguards System, INFCIRC/66/Rev. 2, IAEA, Vienna (1968).

The Structure and Content of Agreements between the Agency and States required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).

Physical Protection of Nuclear Material

Convention on the Physical Protection of Nuclear Material, Legal Series No. 12, IAEA, Vienna (1982).

The Physical Protection of Nuclear Material, INFCIRC/225/Rev. 3, IAEA, Vienna (1993).

Quality Assurance

INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Management for Nuclear Power Plant Operation: A Manual, Technical Reports Series No. 315, IAEA, Vienna (1990).

— Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations: Code and Safety Guides Q1–Q14, Safety Series No. 50-C/SG-Q, IAEA, Vienna (1996).

Training and Qualification of Nuclear Power Plant Personnel

INTERNATIONAL ATOMIC ENERGY AGENCY (Vienna)

Guidebook on the Education and Training of Technicians for Nuclear Power, Technical Reports Series No. 306 (1989).

Common Modelling Approaches for Training Simulators for Nuclear Power Plants, IAEA-TECDOC-546 (1990).

Simulators for Training Nuclear Power Plant Personnel, IAEA-TECDOC-685 (1993).

Nuclear Power Plant Personnel Training and its Evaluation: A Guidebook, Technical Reports Series No. 380 (1996).

Nuclear Safety and Radiation Protection

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

INTERNATIONAL ATOMIC ENERGY AGENCY (Vienna)

Code on the Safety of Nuclear Power Plants: Design, Safety Series No. 50-C-D (Rev. 1) (1988) and associated Safety Guides.

Code on the Safety of Nuclear Power Plants: Governmental Organization, Safety Series No. 50-C-G (Rev. 1) (1988) and associated Safety Guides.

Code on the Safety of Nuclear Power Plants: Operation, Safety Series No. 50-C-O (Rev. 1) (1988) and associated Safety Guides.

Code on the Safety of Nuclear Power Plants: Siting, Safety Series No. 50-C-S (Rev. 1) (1988) and associated Safety Guides.

Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations: Code and Safety Guides Q1–Q14, Safety Series No. 50-C/SG-Q (1996).

INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Basic Safety Principles for Nuclear Power Plants, Safety Series No. 75-INSAG-3, IAEA, Vienna (1988).

— Safety Culture, Safety Series No. 75-INSAG-4, IAEA, Vienna (1991).

— Defence in Depth in Nuclear Safety, Safety Series No. 75-INSAG-10, IAEA, Vienna (1996).

Nuclear Fuel Cycle and Radioactive Waste Management

Code of Practice on the International Transboundary Movement of Radioactive Waste, INFCIRC/386, IAEA, Vienna (1990).

INTERNATIONAL ATOMIC ENERGY AGENCY (Vienna)

Regional Nuclear Fuel Cycle Centres (1977).

Planning and Management for the Decommissioning of Research Reactors and other Small Nuclear Facilities, Technical Reports Series No. 351 (1993).

Assessment and Comparison of Waste Management System Costs for Nuclear and other Energy Sources, Technical Reports Series No. 366 (1994).

Establishing a National System for Radioactive Waste Management, Safety Series No. 111-S-1 (1995).

The Principles of Radioactive Waste Management, Safety Series No. 111-F (1995).

INTERNATIONAL UNION OF PRODUCERS AND DISTRIBUTORS OF ELECTRICAL ENERGY, Western European Nuclear Power Waste Management: A Note on its Actual Cost, UNIPEDE, Paris (1991).

OECD NUCLEAR ENERGY AGENCY, The Cost of High-Level Radioactive Waste in Geological Repositories, OECD/NEA, Paris (1993).

OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD, Paris (1993).

Contributors to Drafting and Review

Bennett, L.L.	International Atomic Energy Agency
Board, J.A.	Nuclear Electric plc, United Kingdom
Boothroyd, A.D.	International Atomic Energy Agency
Chernilin, Y.F.	Kurchatov Institute, Russia
Crijns, M.	International Atomic Energy Agency
Dabek, W.	International Atomic Energy Agency
Davies, M.L.	Consultant, United Kingdom
Eynon, R.T.	Department of Energy, United States of America
Glorian, D.	Electricité de France, France
González-Gómez, E.	IBERDROLA, Spain
Gueorguiev, B.	International Atomic Energy Agency
Han, K.J.	Korea Electric Power Corporation, Republic of Korea
Jacke, S.	Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Germany
Krishnan, S.	Nuclear Power Corporation of India Limited, India
Langlois, L.	International Atomic Energy Agency
Mahadeva Rao, K.V.	International Atomic Energy Agency
Mondino, M.A.	MONDITEC, S.A., Argentina
Rapoport, M.	Nucleoeléctrica, Argentina
Richards, M.	Nuclear Energy Institute, United States of America
Samdani, G.	Pakistan Atomic Energy Commission, Pakistan
Sharma, V.K.	Nuclear Power Corporation of India Limited, India

Skjöldebrand, R.H.A.	International Atomic Energy Agency
Subki, J.	Badan Tenaga Atom Nasional, Indonesia
Thexton, T.	Department of National Resources, Canada
Vélez-Ocón, C.	Instituto Nacional de Investigaciones Nucleares, Mexico
Yanev, Y.	Committee on the Use of Atomic Energy for Peaceful Purposes, Bulgaria

Consultants Meetings

Vienna: 13–17 March 1995, 20–21 March 1996

Advisory Group Meeting

Vienna: 11–15 December 1995

97-03046

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA
ISBN 92–0–104197–7