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Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy Systems: Report of Stage 1

IAEA
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COMMON USER CONSIDERATIONS (CUC) BY DEVELOPING COUNTRIES FOR FUTURE NUCLEAR ENERGY SYSTEMS

REPORT OF STAGE 1

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NUCLEAR ENERGY SERIES No. NP-T-2.1

COMMON USER CONSIDERATIONS (CUC) BY DEVELOPING COUNTRIES FOR FUTURE NUCLEAR ENERGY SYSTEMS

REPORT OF STAGE 1

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

This publication collects and summarizes the opinions of experts from developing countries that are considering the deployment of nuclear power plants in the near term, or are making projections for the deployment of nuclear power plants in the next 40 years (up to 2050). It is intended to establish an early dialogue between these countries (called technology users or user countries here) and the countries that already possess nuclear technology capabilities (called technology holders here). It can also be used in conjunction with other IAEA publications to address institutional and infrastructure needs, to foster the development of additional nuclear energy systems, or as the basis for discussion or domestic planning of the step by step process for the deployment of a new nuclear power plant that in some cases may be the first. The publication also provides substantial background information collected by the IAEA regarding additional characteristics and expectations of these countries.

The countries addressed in this publication were selected using the World Bank's definition of developing economies. The countries included have also given an indication of interest in developing or deploying new nuclear power plants. Countries that already have a significant ongoing nuclear programme (e.g. China and India) were excluded.

This publication was prepared by the IAEA with inputs from about two hundred experts from the countries that participated in this activity. The process used to develop the publication involved multiple meetings between the IAEA and experts from 35 countries. Additional input from experts from some of the countries defined as the technology holders was also included at different steps of the process. The process was intended to develop a consensus and this publication represents an agreement among the experts from the many different countries and organizations represented at the different steps. The publication incorporated lessons learned from user requirement programmes in technology holder countries.

The initial draft of the user considerations and of this publication was developed as a result of discussions with different stakeholders and organizations from seven countries: Bangladesh, Belarus, the Baltic Consortium (Estonia, Lithuania and Poland, represented by Lithuania), Egypt, Indonesia, Malaysia and Mexico. The cooperation of the governments of these countries in accepting visits of the IAEA team and in organizing the discussions is greatly appreciated. Special thanks are due to the local coordinators of these discussions — S.I. Bhuiyan and F.D. Ahmed of Bangladesh, A. Yakushov and B. Popov of Belarus, A. Dainius and R. Karaliute of Lithuania, Y. Ibrahim of Egypt, Adiwardojo of Indonesia, K.I. Jamal of Malaysia and M. Barcenas of Mexico.

This publication was prepared under the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), with direct support from several INPRO member countries and the IAEA Technical Cooperation Fund. The IAEA officer responsible for this publication was M. Moriwaki of the Department of Nuclear Energy.

EDITORIAL NOTE

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SUMMARY

COMMON USER CONSIDERATION ACTIVITY

An activity called Common User Considerations and Actions for Development and Deployment of Nuclear Energy System for Developing Countries was established in response to a resolution at the IAEA's 50th General Conference (GC(50)/RES/13). In this resolution, the General Conference "calls on interested Member States to develop, under the auspices of the Agency, nuclear power reactors reflecting the needs of the developing States that choose the nuclear option, and in this regard:

(a) Encourages the development of small and medium nuclear power reactors that meet grid sizes and economic requirements of developing countries, have very long-lifetime cores, are easily safeguardable, are protected robustly against attempts at sabotage or theft, avoid the use of fissile materials suitable for use in a nuclear weapon or other nuclear explosive device and are safe against accidents that may produce catastrophic consequences;
(b) Stresses_the need to establish, in line with national circumstances, common user criteria for such nuclear power reactors, including infrastructure development requirements, domestic legal and regulatory frameworks, provisions for removal and disposal of the spent fuel, and flexible financing arrangements;
(c) Recommends that INPRO, subject to the availability of resources, refine such common user criteria in a timely manner."

This activity was carried out in two stages, stage 1 being dedicated to the establishment of the common user considerations and stage 2 being dedicated to refining the common user considerations and defining possible actions to be carried out jointly by technology users and technology holders to address these considerations. This publication presents the results of the first stage, which was the identification and the compilation of the common considerations by potential users of nuclear power plants in developing countries. The information herein, particularly the desired features (provided in Section 4), will be useful to a number of stakeholders and decision makers as they consider the development of nuclear power plants and associated fuel cycle facilities for domestic or export deployment. This study, however, should not be considered a detailed scientific analysis or the result of a market study, and should not be used to derive industry wide trends or conclusions.

At the time the activity was initiated, the Secretariat identified 54 countries as potential technology users in this study. These countries are categorized as 'developing economies' according to the definition provided by the World Bank in 2006. Furthermore, they are IAEA Member States that have expressed an interest in considering, introducing or expanding nuclear power programmes, but without ongoing large scale nuclear power construction projects such as China and India.

Given the large number of potential technology user countries, and given the constraints on time and budget faced by the activity, as a first approximation a smaller subset of countries was selected to be representative of the key characteristics of the overall set of technology user countries. A series of detailed discussions were then conducted with various stakeholders and experts from these representative countries to develop a draft set of requirements[1] by technology user countries. The stakeholders and experts included government officials in charge of energy policy and nuclear power programmes, nuclear regulatory bodies, researchers from national laboratories and universities, and representatives of utilities and financial sectors. The first draft set of desired features was then reviewed and revised in a consultants meeting with participation by the representative technology user countries, as well as a number of technology holder[2] countries. A second draft set of desired features was developed incorporating all feedback gathered in the consultants meeting plus some additional input from all interested technology user countries, and a workshop attended by representatives of 32 of the technology user countries and eight technology holder countries was held to produce additional feedback.

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[1] To avoid confusion with the definition of the word 'requirement' provided in the IAEA Safety Glossary, the terms 'consideration' or 'desired feature' were used instead of 'requirement' in this report. '

[2] Technology holder is defined in Section 1.2

The objective of compiling the common considerations by these potential users of future nuclear power plants is to promote early dialogue between the potential technology user countries and technology holders, to address near and longer term institutional and infrastructural issues, to foster development of nuclear power plants, and/or as the basis for discussions at different development and deployment milestones during the introduction or expansion of a nuclear power programme.

CHARACTERISTICS OF TECHNOLOGY USER COUNTRIES

The countries identified as the potential users of future nuclear power plants in this study currently account for about 34% of the world's population and 13% of its gross domestic product. Together, they currently represent 19% of world's electricity generating capacity. By 2030 the installed electricity generating capacity needed in these countries is expected to reach 23% of world generating capacity, reflecting faster population and economic growth rates than the rest of the world. Achieving this capacity level would require that about 30% of all new electricity generating capacity be installed in these countries.

The current population characteristics of these countries show a large variation, with about one third of the countries representing 80% of the total population of this group. In addition, population projections indicate a high growth rate. Therefore, in a few years, the combined population of the technology user countries could become larger than those of India and China.

The current economic characteristics, as measured by gross domestic product, of the technology user countries also show a very large variation, from about US $3 billion to US $1000 billion. However, one third of the countries have 80% of the combined gross domestic product of all the countries in this group. These technology user countries are projected to have high economic growth rates compared to developed countries, but less than China and India.

The installed electricity generating capacity of these technology user countries also shows a very large variation from less than 1 GW(e) to more than 90 GW(e), with a total installed capacity of 700 GW(e). Similar to the population and gross domestic product characteristics, one third of the technology user countries have 80% of the installed generating capacity in this group. All the countries are projected to have high growth rates compared to developed countries but less than countries like China and India. By 2030, 30% of all new electricity generating capacity would be installed in these user countries.

The installed nuclear electricity generating capacity shows an even greater variation with only 13 of the 54 technology user countries currently operating nuclear power plants. Based on IAEA projections for the year 2030, the total nuclear capacity additions in these technology user countries would be in the range of 26 GW(e) with 29 new units (low estimate), all the way to 76 GW(e) with 94 new units (high estimate). This would result in a total nuclear capacity projection in all the technology user countries in the range of 47 GW(e), with 58 units (low estimate) to 104 GW(e) with 132 units (high estimate). 80% of this total nuclear capacity is expected to be concentrated in less than 25% of the technology user countries. By 2030, the number of new countries would double in the high estimate but only increase by about 25% for the low estimate.

The expectations regarding new nuclear power plants, expressed by the experts in the technology user countries themselves, indicate a more optimistic estimate than that based on IAEA projections. According to the opinion of the interviewed experts, more than 50% of the user countries plan to operate nuclear power plants within the same time frame, providing a total nuclear capacity higher than the IAEA projection for the year 2030. In addition to the total new nuclear capacity estimate, experts provided their estimate of the expected unit sizes. The survey results showed that there also was a large variation in the expected unit sizes for newly constructed plants among the different countries. Based solely on the expected total new capacity additions in these countries, and not taking into account other considerations such as the national grid size, the compilation of the experts' input indicated that about 80% of the total new capacity addition would be with plant sizes around 1000 MW(e) or larger, and 20% would be in the small and medium range. However, based solely on the number of new units, 38% of the additional units would be in the small (<300 MW(e)) and medium (<700 MW(e)) range and 62% would be in the 1000 MW(e) or larger range. On an individual basis, out of 31 experts who provided answers to the survey, five expected their country to accommodate only nuclear power plants of less than 700 MW(e) capacity (i.e. small and medium size reactors), twelve experts expected their country to deploy small or medium size reactors as well as larger nuclear power plants, eleven experts expected their country to only accommodate large nuclear power plants (more than 700 MW(e)), and three indicated they did not expect any nuclear power plants to be deployed in their country up to 2050. Another result from the survey regarding country expectations was that non-electrical applications of nuclear power were of interest to around 25% of the experts. The major near term (before 2030) non-electrical application of interest was desalination. There was some interest in hydrogen production in the 2050 time period.

The projected introduction of nuclear power in many of the technology user countries addressed in this study could be hindered by two considerations: grid capacity and investment constraints. Without taking into account interconnected grids with neighbouring countries, grid capacity could limit the size of the nuclear power plant units to be built in the technology user countries. By 2015, based on the projected size of their national grids, about one third of the user countries might only be able to accommodate small reactors (<300 MW(e)) and an additional 10% might only be able to accommodate medium reactors (<700 MW(e)). In addition, total investment required for building nuclear energy systems as well as the large uncertainties in key variables related to nuclear investment (reliable capital cost information for plants in the user or supplier countries, the cost of new infrastructure, development costs and the impact of the economies of scale) may further constrain the projected deployment of nuclear power programmes.

DESIRED FEATURES BY TECHNOLOGY USER COUNTRIES

The desired features related by the potential users of nuclear power technology and collected during the CUC activity are presented in Section 4 of this publication. They are structured into seven major categories:

(1) Economics and financing;
(2) Infrastructure and implementation;
(3) Nuclear Safety; environment;
(4) Resources and waste management;
(5) Proliferation resistance;
(6) Physical protection;
(7) Technical requirements.

Many of the desired features are driven by similar concerns and general desires amongst all the user countries. Some of these concerns and desires are similar to those held by countries having established nuclear energy systems, including technology holder countries. This is particularly true of the-desired features related to safety, economics and spent fuel management, as well as of some of those related to technical performance.

Several of these desired features are driven by a common desire to minimize the risks associated with the construction of nuclear power plants due to the significant scale of investment required and the large resource commitment over a long period. As with any current user of nuclear energy, the potential technology users in developing countries believe that nuclear power plants should be constructed with the objective of successful operation throughout their design life with minimum interruption. The rationale behind some of the considerations is related to the general expectation that the experience of the technology holders should be utilized in helping to achieve this objective. In addition, the technology user countries want to use the same technologies as the technology holder countries and desire to improve their national industrial capability in the process of acquiring the nuclear power plant technology.

The final set of considerations by technology users presented in this publication has been agreed to by experts from technology user countries that participated in a workshop in November 2007. The inputs from all the experts who participated in the survey have been considered equally. The majority of the desired features are common for all the experts in the technology user countries. A few of the desired features represent the views of experts from a limited number of countries and they can be recognized as they are presented as optional in nature.

The common considerations by technology users can be categorized as follows:

(a) Utilization of the experience of technology holders: Examples of such desired features are the use of a turnkey contract for the first nuclear power plant unit, proven nuclear power plant design, and choosing a nuclear power plant that is licensed or licensable in the country of origin.

(b) Improvement of national capability: These considerations are related to the utilization of local infrastructure and skill-sets, involvement of users in the project execution, need for training, need for information to help understand technology, and step-wise increase in national participation.
(c) Safety, security and proliferation resistance: The desired features in this group generally reflect the desire by the technology user countries to use the same nuclear technology deployed in the technology holder countries. Experts in technology user countries do not want additional or more stringent requirements to be imposed on the nuclear power plants that will be deployed in their countries, unless specifically requested by them.
(d) Economics and associated information: Many considerations in this group focus on limitation of project risks, facilitating financing of such capital intensive projects and competitiveness of electricity generating costs from nuclear power plants with the best alternative sources of energy available locally. In addition, other considerations are related to the need to have relevant, consistent, and credible information for use in economic assessments and to support decisions related to the implementation of nuclear power plants.
(e) Project and technical aspects: These include considerations that are currently common practice, such as short project duration, support for financing, good operating performance, ease of operation/maintenance, and adequate intermediate spent fuel storage.

Experts from some countries provided considerations that would ensure sustained operation of the nuclear power plants and specify a long term approach to spent fuel management:

(i) Sustained operation: These desired features are aimed at the avoidance or minimization of significant interruption of the operation of a nuclear power plant caused by unavailability of parts, service, fuel or technical know-how.
(ii) Spent fuel management: The position of the majority of the experts in the technology user countries with respect to spent fuel management is the same as that of the technology holder countries, i.e. to 'wait and see' further technological developments before they adopt a long term solution. This is reflected in the considerations related to adequate intermediate spent fuel storage and flexibility in the use of fuel in the future. Experts in some technology user countries wanted to include a requirement for spent fuel take back by supplier countries as an option.

FINAL OBSERVATIONS

This publication compiles the opinions of experts from developing countries that are considering the deployment of nuclear power plants in the near term or are making projections for the deployment of nuclear power plants in the next 40 years (up to 2050). The input provided by the experts reflects good knowledge of the currently available technologies; however, the knowledge base and resulting discussions and considerations on innovative technologies were very limited. In particular, small and medium sized reactors under development by technology holders may not have been considered to be fully viable options. The publication also provides background information collected by the IAEA staff from other literature regarding additional characteristics and expectations of these countries. It was observed that the projections of the experts were more optimistic in terms of nuclear power plant deployment up to 2030 than IAEA projections for the same time frame.

It was observed that the considerations by experts in technology user countries addressed in this study for the development and deployment of new nuclear power plants showed several interesting characteristics summarized below:

(a) There was a very high degree of commonality among the considerations and opinions expressed by the experts in all the very diverse countries that were part of this effort;
(b) There were no measurable differences between the considerations and opinions expressed by experts on the relative importance of desired features in countries that could be considered to have experience with nuclear power or those countries considering it for the first time;
(c) A few areas indicated some divergence among experts in the countries.

This publication was prepared by a team of IAEA staff with input from about two hundred experts from the countries addressed in this study. Additional refinements of the information by various methods, such as application of the INPRO methodology to identify gaps, or the collection of a larger scientific sample of additional country specific data would be required in order to analyse comprehensive trends and/or to quantify market demand. In particular the issues of grid capacity and likely available investment based on gross domestic product as they might affect near and long term nuclear expansion projections should be more carefully considered as supplementary information is compiled.

This publication is intended to promote early and frequent dialogue between technology users and technology holders. The timing and availability of innovative technology is an important part of future dialogues, and activities that might enable user consideration of small and medium sized reactors, in addition to the larger reactors that are widely deployed today should be explored. The information presented herein and future refinements should be considered in conjunction with other IAEA publications and in conjunction with the in depth discussion associated with a Member State's strategic planning and preparation for introduction or expansion of nuclear power and the infrastructure, regulatory, institutional, technology, economic and other issues that must be addressed during the, safe, secure, peaceful and transparent deployment of nuclear energy. Appendix II includes lessons learned from previous nuclear power programmes in selected technology holder countries.

1. INTRODUCTION

1.1. BACKGROUND AND OBJECTIVE

The 50th IAEA General Conference resolution (GC (50)/RES/13B) [1] invited "all interested Member States to combine their efforts under the aegis of the Agency in the activities of INPRO Phase 2 in considering the issues of innovative nuclear reactors and fuel cycles systems," and called "on interested Member States to develop, under the auspices of the Agency, nuclear power reactors reflecting the needs of the developing States that choose the nuclear option...". It stressed the need "to establish, in line with national circumstances, common user criteria for such (small and medium) nuclear power reactors including infrastructure developments, domestic legal and regulatory frameworks, provisions for removal and disposal of the spent fuel and flexible financing arrangements". Responding to this GC resolution, an activity called Common User Considerations and Actions for Development and Deployment of Nuclear Power Plants for Developing Countries was established. The first stage of the activity was the identification of the considerations by potential users in developing countries for the deployment of nuclear power plants. The second stage of the activity was dedicated to refining the common user considerations and defining possible actions to be carried out jointly by technology users and technology holders to address these considerations.

The objective of this publication is to present the results of the first stage of the common user considerations activity, which compiled the considerations developed by these potential users. The publication also describes the countries identified as potential users, their characteristics, and the process through which the desired features are formulated.

The presentation of common considerations by the potential users of nuclear power plants in developing countries up to 2050 may have multiple uses, such as to promote dialogue between the potential users and current holders of nuclear energy system technologies, to address near and longer term institutional and infrastructural issues, and/or as the basis for discussions and domestic planning at different milestones during introduction or expansion of a nuclear power programme.

1.2. DEFINITION OF TERMINOLOGY

Some important terms used throughout this publication are defined below.

Common user considerations (CUC): Common considerations or desired features provided by experts in developing countries with an interest and the potential for deploying new nuclear power plants in the next 40 years, together with the rationales, background information, and other supporting material presented in this publication. The features desired by users are presented in Section 4 of this publication, while the other materials are presented in Sections 2, 3 and 5.

Nuclear energy system (NES): This term is used to include nuclear power plants, associated fuel cycle facilities (FCFs) including waste management facilities and nuclear facilities for non-electrical applications, as well as any associated support and services.

Technology user countries or **user countries**: Countries categorized as developing economies according to the World Bank classification in 2006 [3] and having expressed an interest in the introduction or expansion of nuclear energy programmes. Countries with an ongoing large scale nuclear power plant construction programme are not included in the definition of technology user countries. More precise criteria for the categorization of technology user countries are given in Section 1.4.

User: Generally a term to denote one or more of the entities engaging in the building of nuclear energy systems in technology user countries. The term User, beginning with a capital 'U', is mainly used in Section 4 (Desired Features). Examples of the entities are:

(a) Government organizations and legislatures;
(b) Nuclear plant owner/operators;
(c) Project managers;
(d) Nuclear regulatory bodies;
(e) Component manufacturers;
(f) Plant designers and constructors;
(g) Other support institutions — including financial institutions and research and training centres, etc.

Technology holder or **technology suppliers** or **supplier countries**: Countries currently having and using nuclear energy and who are willing to supply nuclear power plants and fuel cycle services, technology, or parts of the nuclear power plants.

Supplier: A term to denote one or more of the entities in the supplier countries engaging in the supply of nuclear power plants and fuel cycle services. The term Supplier, with a capital 'S', is mainly used in Section 4 (Desired Features). Examples of the entities are:

(1) Government organizations and legislators;
(2) Nuclear plant designers/vendors;
(3) Project managers;
(4) Component manufacturers;
(5) Nuclear regulatory bodies;
(6) Fuel designers/vendors;
(7) Fuel cycle service providers;
(8) Other support institutions — including financial institutions, research and training centres, etc.

Desired features **by technology user countries**: As presented in Section 4 of this publication, a series of structured statements representing common characteristics expressed by experts in technology user countries for nuclear power plants and fuel cycle services. The desired features are grouped into seven major issues:

(i) Economics and financing;
(ii) Infrastructure and implementation;
(iii) Safety, environment;
(iv) Waste management;
(v) Proliferation resistance;

(vi) Physical protection;
(vii) Technical specifications.

1.3. SCOPE

The common user considerations presented in this publication are the result of the first stage of the CUC activity, which is the identification of considerations by technology user countries that must be met for nuclear power plants to be deployed in these countries. The CUC activity covers general technical and economic characteristics of nuclear power plants and touches upon fuel cycle options including waste management facilities, non-electrical applications of nuclear power and associated support and services. Issues typically managed by the technology user countries hosting the nuclear power plants, such as legal infrastructure and public acceptance, are not directly included in the CUC. The CUC activity includes considerations for the first nuclear power plant unit to be deployed in a technology user country to the subsequent units deployed within the 40 year time frame. All nuclear energy systems relevant to this time frame are included in the CUC activity, including small and medium reactors (SMR) and non-electrical applications of nuclear energy.

Most of the considerations presented through the CUC report address characteristics and needs for nuclear power plants and fuel cycle to a lesser extent, that are common to all technology user countries. However, a few characteristics and needs are unique to a limited number of countries.

1.4. COUNTRIES ADDRESSED BY THE CUC

The IAEA General Conference resolution requested establishment of the CUC activity to formulate common considerations by the potential users of nuclear energy systems in developing countries. Two attributes are used to define who the technology user countries, the countries addressed by the CUC activity, are. First, they need to meet the definition of 'developing country', and second they need to have expressed an interest related to 'potential use of nuclear energy systems'.

The definition of 'developing economies' by the World Bank List of Economies (July 2006) [3] was adopted. For operational and analytical purposes, the World Bank divides world economies into groups according to 2005 gross national income (GNI) per capita of the economies, calculated using the World Bank Atlas method. Countries with a GNI per capita lower than US $10 725 are characterized as developing economies by the World Bank.

Specifically, the technology user countries are defined as follows:

(a) IAEA Member States;
(b) Gross national income per capita <US $10 725$/year;
(c) Countries that expressed interest or potential interest in introducing nuclear power or countries with operating nuclear power plants wishing to increase the nuclear share to some extent,[3] but without ongoing large scale nuclear power projects (fewer than 4 current nuclear power plant projects).[4]

With the above definition, 54 countries were identified as technology user countries at the beginning of 2007, as shown in Table 1 and Figure 1. This list should be considered as a snapshot in 2007 and could change with time.[5]

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[3] IAEA internal information sources were used to identify these countries as well as other information such as media reports, national statements during the IAEA General Conference, previous IAEA related activities, questions and concerns expressed during IAEA workshops, meetings and seminars and international conferences.

[4] China (5 ongoing projects as of Oct. 2007), India (6 ongoing projects as of Oct. 2007) and other countries with a larger scale of nuclear power projects are excluded for this reason. In addition, both China and India have developed indigenous nuclear technology and are almost in a position of becoming technology suppliers.

[5] In the subsequent, 2007 version of the World Bank list of economies, two of the 54 technology user countries that belonged to the upper middle income group based on the 2006 version moved to the high income group.

TABLE 1. THE 54 COUNTRIES IDENTIFIED AS TECHNOLOGY USER COUNTRIES

Algeria, Angola, Argentina, Armenia, Bangladesh, Belarus, Bolivia, Brazil, Bulgaria, Burkina Faso, Cameroon, Chile, Croatia, Czech Republic, Dominican Republic, Egypt, Estonia, Ethiopia, Georgia, Ghana, Hungary, Indonesia, Islamic Republic of Iran, Jordan, Kazakhstan, Kenya, Latvia, Libyan Arab Jamahiriya, Lithuania, Malaysia, Mexico, Mongolia, Morocco, Namibia, Nigeria, Pakistan, Philippines, Poland, Republic of Moldova, Romania, Senegal, Slovakia, South Africa, Sudan, Syrian Arab Republic, Thailand, Tunisia, Turkey, Ukraine, United Republic of Tanzania, Uruguay, Venezuela, Vietnam and Yemen

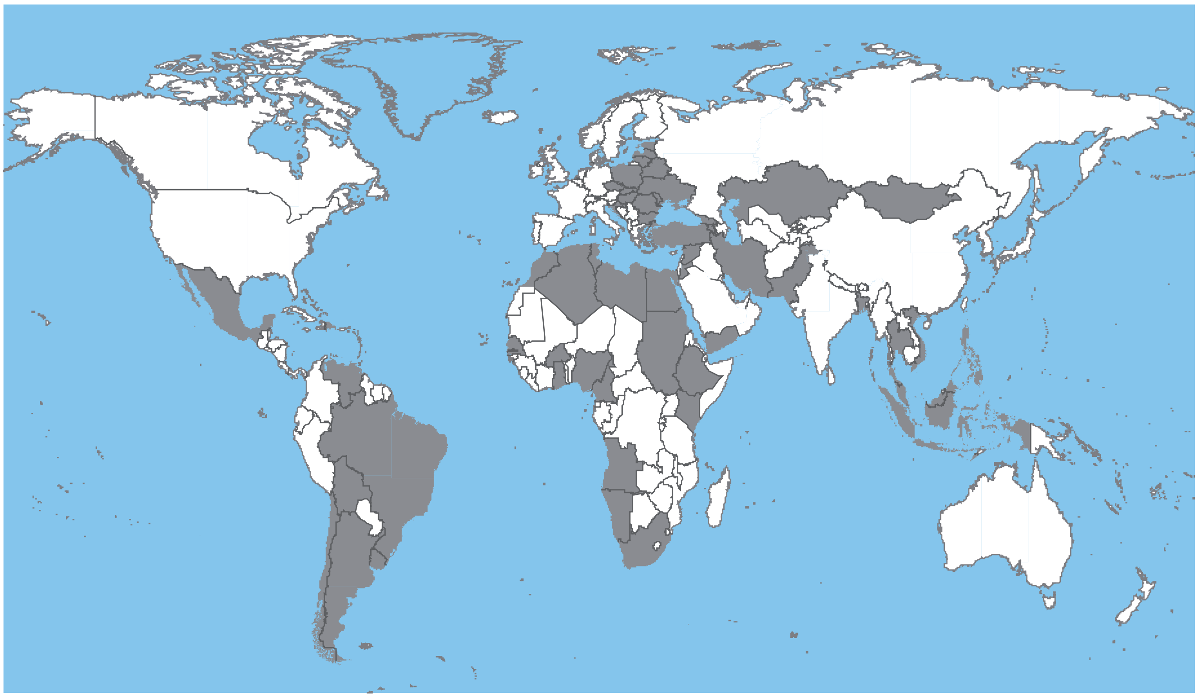

FIG. 1. The 54 countries addressed by the CUC (technology user countries).

1.5. PROCESS FOR DEVELOPMENT OF THE PUBLICATION

The process for the development of this publication was determined by balancing the desire to understand the insight of the considerations by experts in technology user countries through detailed discussions with stakeholders in the countries and by the practical limitation to this approach due to the large number of countries included in the list. As a result, the following two steps were followed:

Step A: Development of a draft set of desired features based on discussions with selected countries representing the characteristics of the technology user countries;
Step B: Compilation of additional feedback to the desired features by technology users.

The key element of step A is a series of detailed discussions with various experts representing stakeholders from a selected number of countries to develop a draft set of considerations. These countries were selected based on a set of guidelines to represent a variety of typical characteristics of technology user countries. Factors considered in the selection guidelines were balanced geographical distribution (countries from Asia, Europe, Africa and Latin America), electric grid size, level of economic development and amounts of natural resources available in the country. These factors were considered to shape their needs and constraints concerning deployment of future nuclear power plants.

A questionnaire was developed to facilitate discussions with experts in these representative countries (see Appendix I, Section I.1). To develop the questionnaire, two existing user requirement documents (European Utility Requirement [14] and EPRI User Requirements Document [15]), INPRO methodology [4] and relevant IAEA-TECDOCs [5–8] were reviewed. Based on these references, relevant issues were included in the questionnaire. Specific sections were dedicated to economics, infrastructure, safety, environment, waste management, proliferation resistance, physical protection and technical requirements.

During the first consultants meeting, held from 5–7 February 2007, potential representative countries were selected based on the guidelines mentioned above. The meeting participants also reviewed and revised the questionnaire, and 85 questions were identified as the most relevant to this study. Finally, a structure for the final report (this publication) was agreed upon.

After negotiations with the permanent missions and government representatives of the potential representative countries selected above, the following 7 countries/consortia agreed to host the CUC team for discussions: Bangladesh, Belarus, Baltic Consortium (Lithuania as a representative, together with Estonia and Poland), Egypt, Indonesia, Malaysia and Mexico.

The CUC team from INPRO (two to three staff each time) visited the seven countries individually from May to August 2007 and had discussions with experts from various stakeholders in the countries to gather different perspectives regarding deployment of future nuclear power plants. These experts included government officials in charge of energy policy and nuclear programmes, nuclear regulatory bodies, researchers from national laboratories and universities, utilities and financial sectors. The content of the discussions was mainly based on, but not limited to, the questionnaire.

Based on the thus identified considerations of the technology user countries visited, the CUC team drafted Sections 3 and 4 of this report in August 2007. The proposed desired features (Section 4) were reviewed and revised during the second consultants meeting, held from 5–7 September 2007, with participants from the 7 countries visited and from eight technology holder countries.

In the subsequent step (step B), a workshop was held with the participants representing a broader group of technology user countries in November 2007. In advance of this workshop, a short questionnaire (see Appendix I, Section I.2) was distributed to the participants to survey future nuclear power plant projections or expectations in their countries and to obtain feedback for the draft considerations by technology users. During the workshop, the draft desired features (Section 4) were reviewed and a general agreement was reached between experts from 32 user countries and 8 technology holder countries.

Among the 54 identified technology user countries, the 35 countries listed in Table 2 contributed about 200 experts to participate in the process in at least one of the following 3 ways:

(1) Detailed discussions with CUC team;
(2) Participation in the workshop held in November 2007;
(3) Participation in a survey by answering a questionnaire for the workshop.

Several technology holder countries have also contributed by providing advice from their perspectives at the two consultants meetings held in February and September 2007, and at the November 2007 workshop. Those countries are Canada, China, France, India, Japan, Republic of Korea, Russian Federation and USA.

TABLE 2. THE 35 USER COUNTRIES THAT PARTICIPATED IN THE PREPARATION OF THIS REPORT

Argentina, Armenia, Bangladesh, Belarus, Brazil, Cameroon, Chile, Croatia, Dominican Republic, Egypt, Estonia, Ethiopia, Georgia, Ghana, Indonesia, Jordan, Kenya, Lithuania, Malaysia, Mexico, Moldova, Mongolia, Namibia, Nigeria, Pakistan, Philippines, Poland, Romania, Sudan, Syrian Arab Republic, Tunisia, Ukraine, Uruguay, Venezuela, Vietnam

1.6. OTHER IAEA RELATED ACTIVITIES

Recently, as the number of countries considering the deployment of additional nuclear energy systems is increasing, more Member States have turned to the IAEA for information and assistance in the preparation of their nuclear power programmes. Several activities have been conducted or enhanced as part of the coordinated effort across the IAEA in providing such assistance. These activities are linked to the CUC activity in a complementary nature, and the major ones are briefly outlined below.

Development of national infrastructure for nuclear power

Infrastructure for nuclear power includes the institutional framework and legislation within which nuclear energy systems operate, as well as industrial, economic, social, technical and scientific capabilities to enable the secure and efficient development, management and operation of the systems. In 2007 the IAEA published a brochure on Considerations to Launch a Nuclear Power Programme [9] to describe three phases of preparation for the development of nuclear power programmes. IAEA Nuclear Energy Series No. NG-G-3.1, Milestones in the Development of a National Infrastructure for Nuclear Power, [10], also published in 2007, identifies the levels of achievement in infrastructures that need to be reached at the end of the three preparation phases.

Assessment of technologies

The INPRO methodology [11] was established to estimate the benefits from the use of innovative nuclear energy systems for long term sustainable development in the context of economics, safety, environment, waste management, proliferation resistance, physical protection and infrastructure. It may help technology users to evaluate and screen the innovative nuclear energy systems and consider scenarios for long term deployment of nuclear power. The Innovative Nuclear Systems in INPRO may include innovative as well as evolutionary components. The CUC activity adopted the framework of the INPRO methodology subject areas to structure the considerations. However a systematic approach including all the INPRO user requirements was not applied. The purpose of the CUC activity is focused on the concerns of users with regard to deployment of near term nuclear power plants, assuming that the decision to initiate a nuclear power programme had already been made in these countries. The process and studies to reach this decision (which may include a holistic assessment using the INPRO methodology) are not covered by the CUC activity.

For the short term, the IAEA has begun to develop guidelines on how to conduct a technology assessment. It is an exercise conducted by a country to determine which nuclear power plant designs could be better suited for the country so that they should be retained for further evaluation for introduction to the country. It provides the technical basis for a decision to launch a national programme for deployment of nuclear energy systems, as well as the technical rationale for several elements of infrastructure development, such as assessment of national capabilities, degree of national participation in the deployment of the nuclear energy system, and fuel cycle strategy. The technology assessment could also be the technical basis for preparation of bid documents and bid evaluation.

Implementation of safety and security

IAEA Safety Standards [12] issued since 1997 in the IAEA Safety Standards Series are designated as Safety Fundamentals, Safety Requirements or Safety Guides. The Safety Requirements and Safety Guides are divided into thematic areas and facilities and activities. The IAEA Safety Standards deal with all the safety related aspects to be considered for the whole duration of a nuclear power programme (management systems, siting, design of facilities, regulatory and licensing process, commissioning, operation and maintenance, decommissioning, fuel cycle, spent fuel, and waste management and storage).

Several publications have been issued by the IAEA [13] on recommendations and guidance related to nuclear security in areas including infrastructure to protect nuclear and other radioactive materials from theft and diversion, protection of nuclear installations, and transport against sabotage and other malicious acts, and measures to combat illicit trafficking of nuclear and other radioactive materials.

Common technologies and issues for small and medium size reactors

Small and medium sized reactors (SMRs) may provide an attractive and affordable nuclear power option for many developing countries with small electric grids, insufficient infrastructure and limited investment capability. Multi-module power plants with SMRs may offer energy production flexibility that energy market deregulation might call for in the future in many countries. SMRs are also of particular interest for co-generation and many advanced future process heat applications. Some SMR designs may reduce obligations of the user for spent fuel and waste management and possibly offer greater non-proliferation assurances to the international community. SMRs have many common technology development issues related to competitiveness and enhanced proliferation resistance and plant security in different energy markets. Reflecting the interest and support from member states, the IAEA carries out a regular budget project that has the objective of facilitating the development of key enabling technologies and the resolution of enabling infrastructure issues common to innovative SMRs of various types. As part of this project, the IAEA periodically produces and updates status reports and other publications on design and technology development for such reactors [5, 6, 8]. The activities also include coordinated research projects (CRP) on important topics of design and technology development and assessment of various SMR options.

1.7. CLARIFICATIONS AND LIMITATIONS ON STAGE 1 OF THE CUC ACTIVITY

The process for stage 1 of the CUC activity and approach to data collection was developed taking into account the short time frame and available resources, as discussed in detail in Appendix I. The basic nuclear growth data provided in this publication has been compiled from public sources for 54 countries, and supplemented with a simplified questionnaire focusing mainly on projections for nuclear power plant deployment over time. Additional characteristics and expectations regarding nuclear power plant deployment from experts of the 35 countries that participated were collected through a questionnaire. The data for Section 4 were collected during seven separate country visits by the Secretariat in 2007. The data collected does not represent a scientific sample, nor should it be considered comprehensive. It is a voluntary and diverse survey of individual experts expressing their opinions but not necessarily the official national position. The group of experts had many levels of expertise and many different perspectives and the countries they came from were at different levels of technology and overall infrastructure development, with varying levels of nuclear power development history and experience, and a wide range of access to qualified domestic human resources. Their inputs were all considered equally qualified and no attempt was made to rank or weight the responses. The experts are all from technology user countries that have developing economies as defined by the World Bank and that have expressed an interest in deploying new nuclear power programmes or expanding existing ones. Countries that already had significant ongoing nuclear programmes (e.g. China and India) were excluded from the study.

The information offered in this report, particularly the desired features given in Section 4, will be useful to a number of stakeholders and decision makers as they consider the development of nuclear power plants and associated fuel cycle facilities. However, this study should not be considered to be a detailed scientific analysis or the result of a market study, and should not be used to derive industry wide trends or conclusions. Since innovation and newer reactor designs that have not been deployed were not discussed in any detail, it is likely that the projections and reactor technology selections for future deployment were based on currently available, licensed, and deployed designs and newer designs. In particular small and medium sized reactors under development by technology holders may not have been considered fully viable options. It is considered to be a snapshot of the current situation as expressed by this group of experts and it is organized according to the traditional INPRO technical areas, but it is not the result of the application of the holistic approach inherent to the INPRO methodology, since the full spectrum of innovative reactors and fuel cycles was not considered. Additional refinements of the information by various methods, such as application of the INPRO methodology to identify gaps, or the collection of a larger scientific sample of additional country specific data would be required to analyse comprehensive trends and/or quantify market demand. In particular the issues of grid capacity, regional synergies and available investment based on gross domestic product as they might affect near and long term nuclear expansion projections should be more carefully considered as supplementary information is compiled.

This publication is intended to promote early and frequent dialogue between technology users and technology holders. In December 2006 the INPRO Steering Committee agreed to support the expansion of the original scope of the study to include large reactors as well as small and medium sized reactors. The timing and availability of innovative technology will be an important part of future dialogues, and activities should be implemented that might enable technology user countries to consider acquiring small and medium sized reactors, in addition to the larger reactors that are widely deployed today.

The information presented herein and future refinements should be considered in conjunction with other IAEA publications and in conjunction with the in depth discussion and assessment associated with a Member State's strategic planning and preparation for introduction or expansion of nuclear power. Other topics that should be addressed during the safe, secure, proliferation resistant, and safeguarded deployment of nuclear energy include infrastructure readiness, regulatory process, institutional functions, technology selection, and economic comparison.

It should also be noted that the terms 'desired features' and 'considerations' were selected during Member State review as a way to avoid confusion with the originally proposed term 'requirements', which has specific meaning as defined in the IAEA safety glossary and used extensively in the INPRO methodology.

1.8. OUTLINE

The following is an overview on the content of the following sections.

Section 2 describes characteristics of technology user countries, including economics, population, electricity generation and its future trends.

Section 3 presents an analysis of the main drivers and impediments for technology user countries for deployment of nuclear energy systems, with special focus on the analysis of the discussion results with experts in the 7 countries visited by the CUC team. Section 3 provides a basis for defining the desired features and their rationales presented in Section 4. Section 4 presents the set of desired features from experts in technology user countries Section 5 summarizes observations drawn from the CUC activity. Appendix I describes in detail the process for development of the Common user considerations. Appendix II is a collection of papers on the experiences of Argentina, Canada, Finland, Japan, Republic of Korea and Spain in the introduction of nuclear power. Each case describes how the country introduced nuclear power, what the user requirements and the major considerations were at that time.

2. CHARACTERISTICS OF USER COUNTRIES

2.1. INTRODUCTION

The CUC activity addresses countries defined in Section 1.4. These countries are classified as developing economies according to the World Bank definition and are considered to be users and potential users of nuclear power to some extent, but do not have large scale current construction projects. Countries such as China and India, which have more than 4 nuclear power projects under construction and are almost in a position to become technology suppliers, have been excluded from this category.

This section gives objective information regarding the future nuclear power potential in these countries. The objectives are to examine:

(a) The general characteristics of these countries in terms of economics, population and electricity use;
(b) Projections on electricity generating capacities in these countries;
(c) Future nuclear power potential.

In order to facilitate an appropriate understanding of the results of this study, the countries of the world are categorized into four groups as described below:

Group 1: User countries — low and middle per capita income countries that have expressed interest in nuclear power, but do not have large scale nuclear power plant construction projects:
Algeria, Angola, Argentina, Armenia, Bangladesh, Belarus, Bolivia, Brazil, Bulgaria, Burkina Faso, Cameroon, Chile, Croatia, Czech Republic, Dominican Republic, Egypt, Estonia, Ethiopia, Georgia, Ghana, Hungary, Indonesia, Islamic Republic of Iran, Jordan, Kazakhstan, Kenya, Latvia, Libyan Arab Jamahiriya, Lithuania, Malaysia, Mexico, Moldova, Mongolia, Morocco, Namibia, Nigeria, Pakistan, Philippines, Poland, Romania, Senegal, Slovakia, South Africa, Sudan, Syrian Arab Republic, United Republic of Tanzania, Thailand, Tunisia, Turkey, Ukraine, Uruguay, Venezuela, Vietnam and Yemen

Group 2: Low and middle per capita income countries including China and India that currently have large scale nuclear power plant construction projects (≥4 projects)

Group 3: Low and middle per capita income countries that have not expressed interest in the use of nuclear power

Group 4: High per capita income countries

2.2. ECONOMICS AND POPULATION CHARACTERISTICS

World Bank data [16–19][6] and US DOE data [20, 21] were used. They show that user countries account for:

(a) About 34% of the world's population (2005),
(b) 13% of the world's gross domestic product (2006);
(c) 19% of the world's installed electricity generating capacity (2005). It is estimated that these countries will represent about 23% of the world's electricity generating capacity by 2030.

2.2.1. Economic aspects

(a) Distribution among user countries

The per capita gross national income (GNI) (2006) in the user countries ranges from US $180 to US $12 680 and the gross domestic product ranges from US $2.7 billion to US $1068 billion.

Figure 2 shows the per capita GNI levels among these countries. It may be observed that 19 countries out of the 54 (35%) have a GNI above US $4000 per capita (2006). Figure 3 shows the gross domestic product distribution among the user countries. Nine countries have a gross domestic product above US $200 billion, 12 countries are in the range of US $100 to US $200 billion and three countries have a gross domestic product between US $60 billion and US $100 billion. Thirty countries (about 56% of the user countries), have a gross domestic product of less than US $60 billion.

Figure 4 shows the cumulative gross domestic product curve for the user countries. It may be observed that 18 countries account for 80% of the total gross domestic product for the user countries.

Figure 5 shows the annual gross domestic product growth distribution among the user countries. The annual growth rate in 39 countries out of 54 (72%) exceeds 4%.

[6] In the discussion of this section, the 2007 version with updated data was used.

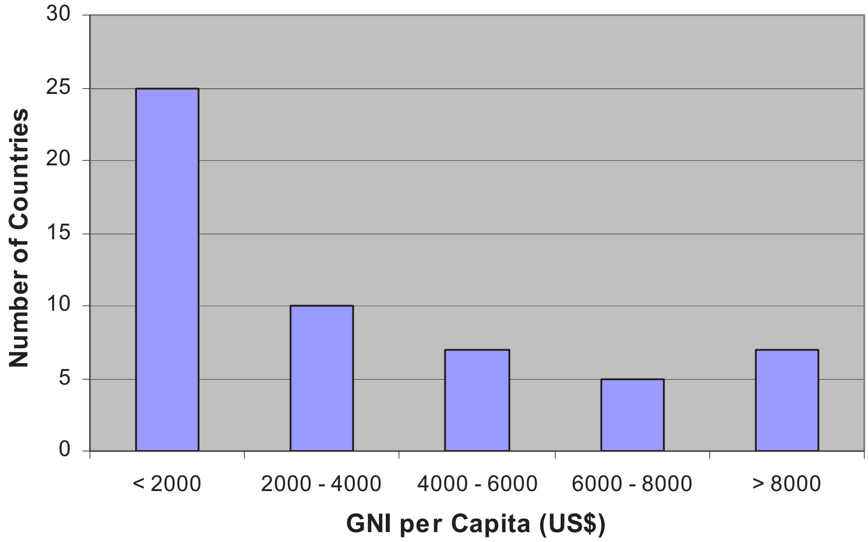

FIG. 2. Per capita GNI (2006) levels among the user countries (based on data from Ref. [22]).

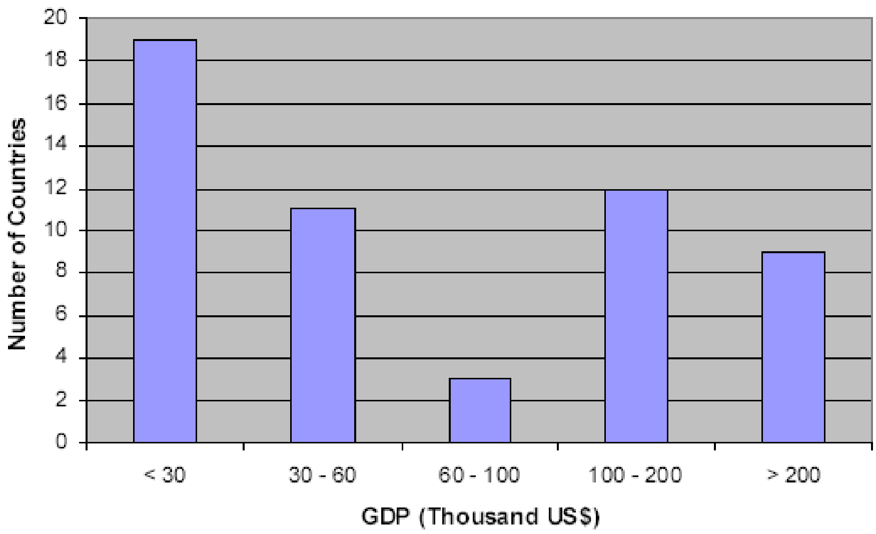

FIG. 3. Gross domestic product distribution among user countries (based on data from Ref. [17]).

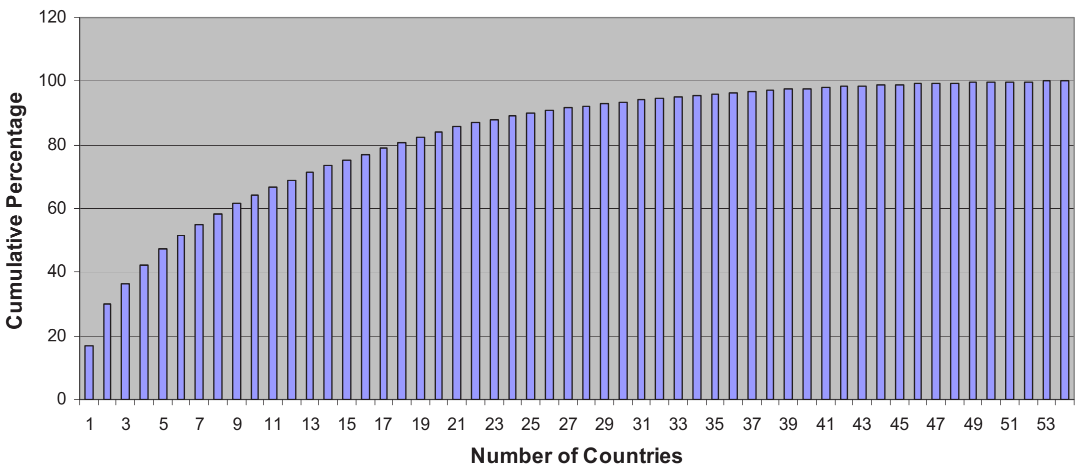

FIG. 4. Cumulative gross domestic product curve for the user countries (evaluated based on data from Ref. [17]).

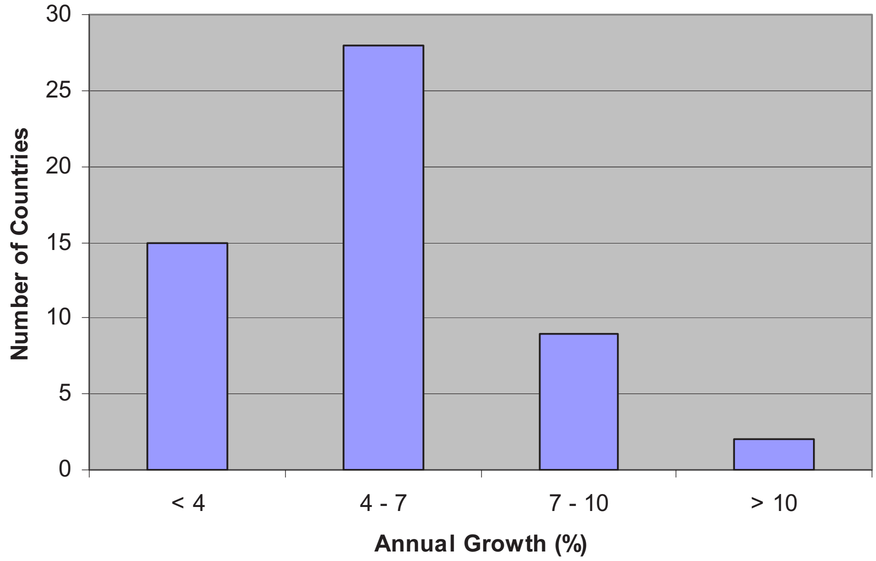

FIG. 5. Annual gross domestic product growth distribution among user countries (based on data from Ref. [17]).

(b) Comparison with other groups

Figure 6 gives a comparison of the gross domestic product among the four groups of countries defined in Section 2.1. A significant observation is that the total gross domestic product of the user countries is US $6.354 trillion, which is 13.4% of the world total. It is the second largest share after that of Group 4. The average gross domestic product growth rates for the four groups are shown in Fig. 7.

Group 1 (user countries) has a growth rate of about 4%, which is nearly double that of Group 4 (high income countries).

2.2.2. Population characteristics

(a) Distribution among user countries

The population distribution among the user countries is shown in Fig. 8. It may be observed that 22 of the 54 countries have a population above 30 million. The population of 17 countries is below 10 million. Another 15 countries have populations between 10 and 30 million.

Figure 9 shows the cumulative population of the user countries. The 54 countries are sorted in descending order of their population. It is observed that 19 countries of the 54 (35%) account for 80% of the total population of user countries.

Figure 10 shows the annual population growth distribution among the user countries. The annual growth rate in 28 countries out of 54 (52%) is seen to exceed 1%.

(b) Comparison with other groups

Figure 11 shows the population distribution among the four groups of countries.

It may be seen from Fig. 11 that the total population of Group 1 is about 2.2 billion (34% of the world total).

The population weighted average growth rate of the population in the four groups of countries is shown in Fig. 12. It is seen that the user countries have a population growth rate that is 60% higher than that of Group 2 and more than 200% higher than that of Group 4.

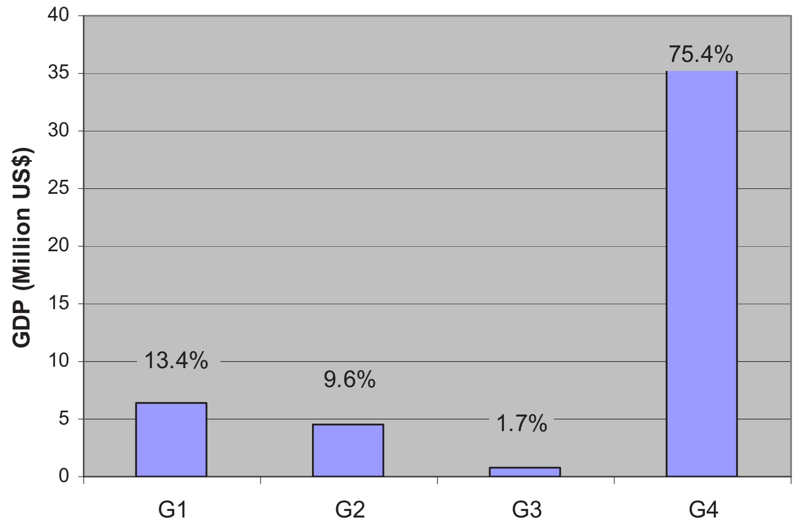

FIG. 6. Gross domestic product distribution as a percentage of the world total among the four groups of countries (based on data from Ref. [17]).

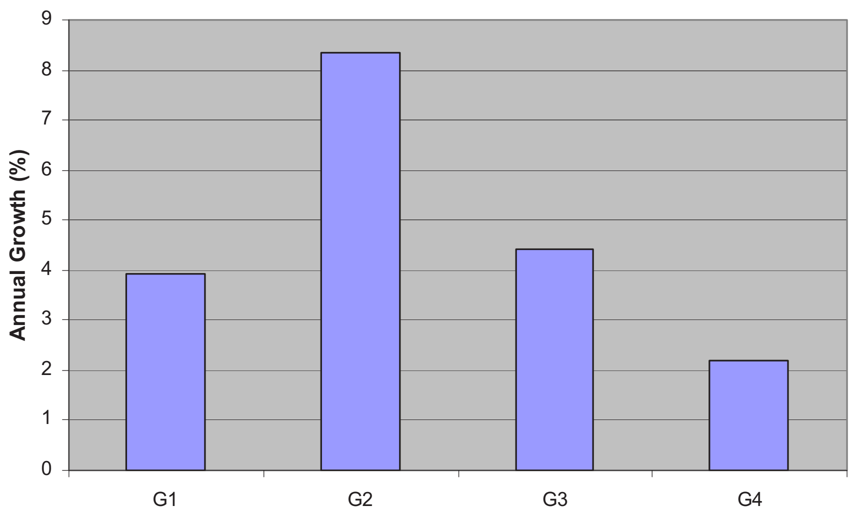

FIG. 7. Average growth rates for the four groups of countries (based on data from Refs [17, 23]).

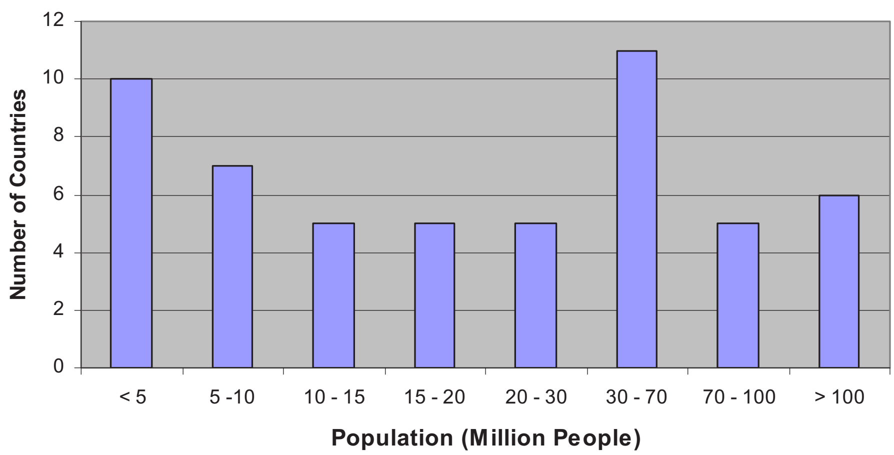

FIG. 8. Population distribution among the user countries (evaluated based on data from Ref. [24]).

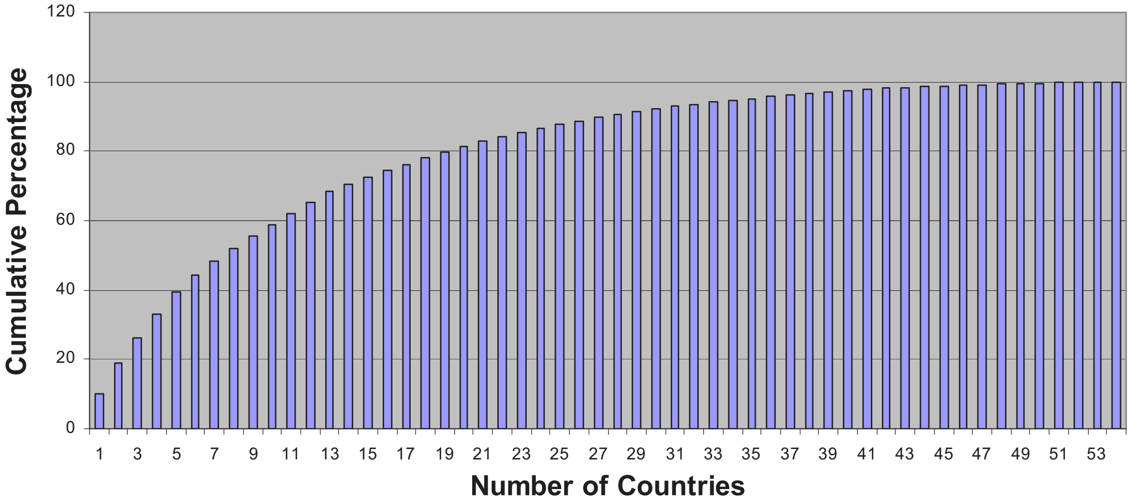

FIG. 9. Cumulative population of the user countries (based on data from Ref. [24]).

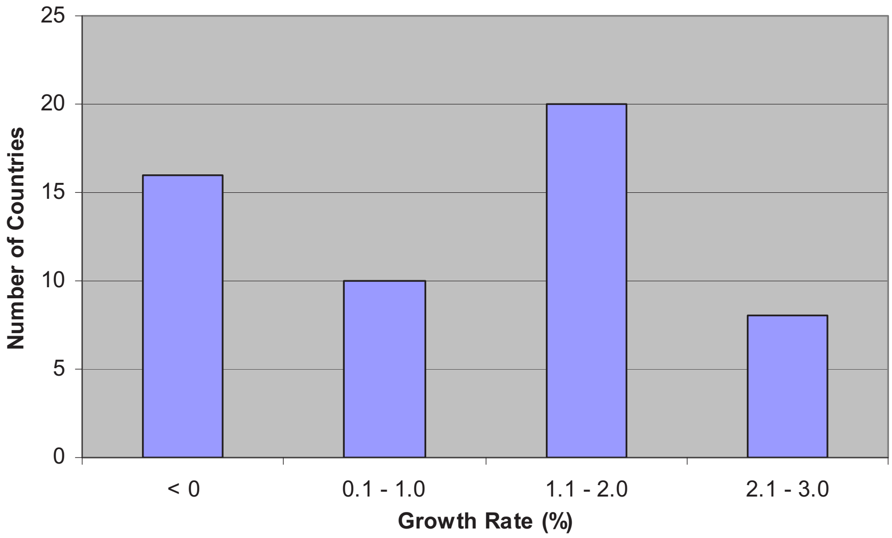

FIG. 10. Population growth rate distribution among the user countries (evaluated based on data from Ref. [24]).

2.3. ELECTRICITY GENERATION — CURRENT STATUS AND PROJECTIONS

2.3.1. Introduction

The World Energy Outlook 2006 [25], published by the International Energy Agency (IEA) projects a 53% increase in global primary energy consumption between now and 2030 at an average annual rate of 1.6%, based on the assumption that current consumption trends and government policies will continue for the next two decades. The IEA projections indicate that more than 70% of that increased consumption will occur in developing countries including China and India.

Projections made by the Energy Information Administration (EIA) of the US DOE are very similar to those of the IEA. The International Energy Outlook 2007 (IEO2007) [20] published by the EIA, in its reference

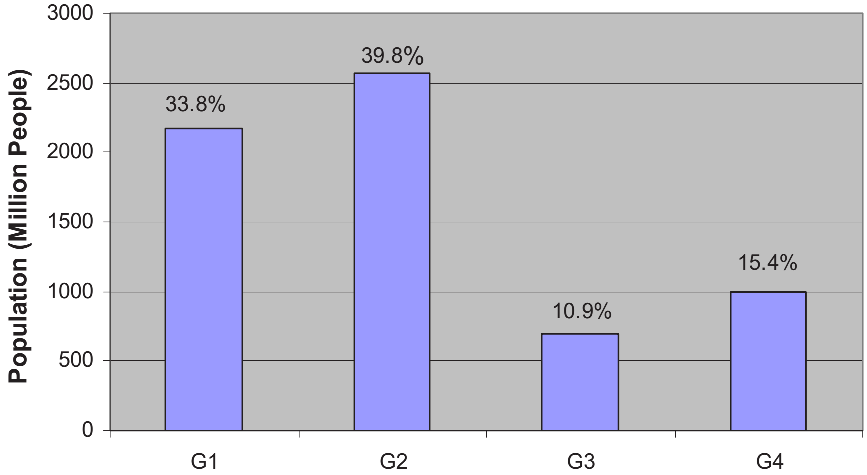

FIG. 11. Population distribution among the four groups of countries (evaluated based on data from Ref. [18]).

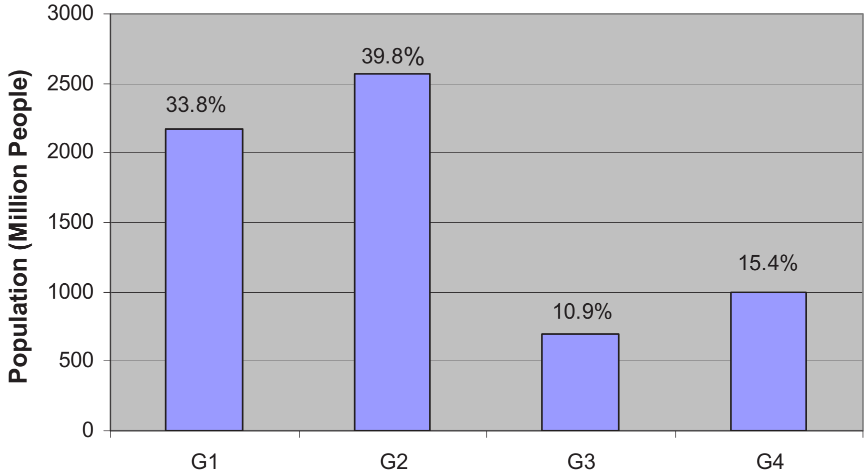

FIG. 12. Average population growth rates in the four groups (evaluated based on data from Refs [18, 24]).

case, projects a growth of 57% in world marketed[7] energy consumption over the period 2004 to 2030. The reference case indicates that non-OECD energy demand will increase by 95%, as compared with an increase of 24% in OECD countries as shown in Fig. 13. The robust growth in demand among the non-OECD nations is largely the result of strong projected economic growth in several developing countries.

2.3.2. Present status of electricity generating capacity

Discussions on the electricity generating capacity in this and the following sections are made based on the US DOE/EIA data [20, 21].

[7] 'Marketed' means bought and sold on the marketplace.

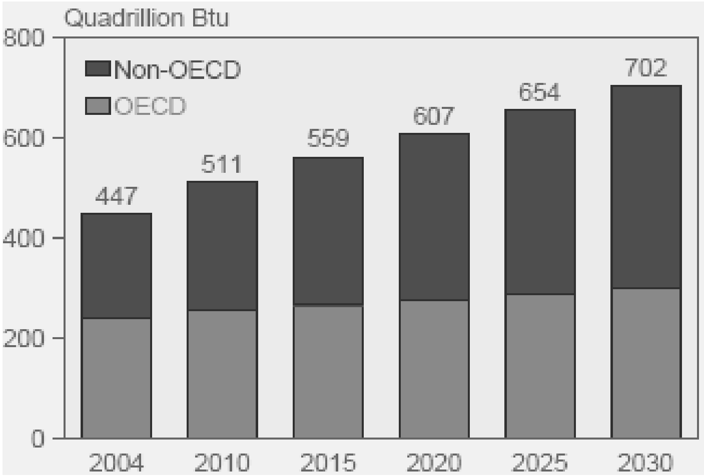

FIG. 13. World marketed energy consumption, 2004–2030
(Source: IEO2007 Report published by the EIA of the US DOE, May 2007).

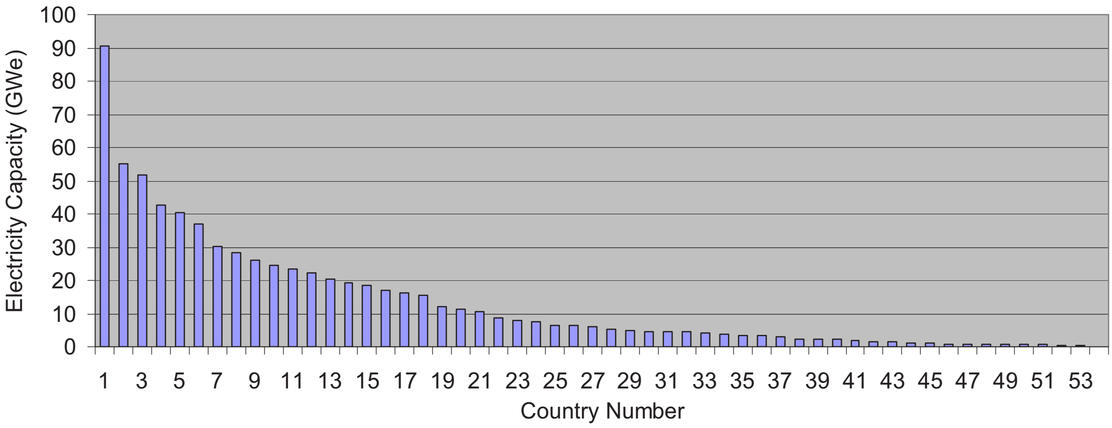

FIG. 14. Installed electricity capacity distribution among user countries (based on data from Ref. [21]).

(a) Distribution among user countries

The installed electricity capacities of the user countries are shown in Fig. 14 in descending order. The installed capacities range from a little over 90 GW(e) to near zero values.

The total installed capacity in user countries is about 700 GW(e). Distribution of annual electricity capacity growth rates (average for the period 2000–2005) among the user countries is shown in Fig. 15. The electricity capacity growth rates of 21 countries are more than 4%.

Figure 16 shows the cumulative electricity capacity in the user countries, which are ranked as shown in Fig. 14.

It may be observed that the first 17 countries (31% of the user countries) account for 80% of the total installed capacity in this group. The remaining 36 countries account for 20% of the total capacity, which is about 140 GW(e).

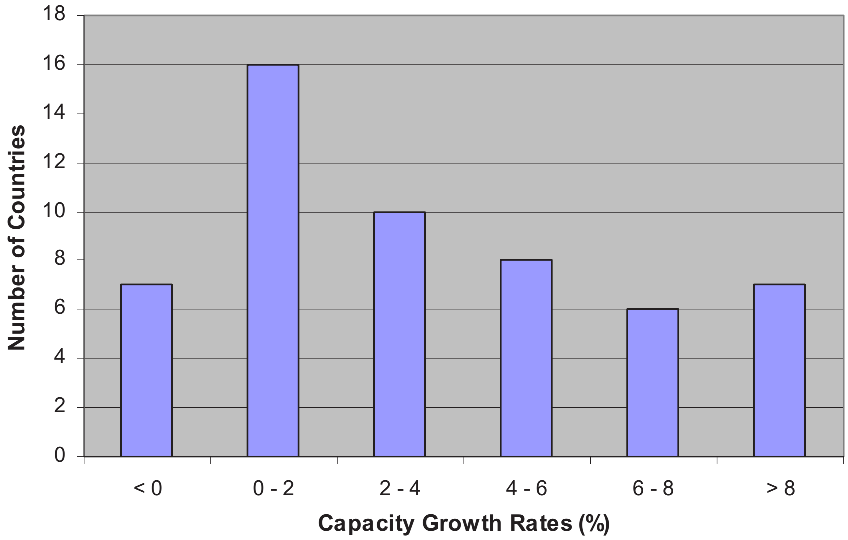

FIG. 15. Distribution of installed electricity capacity growth rates among the user countries (based on data from Ref. [21]).

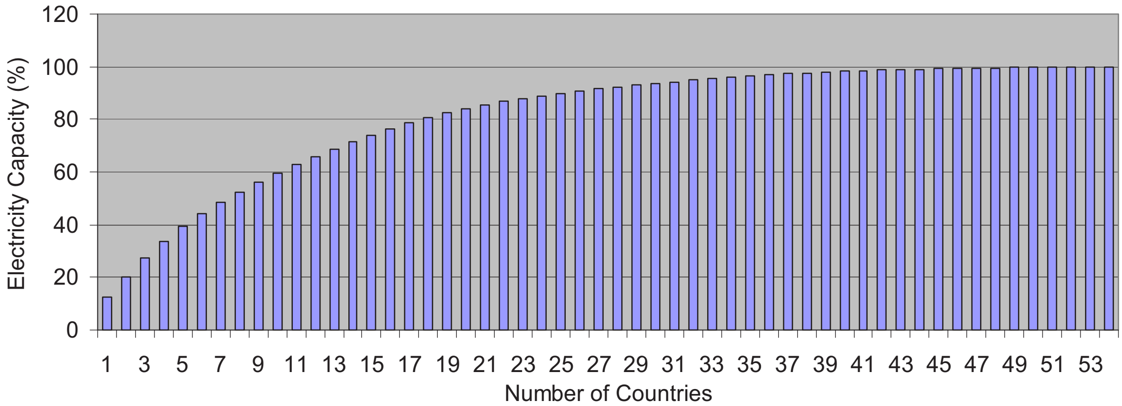

FIG. 16. Cumulative installed electricity capacity in the user countries (evaluated based on data from Ref. [21]).

(b) Comparison with other groups

Present installed capacity for electricity generation in the four groups of countries (based on data from Ref. [21]) is shown in Fig. 17. It is seen that the total installed capacity in Group 1 is about 19% of that of the world total. The projected average growth rates weighted by the installed capacities (based on [21]) are shown in Fig. 18. It is observed that Group 1 is experiencing a significant installed capacity growth rate, which is higher than that of Group 4 and is about 70% of the growth rate of Group 2.

2.3.3. Projection of electricity generating capacity

The projected capacities by 2030 for the 3 groups of countries shown in Figs 19 and 20 were estimated based on the IEO2007 report published by the US DOE [20]. The IEO2007 report contains projected capacities by 2030 for several specific countries and average annual growth rates (2004–2030) for each region as shown in Table 3. The data available for specific countries was used directly and for other countries, region-wise average

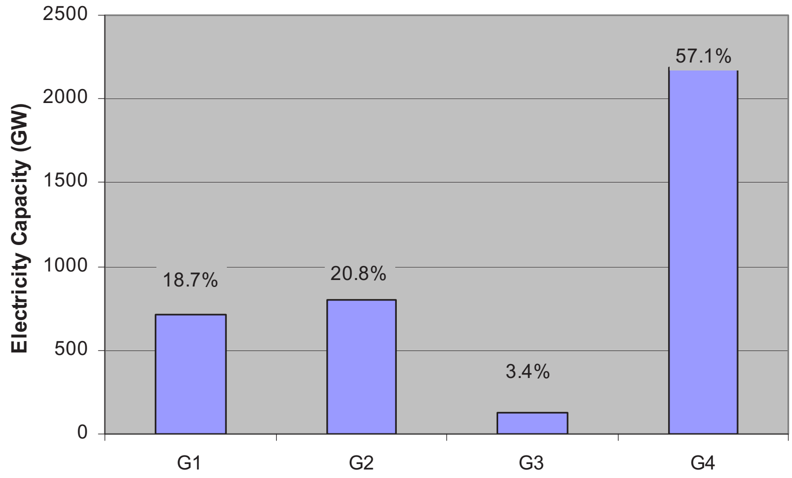

FIG. 17. Installed electricity capacities in the four groups (evaluated based on data from Ref. [21]).

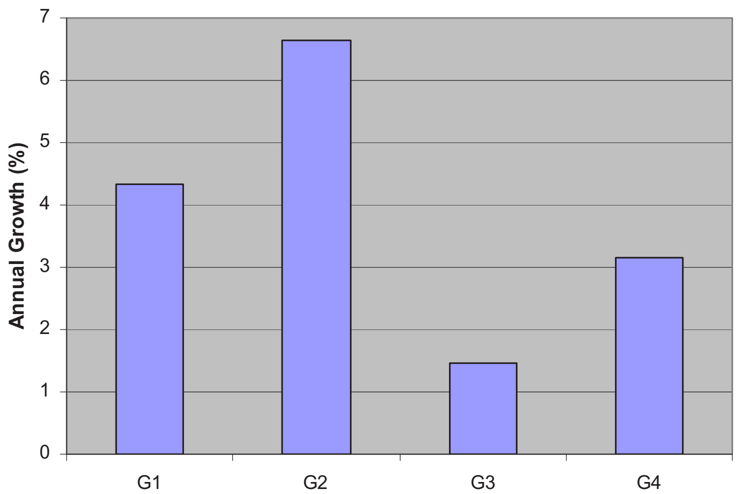

FIG. 18. Average growth rates weighted by the installed capacities (based on data from Ref. [21]).

annual growth rates were used to estimate future capacities for individual countries. Then these values were aggregated for the four groups of countries.

Figures 19 and 20 show the projections of total electricity generating capacities in 2030 and addition of electricity generation capacities between 2005 and 2030, for the four groups.

From Fig. 20 it may be seen that the capacity addition for electricity generation in Group 1 user countries between 2005 and 2030 is about 660 GW(e), which is about 31% of the world total.

2.3.4. Projection of nuclear power generating capacity (IAEA data)

The IAEA estimates nuclear capacity trends in the future and publishes them annually as Reference Data Series No. 1. In the 2007 version [26], the future growth of nuclear power up to the year 2030 is presented as low and high estimates in order to encompass the uncertainties associated with the future. The nuclear generating capacity estimates are derived in a country by country 'bottom up' approach. These data are established by a group of consultants each year and are based upon a review of nuclear power projections and programmes in the Member States. This analysis takes into consideration the replacement of retired nuclear power plants as well as new construction to estimate total nuclear power plant capacity. In this exercise, confidentiality of individual country data is maintained and only regionally aggregated values are published. The analysis in this section was

TABLE 3. BASIC DATA FOR INSTALLED GENERATING CAPACITY PROJECTIONS BY 2030 [20]

Projection on installed generating capacity for specific countries in 2030 (GW(e))	
Australia/New Zealand	81
Brazil	204
Canada	155
China	1014
India	296
Japan	289
Rep. of Korea	94
Mexico	104
Russian Federation	312
United States of America	1159
Expected installed generating capacity growth between 2004–2030 (per cent per annum)	
OECD Europe	0.8
Non-OECD Europe and Eurasia	1.8
Non-OECD Asia	3.5
Middle East	2.6
Africa	3.4
Central and South America	2.5

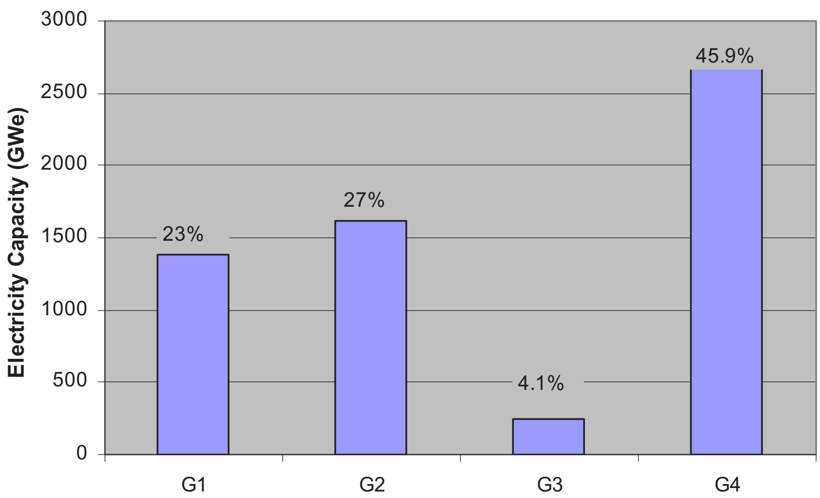

FIG. 19. Projected electricity generation capacities by 2030 in the four groups of countries.

performed by the IAEA by reaggregating country data for the four different groups of countries defined in Section 2.1.

(a) Distribution among user countries

According to the IAEA PRIS database, as of October 2007 13 out of 54 user countries have 46 nuclear power plant units in operation, with a total capacity of about 33.4 GW(e), as shown in Table 4 below.

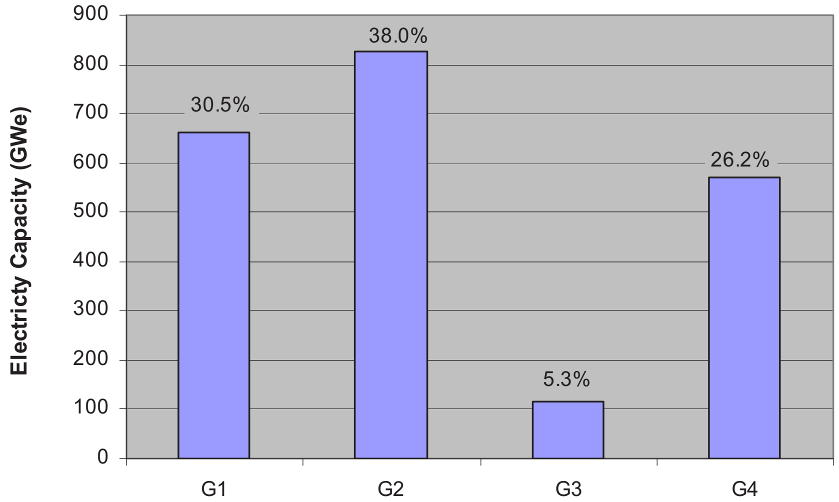

FIG. 20. Projection of electricity capacity additions in the four groups of countries (2005–2030).

TABLE 4. NUCLEAR POWER PLANT UNITS IN OPERATION IN USER COUNTRIES

Country	Number of nuclear power plant units	Corresponding capacity (GW(e))
Argentina	2	1
Armenia	1	0.4
Brazil	2	2
Bulgaria	2	2
Czech Republic	6	3.7
Hungary	4	1.9
Lithuania	1	1.3
Mexico	2	1.4
Pakistan	2	0.5
Romania	2	1.4
Slovakia	5	2.2
South Africa	2	1.9
Ukraine	15	13.8
Total	46	33.4

A total of seven nuclear power plant units are under construction — two each in Bulgaria and Ukraine, and one each in Argentina, the Islamic Republic of Iran and Pakistan.

Table 5 summarizes the results of the IAEA analysis, which shows that by 2030 the total installed nuclear capacity in the user countries would be about 104 GW(e) and 47 GW(e) under the high and the low estimates, respectively. The number of nuclear units corresponding to these figures are 132 and 58, respectively. The new nuclear capacity additions up to 2030, including the replacement of retired nuclear power plants, would be about 76 GW(e) (94 units) and 26 GW(e) (29 units), respectively.

TABLE 5. RESULTS OF THE IAEA ANALYSIS ON PROJECTION OF USER COUNTRIES IN 2030

		High estimates	Low estimates
Total	Installed capacity	104 GW(e)	47 GW(e)
	Number of units	132	58
New construction	Installed capacity	76 GW(e)	26 GW(e)
	Number of units	94	29

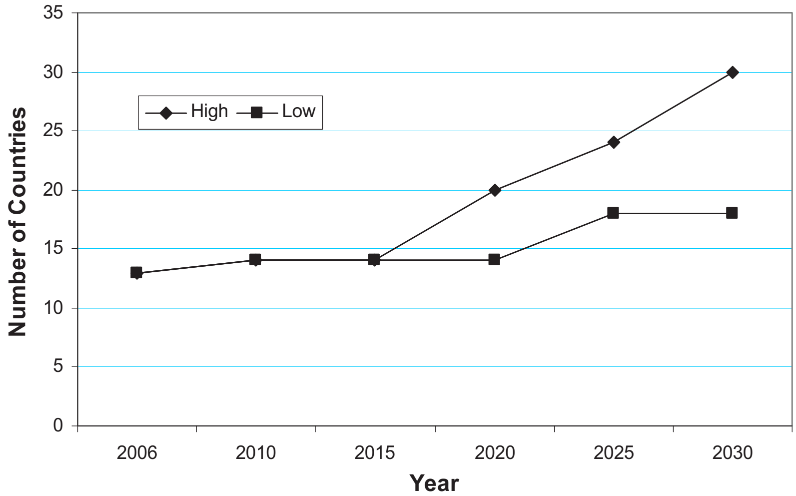

FIG. 21. Projection of the number countries with nuclear power plants among the user countries.

Figure 21 shows the projected number of countries among the user countries to have nuclear power plants in the future, which is expected to be more than doubled (from 13 to 30) in the high estimate, whereas in the low estimate the increase in the number of nuclear countries would be limited to 5 (from 13 to 18). Twenty-four countries in the high estimates and 36 countries in the low estimates are not expected to introduce nuclear power plants by 2030.

Figure 22 shows the high estimates of installed nuclear capacities in 2030 in the user countries as cumulative values of individual country capacities arranged in descending order. It may be observed that about one quarter of the user countries would account for 80% of the total installed capacity in 2030, another quarter would account for the remaining 20%. About 45% of the user countries are not expected to have installed nuclear capacity by 2030.

(b) Comparison with other groups

The high and low estimates of the projected total nuclear installed capacities in the three groups by 2030 are shown in Figs 23 and 24, respectively. The worldwide total nuclear installed capacity by 2030 would be about 740 GW(e) in the high estimates and about 480 GW(e) in the low estimates, of which the user countries would account for 14.1% (104 GW(e)) and 9.9% (47 GW(e)), respectively.

The high and low estimates of the projected total number of nuclear power plant units in the three groups by 2030 are shown in Figs 25 and 26, respectively. The total number of nuclear units in the world by 2030 is estimated to reach 761 units in the high estimates and 506 units in the low estimates, of which the user countries would account for 17.3% (132 units) and 11.5% (58 units), respectively.

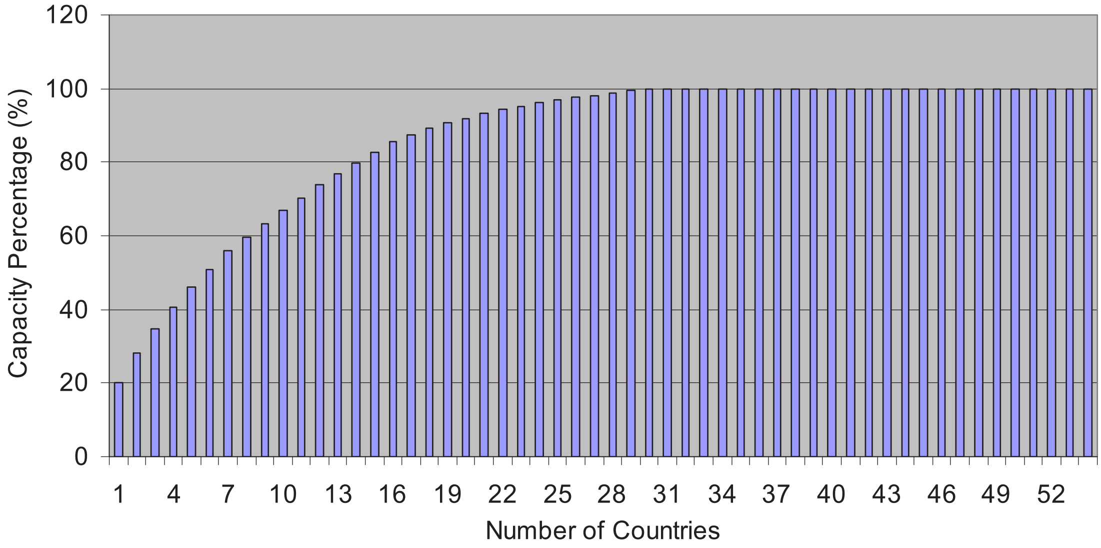

FIG. 22. Projection of cumulative installed nuclear capacities in user countries by 2030 (high estimates).

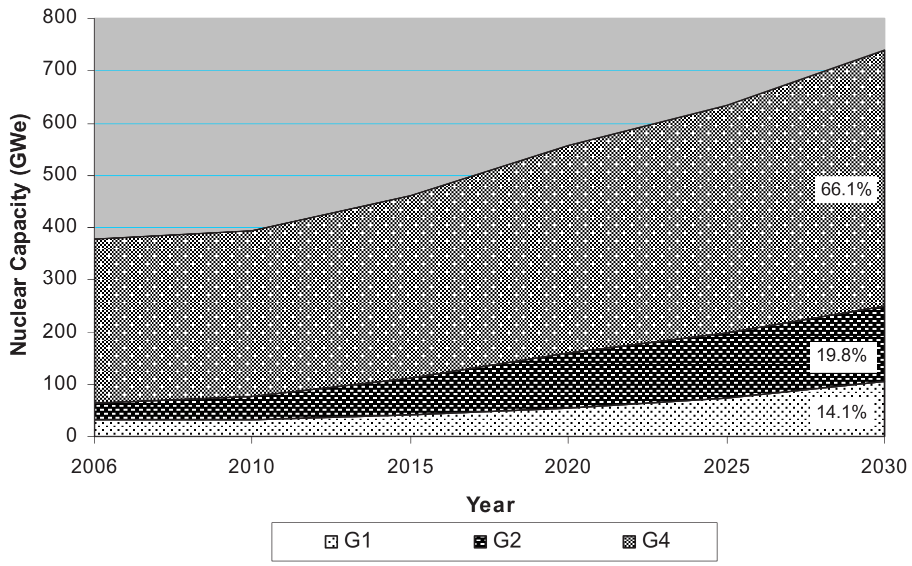

FIG. 23. Projection of total nuclear installed capacities in the three groups by 2030 (high estimates).

With regard to projected new construction of nuclear power plants by 2030, the high and low estimates of new nuclear capacity additions and the corresponding numbers of units in the three groups are shown in Figs 27–29. The world total for new nuclear capacity by 2030 is estimated to be about 410 GW(e) (397 units) in the high estimates and about 205 GW(e) (205 units) in the low estimates. The share of user countries would be 19% of the new capacity (24% of the nuclear power plant units) in the high estimates and 13% of the new capacity (14% of the nuclear power plant units) in the low estimates.

2.3.5. Results of the CUC survey

For the CUC workshop held in November 2007 the workshop participants were requested to answer a questionnaire (see Appendix I, Section I.2) regarding their national plans or expectations of nuclear power plant deployment in terms of both total capacity in GW(e) and also unit capacity sizes by 2025, 2040 and 2050. National experts from thirty-one countries responded to this request.

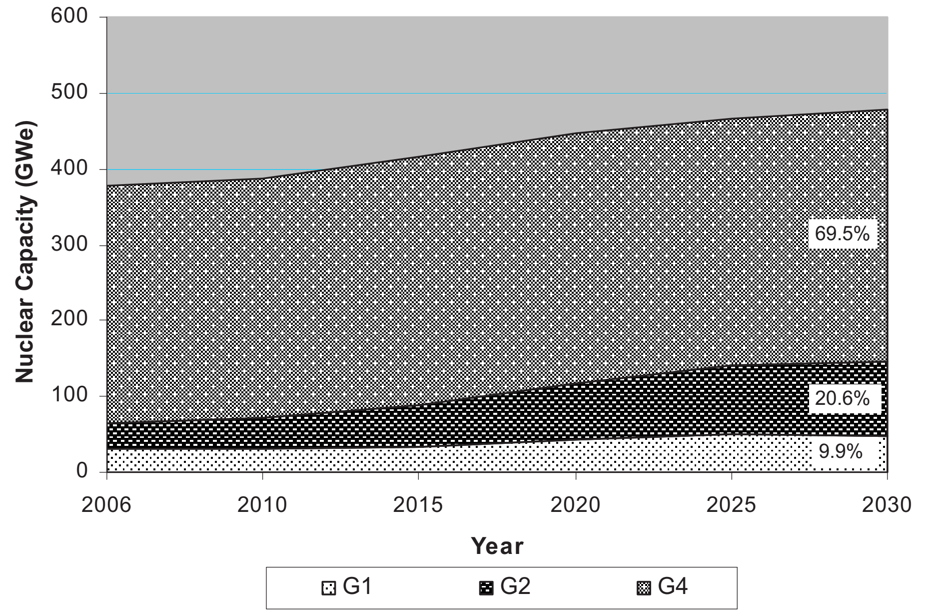

FIG. 24. Projection of total nuclear installed capacities in the three groups by 2030 (low estimates).

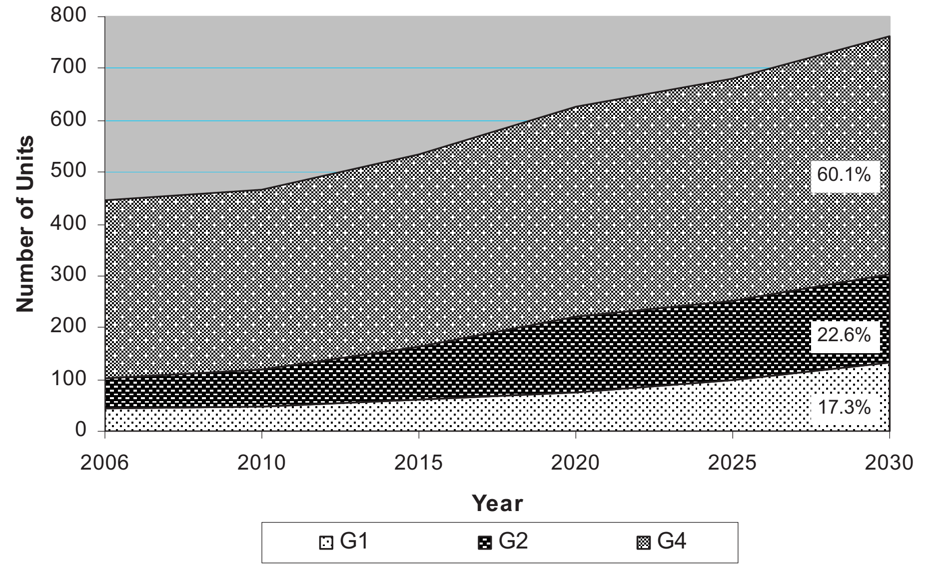

FIG. 25. Projection of total nuclear power plant units in the three groups by 2030 (high estimates).

Table 6 shows the numbers of user countries expecting to install nuclear power plants according to their experts, the expected numbers of nuclear power plant units and the expected total capacities, by 2025, 2040 and 2050. Presently 8 countries out of 31 have nuclear power plants. By 2025, 18 additional countries expect to have nuclear power plants and the total number will increase to 28 by 2040. There is no further increase projected at this time from 2040 to 2050.

Based on the answers from experts from 31 technology user countries, Fig. 31 shows the number of units expected in these countries until 2025, between 2025 and 2040 and between 2040 and 2050.

On an individual basis, of 31 experts who provided answers to the survey five expected their country to accommodate only nuclear power plants of less than 700 MW(e) capacity (i.e. small and medium size reactors), twelve experts expected their country to deploy small or medium size reactors as well as larger nuclear power plants, eleven experts expected their country to only accommodate large nuclear power plants (more than 700 MW(e)), three indicated they did not expect any nuclear power plant to be deployed in their country up to 2050.

TABLE 6. RESULTS OF THE QUESTIONNAIRE FROM 31 EXPERTS

	Current (year 2007)	Additions until 2025	Additions between 2025 and 2040	Additions between 2040 and 2050
Countries with nuclear power plants	8	18	2	0
Nuclear power plant units	27	93	81	76
Nuclear power plant capacity (GW(e))	22	79	71	71

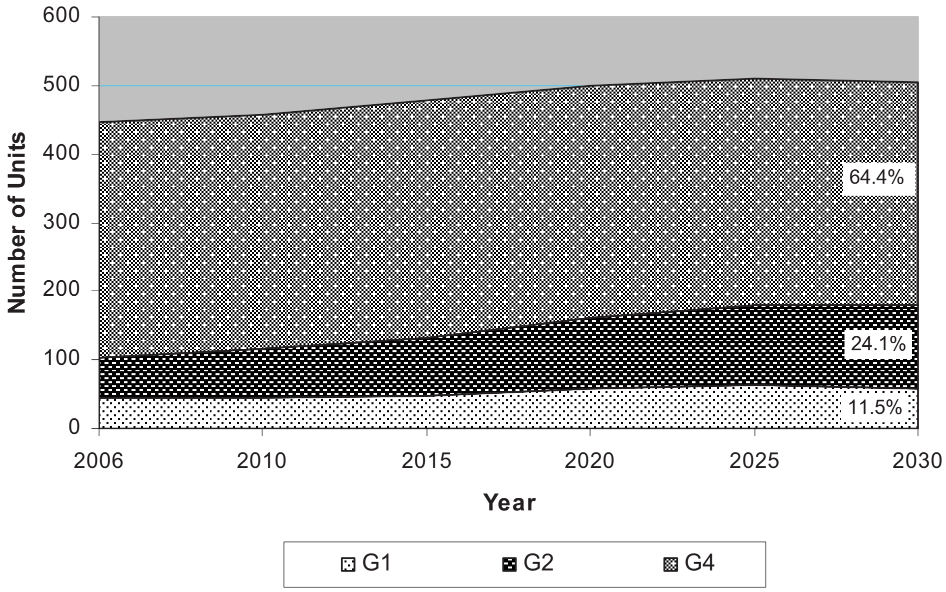

FIG. 26. Projection of total nuclear power plant units in the three groups by 2030 (low estimates).

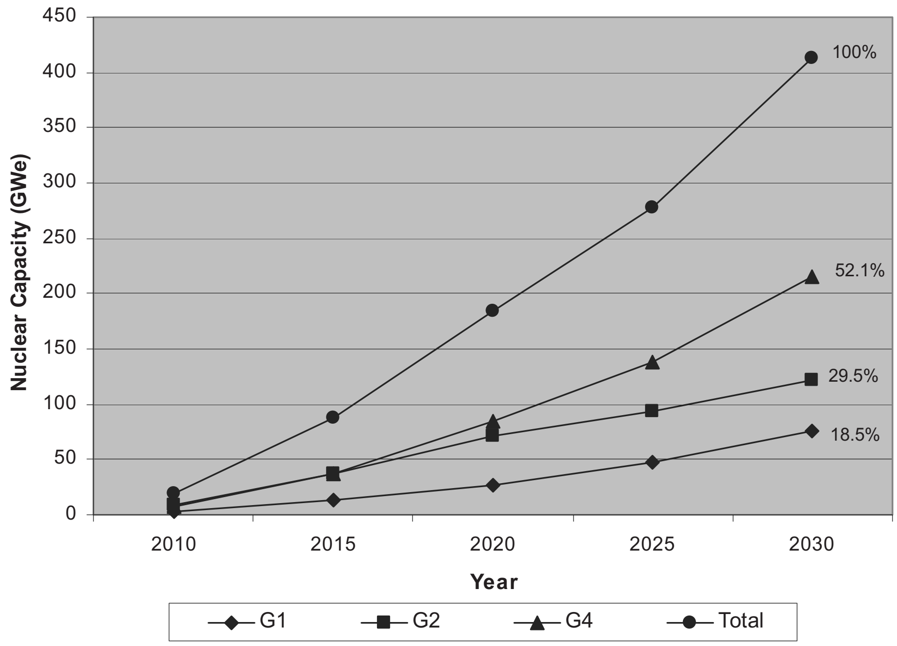

FIG. 27. Projection of new nuclear installed capacities in the three groups by 2030 (high estimates).

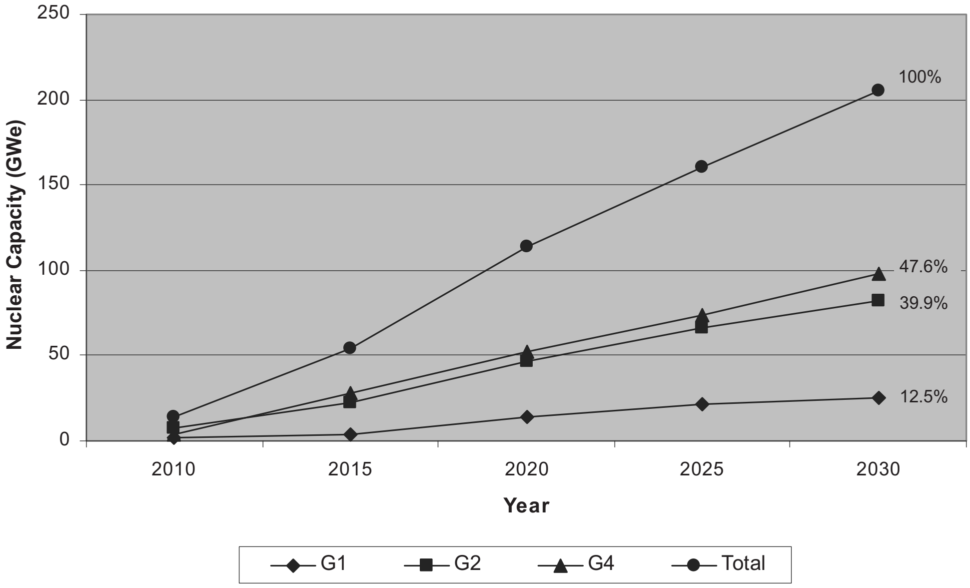

FIG. 28. Projection of new nuclear installed capacities in the three groups by 2030 (low estimates).

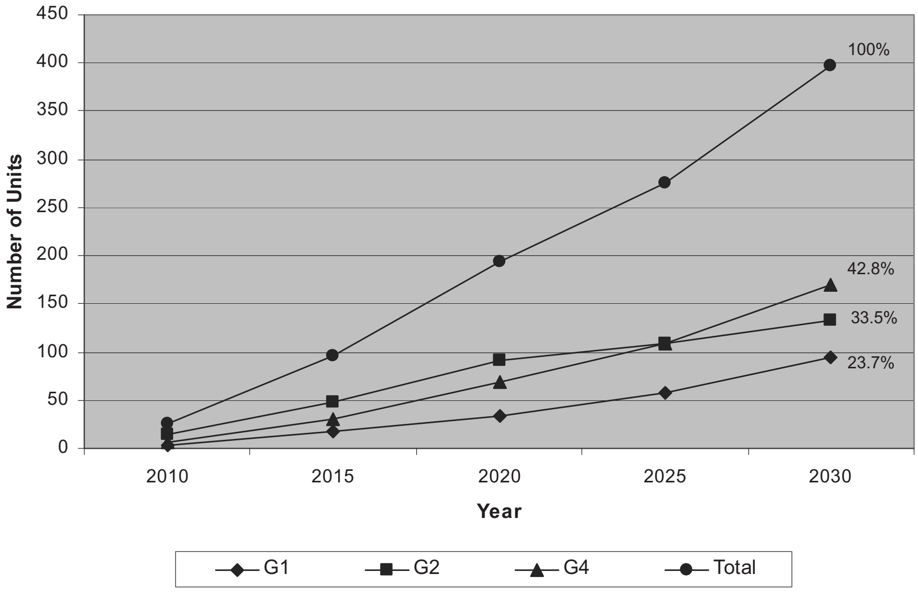

FIG. 29. Projection of new nuclear power plant units in the three groups by 2030 (high estimates).

Another result from the survey regarding country expectations was that non-electrical applications of nuclear power were of interest to no more than 25% of the experts. The major near term (before 2030) non-electrical application of interest was desalination. There was some interest in hydrogen production in the 2050 time period.

Experts from two technology user countries out of 31 provided answers with three possible options for their country. In both cases the different options corresponded to the same generating capacity but with a different number of units (e.g. N large units, or 2 × N units of medium size or 3 × N units of small size). Figure 31 reflects an equal weighting for all these options. It was simply assumed that each option counted only for one third.

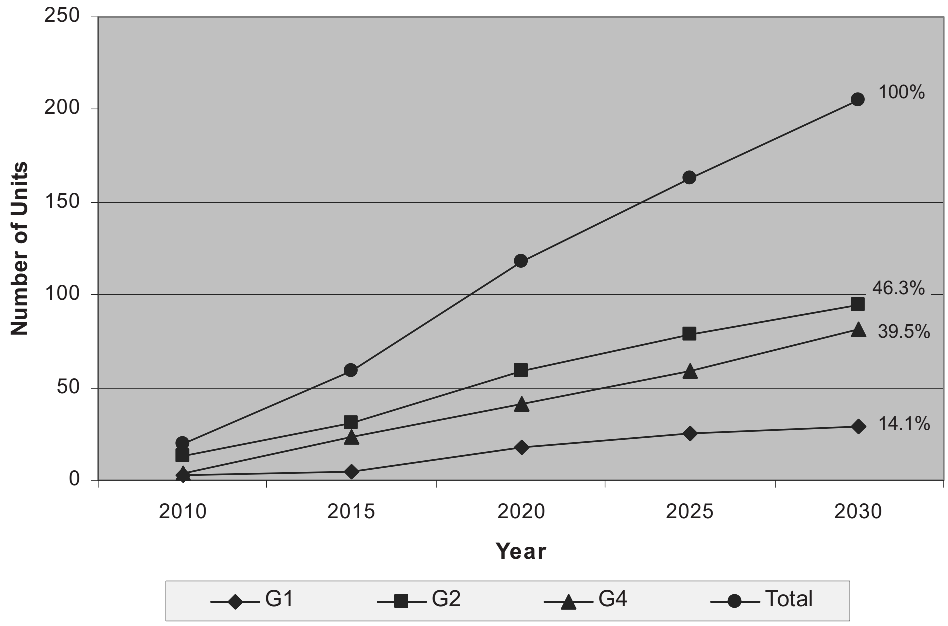

FIG. 30. Projection of new nuclear power plant units in the three groups by 2030 (low estimates).

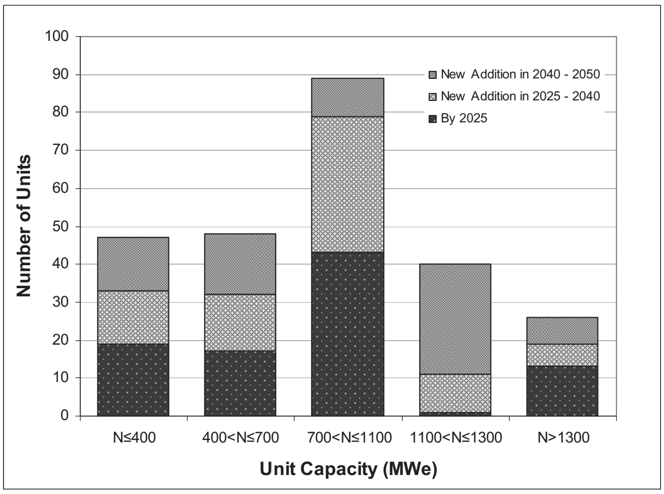

FIG. 31. Results of survey — number of new units in 31 technology user countries (based on answers by 31 experts from these countries).

Also, some experts provided answers including fixed values for unit size, e.g. 350 MW(e), whereas other experts provided answers with ranges, e.g. [400–600 MW(e)]. In order to avoid confusion it was decided to combine all the answers on one chart displaying ranges for the unit size. As a general rule, when a single value corresponded to the limit between two ranges the unit was included in the lower range, (e.g. answers at 400 MW(e) were included in the range [N ≤ 400]. For the same reason, specific answers at 720 MW(e) were included in the range [400–700 MW(e)] rather than in the range [700–1100 MW(e)].

The compiled answers from the 31 experts would lead to small and medium size reactors (equal to or less than 700 MW(e)) accounting for 38% of the total number of new units in these 31 technology user countries, and slightly less than 20% of the new nuclear ‘equivalent’ electrical capacity in these countries up to 2050.

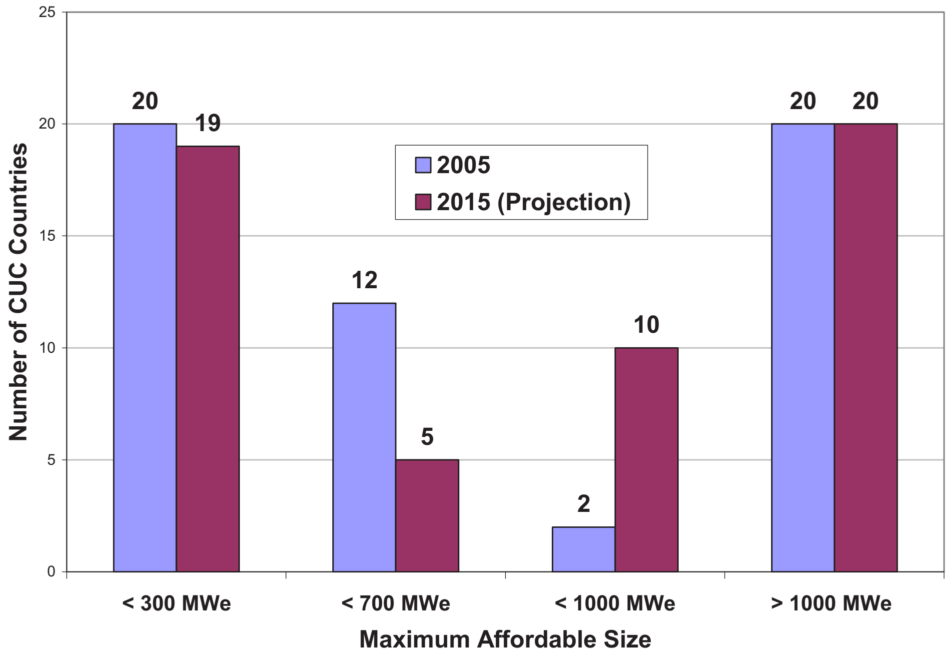

FIG. 32. Number of user countries potentially constrained to limit the maximum unit size of nuclear power plants in 2005 and 2015 due to electrical grid capacity.

2.3.6. Projection on unit size imposed by grid size restrictions

The size of a power plant unit is recommended not to exceed 10% of the total electricity capacity in a country assuming it is all connected to a single grid. As a first approximation, the value of 10% of the grid capacity is a rule of thumb commonly accepted to be the upper limit for the capacity of any single additional unit of any type in order to prevent instability and unreliability of the grid system.[8]

Without taking into account interconnected grids with neighboring countries, grid capacity could limit the size of nuclear power plant units that would be deployed in technology user countries.

Based on the above mentioned rule of thumb and the DOE/IEA databank [23], the maximum size of the first nuclear power plant unit suitable for the user countries considering practical grid restrictions was estimated.

Figure 32 shows the number of countries among those concerned by this study that could deploy a given unit size of nuclear power plant based on their current and projected grid size in 2015. It is observed that 32 countries (59%) might need small (<300 MW(e)) or medium (<700 MW(e)) sized reactors at present, and the number decreases from 32 to 24 countries in 2015.

2.3.7. Implications of level of investment on unit size

The introduction of nuclear power in many of the countries addressed in this study could be impacted by many considerations, among which investment constraints might prevail.

Large uncertainties in key variables related to investment requirements make this issue a major challenge to quantify. Uncertainties include reliable capital costs for plants in the user countries, the cost of new infrastructure, development costs and the impact of the economies of scale, among others.

A commonly accepted rule of thumb, resulting from past experience, is that the total level of investment for electricity generation projects in one country is recommended not to exceed 1% of the gross domestic product each year. Considering that for a nuclear power plant project, the maximum amount of expenses in one

[8] This restriction might be overcome if an appropriate standby generating capacity (hot or spinning) or other fast power balancing measures exist and are capable of coming into service immediately if some unit, even the largest one, fails.

TABLE 7. EFFECT OF INVESTMENT IN ELECTRICITY GENERATING CAPACITY AND GROSS DOMESTIC PRODUCT ON POTENTIAL NUCLEAR UNIT SIZE

Gross domestic product (in Billion US $)	Investment			
	3000 US $/kW(e)	5000 US $/kW(e)	10000 US $/kW(e)	15000 US $/kW(e)
20	<300 MW(e)	<300 MW(e)	<300 MW(e)	<300 MW(e)
50	<700 MW(e)	<700 MW(e)	<300 MW(e)	<300 MW(e)
80	~1000 MW(e)	<700 MW(e)	~300 MW(e)	<300 MW(e)
100	≥1000 MW(e)	<1000 MW(e)	<700 MW(e)	<300 MW(e)
150	≥1000 MW(e)	≥1000 MW(e)	<700 MW(e)	<300 MW(e)
200	≥1000 MW(e)	≥1000 MW(e)	<1000 MW(e)	<700 MW(e)
250	≥1000 MW(e)	≥1000 MW(e)	~1000 MW(e)	<700 MW(e)
300	≥1000 MW(e)	≥1000 MW(e)	≥1000 MW(e)	<1000 MW(e)
350	≥1000 MW(e)	≥1000 MW(e)	≥1000 MW(e)	<1000 MW(e)
≥400	≥1000 MW(e)	≥1000 MW(e)	≥1000 MW(e)	≥1000 MW(e)

single year would in general be about 25% of the total nuclear power plant cost, Table 7 gives indications of the maximum recommended unit size for a country as a function of the gross domestic product of the country and of the cost of installed kW(e) for the nuclear power plant project.

It has to be kept in mind that other factors also need to be considered. For instance, some infrastructure costs are constant and may not be dependent on unit size. Also, the economies of scale may impact unit costs, not to forget that even for large plant sizes being considered in technology holder countries the unit costs bear considerable uncertainties.

2.4. SUMMARY OF FINDINGS

The 54 countries identified for this study account for about 34% of the world's population (2005), 13% of the world's gross domestic product (2006) and 19% of the world's installed electricity generating capacity (2005). It is estimated that these countries together will represent about 23% of the world's electricity generating capacity by 2030.

According to the IAEA projection, the user countries would build new nuclear power plants with a total capacity of about 26 GW(e) (low estimates) to about 76 GW(e) (high estimates) by 2030, which would account for about 13% to 19% of the world's total for new nuclear power plant construction, respectively. The user countries have a significant share of the future nuclear power plant construction that would be comparable to that of China and India combined.

The results of Section 2.3.4 are derived from analyses done by a group of experts, based on the various data and statistics. These estimates expect that the total nuclear installed capacity by 2030 in the user countries would be in the range of 47 to 104 GW(e).

In contrast, the results of Section 2.3.5 are based on the data provided by national experts in some of the technology user countries. These data may include practical projections done with proper energy planning, as well as mere expectations of experts. These survey results show a higher projected nuclear capacity addition than the one estimated by the IAEA. On the other hand, experts from only 31 countries out of the 54 potential technology user countries participated in this survey and the real picture for all the user countries together could be different than this projection. In any case, the results represent the national experts' expectations more directly, which sometimes have the most decisive influence on the introduction of nuclear power.

The Section 2.3.5 survey results show that the share of small and medium size reactors could represent about 38% of the total number of new units, corresponding to a little less than 20% of the total installed new nuclear capacity by 2050, with a potential to play an important role in meeting the specific needs of the countries that have smaller grids. On an individual basis, out of 31 experts who provided answers to the survey, five expected their country to accommodate only nuclear power plants of less than 700 MW(e) capacity (i.e. small and medium size reactors), twelve experts expected their country to deploy small or medium size reactors as well as larger nuclear power plants, eleven experts expected their country to only accommodate large nuclear power plants (more than 700 MW(e)), three indicated they did not expect any nuclear power plant to be deployed in their country up to 2050 and one only provided expected national nuclear capacity without associated unit size.

3. ANALYSIS OF SURVEY RESULTS

Section 3 summarizes the analysis of the discussion with the experts in 7 countries visited for the survey, as well as the results of a short questionnaire survey (Appendix I) that was completed by experts from about 30 countries before the November 2007 workshop.

The discussion materials with the seven countries visited were primarily collected during face to face interviews in the survey, with more than 30 individual experts or groups of experts from 7 countries. They also include, as supplemental information, 15 sets of answers for a long questionnaire from these countries. After meetings and discussions with the CUC teams the experts who had provided written responses to the questionnaires in advance of the meetings recognized that as a result of the discussions and clarifications their written answers were sometimes no longer valid. Therefore, the analysis provided below is primarily based on the results of the meetings and discussions with the experts. In many cases, these discussions were conducted following closely the structure of the questionnaire. In other cases the discussions were open and broader issues not included in the questionnaire were addressed.

As a general rule the analyses provided in this section are grouped into the same classification as the questionnaire. The countries visited were consulted to verify that the content of this section reflected their input.

The word ‘expert’ used in the analyses represents individual experts or groups of experts expressing a consensus view in the meetings with the seven countries visited.

3.1. ECONOMICS

Electricity generating cost

The experts from the seven countries visited unanimously believe that the most important measure of the economic competitiveness of a nuclear power plant is its relative unit electricity cost in comparison with that generated from similar power plants of different energy sources available to the same grid system (in all countries visited these are fossil fuel). The experts also believed that in terms of electricity generating cost nuclear power plants are currently and will in the near future continue to be more economical than competing power plant technologies based on locally available fossil fuel. Such confidence is strengthened by the recent surge in natural gas and oil prices. The prices of gas and oil are expected to continue rising due in part to the increase in demand in developing countries, especially China and India. Coal power plants are economically competitive in some countries that have indigenous coal resources. However, there is a growing concern that due to the need to reduce the negative impact of coal burning on the environment additional measures to clean the discharge from coal power plants will eventually impact their cost competitiveness in an adverse manner. On the other hand, some experts raised a concern about the possible increase in the cost of building and operating nuclear power plants caused by the increase in prices of construction materials (such as steel) and uranium. This is, however, not expected to affect the overall economic advantage of nuclear power. As a matter of fact, the questionnaire survey performed before the CUC workshop in November 2007 showed that experts in the user countries consider cost stability to be one of the major drivers for considering nuclear energy, given the relatively low share of the uranium fuel cost in the electricity generating cost (5–15%) and given the relatively large number of uranium producers.

From the above, it can be concluded that the electricity generating cost is not an impeding factor for considering the deployment of nuclear power plant technology. As a confirmation, the questionnaire survey performed before the CUC workshop in November 2007 showed that most experts in user countries perceive the cost–benefit aspects of nuclear energy as an important driver for considering nuclear energy.

Some experts in the seven countries visited even mentioned that higher electricity generating cost from nuclear power than that from other energy source may be acceptable, especially for the first several units, because of other secondary benefits such as improvements in the national industrial and technical capabilities. Nevertheless, the competitiveness of nuclear power in comparison with other energy sources for the first unit is an important consideration. For the nth unit, nuclear power is expected to be economically superior to any other base load power plants of equivalent capacity.

Construction cost

Among all the contributing components to the unit electricity cost, the capital cost of the nuclear power plant is of the highest importance. Most experts in the seven countries visited think it should be minimized in order to ease raising large investments for the construction of the nuclear power plant. The questionnaire survey performed before the CUC workshop in November 2007 showed that for a majority of user countries the financial risk associated with the high investment cost and project risks such as delays in the completion of the project or interruptions after the start of plant operation are perceived as some of the major challenges to be overcome when considering nuclear energy.

Although there are no clear criteria regarding the total amount of capital needed for the project, there are some discussions regarding unit construction cost. The experts in the seven countries visited assume that the unit construction cost for new nuclear power plants would be in the range of US $1500–US $2000 per kW(e), based on available public information. There is no clear upper limitation in the unit construction cost in most of the countries except one, which said that a nuclear project with a unit construction cost higher than US $3000/kW(e) would not be feasible at all in that country.

Some experts in the seven countries visited are having difficulties in determining the real cost of building nuclear power plants because they find discrepancies between the cost information provided by suppliers and actual past records. Also, what is included and what is not included in the cost information is not always very clear. They feel that accuracy of cost estimation is crucial to make a firm commitment to nuclear power, and therefore they require suppliers to provide reliable cost information as detailed as possible, even in their preliminary study process.

Operating and maintenance (O&M) cost

As the total electricity generating cost is believed to be the most important economic factor to be considered, followed by the capital cost, the other components of the generating cost are of less concern. Therefore, no requirements were expressed with regard to O&M cost. However, users naturally expect that O&M costs will be reduced in the future nuclear units compared with existing nuclear power plants due to the incorporation of more O&M friendly design features. With the availability of a qualified workforce, relatively low local labour costs are expected to become a contributing factor to the O&M costs compared, and will be lower in comparison with those in the existing nuclear power plants in developed countries. In the distant future it is expected that O&M costs will be significantly reduced due to advanced O&M technologies.

Construction period

From the point of view of nuclear power users there are two main reasons that the duration of the nuclear power plant construction period could be important, economics and energy planning. From the economics point of view the actual construction period is important since major payments start with construction and no tariff can be recovered until the commencement of commercial operation. The total interest paid by users during the construction period affects the economics of nuclear power plants, depending on the available interest rates.

Another factor is the overall project period including engineering, procurement and construction, which is sometimes referred to as the engineering-procurement-construction (EPC) period. Licensing should be also included in this period. The reduction of the whole EPC period is also important because the lead time could be longer than the actual construction itself. All these uncertainties may bring significant difficulty to the planning of additional generating capacity in the country.

For the actual construction period, the majority of experts require the best practice achievable at the time of construction. A majority of experts in the seven countries visited expect 5 years between first concrete and connection to the electric grid for the first plant and less than 5 years for the nth units. With regard to the EPC period, one user requested less than 8 years.

The questionnaire survey performed before the CUC workshop in November 2007 showed that the long lead time and long construction time expected for nuclear power plants compared to fossil power plants is perceived to be an important challenge when considering nuclear power.

It is interesting to mention in this context that none of the experts interviewed have considered progressive implementation of small and medium size reactors with shorter construction periods or modular nuclear power plant concepts (with a gradual power output increase) and faster return on investment, as a valuable alternative to the implementation of large nuclear power plants.

Assurance of construction schedule by supplier

Many user countries are concerned with the potential financial loss due to delays in construction schedules, which actually have happened in many past nuclear power plant projects. For the first unit, the experts from the seven countries visited require turnkey projects in order to reduce this risk.[9] Further assurance of the construction schedule provided by suppliers is also required. Some experts feel that normal liquidated damage (LD) clauses in turnkey projects are not adequate to prevent such a risk because they suspect suppliers might take advantage of legal exemptions to effectively limit their responsibilities and subsequent compensation. But, at the same time, they feel that LD is currently the only available practical solution to deal with the risks associated with the construction schedule. Many users require loss of opportunity compensation clauses to be included in the contracts, even though they recognize that this may increase overall project costs. LD usually compensates a fixed amount of money per day for delays against construction milestones, while loss of opportunity compensation covers all the damage associated with delay of the projects due to factors under the supplier's responsibility.

Cost reduction through increased local content

Certain unique situations in developing countries such as lower labour costs and lower manufacturing costs provide an opportunity for cost reduction. Some experts in the seven countries visited believed that this factor should be considered seriously despite the extra effort that may be required to overcome barriers to the utilization of local human, industrial and infrastructure resources. They think an optimum point of this utilization can be achieved as a function of the cost associated with the extra effort, the lower cost of the local resources, and any macro-economic benefit resulting from the utilization of local resources as desired by the country building the nuclear power plant.[10]

3.2. INFRASTRUCTURE AND IMPLEMENTATION

Type of contracts

In order to reduce risks associated with nuclear power plant projects the great majority of the experts in the seven countries visited request turnkey contracts for the nuclear power plant projects in their countries, especially for the first project. They are aware of the fact that they lack experience in project management for the construction of a nuclear facility and procurement of nuclear components. They feel that suppliers with

[9] Please see 'Type of contracts' in Section 3.2.

[10] See also Section 3.2.

extensive experience would be in a better position to deal with problems related to schedule delays, cost overruns and technical problems such as non-conformance with specifications. A limited number of experts even consider the build–operate–transfer (BOT) or even built–own–operate (BOO) options to avoid initial operational troubles. However, most of them think that the ownership of the nuclear power plants should reside in the country. This is even imposed by law in some countries.

Although turnkey contracts may be requested, this does not necessarily mean that the users do not want to be involved in the projects. On the contrary, active involvement of the user is requested.[11] Some experts clearly position the first nuclear power plant project to increase and build sustainable national capability to implement nuclear power projects in the future. Therefore, their target for the nth unit would be a split package contract with several suppliers under their own project management.

Suppliers would be requested to show their track record with regard to their capability to execute a turnkey contract within the budget and schedule, while involving users effectively.

Involvement of users

Although the objective of users' involvement in nuclear power plant projects varies from country to country, none of the experts in the seven countries visited would feel comfortable with total dependence on suppliers. At the same time, none of them expect their country to become an independent nuclear supplier in the future. They foresee that their countries will remain primarily as users of nuclear power technology, with a gradual increase in their competence in handling the technology. The experts commonly consider that the users should play principal roles in the licensing process, both on the applicant and regulatory body sides and in operation, maintenance and decommissioning of the nuclear power plant, although they would need support from suppliers and supplier countries.[12]

Project management is another common aspect they would like to be involved in. The goal for some experts is that the users could follow the progress closely and keep informed in a timely manner to make sure that the projects are implemented as planned. Other experts seek a more active role anticipating management of future nuclear power plant projects by themselves. In any case they expect that the suppliers play the principal role with the turnkey contract in the first project and retain the overall responsibility.

Localization (use of national resources) is also an important factor. The experts require suppliers to maximize their localization effort by integrating national participation in civil work and supply of non-nuclear components. For example, one of the countries visited has clear localization specifications (40%) in conventional power plant projects that could be applied for nuclear power projects as well. Another country announced gradually increasing targets for nuclear power projects: 25% in the first two units, 40% in the next 4 units and optimum participation for the subsequent units.

Some experts indicated that as recipients of nuclear power technology, they would be interested in being involved in all aspects of the nuclear power projects such as design, analysis, manufacturing, construction and R&D by sharing capability with suppliers.

The questionnaire survey performed before the CUC workshop in November 2007 showed that nuclear power plant projects are strongly perceived as potential catalysts for industrialization and development of human resources, as well as a challenge in the user countries due to the need for strengthening the national infrastructure. To a lesser extent it is also perceived as conveying potential support for economic development as well as national prestige.

Technology transfer

For various reasons, the experts in the seven countries visited wish to increase their capability as technology users in various aspects of development and deployment of nuclear power plants. First, they would like to build their own capability for assessing the safety, reliability and performance of nuclear power plants independently from suppliers. Second, they believe that performing certain activities by themselves in the long

[11] See 'Involvement of users' in this section.

[12] See also 'Support from suppliers and supplier countries' in this section.

run would be more economical than by contracting to suppliers, especially for plant maintenance. Finally, they think they could develop and strengthen their national capabilities, especially in the industrial sectors, through these processes. The rate of improving national capability depends on the actual conditions and the progress of infrastructure development in the country, but most experts believe that it should be gradually increased as additional nuclear power plants are built in the country

They regard technology transfer from suppliers (including the supplier countries) as a key to increasing such capabilities. Among technology transfer items the experts are particularly interested in codes and methods on design analysis of the system and associated know-how of their usage for independent checking. They would also be interested in obtaining specifications and design drawings to develop independent capability for maintenance and upgrading of the plant, and know-how on system design, construction and component manufacturing for industry buildup.

Experts from one country indicated they would request suppliers to transfer technology for fuel fabrication in order to be able to fabricate fuel assemblies in their country in the future.

Support from suppliers and supplier countries

In addition to the supply of the nuclear power plant itself, support and services from suppliers (and the supplier countries) in all the associated areas would be strongly requested by users, according to the experts from the seven countries visited. For those countries which have smaller financial resources financial support from suppliers (and the supplier countries) is a prerequisite. For other countries that are capable of independent financing, financial support would also be a preferred option. Suppliers would be requested to provide direct loans or investment in the nuclear power plant project. Supplier countries would be requested to provide soft loan and/ or export credit to prompt commercial loans or investments. One expert also mentioned another possibility: the supplier would be requested to assume the entire financial risk for the project; full payment would be made on the date of commercial operation minus penalties related to delays or poorer performance than expected.

The experts feel that suppliers with wider experience and know-how in nuclear safety should share with the users the responsibility for ensuring the safety of the nuclear power plant. Licensing support is considered an important condition by all the experts. Suppliers would be requested to support owners of nuclear power plants (licence applicant) in preparing the documentation required for licensing. Regulatory bodies in supplier countries would be requested to support the regulatory authorities in user countries for review of licensing documents.

Suppliers and utilities in the supplier countries (or utilities in any other countries that operate the same type of nuclear power plant) would be requested to provide comprehensive human development programmes, especially for operators and maintenance personnel. Such a programme should start sufficiently early, before commissioning the plant, so that personnel is ready to operate the plant by the time commissioning is completed. The suppliers and the utilities would also be requested to provide technical support during operation and maintenance. One expert also mentioned support for development of reliability centred maintenance (RCM), risk based inspection (RBI) and quality assurance (QA) programmes.

Qualification of suppliers

Most experts in the seven countries visited think that qualification of suppliers is a very important factor to be considered in the decision making process for nuclear power plant projects in order to limit the risks associated with project delay or failure. All of the experts prefer suppliers to have recent experience in nuclear power plant construction (in the last 10 years) in their country and overseas, and to show a good track record on conforming to the schedules and budgets in these nuclear power plant projects. They also prefer suppliers to be in sound financial condition to limit the risk of suspension of the project due to the supplier's financial problems.

On the other hand, in view of the lack of nuclear power plant projects and exports in recent decades, most experts also recognize that there may not be a sufficient (in order to create competition) number of suppliers satisfying all these conditions. Some expect the situation to improve by the time their nuclear power plant project is implemented.

Another concern for the experts of developing countries is that suppliers might be overloaded with other projects and might not allocate sufficient capacity for their projects.

From the above perspective, the suppliers would at least be required to show their capability and capacity to manage overseas projects in a reliable and successful manner. They would be required to provide a risk analysis explaining how risks with potential impact on cost and schedule on the one hand and plant performance on the other hand would be managed.

Assurance of fuel supply

For many experts in the seven countries visited assurance of fuel supply is one of the most important issues. However, for some others this front end fuel cycle issue appears to be less of a concern than the back end issues such as long term spent fuel management and ultimate disposal of radioactive waste. Some experts are of the opinion that market mechanisms for uranium or enriched uranium are working properly at present. As a confirmation, the responses to the questionnaire survey performed before the CUC workshop in November 2007 did not list ‘assurance of nuclear fuel supply’ as one of the major challenges for considering nuclear power.

Some experts in the seven countries visited strongly feel that security and stability in fossil material markets, especially for oil and natural gas, are more vulnerable than in the uranium market. The relatively high security of nuclear fuel supply is actually one of the incentives for them to introduce nuclear power, as confirmed by the questionnaire survey performed before the workshop in November 2007 (long term energy security was indicated as the most important driver for considering nuclear power). Furthermore, they recognize that a nuclear power plant with one core and one or more reloads is a unique way to provide energy for a period of up to 5 years.

On the other hand, some experts are very concerned with potential political interference in the supply of nuclear fuel, to the extent that they think this may be a threat to the sustainable operation of the nuclear power plants they are planning to build. One expert indicated that his country had an unpleasant experience with delayed supply of fuel for a research reactor for political reasons. He is concerned that a similar situation could potentially occur with future nuclear power plants.

Most experts in the seven countries visited think that countries that have fulfilled their international obligation related to the Treaty on the Non-proliferation of Nuclear Weapons (NPT) and other relevant international instruments should have open access to the fuel market operated on a commercial basis. The supply of fuel to these countries should not be subject to the potential threat by other countries capable of influencing the supply of fuel, driven by reasons other than those related to the NPT. For this reason, the experts would expect some sort of international fuel supply assurance mechanism to be initiated by the international community and international organizations such as the IAEA as a back-up to the mechanism of commercial markets. However, many of them are not optimistic that the establishment of such a mechanism would be feasible in the near future.

Many of the user countries do not plan to have a large scale nuclear power programme. Therefore, a majority of the experts think that it would not be economical to develop their own indigenous front end fuel cycle infrastructure to support a limited number of nuclear power plants. Because of the combination of economic and political considerations regarding sensitive technologies, many experts do not consider it to be practical to establish indigenous front end fuel cycle infrastructures at the moment. However, many of them feel that as a matter of principle, given the condition that the international obligations are fulfilled by their country, their countries should not be denied the right to choose a given fuel cycle option in the future.[13]

Regarding fuel assembly or fuel bundle fabrication, experts in the seven countries visited recognize that the number of competitors capable of providing fuel assemblies for every nuclear system is very limited. Several experts would require a supply of fuel assemblies for several reloads before starting commercial operation of the plants. Experts from one country indicated that they would opt for technology transfer for the establishment of their own capability to fabricate fuel assemblies/bundles for reloading cores after buying the initial core and first reload(s).

[13] See section 3.8.

Assurance of the supply of critical components

Assurance of the supply of critical components is also very important, considering maintenance and upgrading of nuclear power plants in the future. Many experts in the seven countries visited recognized that the existence of a limited number of suppliers for critical components may restrict supply options. One expert indicated that his country experienced great difficulty in obtaining some replacement components for the existing reactors, since the design of those components differed from the standard design and had become unavailable on the market. Many experts think that standardization of nuclear power plants and major components is a positive way to ensure the supply of such critical components.

Assurance of spare parts

Most of the experts in the seven countries visited would require the establishment of international spare parts pools to ensure a supply of spare parts, even if they understand that currently the present market mechanism is good enough to ensure such a supply.

Compliance with regulations/standards/guidelines

All of the experts in the seven countries visited would require the nuclear power plant design to comply with the IAEA Safety Standards. Some experts indicated that their country is considering how to base their regulations on the IAEA Safety Standards, while some others already have done so.

Another clear requirement for nuclear power plant design from experts would be compliance with nuclear regulations in the country of origin. Suppliers would have to show the ability of the nuclear power plant design to obtain a licence under the regulations in their home country. European countries would request compliance with EUR.

Public perception

The survey performed before the CUC workshop in November 2007 showed that public perception of nuclear safety and of nuclear power in general is considered by most of the user countries that participated to be one of the major challenges when considering nuclear power. Although this is a national issue, some experts in the seven countries visited indicated that they might seek external assistance to develop public communication and information plans and stakeholder involvement in order to modify the negative image of nuclear power, which they believe is often due to lack of information. The questionnaire survey also showed that potential opposition from neighbouring countries or from non-governmental organizations was not perceived as a major challenge by user countries when considering the introduction or expansion of nuclear power.

3.3. SAFETY

Safety analysis approach in support of design

Many experts in the seven countries visited generally prefer an optimum combination of deterministic and probabilistic approaches for safety analysis of nuclear power plants. Some indicate the preference for a safety analysis approach that is mainly deterministic, assisted with additional insight obtained from probabilistic analyses. The experts indicated that probabilistic insights should rely on well established data supported by appropriate experience.

In the longer term, the experts expect the safety analysis to include more probabilistic insight and considerations than in current practice, once again provided that the data and assumptions are backed up by sufficient experience.

Safety systems

The discussions showed that many experts in the seven countries visited believed that passive safety systems can bring higher safety levels in nuclear power plants than active safety systems. They therefore initially required the use of more passive safety features in the design of safety systems. However, after some elaborations, it turned out that in all cases what the experts would actually require was a higher level of safety rather than passive safety systems per se. Therefore, this requirement on the use of passive safety features should be understood as a desire for safety systems based on state of the art technologies. It also indicates the need for a requirement for suppliers to provide the rationale for the type of safety systems included in their design that allows for the achievement of the safety objectives, and any implementation of passive safety systems should be supported by sufficient data and experience to demonstrate their efficiency. For future nuclear power plants they naturally expect that more passive systems will be used.

Generally, it can be derived from the discussions that for an equivalent level of safety there may be a tendency by the experts to opt for the passive systems solution should other factors be similar. If the passive systems option proves to be more expensive than the active systems one for an identical level of safety, the choice might be reconsidered. Many experts concluded that the best compromise could probably be an optimum combination of both active and passive features.

Severe accident frequency

Many experts in the seven countries visited emphasize that the safety of nuclear power plants is the first priority. They are generally satisfied with the safety level achieved by the latest nuclear power plant designs. They do not request significant improvement of nuclear power plant safety by compromising other important factors such as the economics or proof of the systems.

For the longer term, experts in the seven countries visited would also request the best safety level available in the market at the time of their deployment. Still they expect that this level should be about one order of magnitude better than the current level. An exception is one expert, who indicated that even if the future safety requirements set by the national regulatory body remain the same as those at present he would request a higher safety level to improve public confidence in nuclear energy. He said he would be ready to accept an extra cost for that, in the range 10–15% of the cost of the nuclear power plant.

Large early release frequency (LERF)

The same argumentation as for the previous issue can be applied for LERF.

Design features against severe accidents

A majority of experts from the seven countries visited naturally expect that nuclear power plant designs will include features to limit environmental consequences in case of core meltdown or damage, although they cannot specify what kind of features the nuclear power plant should have. The suppliers would be requested to demonstrate that their systems have sufficient capability to mitigate the consequences and meet the safety and environmental objectives.

One expert pointed out that not only hardware issues but also software issues are important to deal with severe accident management. From this point of view, he would require the suppliers to provide guidance on how to cope with severe accidents.

Grace period

A majority of experts from the seven countries visited did not express concrete opinions regarding the requirement on a grace period (generally defined as the minimum time required for operator action to prevent damage to the plant). Without knowing the current nuclear power plant's performance with regard to grace period, many naturally expect that the nuclear power plant design should provide a grace period equal to or more than one day in order to reduce the burden on the operators in case of accidents. Nevertheless, this should be understood as a preference rather than a requirement. Some experts indicated that they would be satisfied with a grace period the same order of magnitude or slightly higher than that for current nuclear power plants (e.g. a few tens of minutes to 3 hours).

For the future, experts in the seven countries visited expect that the grace period of innovative reactors should be higher than that of the latest nuclear power plants.

External event resistance

A majority of experts from the seven countries visited do not find any need to upgrade external event resistance features beyond the capabilities of existing nuclear power plants. They, request, however, that unique regional characteristics be considered in nuclear power plant design, such as frequent flooding, equatorial weather conditions or volcanic hazard.

Instrumentation and control (I&C)

Although most experts in the seven countries visited hope to benefit from up to date technology as much as possible for I&C, the proof of the technology overrides this desire since reliability is the most important characteristic for them. Therefore, the first of a kind I&C system would not be acceptable. The I&C system would also be required to be easily upgradeable with a more advanced proven system in order to prevent the risk of a limitation on the nuclear power plant's operation due to obsolescence and to avoid a long outage for difficult and expensive modifications.

Occupational radiation exposure

A majority of experts from the seven countries visited did not express any other requirement beyond compliance with their national regulations for occupational radiation exposure. One expert mentioned the more stringent targets established by WANO/INPO, which are good indicators to reflect the performance of the plant. Collective doses are considered to be important in this respect.

In any case, the experts realise that not only the system characteristics but also the practices of the plant owner/operator are important to reduce occupational radiation exposures. Nevertheless, suppliers would be required to demonstrate that the nuclear power plant design has the capability to meet national regulation limits for occupational dose and WANO/INPO targets for occupational collective dose.

Off-site release limits during accident

A majority of experts from the seven countries visited did not express any other requirement than compliance with their national regulations for off-site release limits during accidents. No particular requirements were defined for this issue.

Support from suppliers in ensuring nuclear power plant safety

All nuclear power plant designs supplied to the user countries should use the best and well established safety analysis approaches and methodologies prevailing at the time of supply. This philosophy is also the basis for the requirement that the nuclear power plant be licensable in the country of design origin.

3.4. ENVIRONMENT AND USE OF ENERGY RESOURCES

Environmental impact on air pollution and on greenhouse gas emissions

The questionnaire survey performed before the CUC workshop in November 2007 showed that environmental factors are perceived as important drivers for considering nuclear power.

Use of national energy resources

The survey performed before the CUC workshop in November 2007 showed that the potential for saving national fossil resources, the potential for using local uranium resources and the potential for exporting electricity to neighbouring countries are not perceived as major drivers for considering nuclear power.

Off-site release limits during normal operation and incidents

A majority of experts from the seven countries visited think that it is sufficient to comply with their national regulations for off-site release limits during normal operation and incidents within design and operational margins. The degree of margin should be in accordance with international standards and practices. No particular requirements were found for this issue.

Non-radiological environmental effects

A majority of experts from the seven countries visited think that it is sufficient to comply with their national regulations for non-radiological environmental effects. No particular requirements were found for this issue.

3.5. SPENT FUEL AND WASTE MANAGEMENT

Spent fuel management

Long term spent fuel management is a major common concern among user countries and is considered to be one of the major challenges when considering nuclear power. Most of them expect supplier countries to eventually develop long term approaches to spent fuel management. Although the idea of a spent fuel take-back option to the country of origin can be a preferable option for many user countries, many experts recognize that this option may not be feasible. Most experts agree that intermediate spent fuel storage is the most practical option, and they request suppliers to provide assurance of provision for such a facility.

For the long term solution, after the intermediate storage period, the experts have diverse views. Some of them think that this is a national responsibility and that each country should have to develop a final repository. Some experts think that this is not a national responsibility and that supplier countries or the international community should find a solution for them. Others think that regional or international spent fuel centres could be a solution and they should be involved in this process. One expert indicated that his country should leave other options, including the recycling of the spent fuel, open. Their common strategy regarding spent fuel management, however, can be generally described as a ‘wait and see’ policy.

Low and intermediate level waste management

Unlike spent fuel management, experts in the seven countries visited clearly recognize that management of low and intermediate level wastes is their own countries’ responsibility. This is because they are currently dealing with such wastes from their research reactors or medical services under their responsibility. Although some of the experts still prefer to have assurance of provision of intermediate storage facilities for low and intermediate level waste, this should not be understood as a common consideration from users.

Decommissioning services

While all of the experts recognize that decommissioning of nuclear power plants is the responsibility of nuclear power plant owners or their governments, some experts are very concerned that they might have unexpected difficulties when they decommission their nuclear power plants in the future. For this reason, they require that the decommissioning of the plants be considered in the design phase. They also require provision of a guideline on how to decommission the plant from suppliers and how to establish corresponding funding mechanisms.

Amount of solid waste

Although experts naturally request suppliers to minimize the amount of solid radioactive waste for nuclear power plants, a majority of the experts have not provided a specific requirement for the actual amount. Some simply referred this to their national regulations.

Some of the experts are concerned that one particular reactor design could produce more waste than other reactor designs, such that it will become an additional burden to the capacity of the storage facility. They requested that suppliers demonstrate that the amount of radioactive wastes produced by their nuclear power plant designs will not require significantly larger storage space at the intermediate and long term spent fuel storage facilities, as compared with other competitive nuclear power plant designs.

3.6. PROLIFERATION RESISTANCE

Intrinsic feature of proliferation resistance

All experts in the seven countries visited understand that, by ratifying the NPT and related additional protocols, international treaties, conventions and agreements, user countries are responsible for ensuring the limitation of the use of nuclear power to peaceful purposes and to prevent proliferation of nuclear materials from their nuclear facilities. They also understand that they are obligated to show their compliance with the above treaties and agreements by cooperating with the IAEA with regard to safeguards inspections and requests for relevant information.

Most experts accept that intrinsic features of proliferation resistant systems in nuclear power plant designs are necessary parts of the nuclear power plant to prevent nuclear proliferation. Many of them believe, however, that these proliferation resistance measures are for the benefit of the international community (IAEA) as a whole, and some concerned supplier countries in particular. They therefore do not think that the user countries should bear the responsibility for the extra cost or operational inconvenience associated with the proliferation resistant measures. To some experts it is a matter of principle that any intrinsic proliferation-resistant feature for all nuclear power plants built in the user countries should not be any different than that of nuclear power plants of similar design and built in the supplier countries. Furthermore, some experts require that such intrinsic features should not interfere with effectiveness of operation and maintenance. One expert suggested that his country may be willing to consider accepting additional intrinsic features even at its own cost.

The questionnaire survey performed before the workshop in November 2007 did not identify ‘concerns on nuclear proliferation’ as one the major challenges to user countries when considering nuclear power.

Responsibility for enabling safeguards

Experts clearly think that the international community, through organizations such as the IAEA, should be responsible for promoting the availability of nuclear energy systems to safeguards.

3.7. PHYSICAL PROTECTION

Intrinsic features of physical protection

The experts believe that intrinsic features for physical protection against terrorism or sabotage are necessary functions for nuclear power plant design and user countries have the responsibility, together with suppliers/supplier countries and the international community, for ensuring the security of nuclear power plants. They require suppliers to follow international best practices for physical protection design of the system.

The questionnaire survey performed before the workshop in November 2007 did not identify ‘concerns on nuclear security’ as one the major challenges to user countries when considering nuclear power.

3.8. TECHNICAL DESIRED FEATURES

Proven technology

The availability of proven technology for the system is one of the most imperative considerations; all the experts in the seven countries visited commonly emphasize its importance. As the building of a nuclear power plant requires a very large investment and hence involves a high degree of business risk, the experts believe that the minimization of this risk can only be done through joint efforts from the user and the supplier. Since the suppliers have more extensive nuclear power plant experience than the users, they should take more responsibility than the user in proving the merit of the nuclear power plant technology they are supplying. The experts therefore did not think it would be appropriate to have their nuclear power plants serve as a test or as a demonstration of a technology, even if this is made economically interesting. The need for energy in their countries is such that, rather than having the latest technology, they would simply prefer proven, robust and efficient technology to ensure good availability and to avoid the risk of potential accidents, incidents and technical problems associated with immature technologies. The degree of required technical maturity varies among the experts, but the common bottom line is that the nuclear power plant should at least have been licensed in the country of origin. A ‘first of a kind’ (FOAK) or a prototype reactor were only said to be potentially acceptable in one of the countries visited. In that case, the minimum bottom line would be that the nuclear power plant design should be able to receive a licence or be certified in the country of origin.

The majority of the experts require a very high level of technology maturity: “the same type of nuclear power plant design should have been built and operated commercially elsewhere with a good record during several years”. One country has incorporated this requirement into its national regulations: the same type of nuclear power plant design should have been operated commercially elsewhere with an average availability factor of more than 75% for more than 3 years.

Standardization

Standardization is another important consideration. While the experts understand that the nuclear power plant design should be adjusted for the local site conditions, such as seismic design and heat discharge conditions, many of them feel that, mainly for cost reduction, the design of the nuclear power plant and its components should be standardized to the maximum practical extent. Another reason for requiring standardization is that users of standardized nuclear power plants can share information regarding technical problems and can solve the problems together. The experts also expect that standardization will facilitate the replacement of components and the availability of spare parts. An expert from one country described their past experience in having difficulties in replacing some components on an existing facility due to the fact that these components were not of a standard type. The stability and long term viability of the supply market is another important factor in ensuring the availability of critical components over the plant lifetime.

Modularization

From the point of view of improving the economics of the plant, experts generally support the idea of sharing facilities among several units at the same site, such as a common control building and a common radwaste building. A twin unit design for a nuclear power plant is a good example of this idea. However, not all experts are enthusiastic about the concept of modularization based on small units, which when added in series could become the equivalent to a larger single unit. The experts think that there could be advantages to such modularization. These include step-wise investment and just in time supply capability against gradually increased electricity demands. However, as most user countries visited need large quantities of additional electricity generating capacity in the near future, these incentives for modularized reactor designs become less attractive. The lack of availability of proven modularized reactor designs and the concern for their economic competitiveness against larger size single unit designs are other negative factors quoted by the experts.

Prefabrication/modular construction method

The experts generally indicated they would prefer prefabrication construction methods or modular construction methods, since they believe that this is the state of the art construction technique and an effective way to reduce construction time. After discussion, however, most of the experts realized that many existing prefabrication techniques require that the prefabrication be done in the supplier's home country. Considering the lower labour costs in developing countries, the concept of prefabrication/modular construction techniques might conflict with the intention of maximizing the use of local resources and might not necessarily lead to cost reduction. At the end of most discussions, many experts required an optimum combination of utilizing local workforces and prefabrication at factories. In addition, experts required suppliers to consider prefabrication at the site or at factories in the user countries, in order to maximize the use of local resources while pursuing the reduction of the cost and the construction period. The experts also require suppliers to consider applying any other effective and proven construction methods to reduce construction time and costs.

Reactor type

Almost all the experts expect the first units in their countries to be water cooled reactor types — pressurized water reactors (PWR), boiling water reactors (BWR) or heavy water reactors (HWR). The main reason is that the experts require proven technology and only these three reactor types have commercial operating experences at present.

Among them, PWR is the most popular choice of reactor type by the experts, followed by BWR. Since the largest number of operating plants in the world are PWRs, and they can be supplied by the largest number of suppliers, most experts expect them to be the most cost competitive designs and also the ones with most reactor years of accumulated experience in operation and maintenance. Following this trend, they also expect that PWRs offer the best chances to 'survive' in the future competitive market. Following the same reasoning, some experts also suggested that it might be easier to procure components and spare parts from the largest reactor market.

For the subsequent units, on the one hand many experts anticipate deployment of the same type of reactor in their countries in order to develop and optimize the necessary operation and maintenance expertise and to share stockpiles of components and spare parts. On the other hand, some experts expressed the need to have different systems in the future with the objective of technology diversification and assurance of fuel supply. The use of different nuclear technologies in a country would help prevent a total shutdown of all the reactors should a potential common mode defect be detected on a given reactor type. However, this is not an important consideration if the contribution from nuclear power to the country's total electricity generating capacity is not significant. For the longer term, there are no concrete visions in any countries, and options are open for any other reactor type including high temperature reactors and fast reactors.

Unit capacity

For the electricity capacity of the first several units, most of the participating experts consider the range shown in Fig. 31. Among the reasons they appear to be slightly more interested in the large capacity units are:

(a) Recognition that the advanced nuclear power plant designs currently available on the market and 'proven' can only be found in this large capacity range;
(b) Belief that larger units are more economical than smaller ones due to economies of scale;
(c) All the user countries need much additional electricity generating capacity;
(d) They expect that suppliers will devote more effort to development of larger size technology in the next 20 years rather than smaller size.
(e) They recognize that the same effort is needed to secure a site approval, to obtain public acceptance and political commitment and to build human resources and infrastructure, whatever the size of the unit. Therefore, to minimize the ratio between this effort and the electrical capacity, bigger units look preferable to these experts.

Although a majority of experts in the seven countries visited tends to seek larger capacity for nuclear power plant units, several factors need to be considered that could limit this capacity. One of these factors is the required back-up capacity: every power plant unit should have a back-up capacity, the bigger the unit capacity, the bigger the necessary back-up capacity. An optimum must be found so as not to reduce the overall availability, and thus the economics of the national power system. The questionnaire survey performed before the CUC workshop in November 2007 showed that this was actually perceived as an important challenge by user countries when considering nuclear power.

Another factor to be considered is the national experience in operating large electrical power units. In some of the countries visited the biggest existing power plants are 700 MW(e) coal power plants. To prevent unexpected events in terms of grid response, it seems wise to adopt a step-wise approach when increasing the maximum unit capacity level. Any units largely beyond the existing maximum capacity level would therefore be more difficult to implement. The third factor concerns limitations associated with existing physical infrastructure. Experts from one country indicated that the size and weight of the biggest components that could be tolerated by the current local transport infrastructure would limit the unit capacity. According to the experts, except in one of the countries visited, grid compatibility or stability should not be a factor in limiting the size of the nuclear power plant.

For the very near future only a few countries are considering small reactors (less than 300 MW(e)), when they become available and can be competitive with local alternatives. In these countries, small reactors are expected to be appropriate for remote sites such as islands and/or process heat application in case of high temperature reactors. However, these countries have not yet established concrete energy plans with these reactors and even less implementation plans.

Plant lifetime

The experts would expect the first nuclear power plant in their country to be designed for a plant lifetime of 50 to 60 years, as the latest advanced water reactors. For future plants they would like to have the best achievable characteristic at the time of deployment, and they naturally expect that this characteristic will increase compared to current nuclear power plants.

Plant restricted area

The experts generally expect the radius of the restricted area of the nuclear power plant to be in the 1–2 km range. There are no specific requirements to drastically reduce the plant restricted area.

Application

The primary objective for the nuclear power plants is base load electricity production. There are no requests for nuclear reactor systems specially designed for non-electrical applications. However, in the future some experts foresee that nuclear power plants will be used for co-generation in their countries, such as desalination, coal liquefaction, hydrogen production and steam production for enhanced oil recovery. These ideas are still in the brainstorming phase without concrete visions.

Design philosophy/principle

The experts commonly view ‘simplicity’, ‘large design margin’, ‘decommissioning considerations in design’ and ‘user friendly operation and maintenance’ as important design philosophies/principles.

Simplicity: the experts would like to understand the nuclear power plant system to the maximum extent as a user, in order to prevent unexpected events and to operate and maintain the nuclear power plant efficiently and economically. Some of the experts believe that simplicity of the plant well serves this purpose.

Large design margin: the experts require that the nuclear power plant includes enough margins to cope with unexpected events; however plant economy should be kept in mind when implementing extra margins.

User friendly operation and maintenance: almost all of the experts set autonomous capability to operate and maintain the nuclear power plant as an important target. System characteristics of user friendly operation and maintenance are requested to help meet this target.

Decommissioning considerations in design: see '*Decommissioning services*' in Section 3.5

Plant availability

Many experts understand that some of the existing nuclear countries achieve a plant availability factor of more than 90% and thus a plant availability rate of more than 90% is a natural target for some of them. On the other hand, they also understand that not only the system's technical specifications but also the performance of the plant owner/operator for effective operation, maintenance and inspection has an impact on plant availability. Therefore, many of the experts realistically expect that the availability of their first plants should be in the range of 80–90%. For subsequent plants, they naturally expect more than 90% availability.

In this context, experts' requirement is not availability itself, but capability of the nuclear power plant to achieve this availability and provision of the guidance from suppliers on how to achieve it by making the best of this capability.

Expected frequency of failures and disturbances

Almost all the experts require that the frequency of unplanned shutdowns, including scram, should be less than once per year. They recognize that this number is not demanding but common in the existing nuclear countries.

Manoeuvrability

All of the experts expect to use the nuclear power plants as base load in their countries. Therefore, they do not expect load following capability for their nuclear power plants in general. For the future plants, possibility for load following operation is open for some experts.

Capability against load rejection

A majority of the experts does not require more than safe shutdown for capability against load rejection. One of the reasons is that they do not expect loss of load or load rejection to be a frequent event in their countries. Even for a country where the grid system is less reliable and blackouts occur frequently, the capability to operate continuously with house load is not requested because it is recognized that it may increase the cost of plants significantly.

Operation cycle length

A majority of experts requires the best normal practice for operating cycle length, which is 1.5–2 years. They recognize that longer operating cycles might not be feasible when considering a steady and reliable maintenance and inspection programme, and sometimes could be more expensive due, for example, to increased enrichment fuel costs.

Flexibility of fuel

Although almost all the experts assume that enriched UOX fuel will be used for their nuclear power plants in the near term, the long term possibilities of using other types of fuel such as mixed oxide fuel of uranium and plutonium (MOX), thorium fuel, etc., are open options for many of the experts. In the case of MOX or MOX + minor Ac, they mostly expect to outsource the services for the reprocessing of spent fuel, since they most likely will not build a national capacity for reprocessing for economic reasons.[14] Suppliers are required to provide nuclear power plants which have the capacity to use different fuel types in the future with minimum modification.

[14] See Choice of fuel cycle option in this section.

Man–machine interface (MMI)

Although the experts hope that nuclear power plants will benefit from up to date technology as much as possible for MMI, demonstrated maturity and deployment of the technology supersedes this preference since reliability is the most important aspect. The first of a kind MMI system would probably not be acceptable.

Level of automation regarding operation

While the experts require user friendly operation characteristics as design philosophy[15] and better MMI they do not require fully automatic operating capability in the nuclear power plant, since they think that operator participation is crucial to make sure that the plant is under control, instead of entirely depending on the machine. In this context they are satisfied with present semi-automatic operating capability designed to mitigate the operator's burden but still require operator actions. For the future plants, they naturally expect that operating characteristics will be improved by incorporating general technological advances.

Inspectability and maintainability

Similarly to the previous item the experts do not require maintenance/inspection characteristics beyond the present practice, such as full-on-line or remote inspection for their first plants. However, they would not be reluctant to incorporate these innovative technologies once they become practical options in the future, and suppliers are requested to develop and demonstrate them.

Allowed proximity to urban area

Almost all the experts expect nuclear power plants to be built in remote areas. No specific characteristics to enable a nuclear power plant to be built and operated near urban areas are required.

Suitability to site condition

Some of the experts required specific site conditions, such as high seismic condition, necessity of cooling towers, temperature limitation of heat discharge into a lake, transportability of large equipment and components, etc. The experts require the nuclear power plant to be designed for easy adaptation to these different geographic sites.

Choice of fuel cycle option

Many of the experts think that the choice of a nuclear power plant fuel cycle option should balance the nation's independence with economic considerations. None of the experts foresee their country acquiring autonomous enrichment or spent fuel reprocessing capabilities because they think that this would not be economical, except for a plan assuming large scale deployment of nuclear power plants. However, some of the experts think that user countries which are signatories to the NPT should be able to retain the right to choose such options for possible implementation in the future. They think that these capabilities may be necessary to improve the assurance of fuel supply to the user countries.

3.9. SUMMARY OF IMPORTANT DESIRED FEATURES

Many of the desired features described above are driven by similar concerns and general desires. These are summarized as follows:

[15] See Design philosophy/principle in this section.

Proven technology and improvement of the user's capability

Several of the major concerns expressed by the experts are related to a variety of risks resulting from the 'inexperience' with nuclear technology in the user countries. This risk can be minimized by several user desired features in two areas. First, in the area of 'hardware' the experts believe that the nuclear systems, components and methodologies/codes should have been scrutinized and proven in a country with sufficient capability and experience in designing, licensing, safety analysis, operation, maintenance and R&D support.

In the second area of soft skills regarding the management of the technology, the experts would like to minimize the risk associated with their 'inexperience' by initially asking the suppliers to take a greater responsibility. For example, the first project should be based on a turnkey contract. However, the experts believe that it is also important for the user countries to continue to develop national capabilities in as many areas as practically possible, and to gradually assume greater responsibilities in the operation and maintenance of the first nuclear power plant units and in the further deployment of additional units. This desire results in several user considerations such as technology transfer, and utilization of local human, industrial and infrastructure resources.

Sustainable lifetime operation

Several other concerns are related to 'external risks' that may interrupt sustainable operation of a nuclear power plant. Some of these risks are related to potential instability of the international market in the long term, such as market unavailability of fuel, components, spare parts and services; and some are related to the reliance of supply, service and technical know-how on other countries, in combination with possible political considerations by other countries capable of influencing the supply of fuel and critical services. The experts therefore strongly believe that the achievement of sustainable lifetime operation of the nuclear unit should be the responsibility of both the users and the suppliers of the nuclear power plant technology.

Several user considerations related to joint international efforts were derived based on this rationale. Examples are the standardization of nuclear power plants and their components and the selection of popular nuclear power plant design types. Specifically, with regard to fuel supply many experts expressed the hope that all suppliers and users interested in the wider peaceful application of nuclear energy in the world could actively cooperate to increase the assurance of supply of fuel required by all countries that are signatories to and comply with the NPT.

Back end and fuel cycle option

Long term spent fuel management is also a major concern commonly expressed by the experts. They were not confident with most of the options offered or proposed internationally, such as spent fuel take-back and regional spent fuel management facilities. Most experts believe that intermediate spent fuel storage is the most practical option available to their countries, and therefore request suppliers to include the provision of such a facility in the supply of the nuclear power plant. The experts generally feel that spent fuel management is a joint responsibility of the international community and hope an internationally managed approach can be agreed upon.

The experts foresee that countries which are signatories of the NPT and which are not planning large scale deployment of nuclear power would not, for economic reasons, acquire autonomous enrichment or spent fuel reprocessing capabilities if the provision of these services by other countries can be assured. However, as the ultimate back-up, the experts believe that the choice of nuclear fuel cycle option should be taken freely by these countries without concern that this may be used to label the status of the countries or the intention of the users with regard to non-civil use of nuclear energy.

Economics

It is an important consideration by the experts that power generated from a nuclear power plant be economically competitive with that from the best alternative sources available, based on the same local cost calculation basis. However, there is less incentive to require suppliers to develop more economical nuclear power plants, because at present nuclear power is believed to be competitive enough with the locally available alternatives, due to higher and fluctuating prices of alternative energy sources and environmental considerations. Nevertheless, suppliers are required to make sure that nuclear power will continue to be competitive in the future and will provide detailed cost information to the users.

Safety

Although safety is considered to be the first priority there is less incentive to require suppliers to develop 'safer' nuclear power plant designs. The experts are generally satisfied with the safety level achieved by the latest designs. However, they believe that the supplier of a nuclear power plant, which has more extensive experience than the users, shall ensure that the product is equipped with the best and well established safety features, and that the best and well established safety analysis approach and methodology known to the supplier are employed. The experts require that all nuclear power plant designs comply with the IAEA Safety Standards and are licensable in the country of origin. Licensing support is considered to be an important condition by all the experts. Suppliers would be requested to support owners of nuclear power plants (licence applicants) for documentation of licensing. Regulatory bodies in supplier countries would be requested to support regulatory authorities in user countries in the review of licensing documents.

4. FEATURES DESIRED BY TECHNOLOGY USERS

4.1. INTRODUCTION

This section defines common characteristics or desired features requested by potential users of future nuclear power plants in developing countries. It covers general technical and economic characteristics of desired nuclear power plants and associated services and supports. These desired features are divided into major areas, as summarized in Table 8. Although most of them are common, variations among the considerations of different users are pointed out whenever applicable.

The definitions of the terms 'user' and 'supplier' used in the following are provided in Section 1.

TABLE 8. STRUCTURE OF THE USER CONSIDERATIONS

Number	Major issues/Sub-issues	Number of desired features
1	**Economics and financing**	
1.1	Electricity generating cost	2
1.2	Capital cost	1
1.3	Engineering procurement and construction(EPC) duration	2
1.4	O&m cost	3
1.5	Fuel cycle cost	2
1.6	Project financing	1
1.7	Reducing the investment risk	3
2	**Infrastructure and inplementation**	
2.1	Type of contract	1
2.2	Local infrastructure	2
2.3	Licensing and regulatory functions	4
2.4	Electrical grid infrastructure	2
2.5	Assurance of fuel supply	5

TABLE 8. STRUCTURE OF THE USER CONSIDERATIONS (cont.)

Number	Major issues/Sub-issues	Number of desired features
2.6	Assurance of critical materials and components	3
2.7	Local participation	2
2.8	Technology transfer	3
2.9	Human resource development	2
2.10	Development of industrial infrastructure	1
3	**Nuclear safety**	
3.1	Licensing and regulatory considerations	2
3.2	Safety analysis approach	2
3.3	Safety systems	4
3.4	External events	2
3.5	Occupational radiation exposure	2
3.6	Dose to the general public	1
3.7	Accident frequencies	1
4	**Environment, resources and waste management**	
4.1	Environmental impacts	2
4.2	Long term availability of fissile materials	1
4.3	Amount of waste	1
4.4	Waste management	2
4.5	Spent fuel management	2
4.6	Decommissioning	2
5	**Proliferation resistance**	
5.1	Safeguards regime	2
6	**Physical protection**	
6.1	Technical features for physical protection	1
7	**Technical considerations**	
7.1	Proven technology	5
7.2	Standardization	4
7.3	Constructability	2
7.4	Unit size	2
7.5	Plant life	1
7.6	Simplification	2
7.7	Design margins	2
7.8	Ease of operation and maintenance	3
7.9	Plant performance	3
7.10	Manoeuvrability	1
7.11	Operation cycle	1
7.12	Flexibility in the use of fuel	1
7.13	Man-machine interface	2
7.14	Siting	1
7.15	Non electrical applications	1
	TOTAL	96

4.2. CONSIDERATIONS AND RATIONALE

Number		Desired Feature	Rationale/Explanation
1		ECONOMICS AND FINANCING	
1.1		*Electricity generating cost*	
	1.1.1	Levelized unit electricity generating cost of the nuclear power plant should be competitive with that of the comparable base load electricity generation sources in the country.	A prime consideration for investing in nuclear power plants is the achievement of a competitive electricity generating cost over the plant's lifetime against base load electricity generating costs of other sources. The main components of the generating cost include capital cost (see 1.2.1), operation and maintenance cost, fuel cycle cost, decommissioning cost and external costs if applicable.
	1.1.2	Comprehensive and reliable nuclear power plant electricity generating cost information including capital cost breakdown should be made available to enable the user to compare nuclear and other electricity generation sources in the country.	Comprehensive cost information provided by the supplier should be in sufficient detail to enable the user to make a decision.
1.2		*Capital Cost*	
	1.2.1	Capital cost should be minimized to the extent possible without increasing operating costs.	Reducing capital cost is a key consideration for nuclear power plants as they are capital intensive. The two major components of capital cost are overnight capital cost and interest during construction.
1.3		*Engineering, procurement and construction (epc) duration*	
	1.3.1	The total duration of engineering, procurement and construction of the nuclear power plant should be less than 8 years.	The EPC duration is defined as the period from contract signing to commercial operation. It is a consideration to ensure that the nuclear power plant is on-line at the required time based on national energy planning.
	1.3.2	The nuclear power plant construction period from first concrete to commercial operation should be less than 5 years.	Construction period is defined in the IAEA PRIS system as the time taken from the first pour of concrete for a major structure to commercial operation of the nuclear power plant.
1.4		*Operation and maintenance cost*	
	1.4.1	Impacts on operation and maintenance cost arising from the cost and lead time to restock spare parts or spare key components should be quantified.	Although control of operation and maintenance cost is the user's responsibility, the supplier should explain the need and timing for procurement of spare parts and key components to maintain plant operation.
	1.4.2	Impacts on operation and maintenance cost arising from the cost and lead time for supply of additional spare parts or key components should be quantified.	
	1.4.3	The supplier should provide sufficient information to enable the user to assess lifetime operation and maintenance costs under various circumstances including the use of national resources for refueling and maintenance outage.	

1.5		*Fuel and fuel management cost*	
	1.5.1	Fuel and fuel management cost information associated with different fuel management scenarios such as fuel purchase/storage, local fuel fabrication, fuel leasing and fuel purchase/spent fuel take-back should be provided by the supplier.	
1.6		*Project financing*	
	1.6.1	The supplier should provide support for financing of the nuclear power plant project and preproject activities.	Examples of financing support include export credit and soft-loan, when applicable. The supplier could provide support through grants or seed money for preproject activities such as feasibility studies, environmental impact studies, site selection, etc. if required
1.7		*Reducing the investment risk*	
	1.7.1	The supplier should assess potential project risks to project schedule and plant performance and advise on how these risks should be managed.	These potential project risks would generally be the responsibility of the supplier and could include for example completeness of the plant detailed design etc.
	1.7.2	The supplier should assist the user to identify other elements of potential project risk.	Other project risks are generally the responsibility of the user. They include risks arising from change in governmental energy policy, public acceptance, stability of regulations, etc.
	1.7.3	Mechanism for compensation of loss arising from construction delays or poor performance caused by the supplier should be stated and quantified.	Usual mechanisms are liquidated damages, bonus-penalty clauses, etc.
2		INFRASTRUCTURE AND IMPLEMENTATION	
2.1		*Type of contract*	
	2.1.1	If required by the user the first nuclear power plant project should be implemented by turnkey contract.	Turnkey contracts include nuclear steam supply system and balance of plant. Some users are also interested in exploring other types of contracts such as BOT (build–operate–transfer) and BOO (build–own–operate), if applicable.
2.2		*Best use of local infrastructure*	
	2.2.1	Local infrastructure characteristics should be taken into account by the supplier to enable the utilization of available infrastructure to the maximum extent possible.	Local infrastructure could include manufacturing, transportation, man power and supply of material.
	2.2.2	The supplier should develop appropriate solutions to minimize the need for changes to and/or improvement of infrastructure.	
2.3		*Licensing and regulatory functions*	
	2.3.1	The nuclear regulatory body in the supplier's country should provide support to the nuclear regulatory body in the user's country for carrying out its licensing and regulatory functions.	Regulatory functions include site approval, licensing process, codes and methods used for safety analyses, fuel qualification and fuel performance assessment, and human resource development

	2.3.2	The supplier should support the user in the preparation of licence application and associated documentation.	
	2.3.3	The supplier should minimize the needs to change the user's national regulations.	National regulations include areas dealing with industrial, environmental, health and social aspects.
	2.3.4	The supplier should provide support for any changes in the regulation as a result of the nuclear power plant implementation.	
2.4		*Electrical grid infrastructure*	
	2.4.1	The nuclear power plant should be capable of safe, reliable and economic base load operation.	The plant and external grid interface can impact the overall plant performance.
	2.4.2	The nuclear power plant should be capable of operating under local grid frequency conditions and load fluctuations.	The local grid frequency and load conditions may vary from country to country.
2.5		*Assurance of fuel supply*	
	2.5.1	The reactor should be designed to allow for different fuel suppliers.	Assurance of fuel supply is essential for ensuring a sustained operation of nuclear power plant over its plant-life. Most users expect to obtain the assurance through purchase of necessary fuel and related parts/services from a healthy and competitive market with multiple suppliers.
	2.5.2	The supplier should assure fuel reloads for up to one third of the plant life, if the user commits to buy from the supplier for this time period.	One third of the plant lifetime represents a balance between several elements including useful operation of the plant, contract period, etc.
	2.5.3	The supplier should provide up to 5 years of fuel reload if required by the user. Impact on fuel and storage costs of an inventory of multiple reloads should be quantified.	Some users request additional assurance such as fuel reload. Fuel reload includes enrichment, fuel material and final fuel assemblies/bundle. It was recognized that 5 years is a reasonable time to resolve issues that could cause fuel supply disruption.
	2.5.4	The supplier should actively promote the establishment of an appropriate international mechanism for assuring the supply of fuel over the plant's lifetime.	Since assurance of fuel supply at a reasonable cost is a serious concern, an international fuel supply assurance mechanism such as an effective multilateral arrangement would be an important factor to instil confidence in users in the deployment of nuclear energy systems.
	2.5.5	The supplier should not impede development and supply of fuel required over the plant's lifetime for reasons other than compliance with international nuclear related instruments.	Some users are concerned with possible interruption of fuel supply due to factors not related to compliance with international nuclear related instruments (for more information, see cf. http://www-ns.iaea.org/security/legal_instruments_list.htm)
2.6		*Assurance of supply of critical materials and components*	
	2.6.1	The nuclear power plant should be designed to allow supply of critical components by more than one supplier.	Assurance of supply of critical material/components, spare parts is also important for assuring a sustained operation of nuclear power plant over its plant life. In general, the user expects to obtain the necessary critical components at prices dictated by a healthy and competitive market with multiple suppliers.

	2.6.2	The supplier should actively promote the establishment of an international spare parts pool for assuring the supply of critical components over the plant lifetime.	A spare part pool is required for the supply assurance of critical components over the plant's lifetime at a reasonable cost. Such an arrangement would be an important factor to instil confidence in users in the deployment of nuclear energy systems.
	2.6.3	The supplier should not impede development and supply of critical components and materials required over the plant lifetime for reasons other than compliance to nuclear related international instruments.	Some users are concerned with possible interruption of the supply of critical components/materials and spare parts due to factors not related to compliance with international nuclear related instruments. For more information, cf. http://www-ns.iaea.org/security/legal_instruments_list.htm
2.7		*Local participation*	
	2.7.1	The supplier should facilitate the achievement of optimum local participation in the nuclear power plant project.	Optimization will be achieved by balancing local participation and project cost and construction duration.
	2.7.2	In the first few nuclear power plant projects in the user's country, the supplier should utilize local capabilities in civil works, project management and the manufacture of conventional components to the maximum extent possible.	In case of turnkey contract, local participation could be performed under the supervision of the supplier.
2.8		*Technology transfer*	
	2.8.1	The supplier should provide information to increase the user's capabilities to manage all the activities associated with operation and maintenance of the nuclear power plant throughout its life. This should include: Providing electronic documentation* on the plant configuration (system design specifications, logic diagrams, process and instrumentation diagrams, plant arrangement, etc.) and design basis Providing licensed computer codes for analyses and fuel management, and training in their use. Support in getting the computer codes licensed by the national regulatory body	Technology transfer/training can help to improve user's capabilities in areas including the following: understanding of the design; operation and maintenance; research and development; procurement; safety analyses. * Documentation on plant configuration is intended 'as built'.
	2.8.2	The supplier should support the improvement of existing local manufacturing capabilities for conventional components.	Conventional components are non-nuclear grade components.
	2.8.3	The supplier should develop a plan together with the user to transfer the know-how to establish new local manufacturing capabilities for nuclear grade components and fuel fabrication, if required.	
2.9		*Human resource development*	
	2.9.1	The supplier should provide for training of the user's personnel to increase their capabilities to undertake activities associated with construction of the nuclear power plant and its operation and maintenance during its life.	This training should include the provision of: Comprehensive quality assurance programme; Integrated plant maintenance programme; Full scope training simulator and related facilities; Training programme for plant operation and maintenance personnel; Safety analyses; Emergency planning.

	2.9.2	The supplier should arrange a comprehensive human resource development programme to develop the user's capabilities to deal with licensing issues, which include: training for development of licence application; training of regulatory personnel for assessment and approval of licence application.	The user also considers training of the operating personnel by the vendor and the regulatory personnel preferably by the regulatory body of another country. Comprehensive training of regulatory personnel could include an overview of construction, plant commissioning, plant operation, waste management, decommissioning, etc. Training courses in universities might also be considered.
2.10		*Development of industrial infrastructure*	
	2.10.1	The supplier should assist the user in preparing a comprehensive development programme to enable an increase in local participation in successive stages of the nuclear power programme.	Such a programme may be implemented through bilateral agreements between the supplier and the user to develop the local industry through joint ventures and other suiable mechanisms (see consideration 2.8).
3		NUCLEAR SAFETY	
3.1		*Licensing and regulatory considerations*	
	3.1.1	The nuclear power plant shall meet the requirements of the IAEA Safety Standards and comply with those of the user's national nuclear regulatory body.	Imposing country specific safety requirements might affect the standard design (see consideration 7.2).
	3.1.2	The nuclear power plant should comply with nuclear regulation of the country of system origin with regard to design approval.	Compliance with nuclear regulations of the country of origin provides additional confidence in the safety performance of the nuclear energy system.
3.2		*Safety analysis approach*	
	3.2.1	The safety of the nuclear power plant design should be demonstrated by the best combination of deterministic and probabilistic safety analyses and the rationale for the choice of this combination should be explained by the supplier.	Probabilistic safety assessment (PSA) can be used in a complementary manner to the traditional deterministic analysis as part of the decision making process to assess the level of safety of nuclear energy systems.
	3.2.2	Data used in the safety analysis should be justified by the supplier.	
3.3		*Safety systems*	
		The supplier should ensure that:	
	3.3.1	The nuclear power plant uses only proven safety systems.	Examples of possible conditions to be met to qualify a system as 'proven' are listed in 7.1.3.
	3.3.2	Safety systems incorporate the lessons learnt from the extensive past operating experience.	
	3.3.3	Safety systems be designed to minimize the need for operator challenges.	Operator challenges include, time pressure, confusing alternatives for operator action, ambient conditions, etc.
	3.3.4	Selection of passive and active safety features be based on the following: Overall plant safety performance; Overall system reliability; Maintainability; Impact on plant economics. The rationale for the choice of this combination should be explained by the supplier.	

3.4		*External events*	
	3.4.1	The nuclear power plant should be designed to withstand the impact of external site specific events.	External site specific events can include earthquake, tsunami, fire, explosion, flooding, airplane crash, etc.
	3.4.2	The supplier should consider a range of external events parameters that allow development of standard plant design at multiple sites.	Generally, standard plant design for multiple sites would have extra margins and associated costs but would avoid re-engineering costs for most specific sites.
3.5		*Occupational radiation exposure*	
	3.5.1	Annual individual and collective dose should be as low as reasonably achievable (ALARA).	The target for annual individual and collective effective doses to workers are set for use in designing equipment and installations, and for formulating operating and maintenance procedures and rules
	3.5.2	The annual individual and collective effective dose should not exceed internationally recommended limits and national limits.	
3.6		*Dose to the general public*	
	3.6.1	The radiation dose to the general public should not exceed internationally recommended limits and national limits, irrespective of the plant rated power.	
3.7		*Accident frequencies*	
	3.7.1	Objectives for severe core damage frequency and associated consequences should not be more stringent than the limits acceptable in the supplier country, unless requested by the user.	The safety level of the nuclear energy system is expected to be the same as that in the supplier country. No additional safety provisions need to be incorporated in the design of the nuclear energy system, unless specifically requested by the user.
4		ENVIRONMENT, RESOURCES, SPENT FUEL AND WASTE MANAGEMENT	
4.1		*Environmental impacts*	
	4.1.1	The radioactive and chemical releases from the nuclear power plant to the environment should comply with the user's national regulations as well as related international conventions and treaties, and relevant regulations in the region.	
	4.1.2	The nuclear energy system should be designed to operate with minimum water consumption.	
4.2		*Long term availability of fissile materials*	
	4.2.1	The supplier should provide information on the result of assessment and evaluation of scenarios of global nuclear power development for long term availability of fissile materials and discuss with the user any possible options for a sustainable nuclear power programme.	Insufficient or uneconomical supply of fissile material could limit the useful life of the nuclear energy system. The assessment should include different nuclear energy growth scenarios.
4.3		*Amount of waste*	
	4.3.1	Production of solid, liquid and gaseous wastes and effluents during plant lifetime should be kept as low as reasonably achievable (ALARA).	The objective is to minimize the environmental impact while optimizing the overall cost of waste management.

4.4		*Operation waste management*	
	4.4.1	The supplier should provide guidance for managing the waste generated by the nuclear power plant operation in a safe and sustainable manner.	
	4.4.2	The supplier should provide facilities for on-site operational waste management.	
4.5		*Spent fuel management*	
	4.5.1	The nuclear power plant should have adequate storage to accommodate: Spent fuel unloaded for 10 years; A complete core (unloading and maintenance); Various irradiated equipment; Reload of fresh fuel.	The capacity of the spent fuel storage facility is mainly dictated by the need for a long decay time to handle the spent fuel and by the need to provide the operators with large buffers before direct disposal and/or reprocessing. Various irradiated equipment might include fuel loading and inspection equipment, control rod clusters, etc. Fresh fuel is usually stored in dry storage, but just before reloading, it is necessary to have it in the spent fuel pool ready for loading.
	4.5.2	If required by the user, the supplier should actively promote the establishment of mechanisms for spent fuel management.	Mechanisms for spent fuel management could include return of spent fuel to the supplier country, interim storage facilities at a centralized location away from reactor, independent handling of spent fuel management, etc.
4.6		*Decommissioning*	
	4.6.1	The nuclear power plant should be designed for ease of decommissioning. Relevant information should be provided to the user.	Relevant information could include basic scenarios, risks and costs, to demonstrate the feasibility of decommissioning taking into account current knowledge.
	4.6.2	Guidance on the decommissioning should be provided by the supplier before plant operation.	
5		PROLIFERATION RESISTANCE	
5.1		*Safeguards regime*	
	5.1.1	Suppliers should not impose any additional considerations with regard to intrinsic features against nuclear proliferation for signatories of the Non Proliferation Treaty and relevant nuclear related international instruments.	The proliferation resistance of the nuclear energy system is expected to be the same as that in the supplier country. No additional proliferation resistance provisions need to be incorporated in the design of the nuclear energy system, unless specifically requested by the user.
	5.1.2	The supplier should design the nuclear energy system for safeguard friendliness to the current IAEA safeguards regime.	Safeguard friendliness includes provisions to easily install monitoring, supervision, accounting systems, etc.

6		PHYSICAL PROTECTION	
6.1		*Technical features for physical protection*	
	6.1.1	The nuclear power plant design should incorporate technical features and provisions to protect against theft, sabotage and acts of terrorism through integration of plant arrangements and system configuration with plant security design, in accordance with international guidance, practices and the user's national regulations.	These technical features include any intrinsic measures such as fences, walls, doors/gates, alarms, etc.
7		TECHNICAL CONSIDERATIONS	
7.1		*Proven technology*	
	7.1.1	Proven technology should include overall nuclear power plant systems and elements. The elements should include components, plant structures, design and analysis techniques, maintainability and operability features and construction techniques.	
	7.1.2	The provenness of overall nuclear power plant systems should be demonstrated through several years of operation of similar nuclear power plants as a commercial plant with a good operational record.	
	7.1.3	The provenness of the elements as defined in 7.1.1 should be demonstrated through one or more of the following: Several years of operation in existing nuclear power plant; Full or part scale testing facilities; Several years of operation in other applicable industries such as fossil power and process industries.	
	7.1.4	The supplier should review existing databases of operating experience to identify both positive experience as well as causes of significant events and unplanned outages, and incorporate appropriate features in the nuclear power plant design.	The access to existing databases could enable the user to perform an informed assessment of the nuclear power plant performance.
	7.1.5	The reactor system should have been licensed or should be licensable in the country of system origin and the licensing information should be made available.	Reactor system is defined as a nuclear steam supply system with a similar reactor and general system configuration. There are several ways the supplier can demonstrate licensability of the reactor system, such as design certification, or statement by the country of system origin's regulatory body that there is no significant potential issue with the licensing of the reactor system in the country.
7.2		*Standardization*	
	7.2.1	The nuclear power plant should be designed based on standardized plant design and components that should be established to include the maximum numbers of site conditions without significantly increasing costs.	Standardization is cost effective since it allows the cost of developing and launching a new design to be spread over a number of plants. In addition, series ordering and manufacture of plant and equipment should result in significant cost savings. However, the standardized design which takes into account any possible site conditions could have a significant impact on the cost (cf. 3.4.2).

	7.2.2	The supplier should minimize the number of different types of components to the extent possible, without compromising the safety of the plant.	Minimizing number of different types of components improves plant economics, maintainability and availability of components. However, this should not be used to minimize diversification required in the safety systems.
	7.2.3	The design of equipment and components should allow for the supply of their replacement during the life of the nuclear power plant by manufacturers other than the original manufacturers.	The possibility of replacement of equipment and components by different manufacturers greatly improves the assurance of sustainable operation of the plant.
	7.2.4	The Standard International (SI) unit system should be used in the design and related documentation.	
7.3		*Constructability*	
	7.3.1	The design, construction process and procedures should allow optimized utilization of both local workforces at site and prefabrication at factories or at site.	Prefabrication at factory can be an effective way to reduce construction time. However, prefabrication in the supplier country may increase construction costs and suppress local participation. Therefore, optimization of prefabrication and local participation should be considered. In addition, prefabrication at factory in the user country or on-site by using local resources could be an option (cf. 2.7.2).
	7.3.2	The design, construction process and procedures should allow flexibility of construction schedule.	The flexibility on the construction schedule may be needed to facilitate local participation.
7.4		*Unit size*	
	7.4.1	For near term deployment, the nuclear power plant should be designed to meet the plant size considerations of users.	There is no commonality on the generating capacity but a distribution (refer to Section 2.3.5).
	7.4.2	For long term deployment, the nuclear power plant should be designed to meet the plant size considerations of users.	In the longer term, the needs of the users may change (refer to section 2.3.5).
7.5		*Plant life*	
	7.5.1	The design life of the nuclear power plant should be at least 60 years.	This could include replacement of structures and equipment that cannot last 60 years.
7.6		*Design approach*	
	7.6.1	The design of the plant should be simplified with the objective to minimize the number of types of systems and components, without adverse impacts on the economics, and plant performance and safety, while improving ease of operation and maintenance.	Plant simplification with human factors considerations during the design stage of the nuclear power plant could facilitate construction, operation, maintenance and decommissioning.
	7.6.2	An integrated design approach should be used to facilitate ease of construction, commissioning, operation, monitoring, inspection, maintenance and decommissioning of the nuclear power plant.	During the design stage an integrated design approach considers all aspects of costs, layout, safety response, plant operation and maintenance over the plant lifetime.
7.7		*Design margins*	
	7.7.1	The nuclear power plant design should be optimized to incorporate sufficient margins to enable high availability and to minimize the chance of exceeding regulatory limits.	Margins above the regulatory limits provide flexibility during plant operation to account for normal expected operating variation, minor design or operating changes, etc.

	7.7.2	The supplier should provide information on how design margins are allotted for new features or new operating conditions.	New features or new operating conditions can impact the initial margins.
7.8		*Ease of operation and maintenance*	
	7.8.1	On-line maintenance should be incorporated in the plant design.	On-line maintenance is carried out during operation. In addition to improving ease of operation and maintenance, it also improves plant availability.
	7.8.2	On-line monitoring should be incorporated in the plant design to facilitate assessment of plant conditions and component lifetime.	
	7.8.3	Allowable outage time for safety systems should be optimized with regards to plant availability and generating costs.	Components of safety systems are normally required by regulation to be taken off regularly for inspection and maintenance. The outage time is the time the safety systems are out of service. The allowable time for outage is based on a safety analysis. The impact of the allowable outage time on the plant availability can be minimized by adding extra trains, but might result in higher capital cost.
7.9		*Plant performance*	
	7.9.1	The nuclear power plant should be capable of achieving an annual availability factor ≥ 85%. The supplier should provide guidance on the best practices to achieve this performance level.	
	7.9.2	The number of unplanned automatic scrams attributed to the design should be less than 1 scram/year.	
	7.9.3	In case of loss of load, the nuclear power plant should be capable of safe shutdown.	Additional consideration of house load operation capability following loss of load could result in higher capital cost but might be compensated by a higher availability factor due to the possibility for faster restart.
7.10		*Manoeuvrability*	
	7.10.1	The nuclear power plant should be designed for base load operation.	In addition to the base load operation, some users require that the nuclear power plant be designed with a daily and weekly load-following capability. Faster and frequent load changes can impact several aspects of the design, such as control systems, component thermo mechanical cycles, etc.
7.11		*Refuelling cycle*	
	7.11.1	The nuclear power plant design should be capable of a refueling cycle of at least 18 months.	This consideration is only applicable to the design capability of reactor types with batch refueling. It does not preclude an actual refueling period of less than 18 months. Longer operating cycle length between refueling could improve plant availability, but might increase fuel cost. Optimization needs to be carried out to determine the operating cycle length.

7.12		*Flexibility in the use of fuel*	
	7.12.1	If required by the user, the nuclear power plant should have the capability to use different fuels such as uranium and plutonium mixed oxide fuel (MOX) and/or thorium oxide fuel in the future with minimum modification of the facilities.	The capability of using different fuel types increases the diversification of fuel supply but might impact cost and other factors.
7.13		*Man-machine interface*	
	7.13.1	The man-machine interface (MMI) should consider international human factor's practices, optimized plant automation, and units (distance, temperature, etc.), and should be standardized to the extent possible.	
	7.13.2	The man-machine interface (MMI) should be customized based on user required language.	
7.14		*Siting*	
	7.14.1	The nuclear power plant should be designed for easy adaptation to different sites.	Aspects of the nuclear power plant design that should allow for easy adaptation to different sites include layout and general civil structure that can meet the majority of site geophysical conditions (see 7.2.1, Standardization).
7.15		*Non-electrical application*	
	7.15.1	The nuclear power plant should have the flexibility for non-electrical application, if required.	Some countries want to consider co-generation as an option for various applications such as desalination.

5. FINAL OBSERVATIONS

This publication compiles the opinions of experts from developing countries that are considering deployment of nuclear power plants in the near term or are making projections for the deployment of nuclear power plants in the next 40 years (up to 2050). The input provided by the experts reflects good knowledge of the currently available technologies; discussions and considerations on innovative technologies were very limited. The publication also provides background information collected by the IAEA staff regarding additional characteristics and expectations of these countries. It was observed that the expectations of the experts were more optimistic in terms of nuclear power plant deployment until 2030 than the IAEA projections for the same time frame.

It was observed that the considerations by experts in technology user countries addressed in this study for the development and deployment of new nuclear power plants showed several interesting characteristics, which are summarized below:

(a) There was a very strong degree of commonality among the considerations and opinions expressed by the experts in all the very diverse countries that were part of this effort;
(b) There were no measurable differences between the considerations and opinions expressed by experts on the relative importance of desired features in countries that could be considered to have experience with nuclear power or those countries considering it for the first time;
(c) A few areas indicated some divergence among experts in the countries.

This publication was prepared by a team of IAEA staff with input from about two hundred experts from the countries addressed in this study. Additional refinements of the information by various methods, such as application of the INPRO methodology to identify gaps, or the collection of a larger scientific sample of additional country specific data would be required in order to analyze comprehensive trends and/or to quantify market demand. In particular, the issues of grid capacity and likely available investment based on gross domestic product as they might affect near and long term nuclear expansion projections should be more carefully considered as supplementary information is compiled.

This publication is intended to promote early and frequent dialogue between technology users and technology holders. The timing and availability of innovative technology is an important part of future dialogues. Activities that might enable user consideration of small and medium sized reactors, in addition to the larger reactors that are widely deployed today, should be explored. The information presented herein and future refinements should be considered in conjunction with other IAEA publications and in conjunction with the in-depth discussion associated with a Member State's strategic planning and preparation for introduction or expansion of nuclear power and the infrastructure, regulatory, institutional, technology, economic and other issues that must be addressed during the, safe, secure, peaceful and transparent deployment of nuclear energy.

The publication also incorporates in Appendix II lessons learned from previous nuclear power programmes in selected technology holder countries.

Appendix I

PROCESS FOLLOWED DURING STAGE 1 OF THE CUC ACTIVITY

In order to accomplish the activity identified as ‘common user considerations and actions for development and deployment of nuclear energy system for developing countries’, it was decided by the INPRO team that with limited resources and in order to finish the task in a short time frame it would be necessary to collect data from a representative sample of developing countries as opposed to all the countries. It was also decided to collect those data by visiting the countries selected and meeting face to face with as many relevant experts as possible during these country visits in order to validate the set of information provided by each country. The criteria used to obtain a representative group from the 54 countries originally identified for this study were intended to select an unbiased mix of countries with all types of programmes and economies included across the diverse characteristics in this large group of countries. These criteria are defined below in the detailed process description. After a selection period seven countries agreed to be visited and were visited during the summer of 2007.

The first step consisted of visiting and surveying these seven countries that represented a wide spectrum of relevant characteristics at different stages in considering the introduction or the expansion of a nuclear power programme. The outcome of this first step was a draft of a set of considerations that became the early version of Sections 3 and 4 of the present report.

The second step was dedicated to completing the other sections of the report (Sections 1, 2 and 5, plus the appendices) and reviewing Section 4 with additional input and participation by a broader number of user countries (35) and technology holder countries (8). The outcome of the second step is the current report.

The action plan for the whole CUC activity (stage 1 in 2007 and stage 2 in 2008) and the process to conduct Stage 1 were first presented during the 10th INPRO Steering Committee Meeting (SCM) in December 2006. The process was then presented in more detail during the 11th INPRO Steering Committee Meeting (July 2007) while Stage 1 was in progress. Near completion of Stage 1, the process was once again presented during the 12th INPRO Steering Committee Meeting (December 2007), at the same time that the draft CUC progress report was first presented to the Steering Committee.

The IAEA team that performed the CUC activity (CUC team) included regular staff and cost free experts (CFE) from the INPRO ICG, both from technology user and technology holder countries. At the beginning of the activity, the team comprised a manager (regular staff), a responsible technical officer (regular staff) and two supporting officers (CFE). As the activity progressed, the team was reinforced by three additional CFEs from INPRO ICG and by an external consultant.

The process implemented by the CUC team to develop the CUC during Stage 1 of the activity was based on a two step approach. This two step approach for Stage 1 was adopted for practical reasons, since it provided the best use of available time and resources. It is shown in detail in the following:

	Action	By	Date	No. external participants*
0	Presentation of CUC Action plan to 10th SCM	CUC team	Dec. 2006	40
	FIRST STEP			
1	Definition of criteria to help for the selection of user countries for the survey	CUC team	Jan. 2007	
2	Preparation of a questionnaire to serve as a basis for interviews in the countries visited during the survey	CUC team	Jan 2007	3
3	1st consultants meeting		Feb. 2007	30
	Review of user country selection criteria	CM participants		
	Proposal of countries (and alternates) to be visited during the survey	CM participants		

	Action	By	Date	No. external participants*
	Review of the questionnaire	CM participants		
	Review and update of the action plan	CM participants & CUC team		
4	Organization of the meetings in the countries visited for the survey	CUC team	Feb.–July 2007	
5	First visit — Indonesia	CUC team	May 2007	27
6	Second visit — Belarus	CUC team	June 2007	7
7	Third visit — Lithuania	CUC team	June 2007	10
8	Fourth visit — Egypt	CUC team	June 2007	24
9	Fifth visit — Bangladesh	CUC team	July 2007	10
10	Sixth visit — Mexico	CUC team	July 2007	12
11	Seventh visit — Malaysia	CUC team	Aug. 2007	44
12	Drafting Sections 3 and 4 of the CUC progress report	CUC team	Sept. 2007	
	SECOND STEP			
13	Sending invitations for the workshop to all CUC countries and contact with permanent missions and local organisations to promote participation	CUC team	July–Oct. 2007	
14	2nd consultants meeting		Sept. 2007	30
	Presentation of results	CUC team		
	Review draft Section 4	Meeting participants		
	Review of workshop organisation	Meeting participants		
	Preparation of a short questionnaire for workshop participants	Meeting participants		
	Discussion on Stage 2	Meeting participants		
15	Modification of Section 4, finalization of the short questionnaire and sending to the workshop participants	CUC team	Oct. 2007	
16	Completion of the CUC progress report (Sections 1, 2 and 5 and appendices)	CUC team	Nov. 2007	
17	CUC workshop		Nov. 2007	62
	Presentation of process and results	CUC team		
	Review of Section 4	Meeting participants		
	Collection of comments from workshop participants	CUC team		
	Discussion on Stage 2	Meeting participants		
18	Finalization of CUC progress report	CUC team	Dec 2007 to April 2008	
	Internal review			
	External review			
	3rd consultants meeting		March. 2008	18

* Including IAEA staff external to the CUC team.

DETAILED DESCRIPTION OF THE PROCESS

1 — Definition of criteria for the selection of user countries for the survey

After the CUC action plan was presented to the INPRO Steering Committee (10th SCM), in January 2007 the CUC team started developing the process for Stage 1 in coordination with interested members of the INPRO Steering Committee. First, criteria were defined by the CUC team to help select a limited number of countries to be interviewed during the survey. A list of potential user countries was established based on the following characteristics:

(a) IAEA Member States;
(b) Countries defined as developing economies according to the criteria of the World Bank 2006 database;
(c) Public declaration of various level of interest in nuclear power.

The countries to be visited during the survey would have to cover as much as possible a wide spectrum of the following characteristics:

(1) Economics;
(2) Grid capacity and configuration, electrical capacity (current + estimation in 2030);
(3) Availability of natural energy resources;
(4) Existing or non-existing nuclear power plants;
(5) Population;
(6) Geographical distribution in the world;
(7) Geographical configuration of the country;
(8) Individual power programme or consortium.

A preliminary document with a short list was sent to the participants of the 1st CM at the end of January for consideration before the meeting.

2 — Preparation of a questionnaire to serve as a basis for interviews in the countries visited during the survey

The CUC team reviewed various available documents (INPRO methodology, European utility requirements, US EPRI user requirements document) to establish the questionnaire. The questions covered the following aspects:

(a) National energy planning and policy;
(b) Economics;
(c) Infrastructure;
(d) Safety;
(e) Environment;
(f) Used fuel and waste management;
(g) Proliferation resistance;
(h) Physical protection;
(i) Technical specifications.

The CUC team tested the draft questionnaire by performing rehearsal interviews with participants external to the project; namely one nuclear engineer (English native speaker), one IAEA colleague coming from one of the potential user countries and one IAEA colleague coming from a technology holder country.

The draft questionnaire was sent to the participants of the 1st CM at the end of January for consideration before the meeting.

3 — First consultants meeting

The meeting was held in Vienna at the beginning of February 2007. The objective was to validate the process for CUC Stage 1 and in particular to define a list of user countries to be visited for the survey and to validate the questionnaire to be used as a basis for the interviews in the selected countries. The meeting was attended by 35 participants:

(a) 20 participants from governments, permanent missions, suppliers, utilities and research institutes in the 8 ‘friend of nuclear’ countries: Canada (1 member of INPRO Steering Committee), China (2), France (2 members of INPRO Steering Committee), India (2), Japan (5), Republic of Korea (1), Russian Federation (3), USA (5);
(b) 1 participant from Finland (chairman of the meeting);
(c) 14 participants from the IAEA.

After the CUC team presented the criteria that were proposed for the selection of a limited but representative number of countries to be visited during the survey, the meeting participants proposed the following list of countries to be visited, with alternates if necessary:

Region	Proposal for survey	Proposal for alternate
Africa and Middle East	Egypt Morocco	Algeria
Asia and Pacific	Bangladesh Indonesia Vietnam	Thailand
Latin America	Chile	Mexico
Europe	Turkey Baltic Consortium	Belarus

It was highlighted during the meeting that for a country to be selected only meant that the country provided the desirable mix of attributes for the survey but did not in anyway mean that the country’s interest, plans or approach to nuclear power was better or worse than any other. The participants stressed that it would be very important to evaluate the conclusions of the survey with the extended number of user countries during the planned workshop at the end of 2007. It was decided during the meeting to organize a second dedicated consultants meeting, not planned originally, in September 2007, to review the results of the survey, with the participation of the countries visited. It was recommended that the survey meetings should be agreed with the permanent missions but that they could seek experts outside the Government to participate. The participants recognized that a 20 year outlook should be considered rather than a 30–50 year outlook to get more meaningful and realistic information. They also estimated that grouping various countries into logical sets of user requirements might be acceptable, whereas grouping the countries depending on time dependent scenarios would not be appropriate. Finally, it was recommended to be sensitive not to introduce bias when conducting the interviews.

The participants also reviewed and proposed modifications to the questionnaire to be used for conducting the interviews. The questionnaire was sent to the country representatives at least two weeks before the planned interview to provide enough visibility and preparation time for the interviewees.

A detailed meeting report was produced and sent to all the participants during the visit one week after the meeting.

4 — Organization of the meetings in the countries visited for the survey

Following the recommendations of the consultants meeting, the CUC team started contacting the missions of the selected countries in February to explain the background, the objectives and the process of the CUC activity. This phase lasted six months (when three months were planned originally) and the following was achieved.

Proposal by consultants meeting	Result
Egypt	Agreed to participate in the survey
Morocco	Despite frequent communication with the permanent mission, the answer form Morocco did not arrive in time to get organized with the alternate country within the remaining time available.
Bangladesh	Agreed to participate in the survey.
Indonesia	Agreed to participate in the survey.
Vietnam	Difficulties to organize the meeting. Communication was engaged with the proposed alternate country (Thailand) as well as with Malaysia. Malaysia's positive reaction and quick answer made it possible to organize a meeting during the allocated period.
Chile	Declined. Alternate country, Mexico, agreed to participate in the survey.
Turkey	Declined. Alternate country, Belarus, agreed to participate in the survey.
Baltic Consortium (Lithuania, Latvia, Estonia)	Agreed to participate in the survey.

Thanks to the permanent missions and with the active participation of local organizations, seven meetings could be organized in the period allocated for the survey, with four countries from the initial list proposed by the consultants meeting, two countries from the list of alternates plus an additional user country.

The main characteristics gathered at the time of selection of the countries to be visited are summarized below.

	Gross domestic product (Bil. US $)	Population (Mil. Hab.)	Electricity installed capacity (GW(e))	Existing operating nuclear power plant	Indigenous Energy resources	Region
Bangladesh	60	141	4.7	No	Scarce	Asia
Belarus	29.6	10.3	7.8	No	Scarce	Europe
Egypt	89.3	76	17	No	Medium	Africa
Indonesia	287	238	25	No	Medium	Asia
Lithuania	25.5	3.6	5.7	Yes	Scarce	Europe
Malaysia	130	24	20	No	Medium	Asia
Mexico	768	105	50	Yes	Medium	Latin America

Sources:

- gross domestic product: World Bank Group Database 2006.
- Population: DOE/IEA (2004).
- Electricity installed capacity: DOE/IEA (2004).
- Indigenous energy resources: based on data from Oil and Gas Journal (2006) and DOE/IEA 2004.

5 to 11–Meetings in the countries visited

The CUC teams (5 in total) performed seven visits and interviewed in total more than 130 experts from government, nuclear regulatory bodies, industry, utilities, research institutes, universities and finance sectors.

The interviews were either held with groups of experts or with individuals, based on the questionnaire (included in this appendix) that was sent in advance as well as on other topics that were raised freely by the experts. The sets of questionnaires completed in advance by the interviewees were also collected. At the end of each meeting, a debriefing was organized with the meeting coordinators and a synthesis report was written and submitted for approval after the meeting. The details are provided below:

Indonesia: 16 sessions on various topics with a total of 27 experts
Belarus: 5 sessions with 4 experts plus a meeting with the vice-minister of energy, his staff and scientific adviser
Lithuania: 7 sessions with 10 experts from Lithuania (9) and Poland (1) plus input from Estonia
Egypt: 7 sessions with a total of 24 experts
Bangladesh: 8 sessions with a total of 10 experts
Mexico: 7 sessions with a total of 12 experts
Malaysia: 6 sessions with a total of 44 experts

12 — Drafting Sections 3 and 4 of the CUC progress report

After the seven meetings, the drafting was performed by the CUC team. It was based mainly on the results of the discussions with the interviewees and to a lesser extent on the answers to the questionnaire returned by the meeting participants. The answers provided to the questionnaires had to be used carefully since in some cases the experts revised their answers during the interview in the light of discussion and explanations provided by the CUC team but the written answers to the questionnaire could not always be modified accordingly. For that reason, the main source of information used by the CUC team to establish Section 4 was the direct discussions with the experts rather than the sets of questionnaires. When relevant, other sources of information such as press releases, questions asked during IAEA meetings and conferences were also considered in the process.

Figures 33–37 show that the 9 countries that participated in the survey present a good representation of the whole of the user countries, in terms of population, economics (gross domestic product, GNI per capita) and electricity capacity (2005, 2030 estimate).

Although the idea of establishing various sets of user criteria based on various groupings had been considered initially by the CUC team, the results of the survey showed that most of the criteria, needs and concerns were common to all countries. Very little information could be collected on specific needs and non-electrical applications of nuclear power for example and did not provide sufficient material and a basis to establish meaningful different sets of criteria.

13 — Sending invitations for the workshop

All the user countries were sent an invitation through the Technical Cooperation Department at the end of July 2007 to participate in the workshop in November 2007. The background and the objectives of the CUC activity, as well as the specific objectives of the workshop were presented. In August and September the CUC team communicated with the permanent missions and with local organizations to promote participation to the workshop.

14 — Second consultants meeting

The meeting was held in Vienna at the end of September 2007. The objectives were first, to review the results of the survey (draft Section 4 of CUC progress report) in order to obtain the general agreement of the visited user countries and to collect advice from the technology holders, and second to review the organization of the November workshop (including the preparation of a short questionnaire to be sent in advance to the workshop participants). The meeting was attended by 37 participants:

(a) 7 participants from the countries visited: Bangladesh (1), Belarus (1), Egypt (1), Indonesia (1 member of the INPRO Steering Committee), Lithuania (1), Malaysia (1), Mexico (1);
(b) 15 participants from governments, permanent missions, suppliers, utilities and research institutes in the 8 ‘friend of nuclear’ countries: Canada (1 member of INPRO Steering Committee), China (1), France (3 including 2 members of INPRO Steering Committee), India (1 member of INPRO Steering Committee), Japan (3), Republic of Korea (1), Russian Federation (2 including 1 member of INPRO Steering Committee), USA (3);
(c) 1 participant from Finland (chairman of the meeting);
(d) 14 participants from the IAEA including 7 members of the CUC team.

After the CUC team presented the results of the survey, the meeting participants reviewed Section 4 and suggested modifications. A short questionnaire to be sent to the workshop participants was also drafted.

A meeting report was produced and sent to the participants with all the meeting material.

15 — Modification of Section 4 and finalization of the short questionnaire

The recommendations made during the September meeting were taken into account by the CUC team that produced a revised Section 4 and a short questionnaire with an explanatory note.

These were first sent to the participants of the 2nd consultants meeting as agreed during the meeting, and then sent to the workshop participants, with copies to the permanent missions. In particular, the CUC team asked that when providing answers to the questionnaire the participant should make sure these were consistent with their government policy.

The questionnaire gave the participants an opportunity to evaluate the importance of each consideration as well as to provide comments on the user requirements. Additional questions addressed the expected short, medium and long term needs in their country with regard to nuclear power plants (unit size and number of units) for electricity generation and non-electrical applications.

The workshop participants answered the questionnaires and sent them back before the workshop so that the CUC team could present the results during the workshop and integrate them in the draft CUC progress report.

16 — Completing the report

The CUC progress report was completed and a first draft of the report was made available to all the workshop participants one week before the workshop.

17 — CUC workshop

The workshop was held in Vienna at the end of November 2007. The objectives were first to review and reach a general agreement of the user countries on the set of user requirements (Section 4), taking into account observations from technology holder countries, and second to present the plans for the next Stage of the CUC activity.

The workshop was attended by 69 participants:

(a) 34 participants from the user countries: Argentina (1), Armenia (1), Bangladesh (1), Belarus (1), Brazil (1), Cameroon (1), Chile (1), Croatia (1), Dominican Republic (1), Egypt (2), Estonia (1), Ethiopia (1), Georgia (1), Ghana (1), Indonesia (1), Jordan (1), Kenya (1), Lithuania (1), Malaysia (1), Mexico (1), Moldova (1), Mongolia (1), Namibia (1), Nigeria (1), Romania (1), Sudan (1), Syrian Arab Republic (1), Tunisia (1), Ukraine (1), Uruguay (1), Venezuela (1), Vietnam (1);
(b) 16 participants from governments, permanent missions, suppliers, utilities and research institutes in the 8 ‘friend of nuclear’ countries: Canada (1 member of INPRO Steering Committee), China (1), France (4, including 1 member of INPRO Steering Committee), India (1), Japan (1), Republic of Korea (1), Russian Federation (2, including 1 member of INPRO Steering Committee), USA (4);

(c) 4 participants as observers: Belgium (1), European Commission (1), Finland (1, chairman of the meeting), Spain (1);
(d) 15 participants from the IAEA, including 7 members of the CUC team.

Although the main focus was concentrated on Section 4, the whole report was presented and comments were collected on the other sections (mainly Sections 1 and 2). It was agreed to review the report accordingly: explanation on the status and intended use of this report, detailed description of the whole process for the elaboration of the report (the present appendix) and more clear presentation of statistics.

A workshop report was produced and sent to the participants with all the workshop material.

Figures 33–37 show that the 35 countries that contributed to this report are a good representative sample of the whole group of CUC countries in terms of population, economics (gross domestic product, GNI per capita) and electrical capacity (2005, 2030 estimate).

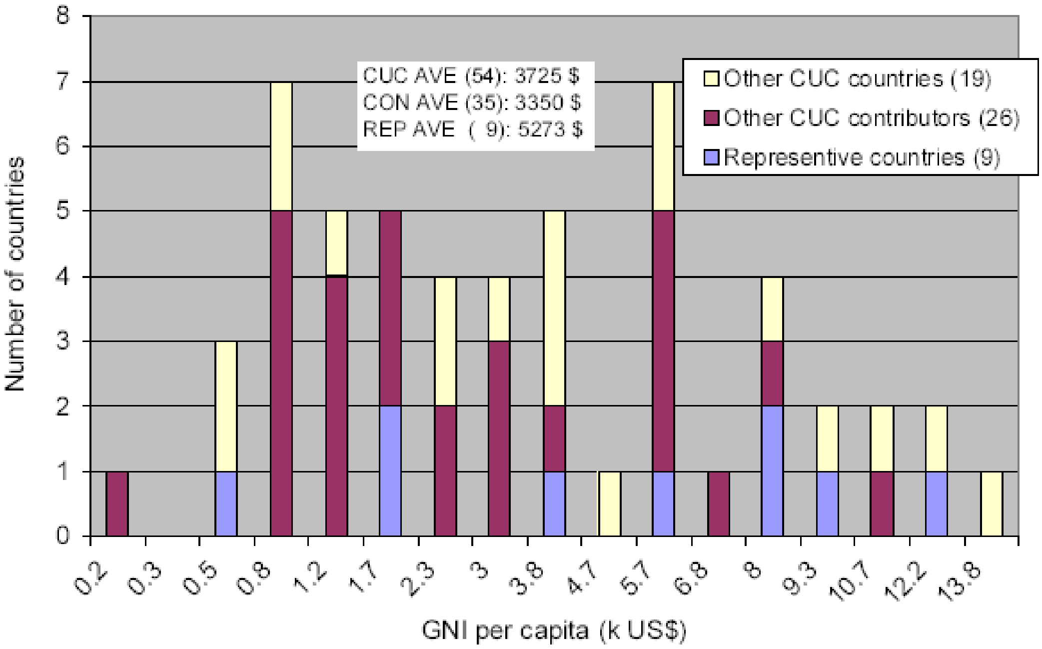

FIG. 33. GNI per capita in technology user countries.

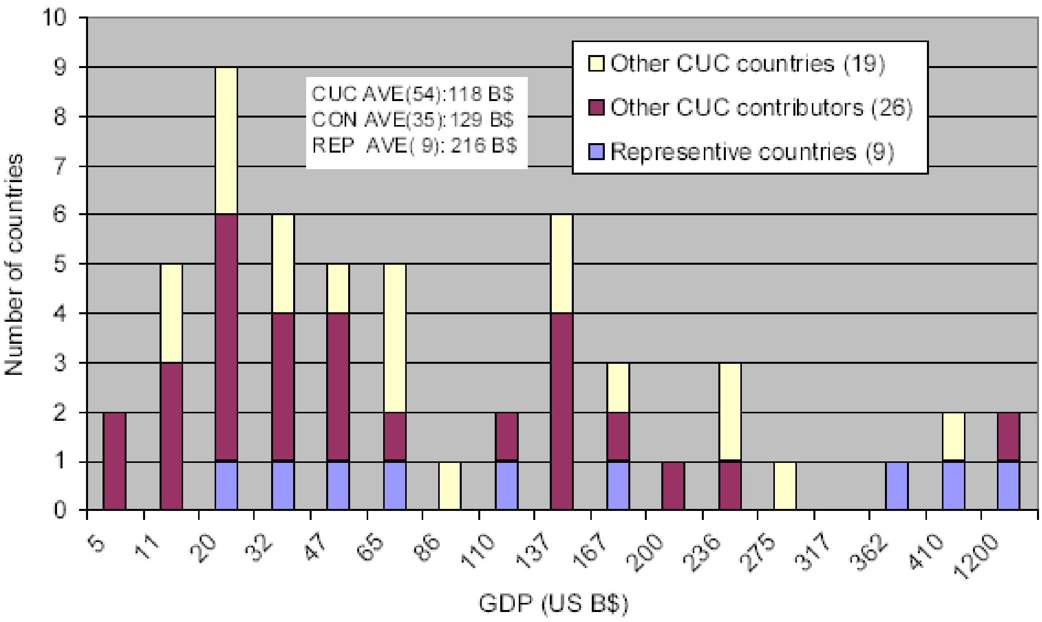

FIG. 34. Gross domestic product in technology user countries.

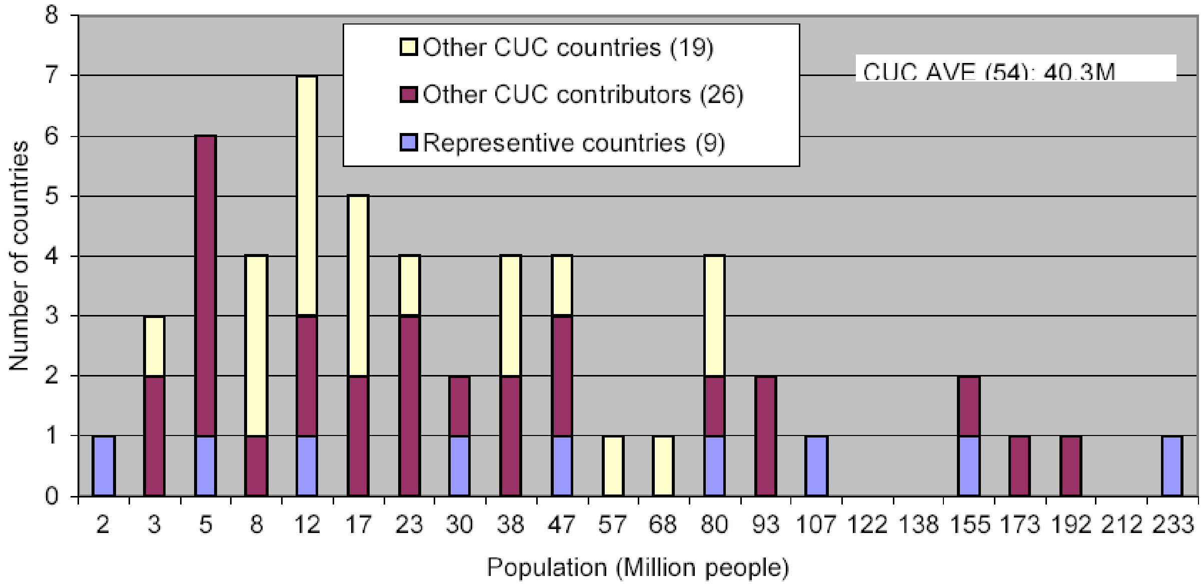

FIG. 35. Population in technology user countries.

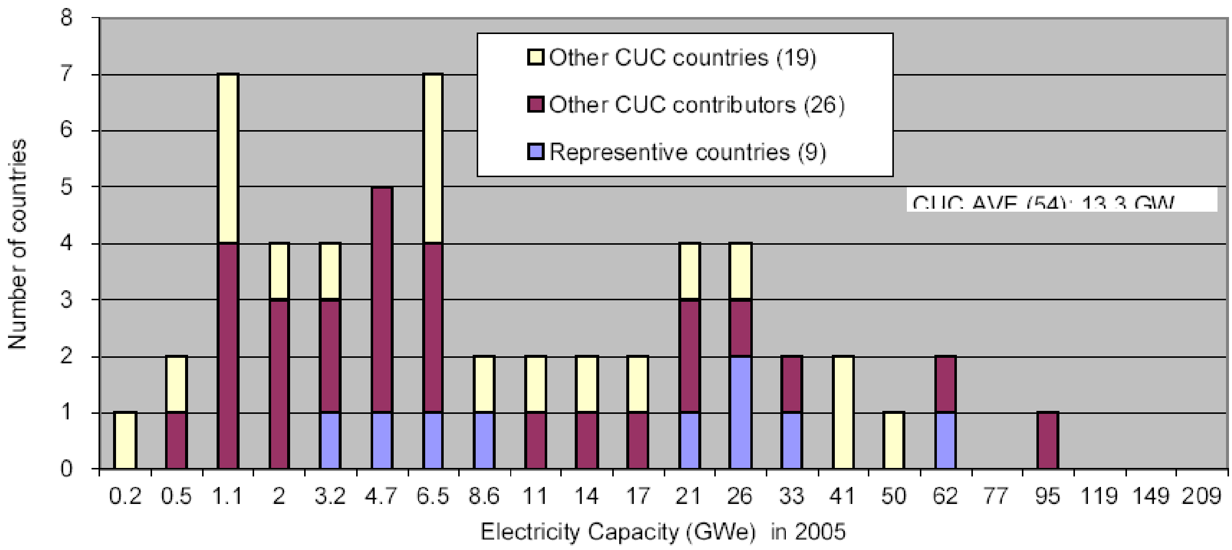

FIG. 36. Electricity capacity in 2005 for technology user countries.

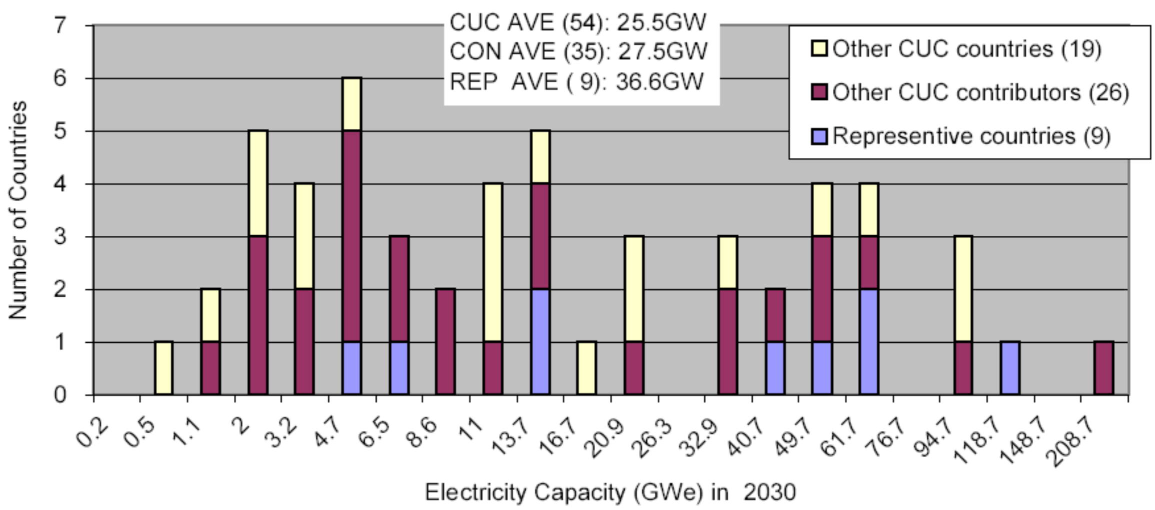

FIG. 37. Forecasted electricity capacity in 2030 for technology user countries.

18 — Finalization of the CUC progress report

The finalization of the report was performed by the CUC team following the recommendations of the workshop and of the INPRO Steering Committee during the 12th and 13th SCMs.

I.1. QUESTIONNAIRE SENT TO THE SEVEN VISITED COUNTRIES

A Questionnaire for discussion with user countries

Common user criteria for development and deployment of nuclear power plants in developing countries

Responding to the General Conference Resolution (GC(50)/RES/13B), INPRO started a new activity called 'Common User Criteria and Actions for Development and Deployment of Nuclear Power Plants for Developing Countries' after approval at the INPRO Steering Committee. The purpose of this activity is to improve understanding between technology users and holders by conveying users' common considerations to technology holders and subsequently to consider necessary actions together to fulfil the needs. In the first phase of this activity, common user criteria (CUC) will be developed to define common characteristics needed by potential users of new plants in developing countries. CUC will cover general technical and economic characteristics of desired nuclear reactor plants and associated services and support.

The first step of this activity is to conduct detailed discussion with various stakeholders in various user countries in order to identify user's considerations. This questionnaire was designed to facilitate those discussions between representative stakeholders in user countries (interviewees) and INPRO team (interviewers)

This questionnaire consists of the following two parts.

(1) General questions regarding interviewee's perspective on energy and nuclear issues;
(2) Specific questions regarding possible requirements on development and deployment of nuclear power plants.

A. General questions regarding interviewee's perspective on energy and nuclear issues

Following questions are intended to establish understanding of your perspective on general issues related to the introduction of nuclear power systems in your country, such as your view on the present and future needs in your country, the drivers and the potential challenges regarding introduction of nuclear option, and so on.

(A.1) Long term outlook on energy consumption

What is your expectation of total energy consumption (including transportation and household) in your country in 2015, 2030 and 2050? Please indicate relative% value compared with 2006.

2015 (%), 2030 (%), 2050 (%)

Additional explanation or comments if any:

(A.2) Long term outlook on domestic energy production

What proportion (%) of this expected consumption would be covered by domestic energy production?

2015 (%), 2030 (%), 2050 (%)

Additional explanation or comments if any:

(A.3) Long term outlook on energy production composition

What is your expectation of the composition in total energy production from power plants in 2015, 2030 and 2050 in your country?

	2005	2015	2030	2050
(a) Natural gas fired	(%)	(%)	(%)	(%)
(b) Coal fired	(%)	(%)	(%)	(%)
(c) Hydro	(%)	(%)	(%)	(%)
(d) hydro	(%)	(%)	(%)	(%)
(e) Nuclear	(%)	(%)	(%)	(%)
(f) Wind	(%)	(%)	(%)	(%)
(g) Biomass	(%)	(%)	(%)	(%)
(h) Solar	(%)	(%)	(%)	(%)
(i) Other renewable	(%)	(%)	(%)	(%)
(j) Geothermal	(%)	(%)	(%)	(%)
Total	(100%)	(100%)	(100%)	(100%)

Additional explanation or comments if any:

(A.4) Long term outlook on competitive energy sources

Which types of power plant do you think will become the most cost effective in, 2015, 2030 and 2050 in your country?

(a) Natural gas fired
(b) Coal fired
(c) Oil fired
(d) Hydro
(e) Nuclear
(f) Wind
(g) Biomass
(h) Solar
(i) Other renewable

2015 ( ), 2030 ( ), 2050 ( )

Additional explanation or comments if any:

(A.5) Present geographical energy demand distribution

How do you describe geographical energy demand distribution in your country right now? Please choose one of following:

(1) Demands are mostly distributed over the country although there are some demand concentration areas
(2) Demands are mostly concentrated in few demand clusters such as big cities although there are some small demands in other part of the countries
(3) The distribution of the demand is not regular with several demand sites of various sizes

Your answer [3]:

Additional explanation or comments if any:

(A.6) Future geographical energy demand distribution

Which direction do you think this demand distribution will go in the future in your country? Please choose one of following:

(1) to be more scattered
(2) to be more concentrated
(3) no significant change is expected — describe the reason why

Your answer [3]:

Additional explanation or comments if any:

(A.7) Present grid characteristics

How do you describe electrical grid characteristics in your country right now? Please choose one of following:

(1) Separate regional grids within country
(2) All grids are interconnected within country
(3) Established in and among regional grids and neighbouring countries

Your answer [3]:

Additional explanation or comments if any:

(A.8) Future grid characteristics

Which direction do you think this grid characteristics will go in the future in your country? Please choose one of following:

(1) Grid system will be more developed (further interconnection among regional grids and with neighbouring countries)
(2) No significant change is expected — describe the reason why

Your answer [2]:

Additional explanation or comments if any:

(A.9) Present load operation characteristics

How do you describe load operation characteristics (base load or load follow) of the power plant operation in your country right now? Please choose one of following:

(1) Base load is mainly covered by base load power plants + peak adjustment with load follow operation by fewer power plants
(2) Load follow operation in most power plants

Your answer [2]:

Additional explanation or comments if any:

(A.10) Future load operation characteristics

Which direction do you think this load operation characteristics will go in the future in your country? Please choose one of followings and provide your reasoning:

(1) More base load operation
(2) More load follow operation

Your answer [2]:

Additional explanation or comments if any:

(A.11) General features of future power plants

Which type of power plants do you think makes more sense in the future in your country considering demand distribution, grid characteristics and load operation characteristics? Please choose one of following:

(1) Mainly smaller distributed power plants
(2) Mainly larger distributed power plants
(3) Mainly smaller concentrated power plants
(4) Mainly larger concentrated power plants

Your answer [4]:

Additional explanation or comments if any:

(A.12) General features of future nuclear power plants

Which type of nuclear power plants do you think makes sense in the future in your country? Please choose one of following:

(1) Mainly smaller distributed power plants
(2) Mainly larger distributed power plants
(3) Mainly smaller concentrated power plants
(4) Mainly larger concentrated power plants

Your answer [4]:

Additional explanation or comments if any:

(A.13) Time frame of the first (next) nuclear power plant

When do you think that the first (or the next) nuclear power plant will: (1) start construction in your country? (2) start operation in your country?

(1):

(2):

Additional explanation or comments if any:

(A.14) Advantage of introduction of nuclear energy

What are the advantages of introducing nuclear energy to your country? Please write your opinion freely, but note that following potential advantages are sometimes mentioned.

- Short/medium term energy security/strategy (uranium as stable and reliable resource)
- Long term energy security (uranium as long lasting resource)
- Cost benefit (cheaper than other energy cost)
- Cost stability (not too much affected by change in fuel cost)
- Stimulate industrialization and development of human resource
- Low environmental impact on air pollution (local and regional impact)
- Low environmental impact on greenhouse effect (global impact)
- Prestige and other soft support for economic development
- Export of electricity to neighbouring counties
- Saving national fossil resources

Your answer:

(A.15) Impediments to the introduction of nuclear energy

What are the impediments when introducing nuclear energy to your country? Please write your opinion freely, but note that the following potential issues are sometimes mentioned.

- Management of spent fuel and/or high level nuclear waste
- Management of low and medium level nuclear waste
- Assurance of imported fuel supply
- Concern on safety (possibility of accident)
- Concern on nuclear proliferation
- Concern on nuclear security (terrorist attack, sabotage)
- High construction cost (difficulty on investment)

- Grid compatibility(size and stability of grid)
- Difficulty on site selection with suitable physical condition
- Difficulty on dealing with technology
- Legal infrastructure building (licensing, regulatory body)
- Industrial infrastructure building (support industries, etc.)
- Human resource development
- Long term political support
- Public acceptance (national and local)
- Financial risk due to large capital and potential delays
- Longer lead time and construction period
- Opposition from neighbouring countries or a region.

Your answer:

(A.16) Advantage and disadvantage of small and medium sized reactors

With respect to the conditions in your country, what is your opinion of the important advantages and disadvantages of small and medium sized reactors (SMR) (less than 700MW(e)) against larger reactors? Please write your opinion freely, but note that following potential features are sometimes mentioned:

Adaptability to electrical grid, absolute total capital outlay ($), capital cost ($/kW(e)), electricity cost ($/kWh), operation and maintenance cost ($/kWh), investment in additional infrastructure needs, construction period, investment risk, investment return (cash flow planning), modular reactor concept, prefabrication construction method, safety characteristics, magnitude of potential accidents, adaptability of innovative technologies, flexibility of site location, co-generation capabilities, easiness of operation and maintenance and simplicity of system/technology, effort for security and plant protection, proliferation resistance and public acceptance.

Advantages of SMR:

Disadvantages of SMR:

Additional explanation or comments if any:

(A.17) Physical constraints on site selection

Regarding site selection, which of the following physical constraints limit your country in developing nuclear power plants?

Constraints	Yes/No	If 'yes', please elaborate
Space (considering the plant exclusion zones)		
Lack of cooling water		
Earthquake		
Extreme weather conditions (hurricanes, flooding, temperature, etc.)		
Lack of easy access		
Security		
Opposition from neighbours		
Others		

Additional explanation or comments if any:

(A.18) Additional criteria on site selection

Which of the following additional criteria are the most important for you to consider/select sites for nuclear power plants? (please rank from 1 to 5, with 1 = absolutely not important, 5 = absolutely important)

(a) Distance from application centres ( )
(b) Overall energy resources distribution ( )
(c) Grid structure ( )
(d) Local government/public supports ( )
(e) Preservation of unique environment ( )
(f) Others: ________________________ ( )

Additional explanation or comments if any:

(A.19) Cost vs. benefit consideration

Which of following ‘cost vs. benefit’ considerations are more important to make a decision to introduce nuclear power plants? (Please rank from 1 to 5, with 1 = absolutely not important, 5 = absolutely important):

Factors	Ranking
(a) Short term financial merit: electricity production cost vs. electricity sales income	
(b) Medium — long term financial merit: initial project investment vs. payback period or IRR (internal rate of return)	
(c) Industrial merit: cost to build up industrial infrastructure (transmission lines, ports, manufacturing facilities) vs. benefit from development of industrial infrastructure	
(d) Social merit: national infrastructure investment necessary to support nuclear installation (establishing organizations and human resources) vs. all direct and indirect benefit to society	
(e) Global merit: Overall cost of global nuclear development vs. benefit from less environmental impact and preservation of fossil resources	

Additional explanation or comments if any:

(A.20) Organizational and human capability

Regarding organizational and human capability, which of the following do you think is necessary for your country to establish in order to support a successful nuclear power programme? Please put number for each column by:

0: I do not know or do not have idea
1: Prefer to totally depend on suppliers, suppliers’ countries or international organizations such as IAEA instead of having own capability
2: Minimum capability to understand;
3: Shared capability with suppliers, suppliers’ countries or international organizations
4: Full capability to perform independently

Areas of organizational/human capability	For 1st Unit or until 2020	For Nth Units or until 2050
Design — reactor		
Design — major equipment		
Overall plant and system engineering design		
Overall site design and preparation		
R&D to support design		
Procurement & bidding process		
Civil engineering work		
Construction & project management		
Manufacturing of major and critical components & equipment (Safety grade)		
Manufacturing of small but critical components & equipment (Safety grade)		
Manufacturing of regular components & equipment (non-safety grade)		
Licensing of nuclear power plant		
Safety analysis		
Radiation protection		
Operation & regular maintenance		
Major maintenance & plant life extension		
Fuel supply and refueling		
R&D to support operation		
Nuclear-grade QA		
Proliferation resistance		
Spent fuel storage and Final nuclear waste disposal		

Additional explanation or comments if any:

(A.21) Regional approach

Would your country be interested in a regional cooperation for the development of nuclear power with neighbouring countries? If so, in your opinion, which of the following areas of cooperation are useful to your country (Please rank from 1 to 5, with 1 = very negative, 5 = very positive):

(a) Regionally consistent licensing approach ( )
(b) Sharing of functions of regulatory bodies ( )
(c) Sharing of investment ( )

(d)	Sharing of industrial capacities for manufacturing, construction, maintenance and repair	( )
(e)	Sharing of ownership of a nuclear power plant	( )
(f)	Sharing of intermediate spent fuel storage facilities	( )
(g)	Sharing of low/medium level waste management facilities	( )
(h)	Sharing of a final disposal facility	( )
(i)	Regional safeguards approach/cooperation	( )

Additional explanation or comments if any:

(A.22) Impediments on financing of nuclear power plant

What do you think are real impediments in your country in attracting investment from inside and outside to the nuclear power plant project in your country, as compared with other projects? Please select **any** of following options:

(1) Investment risk due to high initial investment
(2) Investment risk due to possibility of change of political decision
(3) Investment risk due to licensing instability
(4) Investment risk due to failure of project management of nuclear power plant construction
(5) Investment risk due to technical problems or failures
(6) Investment risk due to possible compensation for accidents
(7) Investment risk due to uncertainty of cost estimation including waste and decommissioning
(8) Investment risk due to low expected profit or uncertainty of future electricity market price
(9) Long payback period of initial investment due to high initial investment
(10) Long payback period of initial investment due to longer lead time and construction period
(11) Limited external financing resources due to low national credit rating
(12) Others (specify)

Your answer [9]:

Additional explanation or comments if any:

(A.23). Solutions on financial impediments

What do you expect, as a potential owner/user of nuclear power plants, from the financial arrangement for a nuclear power plant project to reduce impediments as mentioned above? Please specify who (e.g. government, suppliers and the government of the system origin, international organ such as IAEA) should do what.

(Examples of solutions against impediments):

- Adoption of small & medium sized reactors to reduce the initial investment
- Adoption of proven technology
- Establishment of long term energy policy that includes nuclear option

- Government commitment/support such as loan guarantee/long term power purchase agreement (power off-take)/tax credit, etc.
- Government support to infrastructure building
- Adequate contract options (turnkey, BOT, etc.)
- Establishment of nuclear liability law
- Clarification of financial estimation and responsibility on spent fuel and high level waste management
- Workshop with ECA (Export Credit Agency) for education
- Involve World Bank
- Use multilateral arrangement
- Seek options for mortgage natural resources/commodity etc.
- Lifting nuclear exclusion from CDM/JI (Clean Development Mechanism/Joint Implementation in Kyoto Protocol)
- Some new international institutional arrangement
- Suppliers' dialogue and arrangement with ECA
- Others (specify)

Your answer (free description of actions — Please specify who should do what):

(A.24) Maximum total investment

What is the maximum total investment your country can afford through a financing scheme or can dedicate for the construction of one nuclear power plant unit? Please choose **one** of following options (1–6):

(1) Less than 0.5 Billion US $
(2) Less than 1 Billion US $
(3) Less than 2 Billion US $
(4) More than 2 Billion US $
(5) Anything else (please describe in detail)
(6) I do not know

Your answer [6]:

Additional explanation or comments if any:

(A.25) Fraction of external financial source

What is the required fraction of financing from external financial sources on a nuclear power plant project? Please choose one of following options (1–8):

(1) More than 80%
(2) 60–80%
(3) 40–60%
(4) 20–40%
(5) Less than 20%
(6) No need from external financing source
(7) Anything else (please describe detail)
(8) I do not know

Your answer [8]:

Additional explanation or comments if any:

(A.26) Fraction of financial sources other than equity/bond

What percentage of investment to nuclear power plant project do you expect other than equity/bond?

(1) More than 80%
(2) 60–80%
(3) 40–60%
(4) 20–40%
(5) Less than 20%
(6) No need from other than equity/bond
(7) Anything else (please describe detail)
(8) I do not know

Your answer [8]:

Additional explanation or comments if any:

B. Specific questions regarding possible requirements on development and deployment of nuclear power plant.

Following are specific questions to obtain your personal views on what are the requirements or minimum acceptable/tolerated conditions (instead of just 'preferable') on specific issues regarding the introduction of a nuclear option in your country, both for the 1st unit in the short term (next 10–15 years) and for the Nth units in the long term (15–50 years from now). Please recognize that a higher level of requirements or acceptance/tolerated conditions may increase the cost depending on issues. Each question is designed so *that the answer can lead directly to one requirement or criterion. The questions are related to possible expectations of your country:*

- *How the nuclear power plant should be designed;*
- *What the supplier or the government should offer in addition to the plant itself;*
- *What the government of origin should offer.*

As mentioned at the beginning, using the system developed within the INPRO methodology, the questions are further related to the areas of economics, infrastructure, safety, environment, waste management, proliferation and physical protection except technical specification questions.

Unless specified otherwise, each question should be answered, from your personal point of view, under the following 2 different assumptions (cases):

(a) The case for the first unit in the country (or short term, in the next 10–15 years);

(b) The case for the Nth unit (or long term, 15–50 years from now).

In addition, you are required to suggest the importance of the issue specified in each question by giving an indicator within the range of 1–5 (1: not important, 5: very important).

In each question, an additional short description to explain the issue will be encouraged.

In the interview, additional questions or information, such as "why do you think it is necessary?", "could you elaborate briefly for your reason?" or "did you consider this aspect?" will be added to clarify the meaning of the answer.

1. Economics

(B.1) Electricity generating cost

What is your highest acceptance limit for the electricity generating cost (kW·h) (including cost of decommissioning of facilities and final waste disposal) of nuclear power plant compared with the average electricity generating cost in your country? Please choose **one** of following options (1–8).

(1) Less than 60%
(2) 60–90%
(3) 90–110%
(4) 110–150%
(5) More than 150%
(6) No requirement regarding this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.2) Construction cost

What is your highest acceptance limit for unit construction cost (/kW(e)) of nuclear power plant compared with the unit construction cost of the current water cooled reactors (WR)? Please choose **one** of following options (1–8).

(1) Less than 60%
(2) 60–90%
(3) 90–110%
(4) 110–150%
(5) More than 150%
(6) No requirement regarding this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.3) Operation and maintenance (O&M) cost

What is your highest acceptance limit for O&M cost (kW·h) of nuclear power plant compared with the one of the latest WR? Please choose **one** of following options (1–8).

(1) Less than 60%
(2) 60–90%
(3) 90–110%
(4) 110–150%
(5) More than 150%
(6) No requirement regarding this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.4) Priority of cost components

Which cost components are of more concern to you? Please rearrange the order of 1–6 according to their importance, or select one of 7–9:

(1) Electricity generating cost
(2) Construction cost
(3) Fuel cycle cost
(4) O&M cost
(5) Waste management cost
(6) Decommissioning cost
(7) No priority
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.5) Nuclear power plant construction period

What is your longest acceptable limit for the nuclear power plant construction period from the first concrete to connection to the grid? Please choose **one** of following options (1–7):

(1) Less than 3 years
(2) Less than 4 years
(3) Less than 5 years
(4) More than 5 years
(5) No requirement regarding this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.6) Assurance of construction schedule by supplier

Regarding assurance of construction schedule, choose **one** of following options (1–5):

(1) Liquidated damage condition in the contract is enough to cover the damage of construction delay
(2) There should be additional assurance of construction schedule, recognizing that it may increase the cost
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

2. Infrastructure

(B.7) Type of contracts

What types of contract should your country have for the nuclear power plant projects? Please choose **any** of following options (1–12):

(1) General contract with a single supplier
(2) Split package with several suppliers
(3) Turnkey
(4) BOT (build-operate-transfer)
(5) BOO (build-own-operate)
(6) BOOT (build-own-operate-transfer)
(7) ROT (refurbishment/rehabilitate-operate-transfer)
(8) Nuclear power plant plus fuel cycle full services including fresh fuel supply and spent fuel take back
(9) No requirement for this issue
(10) Anything else (please describe detail)
(11) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.8) Technology transfer

What kinds of technology must be transferred to your country by a system supplier? Please choose **any** of following options (1–9):

(1) Licence of system design and component manufacturing
(2) Specification and design drawings (system design, 3D design, component design, etc.)
(3) Know-how on system design and construction and component manufacturing
(4) Codes and methods on design and analysis of the system, and associated know-how of their usage
(5) Licence, drawing and know-how to produce fuel
(6) Knowledge on fuel performance and qualifications
(7) No requirement for this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.9) Support from suppliers

What kinds of support must be supplied to your project by a system supplier? Please choose **any** of following options (1–12):

(1) Financial support
(2) Licensing support
(3) Human resources programme
(4) Industry development programme
(5) Services during the operation
(6) Fuel supply
(7) Waste and spent fuel management
(8) Assurance of construction schedule
(9) Decommissioning
(10) No requirement for this issue
(11) Anything else (please describe detail)
(12) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.10) Support of the government of system origin

What kinds of support must be supplied to your project by the government of system origin? Please choose **any** of following options (1–12):

(1) Liability of nuclear accident
(2) Financial support/option
(3) Licensing support
(4) Human resources development (which include training and supplier of experts)
(5) Industry development programme
(6) R&D supports
(7) Fuel supply
(8) Waste and spent fuel management
(9) Emergency preparedness
(10) No requirement for this issue
(11) Anything else (please describe detail)
(12) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.11) Qualification of suppliers

What level of qualification must a supplier have? Please choose **any** of following options (1–7):

(1) A supplier must have an experience to construct nuclear power plants in overseas
(2) A supplier must have an experience to construct nuclear power plants in recent 10 years
(3) A supplier must have a good record to keep schedule and budget in its nuclear power plant projects
(4) A supplier must have a sound financial condition
(5) No requirement for this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.12) Assurance of fuel supply which includes uranium, enrichment, fuel fabrication

What level of assurance do you require for nuclear fuel supply? Please choose **one** of following options (1–7):

(1) Some sorts of international fuel supply assurance mechanism should be in place
(2) Market mechanism with more than 1 suppliers
(3) Committed one supplier is enough
(4) Technology transfer so that your country can fabricate fuels by yourself
(5) No requirement for this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.13) Assurance of critical components supply

What level of assurance do you require for large replaceable components (such as steam generators)? Please choose **one** of following options (1–7):

(1) Some sort of international supply assurance mechanism should be in place
(2) Market mechanize with more than 1 suppliers
(3) Committed one supplier is enough
(4) Technology transfer so that your country can supply large replaceable components by yourself
(5) No requirement for this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.14) Assurance of spare parts supply

What level of assurance do you require for spare parts (e.g. vales, cables, relays, etc.)? Please choose **one** of following options (1–7):

(1) International spare parts pools
(2) Market mechanism with more than 1 suppliers
(3) Committed one supplier
(4) Technology transfer so that your country can supply spare parts by yourself
(5) No requirement for this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.15) Compliance with regulation/standard/guideline

Which regulations or standards must nuclear power plant design comply with, other than regulation in your country? Please choose **any** of following options (1–11):

(1) Nuclear regulations in the country of system origin
(2) Nuclear regulations in a specific country (please specify)
(3) ASME
(4) ISO
(5) Other standards (please specify)
(6) IAEA Safety Standards Series, etc.
(7) Other utility requirement documents (e.g. EUR) (please specify)
(8) INPRO methodology
(9) No requirement for this issue
(10) Anything else (please describe detail)
(11) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.16) Involvement of users

Which of following areas do you require to be involved in the nuclear power plant projects? Please choose **any** of following options (1–15):

(1) Reactor design
(2) Design of major equipment: e.g. turbine, main pump, I&C
(3) Plant engineering design
(4) Construction of nuclear power plants
(5) Manufacturing of major equipment and components
(6) Manufacturing of regular spare parts and supply
(7) Project management
(8) Operation and regular maintenance
(9) Major maintenance & plant life extension
(10) Fuel supply and refueling
(11) R&D to support design
(12) R&D to support operation
(13) No requirement regarding this issue
(14) Anything else (please describe detail)
(15) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

3. Safety

(B.17) Safety analysis approach in support of design

Regarding the safety approach for nuclear power plants, please choose **one** of following options (1–5):

(1) Mostly rely on deterministic method (based on design basis accidents)
(2) Mostly rely on probabilistic method (best-estimate method, risk informed method)
(3) No requirement for this issue

(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.18) Passive safety system

To what extent should passive systems be incorporated in the nuclear power plant design? Please choose **one** of following options (1–6):

(1) Passive system should be incorporated essentially (as much as possible)
(2) Passive system should be incorporated at least partially (please specify)
(3) Passive system may be incorporated but does not have to be
(4) No specific requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.19) Severe accident frequency

What is your acceptable level of frequency of severe accidents (core damage accidents)? Please choose **one** of following options (1–7):

(1) Practically eliminated by design
(2) Significantly less than for the latest operating reactors (10^{-7}/year/reactor)
(3) Same level as for the latest operating reactors (10^{-5}/year/ reactor)
(4) Same level of the majority of currently operating reactors (10^{-4}/year/reactor)
(5) No requirement regarding this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.20) Large early release frequency (LERF)

What is your acceptable level of large early release frequency (LERF)? Please choose **one** of following options (1–7):

(1) Practically eliminated by design
(2) Significantly less than for the latest operating reactors (10^{-8}/year/reactor)
(3) Same level as for the latest operating reactors (10^{-6}/year/ reactor)
(4) Same level of the majority of currently operating reactors (10^{-5}/year/reactor)
(5) No requirement regarding this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.21) Design features against severe accidents

Do you require design features for limiting environmental consequences in case of core meltdown or damage? Please choose **one** of following options (1–4):

(1) Yes (please specify what kinds)
(2) No
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.22) Grace period

What is your minimum acceptable length of grace period until human intervention is necessary in the case of accidents? Please choose **one** of following options (1–9):

(1) 1 week or more
(2) 2–3 days
(3) 1 day
(4) 10 hours
(5) 1 hour
(6) Several 10 minutes
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.23) External event resistance

What are your minimum requirements of the nuclear power plant resistance against external events such as earthquake, tsunami, fire and explosion, flooding, and airplane crash? Please choose **one** of following options (1–6):

(1) Additional requirements as compared to the existing nuclear power plants (please specify)
(2) Same level as the existing nuclear power plants
(3) Less requirement than for the existing nuclear power plants
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.24) Instrumentation and control (I&C)

What is your requirement of the I&C system in the nuclear power plant? Please choose **one** of following options (1–6):

(1) Up-to-date technology in the time of the nuclear power plant introduction must be used
(2) Present advanced technology such as digital I&C can be used
(3) Well-experienced technology such as analogue I&C can be used
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.25) Occupational radiation exposure

What is your minimum requirement for occupational radiation exposure? Please choose **one** of following options (1–5).

(1) Accordance to national target (if exist) or national law/regulation (please specify number)
(2) More strict than #1 (please specify target number)
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.26) Off-site release limits during accidents

What is your minimum requirement for off-site release limits during accidents? Please choose **one** of the following options (1–5).

(1) Accordance to national target (if exist) or national law/regulation (please specify number)
(2) More strict than #1 (please specify target number)
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

4. Environment

(B.27) Off-site release limits during normal operation and incidents

What is your minimum requirement for off-site release limits during normal operation and incidents? Please choose **one** of following options (1–5):

(1) Accordance to national target (if exist) or national law/regulation (please specify number)
(2) More strict than #1 (please specify target number)
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.28) Non-radiological environmental effects

Do you have any requirement for non-radiological environmental effects such as chemical products, heat so on? Please choose **one** of following options (1–4):

(1) Yes (please describe it)
(2) No
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

5. Waste management

(B.29) Spent fuel management

What level of services must a supplier or the government of system origin supply in terms of spent fuel management? Please choose **one** of following options (1–6):

(1) Spent fuels must be taken back to the country of system origin
(2) Assurance of available interim storage facilities
(3) Assurance of reprocessing services
(4) No requirement for this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.30) Low and intermediate level waste management

What level of services must a supplier or the government of system origin supply in terms of low level waste (LLW) management? Please choose **one** of following options (1–5):

(1) LLW must be taken back to the country of system origin
(2) Assurance of interim storage facilities
(3) No requirement for this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.31) Decommissioning services

Considering the needs of and situation in your country, and the fact that decommissioning will be done after a long time after the startup of a new nuclear power plant using the most suitable technology developed then who do you think should manage the decommissioning and take the technical responsibility for the decommissioning? Please choose **one** of following options (1–8):

(1) The supplier
(2) The supplier country
(3) An appropriate international organization/mechanism that is yet to be established
(4) The utility organization that owns the nuclear power plant
(5) The government of your country
(6) No requirement for this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.32) Amount of solid waste

Do you have a requirement for the amount of solid waste during operation and/or decommissioning? Please choose **one** of following options (1–4):

(1) Yes (Please specify number by t/KW(e))
(2) No
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

6. Proliferation resistance

(B.33) Responsibility of intrinsic feature of proliferation resistance

Who do you think should require that a nuclear power plant has enough intrinsic features (system features) of proliferation resistance? Please choose **any** of following options (1–5):

(1) Users (please describe your requirements in this regard)
(2) Suppliers
(3) International community such as IAEA
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.34) Responsibility of safeguardability

Who do you think should require that a nuclear power plant has enough safeguardability as system features? Please choose **one** of following options (1–5):

(1) Users (please describe your requirements in this regard)
(2) Suppliers
(3) International community such as IAEA
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

7. Physical protection

(B.35) Intrinsic feature of physical protection

Do you have any requirements for intrinsic feature (system inherent feature) of the nuclear power plant regarding physical protection/security including terrorism, sabotage, and diversion of material? Please choose **one** of following options (1–4):

(1) Yes (please describe them)
(2) No
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

8. Technical specification

(B.36) Proven technology

What is the minimum level of proven technology required for the reactor/plant system? Please choose **one** of following options (1–9):

(1) The same reactors should have been operated elsewhere as commercial plants
(2) A prototype of the reactor should have been built elsewhere
(3) Design certification or final design approval should have been obtained in the country of origin
(4) Major components should have been tested by demonstration experiments
(5) FOAK design should have been finished
(6) Preliminary design should have been finished
(7) No requirement for this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.37) Standardization

Regarding standardization of nuclear power plant, please choose one of following options (1–5):

(1) The nuclear power plant must be a standardized one. Components must be also standardized
(2) The nuclear power plant must be specifically designed for your country
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.38) Modularization

Regarding modularization of units in a nuclear power plant, please choose one of the following options (1–4):

(1) The nuclear power plant should consist of a number of module units
(2) No requirement regarding this issue
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.39) Prefabrication/modular construction method

Regarding the prefabrication method (modular construction method) on construction of nuclear power plant, please choose **one** of following options (1–4):

(1) Prefabrication construction method must be adopted as much as possible
(2) No requirement regarding this issue
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.40) Reactor type

Please choose **any** possible reactor types for your nuclear power plant projects from the following options (1–9):

(1) PWR (pressurized water reactor)
(2) BWR (boiling water reactor)
(3) HWR (heavy water reactor)

(4) HTGR (high temperature gas reactor)
(5) Fast spectrum reactors
(6) Any other innovative reactors
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.41) Unit output (lower boundary)

What is the lowest acceptance limit for the nuclear power plant unit electric output range? Please choose **one** of following options (1–9):

(1) Less than 100 MW(e)
(2) 100–300 MW(e)
(3) 300–700 MW(e)
(4) 700–1000 MW(e)
(5) 1000–1300 MW(e)
(6) More than 1300 MW(e)
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.42) Unit output (higher boundary)

What is the highest acceptance limit for nuclear power plant electric output range? Please choose **one** of following options (1–9):

(1) Less than 300 MW(e)
(2) 300–700 MW(e)
(3) 700–1000 MW(e)
(4) 1000–1300 MW(e)
(5) 1300–1600 MW(e)
(6) More than 1600 MW(e)
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.43) Plant lifetime

What is the lowest acceptance limit for nuclear power plant lifetime (from commissioning till decommissioning)? Please choose **one** of following options (1–8):

(1) Less than 30 years
(2) 30–40 years
(3) 40–50 years
(4) 50–60 years
(5) More than 60 years
(6) No requirement regarding this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.44) Plant restricted area

What is the maximum acceptable limit for the radius of the restricted area of nuclear power plant? Please choose **one** of following options (1–8):

(1) 1 km
(2) 2 km
(3) 5 km
(4) 10 km
(5) more than 10 km
(6) No requirement regarding this issue
(7) Anything else (please describe detail)
(8) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.45) Application

Please choose the most important applications (plural) you can foresee in your future nuclear power plant from following options (1–10):

(1) Electricity
(2) Desalination
(3) H2 production
(4) District heating
(5) Chemical production including oil refinery
(6) Oil extractions
(7) Material production (e.g. steel)
(8) Agricultural applications
(9) No requirement regarding this issue
(10) Anything else (please describe detail)
(11) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.46) Design philosophy/principle

What must be incorporated in the nuclear power plant design as design philosophy or principle? Please choose **any** of following options (1–9):

(1) Simplicity
(2) Integrated design
(3) Elimination of accidents by design
(4) Large design margin
(5) Decommissioning consideration in design
(6) User friendly operation and maintenance
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.47) Plant availability

What is your minimum acceptance limit for plant availability? Please choose **one** of following options (1–7):

(1) More than 95%
(2) 90%–95%
(3) 80%–90%
(4) Less than 80%
(5) No requirement regarding this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.48) Expected frequency of failures and disturbances

What is your maximum acceptance limit for expected frequency of unplanned shutdown, including scram? Please choose **one** of following options (1–7):

(1) Less than once/year
(2) 1–5 times/year
(3) 5–10 times/year
(4) More than 10 times/year
(5) No requirement regarding this issue
(6) Anything else (please describe detail)
(7) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.49) Maneuverability

Regarding maneuverability of nuclear power plant, please choose **one** of following options (1–6), recognizing that higher requirements may increase the cost:

(1) The nuclear power plant must have full control capability including frequency control
(2) The nuclear power plant should have at least daily load following capability
(3) The nuclear power plant can be based load with limited load following capability
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.50) Capability against load rejection

What is your minimum requirement in case of loss of load or load rejection? Please choose **one** of following options (1–5):

(1) Continuous operation with house load
(2) Safe shutdown
(3) No requirement regarding this issue
(4) Anything else (please describe detail)
(5) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.51) Operation cycle length between refueling

What is your minimum acceptance limit for operating cycle length between refueling? Please note that an actual operating cycle length should be determined by the shorter one of (B.51) and (B.52). Please choose **one** of following options (1–11):

(1) No refueling during the plant lifetime or no onsite refueling
(2) Continuous refueling
(3) More than 10 years
(4) 5–10 years
(5) 3–5 years
(6) 1.5–3 years
(7) 1–1.5 years
(8) Less than 1 year
(9) No requirement regarding this issue
(10) Anything else (please describe detail)
(11) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.52) Operation cycle length between inspection/maintenance outages

What is your minimum acceptance limit for operating cycle length between outages? Please note that an actual operating cycle length should be determined by the shorter one of (B.51) and (B.52). Please choose **one** of following options (1–10):

(1) No outages during the plant lifetime
(2) More than 10 years
(3) 5–10 years
(4) 3–5 years
(5) 1.5–3 years
(6) 1–1.5 years
(7) less than 1 year
(8) No requirement regarding this issue
(9) Anything else (please describe detail)
(10) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.53) Flexibility of fuel

Do you have special requirement on the kinds of fuel which must be useable? Please choose **any** of following options (1–9):

(1) Enriched UOX
(2) Natural UOX
(3) MOX
(4) UOX or MOX + Minor Ac
(5) ThOX
(6) Other innovative fuel (Metal, TRISO, Molten salt, etc.)
(7) No requirement regarding this issue
(8) Anything else (please describe detail)
(9) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.54) Effectiveness of fuel utilization

Do you require system characteristics for better preservation of natural fissile material such as breeder reactors? Please choose **one** of following options (1–4):

(1) Yes
(2) No
(3) Anything else (please describe detail)
(4) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.55) Man–machine interface (MMI)

What is your requirement of the MMI system in the nuclear power plant? Please choose **one** of following options (1–6).

(1) Up-to-date technology in the time of the nuclear power plant introduction must be used
(2) Present advanced technology can be used
(3) Well-experienced technology can be used
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.56) Level of automation regarding operation

What is your minimum requirement for level of automation regarding operation of the nuclear power plant? Please choose **one** of following options (1–6):

(1) Full automatic or operator's action is not needed for usual operation
(2) Semi-automatic like the latest WR
(3) Operator's action is needed
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.57) Inspectability and maintainability

What is your minimum requirement for inspectability and maintainability? Please choose **one** of following options (1–7):

(1) Full on-line/remote inspection/maintenance during operation
(2) Advanced technologies are required
(3) Existing technologies are sufficient
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.58) Allowed proximity to urban area

What is your target on allowed proximity of the nuclear power plant site to the nearest urban area? Please choose **one** of following options (1–6):

(1) Can be located within 1 km or less
(2) Can be located within 5 km or less
(3) Can be located within 10 km or less
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

(B.59) Suitability to site condition

What is your requirement for a nuclear power plant to be suitable for specific site conditions? Please choose **one** of following options (1–6):

(1) The nuclear power plant must be suitable to inland conditions such as good adaptability of a cooling tower (please describe how)
(2) The nuclear power plant must be suitable to coastal conditions (please describe how)
(3) The nuclear power plant must be suitable to island conditions (please describe how)
(4) No requirement regarding this issue
(5) Anything else (please describe detail)
(6) I do not know

Importance of this issue [1–5]:

Your answer for 1st unit (–15 years):

Your answer for Nth unit (15–50 years):

Additional explanation or comments if any:

Thank you very much for your cooperation!

I.II QUESTIONNAIRE SENT TO THE NOVEMBER 2007 WORKSHOP PARTICIPANTS

QUESTIONNAIRE

for

IAEA Workshop on Common User Criteria for Development and Deployment of Nuclear Power Plants for Developing Countries

(Vienna, 27–30 November 2007)

Technical Co-operation Project INT/4/141: Status and Prospects of Development for and Applications of Innovative Reactor Concepts for Developing Countries

Participants in the titled IAEA workshop are requested to fill in this questionnaire. Please refer a separate document attached to this questionnaire that provides explanations and examples to help you fill-in the questionnaire. Once completed, would you please send back the questionnaire by email **by 2**nd **of November** to A.CAHYONO@iaea.org.

Name of Country:

Name of responsible person to fill in:

Affiliation of the person:

Telephone number of the person:

Email of the person:

Date:

Part 1 – Information on future needs

Question 1-A: Future nuclear capacity

Please indicate what are the expectations for ***new*** *nuclear capacity in your country for the short term (until 2025), medium term (2025–2040) and longer term (2040–2050). Two examples are provided to help you fill-in the following table.*

Time frame	Unit size or range (MW(e))	Number of units	If more than one unit size				Explanations
			Unit size or range (MW(e))	Number of units	Unit size or range (MW(e))	Number of units	
Until 2025							
2025–2040							
2040–2050							

Question 1-B: Non-electrical applications

Please indicate whether non-electrical applications of nuclear power (e.g. water desalination, district heating, hydrogen production, process heat for industrial purpose, steam for oil recovery…) or co-generation (electricity + non-electrical application) are planned in your country.
In such a case, please fill-in the following table, indicating which application would be needed and the associated capacity. For ease of answer, feel free to use the most convenient unit (e.g. cubic metres/day for water desalination, cubic meters of hydrogen per day, MW·th for district heating …).

Time frame	Type of application and associated capacity	Explanations
Until 2025		
2025–2040		
2040–2050		

Part 2 — Common user criteria

Question 2-A: Importance of requirements

For each requirement

- *indicate the level of importance according to your opinion by clicking just* ***one*** *of the appropriate boxes;*
- *include your comments in the appropriate box, if any.*

Number		**Requirement**	**Your opinion**					
1		ECONOMICS AND FINANCING	Not important	Less important	Important	More important	Very important	Comments
1.1		Electricity generating cost	☐	☐	☐	☐	☐	
	1.1.1	Electricity generating cost of nuclear power plant should be competitive with that of the comparable base load electricity sources in the country.	☐	☐	☐	☐	☐	
	1.1.2	Comprehensive and reliable nuclear power plant electricity generating cost information should be made available to the users for comparing nuclear and other generation sources in the country.	☐	☐	☐	☐	☐	
1.2		Capital cost	☐	☐	☐	☐	☐	
	1.2.1	Capital cost should be minimized to the extent possible.	☐	☐	☐	☐	☐	
	1.2.2	Comprehensive and reliable nuclear power plant capital cost information should be made available to the users for comparing nuclear and other generation sources in the country.	☐	☐	☐	☐	☐	
1.3		Engineering, procurement and construction duration	☐	☐	☐	☐	☐	
	1.3.1	The total duration of the engineering, procurement and construction should be less than 8 years.	☐	☐	☐	☐	☐	
	1.3.2	The nuclear power plant construction duration from first concrete to connection to start of commercialization should be less than 5 years.	☐	☐	☐	☐	☐	
1.4		Operation and maintenance cost	☐	☐	☐	☐	☐	
	1.4.1	Impact on operation and maintenance cost of having additional spare parts or key components should be quantified.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
1		ECONOMICS AND FINANCING	Not important	Less important	Important	More important	Very important	Comments
	1.4.2	The suppliers should provide sufficient information to assess lifetime operation and maintenance cost under various circumstances including the use of national resources for refueling and maintenance outage.	☐	☐	☐	☐	☐	
1.5		Fuel and fuel management cost	☐	☐	☐	☐	☐	
	1.5.1	Fuel and fuel management cost information associated with various different fuel management options required should be provided by the suppliers, such as fuel purchase/storage, local fuel fabrication, fuel leasing and fuel purchase/spent fuel buy-back.	☐	☐	☐	☐	☐	
	1.5.2	Impact on fuel cost of having multiple reloads should be quantified.	☐	☐	☐	☐	☐	
1.6		Project financing	☐	☐	☐	☐	☐	
	1.6.1	The supplier should provide support for financing of the nuclear power plant project.	☐	☐	☐	☐	☐	
1.7		Reducing the investment risk	☐	☐	☐	☐	☐	
	1.7.1	The supplier should identify potential risks to project schedule and plant performance, and advice on how they should be managed.	☐	☐	☐	☐	☐	
	1.7.2	Mechanism for compensation of loss induced by construction delays or poor performance caused by supplier should be addressed.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
2		INFRASTRUCTURE AND IMPLEMENTATION	Not important	Less important	Important	More important	Very important	Agreed/comment
2.1		Type of contract	☐	☐	☐	☐	☐	
	2.1.1	The first nuclear power plant project should be implemented by turnkey contract.	☐	☐	☐	☐	☐	
2.2		Best use of local infrastructure	☐	☐	☐	☐	☐	
	2.2.1	Local infrastructure characteristics should be taken into account by the supplier to enable the utilization of available infrastructure to the maximum extent possible.	☐	☐	☐	☐	☐	
	2.2.2	The supplier should develop appropriate solutions to minimize the need for changes to and/or improvement of infrastructure.	☐	☐	☐	☐	☐	
2.3		Licensing and regulatory functions	☐	☐	☐	☐	☐	
	2.3.1	The regulatory body in the supplier's country should provide support to the regulatory body in the user's country for carrying out its licensing and regulatory functions.	☐	☐	☐	☐	☐	
	2.3.2	The supplier should support the user in the preparation of licence application and associated documentation.	☐	☐	☐	☐	☐	
	2.3.3	Demands on changes to national regulatory infrastructure should be minimized.	☐	☐	☐	☐	☐	
	2.3.4	The supplier should provide support for any changes in the regulation as a result of the nuclear power plant implementation.	☐	☐	☐	☐	☐	
2.4		Electrical grid infrastructure	☐	☐	☐	☐	☐	
	2.4.1	The nuclear power plant should be capable of safe, reliable and economic base load operation.	☐	☐	☐	☐	☐	
	2.4.2	The nuclear power plant should be capable of operating under local grid frequency conditions and load variations.	☐	☐	☐	☐	☐	
2.5		Assurance of fuel supply	☐	☐	☐	☐	☐	
	2.5.1	The reactor should be designed to allow for different fuel suppliers.	☐	☐	☐	☐	☐	
	2.5.2	The supplier should provide up to 5 years of fuel reload.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
2		INFRASTRUCTURE AND IMPLEMENTATION	Not important	Less important	Important	More important	Very important	Agreed/comment
	2.5.3	The supplier should actively promote the establishment of appropriate international mechanism for assuring the supply of fuel over the plant lifetime.	☐	☐	☐	☐	☐	
	2.5.4	The supplier should not impede development and supply of fuel required over the plant lifetime, for reasons other than compliance to international instruments.	☐	☐	☐	☐	☐	
2.6		Assurance of critical materials and components	☐	☐	☐	☐	☐	
	2.6.1	The nuclear power plant should be designed to allow for key components to be supplied by more than one supplier.	☐	☐	☐	☐	☐	
	2.6.2	The supplier should actively promote the establishment of international spare part pool for assuring the supply of critical components over the plant lifetime.	☐	☐	☐	☐	☐	
	2.6.3	The supplier should not impede development and supply of critical components and materials required over the plant lifetime, for reasons other than compliance to international instruments.	☐	☐	☐	☐	☐	
2.7		Local participation	☐	☐	☐	☐	☐	
	2.7.1	The supplier should facilitate the achievement of optimum local participation in the nuclear power plant project.	☐	☐	☐	☐	☐	
	2.7.2	In the first few nuclear power plant projects in the user's country, the supplier should utilize local capabilities in civil works, project management and the manufacture of conventional components to the maximum extent possible.	☐	☐	☐	☐	☐	
2.8		Technology transfer	☐	☐	☐	☐	☐	
	2.8.1	The supplier should provide information to increase the user's capabilities to manage all the activities associated with operation and maintenance of the nuclear power plant throughout its life. This should include: Providing electronic documentation on the plant configuration (system design specification, logic diagram, process and instrumentation diagram, plant arrangement, etc.) and design basis Providing computer codes for analyses and fuel management, and training in their use.	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
2	INFRASTRUCTURE AND IMPLEMENTATION	Not important	Less important	Important	More important	Very important	Agreed/comment
2.8.2	The supplier should support the improvement of local existing manufacturing capability of conventional components.	☐	☐	☐	☐	☐	
2.8.3	The supplier should develop a plan together with the user to transfer the know-how to establish new local manufacturing capability of key components.	☐	☐	☐	☐	☐	
2.9	Human resource development	☐	☐	☐	☐	☐	
2.9.1	The supplier should provide assistance for training the user's personnel, with the objective to increase their capabilities to undertake activities associated with construction, operation and maintenance of the nuclear power plant throughout its life. This assistance should include the provision of: Comprehensive quality assurance programme; Integrated plant maintenance programme; Full scope training simulator and related facility; Training programme for plant operation and maintenance personnel	☐	☐	☐	☐	☐	
2.9.2	The supplier should arrange a comprehensive human resource development programme for licensing issues, which include The supplier should support training for development of licence application The nuclear regulatory bodies in the supplier side should support training for assessment and approval of licence application	☐	☐	☐	☐	☐	
2.10	Development of industrial infrastructure	☐	☐	☐	☐	☐	
2.10.1	The supplier should assist the user in preparing a comprehensive development programme to enable an increase in local participation over the life of the nuclear power programme including future nuclear power plants.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
3		NUCLEAR SAFETY	Not important	Less important	Important	More important	Very important	Agreed/comment
3.1		Licensing and regulatory requirements	☐	☐	☐	☐	☐	
	3.1.1	The nuclear power plant shall meet the requirements of the IAEA Safety Standards and comply with those of the national regulatory organization.	☐	☐	☐	☐	☐	
	3.1.2	The nuclear power plant should comply with nuclear regulation of the country of system origin.	☐	☐	☐	☐	☐	
3.2		Safety analysis approach	☐	☐	☐	☐	☐	
	3.2.1	The safety of the nuclear power plant design should be demonstrated by the best combination of deterministic and probabilistic safety analyses. The rationale for the choice of this combination should also be explained.	☐	☐	☐	☐	☐	
	3.2.2	Data used in the probabilistic approach should be justified.	☐	☐	☐	☐	☐	
3.3		Safety systems	☐	☐	☐	☐	☐	
	3.3.1	The nuclear power plant should use only proven safety systems	☐	☐	☐	☐	☐	
	3.3.2	Safety systems should incorporate the lessons learnt from the extensive operating experience over the past five decades.	☐	☐	☐	☐	☐	
	3.3.3	Safety systems should be designed to minimize operator challenges.	☐	☐	☐	☐	☐	
	3.3.4	Selection of passive and active safety features should be based on the following; Overall plant safety performance Overall system reliability Maintainability Impact on plant economic The rationale for the choice of this combination should also be explained	☐	☐	☐	☐	☐	
3.4		External events	☐	☐	☐	☐	☐	
	3.4.1	The nuclear power plant should be designed to withstand the impact of external site specific events.	☐	☐	☐	☐	☐	
	3.4.2	The supplier should consider a range of external events parameters that allow development of standard plant design at multiple sites	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
3		NUCLEAR SAFETY	Not important	Less important	Important	More important	Very important	Agreed/comment
3.5		Occupational radiation exposure	☐	☐	☐	☐	☐	
	3.5.1	Annual individual and collective dose should be as low as reasonably achievable (ALARA)	☐	☐	☐	☐	☐	
	3.5.2	The annual individual and collective effective dose should not exceed internationally recommended limits and national limits.	☐	☐	☐	☐	☐	
3.6		Dose to the general public	☐	☐	☐	☐	☐	
	3.6.1	The radiation dose to the general public should not exceed internationally recommended limits and national limits, irrespective of the plant rated power.	☐	☐	☐	☐	☐	
3.7		Accident frequencies	☐	☐	☐	☐	☐	
	3.7.1	Overall accident frequency and large early release frequency should be the same as those licensable in the supplier countries.	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
4	ENVIRONMENT, RESOURCES AND WASTE MANAGEMENT	Not important	Less important	Important	More important	Very important	Agreed/comment
4.1	Environmental impacts	☐	☐	☐	☐	☐	
4.1.1	The radioactive and chemical releases from the nuclear power plant to the environment should comply with the national regulations as well as relevant regulations in the region.	☐	☐	☐	☐	☐	
4.1.2	The nuclear power plant should be designed to operate with minimum water consumption	☐	☐	☐	☐	☐	
4.2	Long term availability of fissile materials	☐	☐	☐	☐	☐	
4.2.1	Based on several scenarios of global nuclear power development, the supplier should provide assessment and evaluation on long term availability of fissile materials and discuss with the user any possible options for sustainable nuclear power programme.	☐	☐	☐	☐	☐	
4.3	Amount of waste	☐	☐	☐	☐	☐	
4.3.1	Production of solid, liquid and gaseous wastes and effluents during plant lifetime should be kept as low as reasonably achievable.	☐	☐	☐	☐	☐	
4.4	Operating waste management	☐	☐	☐	☐	☐	
4.4.1	The supplier should provide guidance for waste management in a safe and su stainable manner with the waste generated by the nuclear power plant operation.	☐	☐	☐	☐	☐	
4.5	Spent fuel management	☐	☐	☐	☐	☐	
4.5.1	The nuclear power plant should have adequate storage to accommodate Spent fuel unloaded for 10 years; A complete core (reloading and maintenance); Various irradiated equipment; Reload of fresh fuel.	☐	☐	☐	☐	☐	
4.5.2	Appropriate international institutional arrangements should be established to manage spent fuel and the supplier should take leading role in its development.	☐	☐	☐	☐	☐	
4.6	Decommissioning	☐	☐	☐	☐	☐	
4.6.1	The nuclear power plant should be designed for ease of decommissioning. Relevant information should be provided to the user.	☐	☐	☐	☐	☐	
4.6.2	Guidance on the decommissioning should be provided by the supplier before plant operation.	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
5	PROLIFERATION RESISTANCE	Not important	Less important	Important	More important	Very important	Agreed/comment
5.1	Safeguards regime	☐	☐	☐	☐	☐	
5.1.1	Suppliers should not impose any additional requirements with regard to intrinsic features against nuclear proliferation for signatories of the NPT and relevant international instruments.	☐	☐	☐	☐	☐	
5.1.2	The supplier should design the nuclear power plant for safeguards friendliness to the current IAEA safeguards regime.	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
6	PHYSICAL PROTECTION	Not important	Less important	Important	More important	Very important	Agreed/comment
6.1	Technical features for physical protection	☐	☐	☐	☐	☐	
6.1.1	The nuclear power plant design should incorporate technical features and provisions to protect against theft, sabotage and acts of terrorism through integration of plant arrangements and system configuration with plant security design, in accordance with international guidance, practices and user's national regulations.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
7		TECHNICAL REQUIREMENTS	Not important	Less important	Important	More important	Very important	Agreed/comment
7.1		Proven technology	☐	☐	☐	☐	☐	
	7.1.1	Proven technology should include overall system and elements. The elements should include components, plant structures, design and analysis techniques, maintainability and operability features and construction techniques.	☐	☐	☐	☐	☐	
	7.1.2	Provenness of overall system should be demonstrated through several years of operation of similar nuclear power plants as a commercial plant with a good operational record.	☐	☐	☐	☐	☐	
	7.1.3	Provenness of the elements should be demonstrated through one or more of the following: Several years of operation in existing nuclear power plants; Full or part scale testing facilities; Several years of operation in other applicable industries such as fossil power and process industries.	☐	☐	☐	☐	☐	
	7.1.4	The supplier should review existing databases of operating experience to identify both positive experience as well as causes of significant events and unplanned outages, and incorporate appropriate features in the plant design.	☐	☐	☐	☐	☐	
	7.1.5	The reactor system should have been licensed or should be licensable in the country of system origin and the licensing information should be made available.	☐	☐	☐	☐	☐	
7.2		Standardization	☐	☐	☐	☐	☐	
	7.2.1	The nuclear power plant should be designed based on standardized plant design and components that should be established to envelop the maximum numbers of site conditions without significantly impacting costs.	☐	☐	☐	☐	☐	
	7.2.2	The supplier should minimize the number of different types of components.	☐	☐	☐	☐	☐	
	7.2.3	The design of the equipments and components should allow supply from additional manufacturers during the life of the nuclear power plant.	☐	☐	☐	☐	☐	
	7.2.4	International standard unit system should be used.	☐	☐	☐	☐	☐	

Number		Requirement	Your opinion					
7		TECHNICAL REQUIREMENTS	Not important	Less important	Important	More important	Very important	Agreed/comment
7.3		Constructability	☐	☐	☐	☐	☐	
	7.3.1	The design, construction process and procedures should allow optimized utilization of both local workforces at site and prefabrication at factories or at site.	☐	☐	☐	☐	☐	
	7.3.2	The design, construction process and procedures should allow flexibility of construction schedule.	☐	☐	☐	☐	☐	
7.4		Unit size	☐	☐	☐	☐	☐	
	7.4.1	For near term deployment, the nuclear power plant should be designed to meet the plant size requirements of users.	☐	☐	☐	☐	☐	
	7.4.2	For longer term deployment, the nuclear power plant should be designed to meet the plant size requirements of users.	☐	☐	☐	☐	☐	
7.5		Plant life	☐	☐	☐	☐	☐	
	7.5.1	The design life of the nuclear power plant should be at least 60 years.	☐	☐	☐	☐	☐	
	7.5.2	Structures and equipment that cannot meet the 60 year target should be replaceable.	☐	☐	☐	☐	☐	
7.6		Simplification	☐	☐	☐	☐	☐	
	7.6.1	Number of types of systems and components of the nuclear power plant should be minimized as far as possible, without adverse impacts on the economics, and plant performance and safety.	☐	☐	☐	☐	☐	
7.7		Design margins	☐	☐	☐	☐	☐	
	7.7.1	The nuclear power plant design should be optimized to incorporate sufficient margins to enable high availability and to minimize the chance of exceeding regulatory limits.	☐	☐	☐	☐	☐	
	7.7.2	The margin for new features or operating conditions should allow for uncertainties.	☐	☐	☐	☐	☐	
7.8		Ease of operation and maintenance	☐	☐	☐	☐	☐	
	7.8.1	An integrated design approach should be used to achieve ease of operation, monitoring, inspection and maintenance of the nuclear power plant.	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
7	TECHNICAL REQUIREMENTS	Not important	Less important	Important	More important	Very important	Agreed/comment
7.8.2	On-line maintenance should be incorporated in the plant design.	☐	☐	☐	☐	☐	
7.8.3	On-line monitoring should be incorporated in the plant design to facilitate assessment of plant conditions and component lifetime.	☐	☐	☐	☐	☐	
7.8.4	Allowable outage time for safety systems should be optimized with regards to plant availability and generating costs.	☐	☐	☐	☐	☐	
7.9	Plant performance	☐	☐	☐	☐	☐	
7.9.1	The nuclear power plant shall be capable of achieving an average availability factor ≥85%. The supplier should provide guidance on the best practices to achieve this performance level.	☐	☐	☐	☐	☐	
7.9.2	The number of unplanned automatic scrams shall be less than 1 scram/year.	☐	☐	☐	☐	☐	
7.9.3	In case of loss of load, the nuclear power plant should be capable of safe shutdown.	☐	☐	☐	☐	☐	
7.10	Maneuverability	☐	☐	☐	☐	☐	
7.10.1	The nuclear power plant should be designed for base load operation.	☐	☐	☐	☐	☐	
7.11	Operating cycle	☐	☐	☐	☐	☐	
7.11.1	The nuclear power plant design should be capable of refueling cycle of at least 18 months.	☐	☐	☐	☐	☐	
7.12	Flexibility in the use of fuel	☐	☐	☐	☐	☐	
7.12.1	The nuclear power plant should have the capability to use different fuel material types such as mixed oxide fuel of uranium and plutonium (MOX) and/or thorium oxide fuel in the future with minimum modification of the facilities. The supplier should indicate the necessary modifications.	☐	☐	☐	☐	☐	
7.13	Man–machine interface	☐	☐	☐	☐	☐	
7.13.1	The control room of man–machine interface (MMI) should be standardized by considering all plant conditions based on international human factor's practices, optimized plant automation, and units (distance, temperature, etc.).	☐	☐	☐	☐	☐	

Number	Requirement	Your opinion					
7	TECHNICAL REQUIREMENTS	Not important	Less important	Important	More important	Very important	Agreed/comment
7.13.2	The control room of man–machine interface (MMI) should be customized based on local language.	☐	☐	☐	☐	☐	
7.14	Siting	☐	☐	☐	☐	☐	
7.14.1	The nuclear power plant should be designed for easy adaptation to different geographical sites.	☐	☐	☐	☐	☐	
7.14.2	For inland sites, important aspects that should be considered are adaptability of the nuclear power plant to the use of cooling towers, and transportability of the large equipment and components.	☐	☐	☐	☐	☐	
7.14.3	For coastal sites, important aspects that should be considered are the use of seawater for condenser cooling and the use of higher corrosion resistant materials to cope with atmospheric conditions.	☐	☐	☐	☐	☐	

Question 2-B: General comments on draft CUC

Please write your general comments on draft CUC here.

Part 3 — Opportunities and challenges on introduction of nuclear energy

Question 3-A: Advantage of introduction of nuclear energy

What are the advantages of introducing nuclear energy to your country? Please select the level of importance according to your opinion by clicking just ***one*** *of the appropriate boxes in each issue. You can also add any other advantages if any.*

	Not important	Less important	Important	More important	Very important	Comments
Short/medium term energy security/strategy (uranium as stable and reliable resource)	☐	☐	☐	☐	☐	
Long term energy security (uranium as long lasting resource)	☐	☐	☐	☐	☐	
Cost benefit (cheaper than other energy cost)	☐	☐	☐	☐	☐	
Cost stability (not too much affected by change in fuel cost)	☐	☐	☐	☐	☐	
Stimulate industrialization and development of human resource	☐	☐	☐	☐	☐	
Low environmental impact on air pollution (local and regional impact)	☐	☐	☐	☐	☐	
Low environmental impact on greenhouse effect (global impact)	☐	☐	☐	☐	☐	
Prestige and other soft support for economic development	☐	☐	☐	☐	☐	
Export of electricity to neighbour counties	☐	☐	☐	☐	☐	
Saving national fossil resources	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	
Please add any additional advantage here	☐	☐	☐	☐	☐	

Question 3-B: Impediments on the introduction of nuclear energy

What are the impediments when introducing nuclear energy to your country? Please select the level of importance according to your opinion by clicking just ***one*** *of the appropriate boxes in each issue. You can also add any other impediments if any.*

	Not important	Less important	Important	More important	Very important	Comments
Management of spent fuel and/or high level nuclear waste	☐	☐	☐	☐	☐	
Management of low and medium level nuclear waste	☐	☐	☐	☐	☐	
Assurance of imported fuel supply	☐	☐	☐	☐	☐	
Concern on safety (possibility of accident)	☐	☐	☐	☐	☐	
Concern on nuclear proliferation	☐	☐	☐	☐	☐	
Concern on nuclear security (terrorist attack, sabotage)	☐	☐	☐	☐	☐	
High construction cost (difficulty on investment)	☐	☐	☐	☐	☐	
Grid compatibility (size and stability of grid)	☐	☐	☐	☐	☐	
Difficulty on site selection with suitable physical condition	☐	☐	☐	☐	☐	
Difficulty on dealing with technology	☐	☐	☐	☐	☐	
Legal infrastructure building (licensing, regulatory body)	☐	☐	☐	☐	☐	
Industrial infrastructure building (support industries, etc.)	☐	☐	☐	☐	☐	
Human resource development	☐	☐	☐	☐	☐	
Long term political support	☐	☐	☐	☐	☐	
Public acceptance (national and local)	☐	☐	☐	☐	☐	
Financial risk due to large capital and potential delays	☐	☐	☐	☐	☐	
Longer lead time and construction period	☐	☐	☐	☐	☐	

	Not important	Less important	Important	More important	Very important	Comments
Opposition from neighbouring countries or a region	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	
Please add any additional impediment here	☐	☐	☐	☐	☐	

Appendix II

NUCLEAR POWER INTRODUCTION EXPERIENCES IN PRESENT NUCLEAR COUNTRIES

Currently, 439 nuclear reactors operating in 30 countries altogether provide 15% of the world's total electricity. Many of these counties had introduced nuclear power as technology users in the beginning, although some of them became technology holders later on. It must be beneficial for potential user countries, which the CUC addresses in this report, to know the past experiences and lessons learnt in these countries in order to take these experiences into account in their coming nuclear programmes, and finally to establish user requirements.

This appendix includes papers from 6 countries, which briefly describe how they introduced nuclear power or developed it by themselves (especially in the case of Canada), what their considerations and user requirements were at that time, and suggestions to new users. These 6 countries are:

— Argentina;
— Canada;
— Finland;
— Japan;
— Republic of Korea;
— Spain.

Although the times of deployment of the first nuclear power units in these counties are from a long time ago, varying from the early 1960s to the late 1970s, it is fully expected that many of the issues they addressed remain important for today's users as well. The potential user countries are strongly encouraged to study the papers thoroughly and obtain insights for the preparation of coming nuclear power projects.

EXPERIENCE OF ARGENTINA IN THE DEVELOPMENT AND DEPLOYMENT OF NUCLEAR POWER PLANTS

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1. BRIEF HISTORY AND CURRENT SITUATION OF NUCLEAR POWER PLANTS

1.1. The beginning of nuclear activities in Argentina

Nuclear activities were launched in Argentina very early, in 1950, with the creation of the National Atomic Energy Commission — Comisión Nacional de Energía Atómica (CNEA) — as a governmental agency responsible for the "peaceful uses of atomic energy in energy generation, health, industry and agriculture, and the protection of the population from radiation".

Those activities consisted mainly of prospecting of uranium resources in the country and research and development in radiochemistry, reactor theory, radioisotopes application and production, and metallurgy.

Uranium prospecting started in the late 1940s, and it soon became clear that Argentina had reserves sufficient to back a nuclear programme.

The whole mode of nuclear development in Argentina was sustained on ideas of technological autonomy, supported by continuous education in the new areas, and performed in a 'step by step' way, via incremental innovation and accumulating knowledge by doing.

The first 'large' facility built was a synchrocyclotron devoted to research in nuclear physics and radioisotope identification, assembled and put into operation in 1954 by CNEA staff. Assembly and operation demanded the formation of a group in electronics, which later on became the instrumentation and control sector, important in reactor development.

Results from this early research were presented in 37 papers at the 1955 First Geneva Conference on the Peaceful Uses of Atomic Energy, including the discovery of 13 new isotopes [1].

The then president of CNEA, P. Iraolagoitía, in a presentation on The role of Atomic Energy in the Argentine Republic given at the 1955 Geneva Conference, analyzed energy resources and demand in the country, concluding on the convenience of adding nuclear generation to the electricity matrix in the mid-eastern part of Argentina, the so-called Gran Buenos Aires — Littoral region (GBAL), which concentrated most of the population and the growing industry of the country.

Regarding energy sources, there was an important hydroelectric potential, nowadays exploited, but far away from the area of demand; Argentina was using hydrocarbons and coal, but the most relevant gas reserves had not yet been found. Under this scenario, nuclear generation became attractive.

In order to attain the main objective of nuclear generation, a strategic decision was taken: to accumulate knowledge and skills step by step through a series of projects of increasing complexity.

1.2. Initial projects

The initial phases of the nuclear programme were undertaken in the context of an ideal of independent development of the country through industrial modernization and technological updating shared by most of Argentine society. Even though those were times of political instability and periodic economic crisis — as most of the 20th century in Argentina — there was agreement between different political sectors, both civilian and military, on supporting nuclear energy as a means of attaining growth of the country. As it used to be said in those days, "nuclear is an industrializing industry".

Development, technological autonomy and national/regional independence were common goals for important sectors in the Latin America region during that period.

Development of nuclear activities in Argentina was facilitated by the continuity of CNEA policy, which in turn reflected the continuity of these ideas in the local and regional societies. The main objectives of Argentina's nuclear programme in the 1950s and 1960s are reflected in the words of Prof. Jorge Sabato, CNEA Technology Branch Manager [2]:

(a) To build up an autonomous decision making capability;
(b) To develop the necessary scientific technological infrastructure required for the optimum social utilization of nuclear energy;
(c) To be used as a 'demonstration effect', showing that R&D is feasible and can be useful, even if being carried out in a developing country immersed in a long and deep socio-political and economic crisis.

These goals were translated into a coherent set of actions which would define the nuclear activities for the next three decades:

(1) Incremental acquisition of capabilities in order to achieve technological autonomy by means of a series of projects of increasing complexity;
(2) Self-sufficiency in the fuel cycle;
(3) Maximum participation of local industry;
(4) Transfer of technology to specifically created, mixed private–government companies.

In order to carry out these activities, it was necessary to set up an educational programme in the nuclear areas.

In this step by step process of developing knowledge and skills by experience, it was decided to start with the design and construction of research reactors whose main purpose was the production of radioisotopes for health related and industrial uses, but which were also devoted to the performance of various experiments, and to help to test engineering and construction capabilities [3].

An Argonaut type critical facility called RA-1 was constructed in the country in 1957 following a basic design provided by Argonne National Laboratory. When it became critical in January 1958 it was the first in Latin America. One year later RA1 was totally redesigned locally as a 150 kW research reactor.

Exploitation of uranium mines started in the 1950s, and technology was developed for ore concentration and production of uranium metal. RA-1 research reactor fuel was designed and produced domestically, starting from enriched uranium provided by the US Atoms for Peace programme. This involved developing the technology for conversion, production of oxides, metal alloys and fabrication of various types of fuel elements.

In the 1950s CNEA launched a programme for promotion of the use of radioisotopes in medicine, industry and agriculture. Production of some radioisotopes in RA-1 and the synchrocyclotron was soon surpassed by demand, and the need for a larger facility became obvious.

In the early 1960s CNEA began the design of RA-3, a 5 MW open tank reactor for radioisotope production. The reactor became critical in 1967. Its construction used local suppliers almost exclusively.

RA-3 and its associated radioisotope production plant permitted a drastic increase in the use of radioisotopes in Argentina. It was also a milestone in achieving expertise in the field of research reactors, which were later exported to many countries.

The policy of incremental innovations also showed its possibilities in the field of radioisotopes production. In the 1980s CNEA began the production of ^{99}Mo by fission in the RA-3 reactor, based on local technology. In the present decade, CNEA became the world leader in the development of low enrichment targets for Mo production, a technology that has also been exported.

Other radioisotopes are produced as well, either for the local market or export. ^{60}Co produced in the Embalse nuclear power plant is a good example, Argentina being a major world exporter of this product.

The research reactor programme as it was planned had another important consequence. It opened the way to power reactors, providing experience and skills to be applied to:

(i) Preparation of the feasibility report of the first nuclear power plant;
(ii) Evaluation of offers;
(iii) Participation of CNEA staff in the nuclear power plant project and preparation of the operating staff, incorporating important embedded knowledge;
(iv) Analysis of safety aspects and development of a regulatory framework;
(v) Development of local industry by introducing new technology and QA requirements.

1.3. The 1960s and the first nuclear power plant

In 1965 the government requested CNEA to prepare a feasibility report on the construction of a nuclear power plant in the GBAL region, were most of the population and industry were concentrated. There was no electrical grid connecting the whole country as it exists today, but there was a regional GBAL grid.

At that time, feasibility studies for large projects in Argentina were usually prepared by foreign consultants. CNEA decided to do it on its own, again as a way of ‘learning by doing’, as well as testing local capabilities in engineering.

The report [4] showed the feasibility of installing a nuclear power plant. The selected site was Atucha, some 100 km north-east of Buenos Aires, by the Paraná de las Palmas River.

In 1966 CNEA was authorized to start the bidding procedure. A bidding process was opened and 17 offers were presented.

By the end of 1967 the decision was taken to build a pressure vessel design, moderated and cooled by heavy water, with natural uranium fuel, of German design. Construction started in 1968, and the 345 MW(e) plant was connected to the grid in 1974.

Involvement of local industry was a very important consideration in that bid. Thanks to the decision to develop local suppliers and the conditions established in the contracts, local industry participation in the project ended up being around 40%, including 13% of the electromechanical components.

1.4. The 1970s and the second nuclear power plant

In 1971 EPEC, the public electric utility of the province of Córdoba, an important industrial region in the centre of the country, requested a feasibility study for a nuclear power plant from CNEA.

In 1972 the decision was taken to construct a second nuclear power plant in Embalse, province of Córdoba, connected to the national grid. The call for bids followed the same trend as the Atucha one and at least 50% participation of the local industry was requested.

The offer of a 600 MW natural uranium–heavy water reactor with pressure tubes, made jointly by Canadian and Italian firms, was selected in March 1973. Having pressure tubes in a calandria vessel instead of a pressure vessel made it more likely that domestic industry would be able to supply subsequent units.

A very wide technology transfer agreement was negotiated between Argentina and Canada, and signed in March 1974. According to it CNEA would receive the technology for the design and construction of pressure tube nuclear power plants. CNEA would have the rights to build similar units in Argentina, without any further payments. Canada would negotiate the transfer of technology and fabrication licences to Argentine corporations with the fuel producers.

For various reasons there were delays in the construction and only partial fulfilment of the technology transfer agreement. Among them were distortion of the agreed costs and prices — due to world inflation after the oil crisis of the 1970s and acute inflation and currency devaluation in Argentina, a deeper concern on non-proliferation issues following the nuclear explosion in 1974 and the formation of the Nuclear Suppliers Group.

Construction was severely delayed but the negative effects of the delays were compensated for by an increasing participation, more than 50%, not only of the local industry, but also of Argentine engineering, including participation in the supervision of work during the final stages. In 1979 CNEA became the main contractor for the assembly works, and Argentine firms were responsible for the assembly of many systems.

The fuel ended up being designed in Argentina and has been produced there since 1984, after initial loads provided by Canada. Local technology developments for the fabrication process, including different industrial equipment, were undertaken by CNEA and later transferred to a new fuel fabrication company.

In 1982 a mixed private–government company, CONUAR, started Atucha fuel fabrication and a couple of years later Embalse fuel production began. In 1986 FAESA, having a structure similar to CONUAR and using technology transferred by CNEA, began to produce zircaloy cladding for both nuclear power plants and other special alloys.

The next step in the policy of knowledge transfer was the creation of a company that would become ‘a technology factory’. INVAP was created in 1976, and in the following years became involved in many technological projects: uranium enrichment, research reactors for Argentina and for three other countries, satellite development and fabrication, radars, etc.

In 1977, in response to demands from the growing nuclear activities, CNEA created an education programme on Nuclear Engineering at its Balseiro Institute in Bariloche, northern Patagonia, which has produced more than 320 graduates and post-graduates to date.

A research and training reactor (RA-6) was designed and built by INVAP, upon commitment from CNEA, to back the academic programme, as well as different engineering laboratories, with the financial support of an UNDP project.

In 1978 construction started of a nuclear research centre exported by CNEA to Peru. It consisted of a 10 MW research and radioisotope production reactor, a radioisotope production plant, and auxiliary installations. Argentina had joined the RERTR programme to reduce enrichment of research reactor fuel, and development of new fuel for the RA-3 and the Peruvian reactors began.

As part of the already mentioned policy of incremental development of technology and self-sufficiency in the fuel cycle, CNEA had started research in uranium enrichment and in spent fuel reprocessing. Interruption of the supply of 20% enriched uranium for research reactor fuel at the end of the 1970s catalyzed the CNEA decision to start a demonstration project on uranium enrichment technology.

In 1983 Argentina announced that enriched uranium had been obtained in the Pilcaniyeu pilot plant in northern Patagonia. Imports of enriched uranium restarted and the RA-3 reactor was fully converted to reduced enrichment fuel in the late 1980s.

1.5. From the third nuclear power plant to the present time

In 1979 the military government of Argentina launched an ambitious plan for construction of four nuclear power plants and a heavy water production plant by the year 2000. The choice of natural uranium–heavy water reactors was reinforced and made explicit.

The call for offers for the third nuclear power plant was therefore restricted to vendors from Canada and Germany. Argentina was requesting a nuclear power plant to be built next to the Atucha I nuclear power plant (already operational), a heavy water production plant, and the constitution of a joint company between CNEA and the supplier, which would become the architect/engineer for the construction of the present and future nuclear plants in the country.

The German and Swiss offer of a 700 MW(e) version of the Atucha I pressure vessel reactor and a heavy water production plant was selected. One of the reasons was that it provided stronger guarantees and better conditions for the formation of the architect–engineering company. Argentina clearly stated that this decision did not imply that future plants would be of the Atucha type, thus opening the possibility of new pressure tube reactors.

By that time many of the original goals of the nuclear programme had been attained. Involvement of the local industry in the nuclear works had had an important spin-off effect, largely contributing to the introduction of updated technology and quality assurance in areas of the Argentine industry, such as metal–mechanical and electronics.

In 1981 the architect–engineering company, named ENACE — Empresa Nuclear Argentina de Centrales Eléctricas — was formed as a joint venture with Germany, and construction of Atucha II started. German participation in ENACE was intended to gradually decrease until the company became totally Argentine by the end of the 1990s.

Participation of local industry was planned to be very important; for example thanks to CNEA efforts in developing suppliers, the steam generators were fabricated by an Argentine private company. On the other hand, this greater involvement of local firms meant that German financing was mainly restricted to the imported supplies and a large proportion of the investment had to be covered by the government budget.

In 1982 Argentina suffered a deep economic crisis, and the resulting smaller budget allocation elicited several delays in the fulfilment of the project. These delays grew in importance from 1984 onwards, when lower priority was given to nuclear energy by the new democratic government. Budgetary problems became acute and construction was formally stopped in 1994.

Meanwhile, the policy of incremental acquisition of technological autonomy kept on yielding results, now in the field of autonomous nuclear plant design. In 1984 the CAREM concept [5], a small, innovative, inherently safe nuclear power plant was presented by Argentina at an international meeting. Later CAREM was selected within Generation IV designs.

In the area of nuclear medicine, promoted since the 1950s by CNEA, there were continuous advances. In the early 1990s CNEA took part in the creation of a nuclear medicine school and centre for diagnosis and therapy with advanced equipment, including PET and a cyclotron. At the beginning of the current decade CNEA started producing short lived cyclotron radioisotopes for PETs in hospitals at Buenos Aires. A second PET centre has recently been inaugurated as well. In 2003 CNEA created a course on Medical Physics at its Balseiro Institute.

In the 1990s Argentina underwent a process of economic and institutional change. The opening of the economy and revaluation of the local currency resulted in a shrinking of the industrial sector and expansion of the financial one. Following international trends the decision was taken to privatize all government agencies and companies involved in production and public services.

As part of this policy, in 1994 the Argentine nuclear sector was restructured. By then the construction of the heavy water plant had been completed and an 80% advance had been reached in Atucha II work. A new company, ENSI, was created for the operation of the heavy water plant and for providing engineering services to the industry.

A state owned shareholder company to be privatized, Nucleoeléctrica Argentina S.A. (NA-SA), was created for the operation of the two nuclear installations and the construction and subsequent operation of the third one. Construction of Atucha II was stopped, waiting for the private operator of the nuclear power plants. ENACE was closed, and some of its critical staff joined NA-SA. Attempts to privatize the operation of the nuclear stations failed and at the end of the 1990s privatization ideas were abandoned.

In 1997 the production of UO_2 for the nuclear power plant fuel was transferred by CNEA to a new government company, DIOXITEK. Later on this company expanded its activities, including the production of ^{60}Co sealed sources for the local market and for export.

The current Argentine government, for environmental, socio-economic and technical reasons, decided to complete the construction of Atucha II, to extend the life of operating units and to study the construction of new ones.

1.6. Current situation

In 2003 a new government asked NA-SA and CNEA to perform studies on the re-initiation of Atucha II construction. Reports and studies were done and discussed with government officials, and the general situation was also analyzed with the vendor and its successors in the nuclear business.

In August 2006 the government decided to restart construction of Atucha II, allocating funds and launching a set of nuclear projects, including refurbishment and life extension of the Embalse nuclear power plant, feasibility study for a fourth nuclear power plant and eventually a fifth one, development and construction of the locally designed CAREM prototype, and renewed operation of the uranium enrichment pilot plant. Table 1 summarises the situation regarding nuclear power generation inArgentina.

TABLE 1. NUCLEAR POWER PLANTS IN ARGENTINA

	Atucha I	Embalse	Atucha II	4th/5th nuclear power plant
Beginning of construction	1968	1974	1981	—
Interruption of construction	—	—	1994	—
Restart of construction	—	—	2006	—
Connection to grid	1974	1984	Planned 2010	—
Present status	Operation	Operation	Construction	Feasibility study
Reactor type	PHWR 345 MW, pressure vessel	PHWR 600 MW, pressure tubes	PHWR 700 MW, pressure vessel	—

The present nuclear power situation in Argentina is characterized by a firm decision to expand the nuclear share in electricity generation and promote the participation of local industry in the projects under way.

The situation of the local industry and engineering companies has undergone significant changes since the early phases of nuclear activity. Even though many industries that had participated in the construction of the first units have disappeared as a result of the economic policy prevailing in the 1990s, those which have survived have a solid technical and quality background and have successfully operated globally. There is now a local industrial and engineering background to sustain the new nuclear programme.

A key issue in order to be able to incorporate, develop and use technology, especially in developing countries, is having adequate human resources.

From its very beginning, CNEA started a programme of development of human resources; in its first stages it focused in branches underdeveloped in the local universities at that time, such as radiochemistry, metallurgy and physics. Later it expanded to cover all the main nuclear areas, always based on:

Academic programmes for graduate and post-graduate studies in three CNEA institutes;

(a) 'On the job' training backed by fellowships;
(b) Courses on specific and needed subjects.

CNEA Institutes are located in the research centres, as a result of which their faculty members are active researchers and technologists and updated laboratories are available, including research reactors. The main academic programmes are nuclear engineering, materials science and engineering, nuclear applications, physics and nuclear medicine. Close to 1700 professionals have graduated from them, including almost 400 PhDs.

In the 'on the job' educational programme, around 200 fellows annually are trained in CNEA laboratories under the supervision of CNEA staff. The main areas are nuclear reactor development, fuel cycle from prospecting to fuel fabrication, radwaste and environmental protection, nuclear medicine, radioisotope production and its applications, alternative energy sources and some basic physics, chemistry and biology.

It is important to point out that CNEA, in its role of developer and supplier of technological knowledge in the country, has kept its human resources development programme, regardless of the ups and downs of the nuclear sector.

When no new projects existed in the 1990s, these human resources were mainly required by the industry, the engineering companies, universities or R&D institutions. This significant set of qualified professionals is presently recoverable for nuclear programmes, facilitating the present nuclear renaissance. They are also a relevant part of the present plans of knowledge transfer.

2. MAIN REASONS FOR THE INTRODUCTION FOR OF NUCLEAR POWER

2.1. Reasons for the decision to introduce nuclear power plants

As has already been stated in the previous section, the idea of introducing nuclear energy generation into the energy matrix of the country was present from the very beginning of nuclear activities.

In the 1960s the most important gas reserves in the country had not yet been found. There was a relevant hydroelectric potential, but it was far away from densely populated and industrial centres, meaning that the low cost of hydroelectricity was increased by the extension of the transmission lines. Argentina was at that time just self-sufficient in oil, and coal was limited and of rather low quality. Uranium resources enough to feed several nuclear plants had been found. Demand for electricity was rapidly expanding due to the industrialization process and the expected increasing quality of life of the population.

In 1965 the government asked CNEA to prepare the feasibility study for a nuclear power plant in the GBAL region of the country.

The study analyzed the expected growth in electricity demand in the region in the following 6 years, the nuclear power plants under construction at that time in 14 countries, and the generating costs in Argentina for the different sources.

Technical, economic, political, financial, legal, social and public health implications were taken into account, as well as the impact of a nuclear power plant on the preservation of natural resources, energy self-sufficiency, local industry development and socio-cultural aspects.

Generating costs for 4 different types of reactors were compared with those for conventional thermal power plants. The study showed that the project could become an important source of contracts for Argentine industry. The final conclusion showed the convenience of installing a nuclear power plant in the selected site.

These mainly economic reasons were not the only ones taken into account for the introduction of nuclear power in the country. Nuclear energy was a worldwide symbol of modernization and high technology. For the last 20 years the country had been in a process of industrialization based on substituting imports of manufactured goods for local ones. Introducing modern technology into Argentine industry, both to improve quality and to reduce costs, became a necessity.

In that context, nuclear power was considered to be a path to development, a notion embedded in the then popular concept of 'nuclear industry as an industrializing industry'. It was clear that in order to fulfil this potential, human resources development, incremental innovations, maximum participation of local industry and self-sufficiency in the fuel cycle had to be attained.

2.2. Reason for the decision to expand nuclear power

Nowadays, relaunching nuclear power plant construction in Argentina is promoted under a new world scenario, dominated by the concerns regarding global warming and potential limitations on the supply of oil and gas.

The global trend of nuclear renaissance is reinforced in our case by national conditions, such as the need to balance the generation park between different sources. Table 2 shows electricity sources in 2005.

Energy demand is increasing due to sustained economic growth for the past 4 years. The decision to reinforce nuclear generation has been taken based on the worldwide perception of the convenience of achieving flexibility by having a balanced energy supply matrix.

Taking into account the degree of technological development of local industry and engineering when compared to the situation in the 1960s and 1970s, a large local involvement in the present projects can be predicted. That will induce general development, and may have beneficial spin-off effects.

3. MAIN CONSIDERATIONS IN INTRODUCING NUCLEAR POWER PLANT

Once the decision has been taken to introduce nuclear power, new questions arise: type of technology, power level, site selection, role of the different local actors, financing, etc. We can take the feasibility study and the bid selection of the first Argentine nuclear power plant as references for the analysis.

Regarding site selection, the feasibility study [4] took several elements into account:

(a) Easy integration to the regional grid;
(b) Availability of cooling water;
(c) Suitable topography and seismological conditions;
(d) Adequate soil for foundation of the plant;
(e) Accessibility by land and/or water;
(f) Meteorological conditions;
(g) Neighbouring population and other issues related to radiological impact.

TABLE 2. ARGENTINE NATIONAL ELECTRICAL SYSTEM, 2005

Source	Generation (%)	Installed capacity (%)
Hydroelectric	31.9	41.1
Thermal	60.9	54.7
Nuclear	7.2	4.2

The call for bids also reflected some criteria and decisions already taken by CNEA:

(1) About the fuel. There was a debate on natural or enriched uranium, in a scenario where the only eventual suppliers of enriched uranium were the USA and the USSR. Natural uranium seemed to be more adequate to the objective of attaining self-sufficiency in the fuel cycle.
The way in which this choice was resolved was explained by CNEA's technology manager at the time [2]: "The final decision taken by CNEA and supported by the Government, was a very pragmatic one: natural uranium would not be selected a priori, but offers would be accepted in both fuels, enriched and natural, and the choice would then be made, after a careful comparison of concrete offers, and not be just a selection in vacuo".
CNEA thought that in this way it would induce fierce competition among suppliers (and also countries), which would help to get better offers. CNEA's position was that if it was true that natural uranium had advantages for Argentina, it was also very important to quantify them, and the only way to do so was through a comparison among different offers".
(2) About power level and delivery time: the expected growth of electrical demand and the grid capacity were the main factors taken into account. Uncertainties arising from the difficulties of introducing nuclear power in a developing country were dealt with by slightly reducing the power level and in that way reducing the risks which could lead to failure of the project.
(3) About financing. Experience had shown that projects financed solely by the government budget may suffer long delays. Besides, international financial organizations would not necessarily assign priority to a request for the construction of a nuclear power plant. Consequently, requiring financial conditions to the bidders, and assigning high priority to the amount being financed was thought to be important.
(4) About fuel elements. It was clear that the supply of fuel elements would be a key element in the atomic energy programme, not only due to its technological and economic importance, but also because it would guarantee a full command of the fuel policy. It was decided that offers should include explicit references to the manufacture of the fuel in Argentina, and conditions under which the corresponding technology would be transferred.
(5) About local participation. CNEA policy was to make Atucha the point of departure for a nuclear sector in Argentine industry. Offers should contemplate maximum participation of local industry, covering not only traditional items such as civil work and ancillary systems, but also important components of advanced design and technology.

Selection was based on a multi-attribute analysis of the offers. No less than 70 variables were taken into consideration, including technical aspects, economics, costs, safety, local involvement, financial conditions, vendor experience, operating experience, etc.

Assigned priorities were reflected in the weights given to the different variables. For instance:

(i) Fuel: In principle natural uranium got 100 points, and enriched uranium 0 points. The British AGR offer, using enriched uranium but guaranteeing more than one supplier for it, got 30 points.
(ii) Financing: it got a high priority, particularly regarding the total amount to be financed.
(iii) Technical data: included not only the nuclear island, but also the balance of plant. In the case of the nuclear island, considerable weight was assigned to the most experienced design.
(iv) Economics: both the capital cost and the generating costs were considered.
(v) Local participation: Weight was assigned to 'semi-turnkey' contracts, allowing higher local industry participation.

General factors not included in the bids were also considered in the evaluation. Examples are the balance of trade with the vendor's country, the vendor's operational experience in Argentina, and support given to the offer by the vendor's government.

By the end of 1967 the decision was made in favour of a German heavy water pressurized reactor, a pressure vessel design moderated and cooled by heavy water, with natural uranium fuel. It is interesting to point out that total financing of the whole project was obtained, including local supplies up to their price in Germany.

Construction started in 1968, and the 345 MW(e) plant was connected to the grid in 1974.

Participation by local industry ended up being around 40%, including 13% of the electromechanical components.

4. LOCALIZATION EFFORTS

4.1. Reasons for promoting local participation

Argentina decided to maximize local participation in the construction of nuclear power plants in order to contribute to the development and modernization of the country. This implies participation of local firms in the construction itself, fabrication of components and equipment, assembly, engineering and other services such as transport, insurance, etc.

4.2. Ways to promote local participation in the first nuclear power plant

Knowledge of present and potential capabilities of the Argentine industry was a basic starting point.

In 1962 CNEA, jointly with ADIMRA, the association of metal-mechanical national industries, created SATI — Service for Technical Assistance to the Industry. Its purpose was to use the capabilities of the CNEA Technology Branch in solving technical problems and introducing innovation in the local industry, and it also became a tool for knowing real capabilities.

Defining an adequate contractual structure in order to facilitate maximum local participation was another step. A developing country is generally unable to take the role of architect-engineer of its first nuclear power plant due to a lack of knowledge and skills to perform such a job. But that fact does not imply that the only alternative is a turnkey contract for a black box, leaving to the vendor all decisions as regards to who will provide the different supplies and components, and who will perform the various tasks of the project.

Usually a foreign vendor will contact local companies to perform some tasks related to civil works or transportation, or for the supply of low technology items. When the decision has been taken to also include the most complex items, something different from a classic turnkey contract must be negotiated with the vendor. The whole nuclear power plant must be decomposed into systems, components, materials, and the possibility of locally producing each one should be defined by analyzing technical and proprietary issues.

This procedure, the so-called ‘opening of technology packages’, demands knowledge of the real capabilities of the local industry, in this case gained through SATI and the programme of design and local construction of research reactors. It also demands a detailed description of the supply in the bids and manpower having a solid technological background to do the job.

4.3. Negotiation with the vendor

By opening the technology packages and separating their elements, it was possible to negotiate with the supplier a contract defining the conditions for participation of local industry. Relevant issues are technical guarantees of local supplies and how to finance them.

In the contract with the supplier for our first nuclear power plant, the main issues included were:

(a) Technical guarantees: it was agreed that, once a local supplier became qualified, the corresponding item would have the same guarantees as those imported.

(b) Amount of local supplies: a minimum amount of 30% of local supplies was fixed. 60% of those minimum local supplies corresponded to civil works, 22% to assembly, 4% to transportation, 1% to insurance and 13% to electromechanical components.

(c) Financing local supplies: the vendor had offered total financing for the project. As a result of negotiations, it also included local supplies, up to their price in the German market; any surplus should be charged to CNEA.

(d) Local electro-mechanical supplies: 96 items, identified by opening technology packages, ended up being supplied by local industry. They included, among others, most of the ventilation system, emergency diesels, part of the primary and secondary circuit piping, pumps, most of the condenser, cranes, tanks, heat exchangers, transformers, motors and boilers.

4.4. Local production of nuclear fuel

As previously stated, self-sufficiency in fuel production was another key objective. Technology transfer and training of CNEA staff in Germany, added to the experience gained in the design and production of research reactor fuel, allowed CNEA to develop a pilot plant for production of Atucha fuel. In the late 1970s several batches of locally produced fuel were irradiated in the reactor.

In 1982 the fuel fabrication factory started production. CONUAR became the first relevant example of technology transfer to the private sector.

Production of fuel for the second nuclear power plant, Embalse, was a different experience. Due to problems in the transfer of fuel fabrication technology, CNEA decided by the end of 1976 to develop the fuel production technology on its own. This development included design and production of equipment for end-cap welding, brazing and graphite coating. By the late 1980s Embalse fuel was being regularly produced by CONUAR.

CNEA developed zircaloy tubing technology; in 1986 FAESA, having a similar structure to CONUAR, began production of fuel cladding.

Several technological innovations have been introduced to the Atucha fuel since the late 1990s, including slightly enriched fuel (0.85%) and simplification of production of the spacers.

4.5. After the first nuclear power plant

As regards Embalse, the second nuclear power plant, local participation ended up being more than 50%, including part of the engineering and of the supervision of the final assembly.

Local participation in Atucha II, presently under construction, will be even greater. For instance, some important components, such as the steam generators and pressurizer, have been locally fabricated.

After 33 years of nuclear generation in the country there are many local industries and engineering companies qualified for the nuclear business who have participated in maintenance and supplies to the operating stations. They are candidates for participation in the life extension of Embalse nuclear power plant, and in the construction of future units.

5. LESSONS LEARNED AND SUGGESTIONS, ESPECIALLY DURING KEY PHASES OF THE PROGRAMME

The experience of our country on the introduction and later development of nuclear power generation has taught us several lessons.

5.1. Technological autonomy

The permanent search for technological autonomy has proved extremely beneficial.

Technological autonomy does not mean that all technology must be local, but to have developed the capability for consciously deciding on technology. It is an incremental process demanding human resources with problem solving skills, where autonomy grows with the execution of increasingly complex projects. As new nuclear power plants are added to the system and more local capacities and experience are developed, the degree of technological autonomy becomes substantial.

Benefits of this policy are, for example, better negotiating capability when buying or in eventual associations with foreign vendors, the possibility of nuclear exports, reduction in operating costs, easier response to problems and changes, etc.

5.2. Need for human resources

A relevant and creative staff is necessary to introduce nuclear power in a developing country. Human resources are required not only for nuclear power plant operation, but also for:

(a) Preparing the call for bids.
(b) Analyzing and selecting the bids for the most appropriate choice.
(c) Defining local participation in works, components and engineering.
(d) Having a fast local response to problems, incidents, need of spare parts, regulatory requirements, changes in the regulatory framework. (Pecautions should be taken against the possibility that, during the 40–60 years of life of the nuclear power plant, the vendor goes out of business or the plant design is abandoned.)
(e) Defining and/or expanding the regulatory framework.
(f) Developing the radioactive waste management capabilities.

A nuclear education programme may be needed in many developing countries due to lack of the required courses at the universities. Such a programme may profit from many of the alternatives existing nowadays on nuclear education. The required personnel could be trained in-house or abroad, but they should be educated as creative people and problem solvers. The programme should have continuity, because the long time spans involved in the operation of a nuclear power plant demand staff renewal and preservation/transfer of knowledge.

5.3. Contracting modalities

The type of contract influences the possibilities of local participation and technology learning.

(a) A developing country will rarely have the experience and capabilities to become the architect-engineer of its first nuclear power plant.
(b) That does not necessarily mean signing a turnkey contract for a sealed technological package ('black box'); that would make local participation difficult and impede knowledge acquisition and growth of technical capabilities.
(c) The total nuclear power plant supply can be open in systems, subsystems, components, equipment, in order to identify items that can be provided locally (the so-called opening and de-aggregation of technological packages). Technical and proprietary issues must be considered in this process.
(d) In this way, a 'semi-turnkey' contract can be negotiated.
(e) Guarantees and financing of locally provided items are important subjects to be clearly defined with the vendor.

5.4. Participation of local industry and engineering

In a developing country, relevant local participation in the construction of the nuclear power plant is very convenient. It should include not only common items, such as civil works and low technology parts, but also as many high technology components as possible.

This participation will help to:

(a) Promote technical and industrial development of the country;
(b) Provide a solid basis for solving problems and requirements that will arise during the long operating period;
(c) Increase the social benefits of nuclear activities by promoting development and generating new qualified jobs.

Local participation requirements should be introduced in the feasibility report as a way to make sure all spin-off effects of nuclear power are taken into account. This is another advantage of performing the feasibility analysis by our own, instead of leaving it to international consultants.

5.5. Development of suppliers

In a developing country, maximization of local participation in the first nuclear power plant may demand a policy of developing local suppliers. In our experience it is convenient and sometimes necessary:

(a) To begin with increasing participation of local industry in a series of projects of growing complexity;
(b) To have technically qualified staff to interact with the industry;
(c) To know the real capabilities of the local industry.

5.6. Self-sufficiency during operation

This is mainly related to fuel, maintenance and spare parts. Self-sufficiency allows:

(a) Making operation of the nuclear power plant safe and sure, more independent of the ups and downs of international trade and eventual crisis in the balance of payments, events not unusual in developing countries;
(b) Promotion of the industrial and technological development of the country;
(c) Having a faster response to incidents, problems or regulatory requirements;
(d) Improving negotiating capabilities for future nuclear power plants.

In our experience, self-sufficiency in operation is greatly enhanced if a creative engineering sector exists at the nuclear power plant. Such a group may improve the consolidation of operating experience and facilitate relations with the suppliers, contractors and regulatory body. It is also a kind of insurance if the vendor starts losing knowledge on a type of reactor, and in the extreme case that it changes its business.

5.7. Financing

Inadequate financial provisions have delayed or interrupted technically sound nuclear power programmes, not only in Argentina but also in other countries.

All financial aspects must be considered: the total amount being financed, conditions such as interest rate and grace periods, the status of locally provided items, guarantees, etc.

In the selection of bids our experience shows the convenience of assigning a high priority to financial terms.

5.8. Relations with the community and public opinion

Public perception has changed radically since the days of our first nuclear power plant. In the 1960s the public took nuclear energy as a symbol of modernization and development; nowadays, that is still valid but as long as it is shown to be safe and not to damage the environment and the population.

Our experience is that in a developing country like ours the public must feel not only that nuclear power is safe and environmentally friendly. The public must also perceive that nuclear power means development and modernization of the country and, as a consequence, it will help to improve living conditions.

5.9. A final remark

Quoting J. Sabato [2], CNEA Technology Manager during the 1960s, in developing countries it can be a naive position to wait for security and continuity as necessary conditions for planning and executing projects. Instead of dreaming up a ‘strategy for order’, the path to development should be unraveled from a ‘strategy for chaos’.

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NUCLEAR POWER INTRODUCTION EXPERIENCES IN SPAIN

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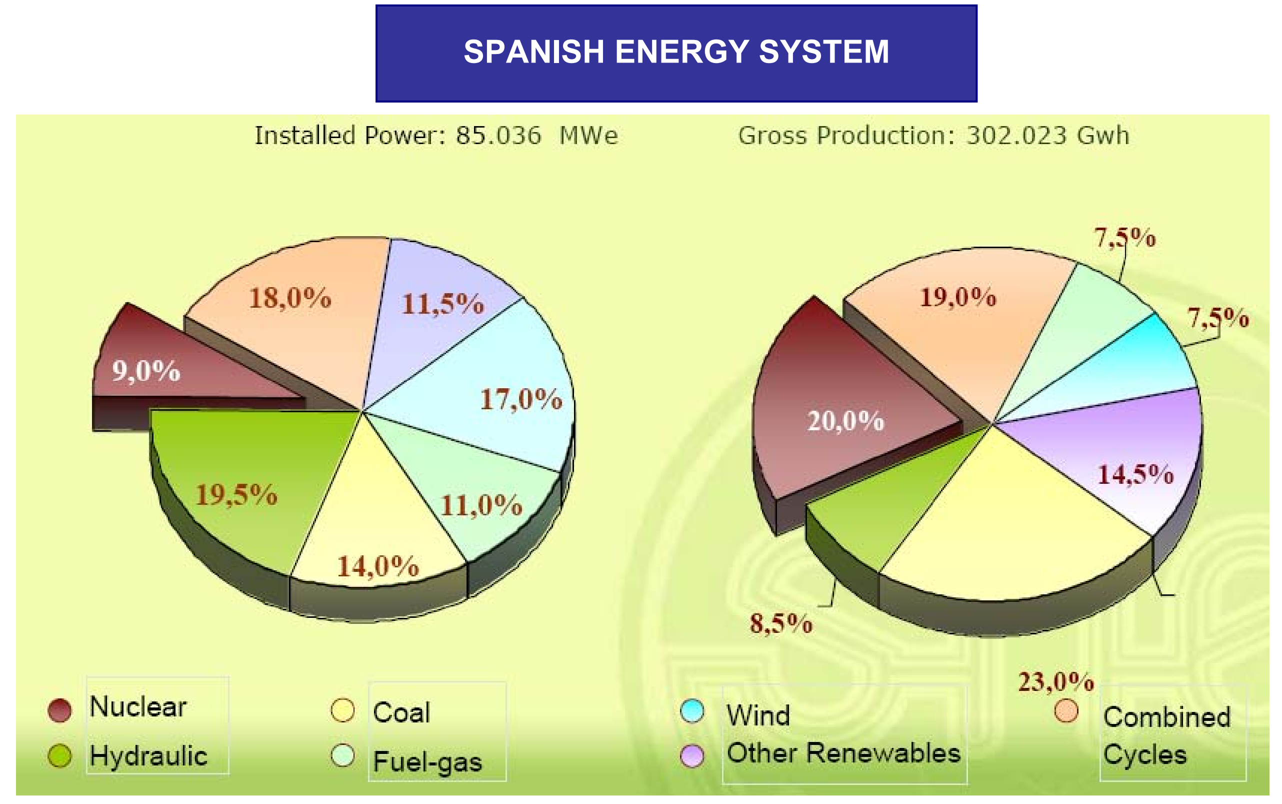
THE SPANISH ENERGY SYSTEM

In terms of its electrical system, Spain is an island weakly linked with its neighboring countries. Spain currently connects to the European market through a line with a capacity of 2000 MW. Moreover, Spain has few natural energy resources of its own and thus imports 82% of its domestic energy needs. This leaves Spain highly vulnerable to movements in market prices as well as to potential supply interruptions triggered by events occurring in the Spanish supplier countries, which are themselves not always stable. As a result, securing supply has become an important issue in the Spanish energy system.

The following figures show the structure of the Spanish energy supply by source in 2006, featuring data on installed power and gross production:



In Spain, the demand for electricity has grown in the last ten years at a rate of approximately 4% per year. The operator of the high voltage grid, REE, is in charge of matching the supply and demand, both in energy as well as in instant power.

In an isolated system such as Spain's, a considerable margin of installed power is needed to attend to the peaks of demand and possible failures in supply from sources that depend on unpredictable factors.

It is essential in these environmental conditions to have power plants able to deliver energy reliably and in large amounts to ensure the base supply and be available whenever the demand peaks. Such is the case with nuclear power plants in Spain, which account for only 9.4% of the installed power and yet produce 20% of the electricity. The figure below provides data on the nuclear power plants in operation in Spain and their location in the country.

SPANISH NUCLEAR POWER PLANTS

5 Single-unit site

Name	Rating (Mwe)	Type	Origin of	Initial
José Cabrera	150.05	PWR	USA	1968 (1)
Garoña	466	BWR	USA	1971
Cofrentes	1.092	BWR	USA	1984
Vandellós II	1087.1	PWR	USA	1987
Trillo	1066	PWR	Germany	1988

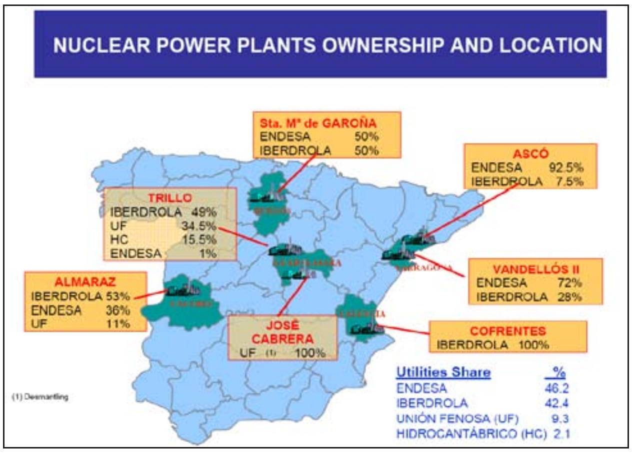
(1) Desmantling

1 two-units site (common buildings)

Name	Rating (Mwe)	Type	Origin of	Initial
Almaraz 1	977	PWR	USA	1981
Almaraz 2	980	PWR	USA	1983

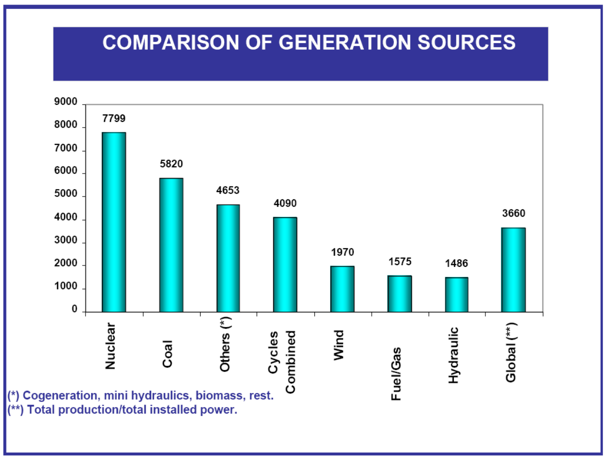
1 two-units site (separate buildings)

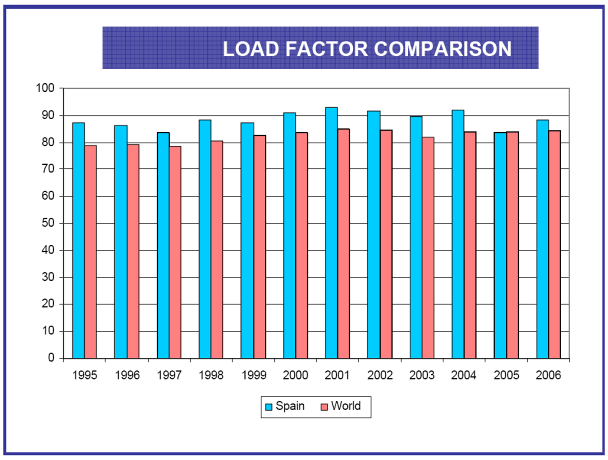
Name	Rating (Mwe)	Type	Origin of	Initial
Ascó 1	1032.5	PWR	USA	1983
Ascó 2	1027.2	PWR	USA	1985

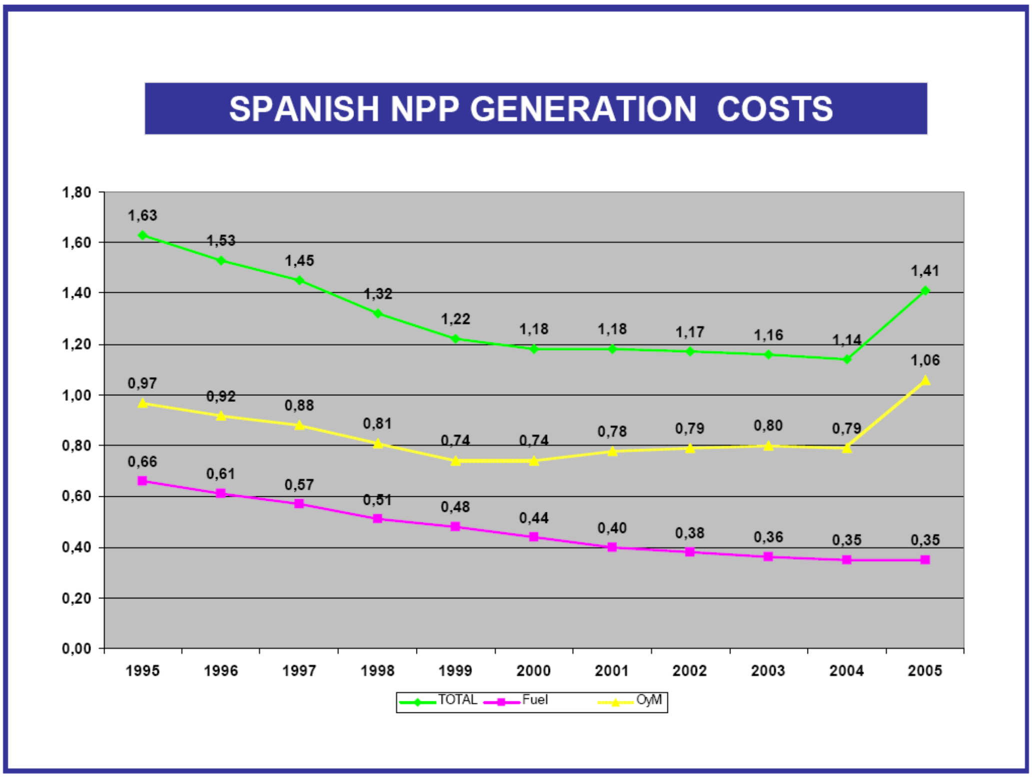


These Spanish nuclear power plants have been operating for decades with outstanding behaviour, often topping the lists of best-performing plants worldwide. Their role has been irreplaceable in the basket of energies supplying the Spanish electricity market. The data on load factor, availability and cost shown in the following figures support this statement.

Therefore the nuclear power plants built in Spain during the second half of the 20th century are today an important asset in the Spanish electric power market. Technology has proven capable of keeping them operational and of incorporating technological enhancements as they develop through a recurrent investment of roughly 195 MW/year, thereby providing continuous and safe operation. This would not, however, be possible if it were not backed by consolidated institutions and a highly qualified industry ensuring the application of advances in technology and operational practices. Details of these two main elements in the Spanish nuclear programme, institution and industry, are described hereinafter to share our experience with other countries to which this scheme could be translated.

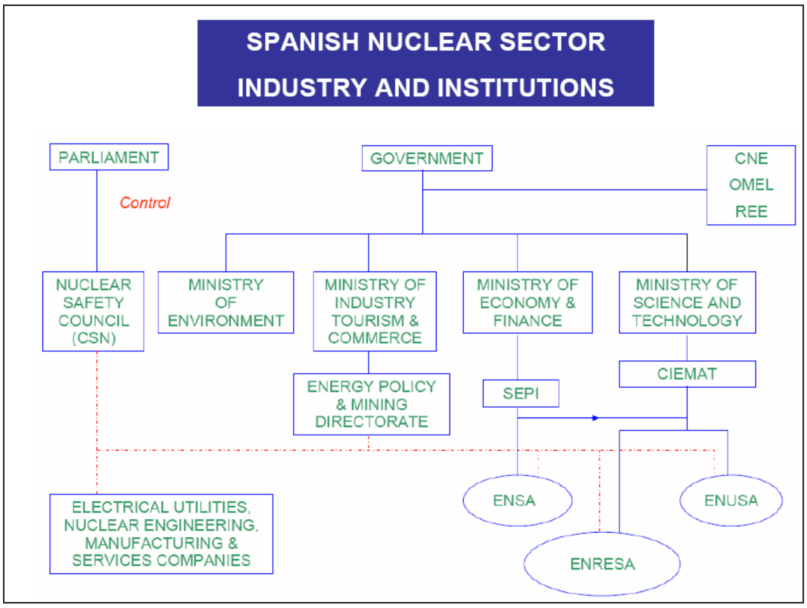






THE SPANISH NUCLEAR SECTOR: INSTITUTIONS AND INDUSTRY

The Spanish nuclear programme, begun in 1948, was based on the existing reactor technologies coming from France (gas cooled reactors) and the USA (light water reactors) at that time, and later on for Trillo (the last nuclear power plant installed), from Germany (light water reactors). Nevertheless, even though there was no concerted plan to create our own reactor technology, two important pillars were constructed to support the Spanish nuclear programme: firmly consolidated institutions and a strong industrial sector have together been key factors in the success of the Spanish nuclear programme. The following paragraphs outline the main characteristics and dimensions of this Spanish nuclear sector organized as shown in the figure below.



INSTITUTIONS

The nuclear programme in Spain has been supported from the very beginning by institutions both governmental and private. The first idea of having a nuclear research centre in Spain was in 1948 and was consolidated in 1951 as the Nuclear Energy Institute (JEN, today called CIEMAT) created to promote nuclear energy and supervise its implementation. In 1980 the Spanish Nuclear Council (CSN) was constituted as an independent organization in charge of controlling and regulating the conditions for the operation of the nuclear power plants and other radioactive installations. In 1984 the Spanish government created ENRESA, an agency for waste management. In 1985 REE, the operator of the high voltage grid, was constituted. The Spanish electrical market was deregulated in 1997 and in that same year the market operator OMEL was created to match the supply and demand for electricity.

Educational institutions soon followed step. Early after the start of nuclear activities, several universities and polytechnics in Spain created nuclear departments for students to start training in the nuclear field. Four experimental reactors were constructed, two of them located in the JEN research centres and two more at the Polytechnical Universities of Bilbao and Barcelona.

The private sector was also well organized from the very beginning. The utilities association UNESA, created in 1944, has been coordinating the activities of the nuclear sector since 1971 up to today. The Spanish Industrial Forum (Spanish Atomic Forum (FAE), now FORO) was created in 1962 and the Spanish Nuclear Society (SNE) in 1974.

All this means that Spain had the vision to support the nuclear programme with top level institutions from the government and from the private sector that, as shown in the diagram, has been linked in its contribution to the nuclear sector.

INDUSTRY

The Spanish nuclear industrial structure had its beginnings in the 1960s as a result of the decision to build the first nuclear power plants, José Cabrera in Zorita, Santa María de Garoña, and Vandellós I.

The Spanish government's decision was to build the nuclear facilities based on technologies developed abroad while also creating a strong and innovative domestic industry in the nuclear sector. Thus, gas cooled reactor technology from France was chosen for the Vandellós nuclear power plant, and light water reactors from the USA were chosen for the Zorita and Santa María de Garoña nuclear power plants. Meanwhile, the aforementioned institutions supported Spanish industrial development by fostering the creation of qualified jobs, knowing that advances in technology would contribute to the general improvement of the industry and grant greater independence from abroad in a strategic sector, especially considering the need for suitable technological services once the power plants were up and running.

The first three power plants, José Cabrera (Zorita), Santa María de Garoña and Vandellós I, were thus built mainly by foreign companies, though with the collaboration of Spanish industry in engineering, construction, erection, and equipment supply, particularly in the civil and electrical areas.

For the second group of nuclear power plants (Almaraz I&II, Ascó I&II, and Cofrentes) the system of contracting by components was adopted, and great strides were made in engineering firms as well as in equipment manufacturers and other industrial services that were created or whose methods were modernized. As an example, the table below shows the projects in which Empresarios Agrupados supports the engineering execution in six of them as the architect engineer.

The Spanish nuclear industry became consolidated during the construction of the third group of power plants: Vandellós II, Valdecaballeros[16] and Trillo. In addition to the architect engineer support, a factory was built to produce heavy equipment, including main primary components (RPV) and steam generators, facilities for mining and fuel manufacturing, as well as a considerable number of specialized services companies. The following illustrations list the main industrial organizations supporting the NNPs and their location in Spain.

[16] Valdecaballeros was cancelled before starting operation.

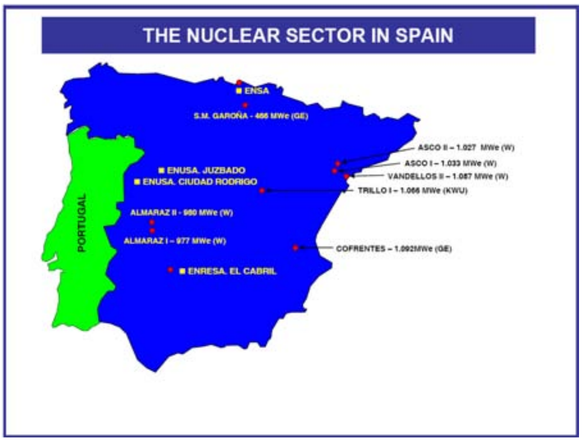
The decade of the 1980s was the time of maximum activity in the Spanish nuclear industry, providing jobs to more than 20 000 people, among them more than 5000 highly qualified technicians. In addition, some 20 000 more people were in indirect jobs in numerous companies supplying goods and services.

All this activity involved an important effort to assimilate technology and train technicians and specialists, resulting in a highly qualified nuclear power industry, highly expert operating teams, and very high degrees of national participation in the construction of the nuclear plants, leaping from a total participation of 43% in the first generation plants to 75% participation in the second generation and 85% in the third.

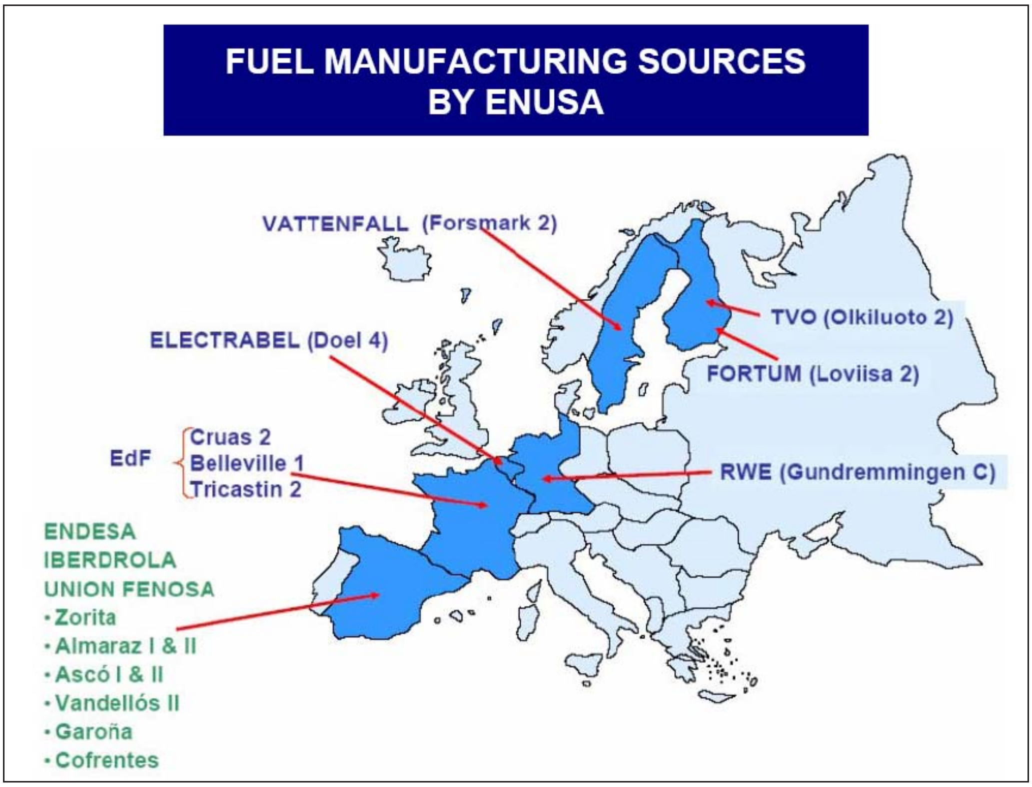
Once construction of the Spanish nuclear plants was finalized and it was decided not to continue building new nuclear power plants, the companies in the nuclear sector have continued their nuclear activities by supplying engineering services, fuel, and components to support the operation. Such activities include power up-rate, steam generator replacement, I&C modernization and several other areas with a relevant impact in the plant design.

MAIN COMPANIES IN THE NUCLEAR INDUSTRY

- Heavy components company: Equipos Nucleares - ENSA
- Fuel manufacture company: ENUSA
- Engineering Companies:
  - Tecnatom
  - Empresarios Agrupados
  - Iberinco
  - Initec
  - Soluziona
- Components Suppliers and Services



In addition to its involvement in the domestic market, the Spanish nuclear industry has successfully been able to enter the international market despite the difficulties caused by the nationalistic character of many of the countries hosting nuclear power plants. Noteworthy is the strong activity in specialized services provided to countries in Central and Eastern Europe through aid programmes from the EU. In the USA, the Advanced Reactors Program was launched in the 1990s, as well as in the ongoing DOE programme 2010, and in other international nuclear programmes such as GEN IV and INPRO. Examples of the international activity performed by Spanish companies in the nuclear sector are presented in the following paragraphs. ENUSA, as fuel manufacturer, has been available to supply the fuel to the Spanish nuclear power plant, but also to the European market, as is illustrated in the figure.



In engineering, one example is EMPRESARIOS AGRUPADOS that is participating actively in the development and construction of advanced reactors and utilities requirements through the EU framework programme or through their own contracts, as is shown in the following table.

In the area of equipment, manufacturers are also exporting components for replacement in the existing plants in operation and for installation in new power plants under construction, from steam generators to pressure vessels and containers, valves, piping, tubing, etc. The table below shows ENSA's activities in the domestic and international markets.

Nevertheless, some service companies have accounted for a lesser exposure abroad and consequently the size of the industry has adjusted itself to the new situation, and it may be estimated that in Spain there are currently more than 30 000 people employed in the nuclear sector.

This success of Spanish industry in the domestic and international market has been driven by continuous evolution to provide high quality services based on the best practices available at all times, while maintaining a competitive structure.

The excellence and reliability of the performance of the nuclear sector have set an example for other industrial sectors, which have benefited from the great leaps in technology made by the nuclear industry, and vice versa, other sectors have also opened up new areas of activity for the nuclear industry.

ENGINEERING SERVICES. ADVANCED REACTORS BY EMPRESARIOS AGRUPADOS

PWR Westinghouse		BWR General Electric	
AP-1000	Advanced PWR, Passive type, 1000 MW	ESBWR	Economic Simplified BWR, Passive type, 1550 MWe
AP-600	Advanced PWR, Passive type, 600 MW	ABWR	Advanced BWR, Evolutionary type,1350 MW
EPP	European Passive Plant	SBWR	Simplified BWR, Passive type,650 MWe
PBMR	Pebble Bed Modular Reactor	Lungmen	ABWR in Taiwan
UE 5th and 6th FrameWork Programmes and Generation IV		**EUR (European Utility Requirements)**	
V / HTR	High Temperature Reactor / HYDROGEN	EUR	
GCFR / LFR	Gas Cooled / Lead Fast Reactor		
ADS	Accelerator Driven System / Transmutation		

Being competitive and knowledgeable, the Spanish nuclear industry has responded well despite the pressure from the Spanish decision not to continue building nuclear power plants, and is fully prepared to continue providing high quality engineering services, components, fuel manufacturing, and operational services in the growing international market and in Spain just as the decision will change to build anew.

It can be concluded that Spain designed its nuclear programme based on a structured nuclear reactor, becoming a real motor for innovation and preparation of the industry with competences to success in the international market. The Spanish experience could be adopted by countries which would like to start a nuclear programme based on the reactor designs currently available from different vendors in the market but with the strategy of promoting industrial development in the country.

NUCLEAR STEAM SUPPLY SYSTEM (NSSS) COMPONENTS SUPPLIED BY ENSA

NUCLEAR POWER PLANT	VALDECABALL. 1/2	SAYAGO	TRILLO 1	VANDELLOS 2	LEMONIZ 1	TRILLO 2	INDIA	ISAR 2	GKN 2	ATUCHA 2	KONVOI	KAKRAPPAR	DÖEL-3	ASCO 1&2	ALMARAZ 1&2	QINSHAN-2	FRENCH PLANTS	OLKILUOTO UPPER	ALMARAZ 1/2	ZORITA	SHEARON HARRIS	SOUTH TEXAS 1	KORI	KRSKO	OSKARSHM UPPER	ASCO 1	ASCO II	ANO-2 (US)	FARLEY 1 & 2	SOUTH TEXAS 2	BEAVER VALLEY	COMANCHE PEAK	DIABLO CANYON	QINSHAN-2 (Phase 2)	SUMMARIZE	FROM WHICH					
																																			TOTAL:	COMPLETE	PARTIAL	HEADS	END PLATES	TOTAL EXPORT	COMPLETE EXPORT
RPV	2	1	1	1		1	4			1/C/P									2/C	1/C						1/C	1/C				1/C	1/C			18	6		8	4	7	4
SG`s		3/P	3	3	1	3					4/P	4	3	6	6	4	8/P				3/P	4/P	2/P	2				2	6	4	3	4	8	3p+1	86	62	24/P			58	40
Pressur.		1	1	1		1		1	1																										6	6				2	2
Internals		1	1	1/P		1												2/P							1/P										7	3	4/P			3	0
M Piping		1	1	1																															3	3				0	0
TYPE	BWR	PWR	PWR	PWR	PWR	PWR	PHWR	PWR	PWR	PHWR	PWR	PHWR	PWR	PWR'S	PWR'S	PWR	PWR	BWR	PWR	PWR	PWR	PWR	PWR	PWR	BWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR		TOTALS						
																																			120					70	46
Country	SPAIN	SPAIN	SPAIN	SPAIN	SPAIN	SPAIN	INDIA	GERMANY.	GERMANY.	ARGENTINA	GERMANY.	INDIA	BELGIUM	SPAIN	SPAIN	RPCHINA	FRANCE	FINALAND	SPAIN	SPAIN	US	US	KOREA	SLOVENIA	SWEEDEN.	SPAIN	SPAIN	US	US	US	US	US	US								
cancelled.	*	*			*	*																																			
year	1980	1981	1982	1983	1984	1984	1986	1987	1988	1988	1988	1988	1991	1995	1995	1998	1995	1996	1995	1997	1998	1999	1999	2000	2003	2004															

References in red are export contracts

P=Partial fabrication of the component.

C=vessel heads.

NOTA: or to be supplied in the near future.

NUCLEAR POWER INTRODUCTION: EXPERIENCES IN FINLAND

AMI RASTAS
Consultant, Finland

1. HISTORY OF THE NUCLEAR POWER PROGRAMME IN FINLAND

1.1. Initial considerations

In Finland, like in many other countries in the middle of the 1950s, nuclear power plants were considered to be a promising new energy source in the wake of the worldwide enthusiasm for peaceful use of nuclear energy. In 1955 the Government established an Energy Committee whose task was to make proposals for future energy sources in Finland. In addition to existing energy sources, special attention should be paid to the possible use of nuclear power.

The Energy Committee issued its comprehensive report in the autumn of 1956. Although the committee envisioned the application of nuclear power to actualize in Finland only later, it emphasized the importance of training and research in the nuclear field. The committee did not recommend establishing a nuclear research centre as had been done in other Nordic countries. However, the Committee regarded it to be necessary to purchase a research reactor as soon as possible. In line with the recommendation of the committee, a research reactor (Triga MK II) was commissioned in 1962 at the Helsinki University of Technology. Before that, some neutron physical experiments were done in a sub-critical pile in the same university.

An atomic energy law went into effect in 1958. It prescribed needed licences for handling and trade of nuclear materials as well as for construction and operation of nuclear facilities. It also included legal provisions for an Atomic Energy Council whose duty was to follow nuclear development worldwide, to plan nuclear training, to keep contact to foreign nuclear organizations and to make initiatives in the nuclear field.

in 1961 the Atomic Energy Council initiated, together with IAEA, a study on Prospects of Atomic Energy in Finland. The main result of the study was that nuclear power is technically and economically feasible only if annual electricity consumption is more than 16 TW·h, preferably in the range of 20 TW·h. According to the prospects that situation would prevail in Finland at the earliest the end of the 1960s or in the beginning of the 1970s. However, preparations for nuclear power utilization were continued without any interruption, e.g. legislation was improved and training activities were enhanced domestically and abroad. Also, a regulatory body, established in 1958, elaborated its organization and expertise.

In 1964 the state owned power company, Imatran Voima Oy (IVO), launched a feasibility study on the construction of a 275 MW(e) heavy water reactor (CANDU type) in Finland. The Finnish manufacturing industry also participated in the study. A comprehensive feasibility report, including technical specifications for the plant, was issued in 1965.

To find out the competitiveness of various reactor types, IVO in 1965 sent bid invitations to eleven vendor companies. Bids based on a turnkey delivery model were received from nine western companies before the end of 1965. During the bid evaluation the Soviet Union declared its willingness to construct a nuclear power plant in Finland and later submitted a bid. IVO short listed three vendor candidates for more detailed bid negotiations. The reactor types were a BWR from the Federal Republic of Germany, a PWR from the USA and a heavy water reactor from Canada. The BWR and the PWR were selected for the final round. At this stage foreign policy interfered in the plant purchase. The Government intervened and the bidding round was stopped in the spring of 1967.

The second set of bids was received by IVO in the spring of 1968: a BWR from Sweden, a steam generating heavy water reactor (SGHWR) from the UK and a PWR (WWER) from the Soviet Union. Also this bidding round was halted by the Government in summer 1968.

1.2. Loviisa 1 and 2 projects

In summer 1969 the Government made a decision to start negotiations with the Soviet Union on a nuclear power plant supply. As a result of the negotiations, in September 1969 IVO and V/O Technopromexport from the Soviet Union signed a preliminary contract on a WWER plant unit (LO1) having an output of 440 MW(e) to be constructed at the Loviisa site.

The civil construction work of the LO1 unit was started in November 1970. The unit commenced commercial operation in May 1977, about two years behind the original schedule. In August 1971 IVO and V/O Technopromexport signed a delivery contract on an identical WWER unit (LO2) to be constructed at the Loviisa site. The LO2 unit entered into commercial operation in January 1981, about two years behind the original schedule.

1.3. Olkiluoto 1 and 2 projects

Parallel with IVO's efforts, private industry was also active in starting a nuclear power plant project. In 1956 a group of private companies established an organization called Power Association Nuclear. Its function was to promote the peaceful use of nuclear energy by following the development and experiences, as well as by arranging training in the nuclear field. Later this cooperation between industrial companies took on more concrete forms.

Sixteen industrial companies, representing mainly the pulp and paper industry, established a new company, Teollisuuden Voima Oy (TVO) in 1969. Its business was to construct power plants and power transmission systems, as well as to generate electricity to its owners.

Olkiluoto was selected to be a site for TVO’s nuclear power plant. Due to the experiences from IVO’s complicated plant selection process, TVO decided not to go to an open bidding process. The main criteria for a new plant were the size range of 600 MW(e) and the proven light water reactor (LWR) design. In the final phase there were two BWR candidates and one PWR candidate from western vendor companies.

At the end of 1972 TVO selected Asea-Atom from Sweden to be the supplier of a BWR plant unit (OL1), having an output of 660 MW(e). The final turnkey delivery contract was signed in summer 1973. Construction started at the beginning of 1974. The plant unit was commissioned in 1979, about 14 months behind the original schedule. The main reasons for the delay were the strikes of civil construction workers, a major fire in the reactor building and the technical problems in the generator.

The OL1 delivery contract included an option for another identical unit. The final delivery contract of the second unit (OL2) was signed 1975. Contrary to the OL1 contract, civil construction works were under TVO’s responsibility. The OL2 unit was commissioned in 1981, more than one year later than originally scheduled. The delay was caused mainly by technical problems in the generator.

1.4. Operational results of the existing nuclear power plant units

The operation of the existing Loviisa and Olkiluoto units has been successful. The lifetime load factors until the end of 2006 have been 87.0% and 92.6% in average for the Loviisa units and for the Olkiluoto units, respectively. All units were extensively modernized in the 1990s. The main goals of the modernization programmes were safety enhancement, power uprating and lifetime extension. The net outputs of the Loviisa units and the Olkiluoto units are now 488 MW(e) and 860 MW(e), respectively. This means a power uprate of 9% in case of Loviisa and 30% in case of Olkiluoto compared to the original outputs.

1.5. Failed attempts for the fifth nuclear power plant unit

There have been several attempts to start constructing a new nuclear power plant unit after the commissioning of the existing ones. These efforts have been made in cooperation between IVO and TVO. In 1982, IVO and TVO signed a contract on cooperation in the construction of 1000 MW(e) of nuclear capacity. In the framework of that contract IVO and TVO investigated some PWR and BWR concepts, respectively. The cooperation led to the formation of a new company, Perusvoima Oy (PEVO), owned by IVO and TVO on a fifty–fifty basis.

In the beginning of 1986 PEVO sent the Government an application for a decision in principle concerning the construction of 1000 MW(e) of LWR capacity, as one or two units. Both existing nuclear sites, Loviisa and Olkiluoto, were presented as alternative locations. The main argument in the application was an increasing demand of base power capacity in the country. The forest industry in the beginning of 1986 needed, for its own investment decisions, an assurance that there would be available economic electricity in the future. The application was withdrawn a couple of months after the Chernobyl accident in 1986.

The second attempt was made in the early 1990s. IVO and TVO sent the Government a joint application for a decision in principle in 1991. According to the application, if a PWR unit were to be chosen, its owner would be IVO and its site would be Loviisa. Respectively, a BWR unit would be owned by TVO and its site would be Olkiluoto. Simultaneously, bids were invited from several LWR vendor companies. Bids were received in the autumn of 1991 and technically evaluated after that. The Government made a positive decision in principle in the beginning of 1993. However, the negative result of the Parliamentary vote on the ratification of the decision in principle ended the effort in the autumn of 1993.

1.6. Olkiluoto 3 project

The third attempt led to the construction start of the fifth nuclear power plant unit (FIN5) in Finland. According to the energy strategy report issued by the Government and accepted by Parliament in 1997, preparations should be made for the option that the construction of additional nuclear power will become topical. Encouraged by this statement, TVO initiated a study programme in 1998. It consisted of among other things an environmental impact assessment (EIA) for the Olkiluoto site and feasibility studies for six LWR designs (three BWRs and three PWRs). Fortum (previously IVO) simultaneously carried out an EIA for the Loviisa site.

Fortum and TVO agreed in 1999 that TVO would be the owner/operator of the FIN5 unit and would be responsible for all related activities. It was also agreed that both existing nuclear sites, Loviisa and Olkiluoto, would be the optional locations for the unit.

Based on the positive results of the study programme, TVO submitted in November 2000 to the Government an application for a decision in principle on the construction of a 1000–1600 MW(e) LWR unit at the Loviisa or Olkiluoto site. In connection with the decision in principle, the Government decides whether the construction of the nuclear facility is in accordance with the overall good of the society. If the decision is positive it needs the ratification of Parliament.

After an extensive procedure involving statements from numerous organizations, the Government made a positive decision in principle in January 2002.

During the spring of 2002 the Government decision was extensively debated in Parliament. The result of the decisive Parliamentary vote in May 2002 was in favour of ratification.

TVO issued the bid inquiry specifications for a new nuclear power plant unit in September 2002. Bids were received from several supplier candidates in March 2003. In October 2003 TVO selected Olkiluoto to be the site of the new unit. In December 2003 TVO signed a turnkey delivery contract with the consortium formed by Framatome ANP (now Areva NP) and Siemens. The unit will have an output of about 1600 MW(e). The reactor design is based on the Areva NP's EPR type and the turbine is of Siemens technology.

TVO filed an application for the Olkiluoto 3 construction licence in January 2004. The Government granted the construction licence in February 2005. The 'first concrete' took place in August 2005. According to the delivery contract plant commissioning was to take place in 2009. However it will be delayed by more than two years.

1.7. Future expansion of nuclear capacity

In the spring of 2007 TVO launched an EIA for the fourth LWR unit (1000–1800 MW(e)) at the Olkiluoto site. TVO filed the application of the decision in principle for that unit in the spring of 2008. Simultaneously, Fortum was finalizing an EIA for the third LWR unit (1000–1800 MW(e)) at the Loviisa site. The commercial operation of TVO's and Fortum's new units is planned to be started around 2018–2020.

Fennovoima Oy, a new company established in 2007, is conducting EIAs for four green field sites in Finland. Fennovoima's intention is to construct a nuclear capacity of 1500–2500 MW(e) (one or two units) so that the commercial operation can be started in 2018–2020.

2. MAIN REASONS TO INTRODUCE AND EXPAND NUCLEAR POWER IN FINLAND

Annual energy consumption per capita in Finland is one of the highest in the Western countries. It is attributable to the energy intensive structure of industry, high standard of living, cold climate and long distances. Concurrently the proportion of indigenous energy sources is low and hence, energy and its price and efficient use are more significant issues than in most other countries.

The share of electricity of all energy consumed in Finland is exceptionally high. Industry's share is more than half of total consumption of electricity. For industry, electricity is an important production factor, especially in many Finnish forest industry export products . The large share of industrial consumption maintains a high demand for the base load power. Therefore it is natural that nuclear power has been considered as a viable source of electricity.

Demand of additional electricity generating capacity as well as the competitive and predictable electricity price of nuclear generation were the main arguments for the construction of the current nuclear power plants in the 1970s in Finland. In addition to those arguments, replacement of the aging power plants, greenhouse gas free generation in order to fulfil Finland's Kyoto commitment and domestic generation in order to reduce electricity imports were important reasons for the current construction of the OL3 unit. The last reason was emphasized by the development of the Nordic electricity market situation. It indicates that the possibility of importing electricity from other Nordic countries will decline significantly in the future.

The same arguments as in the case of the OL3 unit are still valid and even strengthened for additional nuclear capacity in Finland.

3. MAIN CONSIDERATIONS ON REACTOR TYPE AND SIZE

In the first considerations to launch a nuclear programme, technical evaluations were made for light water reactor types (BWR and PWR), as well as heavy water moderated reactor types (CANDU and SGHWR). The reactor type of the LO1 and LO2 units was selected based mainly on criteria established by foreign policy. However, it was a definite requirement from the Finnish side that the LO1 and LO2 units must fulfil the Finnish safety requirements based on western safety principles. This led to difficult negotiations with the supplier. The outcome was that the scope of the Soviet supply was limited to the reactor primary circuit and the turbine plant with auxiliary systems. Examples from other deliveries are I&C systems from the Federal Republic of Germany and the ice containment from the USA. Surprisingly, the mixture of political and technical criteria has proved to be successful. The LO1 and LO2 units have had an excellent operational record.

The selection of the reactor type for the OL1 and OL2 units was made mainly on technical bases although the final choice was also in conformance with the prevailing foreign policy to keep a balance in relations to the neighbouring countries. Only BWR and PWR types were considered. Although operating experience was set to be one of the main evaluation criteria the selected plant type, a Swedish BWR, included several advanced and unproven design features such as internal main circulation pumps, fine motion control rod drives, four train safety systems and forest industry prestressed concrete containment with embedded steel liner. Those design features have turned out to be very beneficial and have contributed to the good operational results of the OL1 and OL2 units. Only one novel design feature, a totally water cooled generator, caused some problems during the commissioning phase.

In the case of the FIN5 unit only bids based on BWR or PWR designs were invited. This limitation was a natural choice, taking into account good operational experiences of those types and the existing infrastructure in the country. New designs, e.g. passive light water reactor designs, were not excluded when the bids were requested. Bids were invited for both sites, Loviisa and Olkiluoto. The following general criteria were established at the beginning of the preparation of the bid inquiry specifications (BIS):

(a) The nuclear power plant unit shall be economically competitive;
(b) The design must be safe and licensable;
(c) The project schedule must be adapted to the new generating capacity demand;
(d) The plant size shall be compatible with the grid;
(e) Possible additional units shall be taken into account in the location and implementation of the unit;

(f) The existing infrastructure at the site shall be utilized as much as possible;
(g) The failure risk of the project shall be as low as possible.

The European Utility Requirements (EUR) document was used as a reference when compiling more detailed technical requirements included in the BIS. While the EUR defines the requirements for a European standard nuclear power plant, the BIS for a Finnish nuclear power plant unit had to be adapted to the local conditions and the Finnish licensing requirements. This required several modifications to the EUR text. Also, the experiences gained while operating the existing nuclear power plant units were considered. Examples of the specific requirements are listed below:

(1) General technical lifetime applied in the design of major plant components at least 30 years, however, for components difficult to be replaced at least 60 years;
(2) Plant cooling based on seawater;
(3) High and low seawater levels;
(4) Blockage of the cooling water intakes;
(5) Severe weather conditions, such as air and seawater temperatures, wind, snow and ice;
(6) External events including passenger airplane crash and electromagnetic interaction;
(7) Grid requirements;
(8) Availability target and durations of refueling/maintenance outages;
(9) Daily and weekly load cycling;
(10) Special operating cases such as house load operation and turbine trip without reactor scram;
(11) Fuel cycle flexibility, such as cycle length until two years, use and storage of MOX fuel and storage capacities of fresh and used fuel;
(12) Limits for occupational doses and releases of radioactive materials.

The objective was to make the BIS as generic as possible, which meant that concept-specific adaptations were kept to the minimum. On the other hand, the BIS provided the bidders the liberty to select such plant and delivery alternatives that they considered most competitive. They were allowed to present bids for the turnkey delivery of a complete plant, for the delivery of a nuclear island only or for the delivery of a turbine island only. Civil construction works could also be excluded from the delivery as an option. In all cases, the responsibility for coordinating the supplies as well as functionality and licensability of the complete plant would belong to the nuclear island supplier.

Bids representing all the categories described above were received. Bid evaluation criteria were purely technical and economical. They were related to technical characteristics, safety and reliability, economic aspects, contractual conditions as well as the bidder's references and experience. Political aspects, counter trades, etc. did not play any role in the evaluation. Crucial criteria affecting the choice were connected to the electricity generating cost.

Identical reference plants and proven design are generally emphasized in the reactor type selection. However, strict adherence to this would stop the development of nuclear power plant technology. Finnish experience shows that new advanced design features can also lead to good operational results.

The unit size of the Finnish nuclear power plant units has always been in the order of ten per cent of the total installed generating capacity in the country at the moment of commissioning. Both existing plants, Loviisa and Olkiluoto, consist of two identical plant units. Those two units were commissioned within about two years of one another. The time interval was utilized for optimization of the use of labour at the site during the construction. In addition, the interval also helped to accommodate new generating capacity to the ascending demand curve in a smooth way. In the case of the OL3, the big unit size was advocated by the great demand for new generating capacity and the economies of scale.

4. MAIN CONSIDERATIONS ON SITE SELECTION

Site investigations were carried out at almost 20 locations in Finland in the late 1960s. Main criteria for site selection have been good cooling water conditions, the proximity to the electricity consumption clusters and demography. Geology and seismology are of less importance. Bedrock conditions are good almost everywhere in the country. Finland is situated in a low seismic area. Both existing sites, Loviisa and Olkiluoto, benefit from cold sea water for direct cooling of turbine condensers. There are no major population centres in the vicinity of the sites.

Only the existing nuclear sites were considered for the location of the FIN5 unit. They were in a largely equal position in the site selection process. Both sites had extensive infrastructure available for an additional unit. A broad majority of the local population was in favour for the project at both sites. There was even strong competition between two alternative municipalities to get the project to their own territory. One argument speaking for the selection of the Olkiluoto site was that the used fuel repository is being constructed at that site. There is also a shipping route and a pier that makes possible the direct sea transport of heavy components to the site.

5. LOCALIZATION EFFORTS AND EXPERIENCE TRANSFER FROM SUPPLIER COUNTRY

Connected to the construction of the existing nuclear power plant units there were serious efforts to localize component deliveries to Finland. The Finnish manufacturing industry formed a dedicated organization, Finnatom Oy, for that purpose. The efforts were successful. The main circulation pumps and plant computer systems for the Loviisa units and reactor internals for the Olkiluoto units, as well as fuel transfer machines, are examples of nuclear grade deliveries.

IVO was responsible for a large part of the LO1 and LO2 design work. IVO carried out layout, architectural and civil design as well as design of electrical and I&C systems in cooperation with Finnish and foreign consulting companies. IVO also took care of scheduling, cost control and quality assurance activities of the project.

In spite of the turnkey (OL1) and semi-turnkey (OL2) delivery model, the Finnish manufacturing industry participated as sub-suppliers in the Olkiluoto construction projects also. For instance, the share of domestic deliveries in the OL2 project was about 60%.

The Finnish industry also received some orders from Swedish nuclear power plant units in the 1970s. After that, due to a long period without any nuclear construction, the Finnish industry lost interest in maintaining the capability for nuclear grade manufacturing. This has become apparent in connection with the OL3 project. The share of the Finnish components may be smaller than expected.

It is worth recognizing that the European Commission competition directives forbids giving any preference to domestic suppliers. All European Union companies must betreated equally.

The delivery contracts of the Finnish nuclear power plant units do not include formal arrangements regarding technology transfer from supplier countries. In the case of the existing Olkiluoto units there are long term service contracts with the plant supplier, as well as the suppliers of the main components.

6. LESSONS LEARNED AND SUGGESTIONS

6.1. Initial decision making process

The start of a nuclear power plant project involves several interrelated activities and liabilities of long duration. Therefore, it is natural that political decisions are needed. A challenge is to separate politics from the technical decision making. In connection with the reform of Finnish nuclear legislation in the late 1980s a new licensing step, the decision in principle, was introduced. It has to be applied prior to any investment in the nuclear power plant project. In connection with the decision in principle, the Government decides whether the project is in accordance with the overall good of society. If the Government decision is positive, it has to be ratified by Parliament.

It is exceptional for parliaments to be required to handle a single investment project. It has advantages and disadvantages. A disadvantage is that it can be difficult to gain acceptance from Parliament. A significant advantage is that the parliamentary acceptance in an early phase of the project makes it possible to concentrate on project implementation without further political involvement. Finland has experienced both, advantages and disadvantages. In the early 1990s the negative result of a parliamentary vote stopped the attempt to start the nuclear power plant project. Ten year later the positive result of a parliamentary vote stopped the political debate on the necessity of the fifth nuclear power plant unit.

6.2. Well defined responsibilities

The initiation of a nuclear power plant project is a complex process. Therefore it is important that there is a single organization dedicated to lead the process. In the very early phases of the Finnish nuclear programme there were some uncertainties related to the roles of the utility and Governmental organizations.

The failed attempts to start a nuclear power plant project the late 1980s and early 1990s were made in cooperation between two utilities, IVO and TVO, which shared equal power in all decision making. Occasionally it was difficult to reach unanimity due to the divergent company cultures. In the case of the latest and successful attempt leading to the OL3 construction, all related activities, including public communications, were concentrated in one utility, TVO. It contributed to the systematic progress during the preparatory phases of the project.

6.3. Proper company model

A nuclear power plant project is a huge investment and includes economic risks. The bylaws of the owner/operator utility must be enacted to cope with those risks and long term liabilities. In many countries it is arranged so that the utility responsible for nuclear power plant construction and operation is a state owned company. TVO is an example of a different approach. TVO is owned by several Finnish industrial and public companies. All electricity produced by TVO is supplied at cost to the owner companies for their own use or for further distribution. They are entitled to electricity produced by TVO in proportion to how many TVO shares they own. They are also committed to paying TVO's annual fixed cost in the same proportion, regardless of whether they take electricity from TVO or not. The variable cost of the electricity is covered by the owner companies in proportion to the electricity they take from TVO.

According to the TVO company model the economic risk of TVO's owner companies is restricted to their ownership shares.

TVO's company model has been trusted by financial organizations as well. TVO has had no difficulties in arranging financing for the OL3 project from banks and financial institutions without any Government or shareholder guarantees. There are no government subsidies either.

6.4. Proper waste management programme

The nuclear waste management issue was recognized but not of major importance during the initial decision making process of the existing nuclear power plant units in Finland. It had a more important role in the operating licence phase. For instance, the Government granted only a three year licence for the first operating licence for the OL1 unit because TVO had no contract for the reprocessing of spent fuel. There were no corresponding problems in the case of the Loviisa units because spent fuel was transported back to the supplier country, the former Soviet Union.

TVO selected the direct disposal approach for spent fuel and started an extensive programme for that purpose in the early 1980s. IVO (now Fortum) joined the programme in the middle of the 1990s and a dedicated company, Posiva Oy, was established. It is owned by TVO (60%) and Fortum (40%). Posiva's task is to dispose of the spent fuel of the owner companies and carry out all related activities. The Government made and Parliament ratified a decision in principle regarding the construction of the used fuel repository at the Olkiluoto site. The excavation of the investigation tunnel and shaft was started in 2004. The disposal of spent fuel will commence in 2020.

Both nuclear power plant sites, Loviisa and Olkiluoto, have repositories excavated in the bedrock for low and medium level waste. There is also a funding arrangement based on the principle that after a 25 year period the amount of funded money has to be sufficient to cover all future waste management costs, including decommissioning, if the operation of a nuclear power plant unit were to be stopped now. The cost is recalculated every year and the amount of money in the fund is adjusted accordingly by the utilities.

Experience shows that obtaining public and political acceptance for a new nuclear power plant unit would be very difficult without advanced waste management and funding arrangements. It can be said with certainty that the positive decision in principle for the OL3 unit would not be possible without a preceding decision in principle for the used fuel repository.

6.5. Outside expertise

Several nuclear power plant vendors have merged with other companies and are no longer offering their earlier designs. This is the situation regarding the supplier of the OL1 and OL2 units. Some component manufacturers have also disappeared or ceased to offer nuclear grade components. Many research organizations have drastically reduced activities related to nuclear science and technology.

This declining overall trend especially affects organizations like TVO which is used to relying on outside services. An obvious remedy would be to strengthen its own capabilities. However, it is impossible to gather to a company like TVO all the expertise and knowledge needed for successful construction and operation of nuclear plants. Anyway, technical support services from outside are needed. TVO's main tool is long term contracts with companies providing services. TVO has agreements with tens of companies, including nuclear power plant vendors, component manufacturers, maintenance companies, inspection companies and consulting organizations. There is quite a large variation in the scope of agreements. Some of them are only frame contracts for tasks to be specified in detail when the need arises.

6.6. Harmonization of safety requirements

Harmonization of the regulatory requirements has been a long lasting goal worldwide. However, only the basic safety principles can be regarded as common for the moment. The more detailed safety requirements still differ considerably between countries. This problem has been encountered in all Finnish nuclear power plant projects. For instance, none of the original plant types offered for the OL3 plant unit met all Finnish requirements. A lot of modifications had to be incorporated into the original designs. In this respect the feasibility studies, before entering the bidding stage, had a very significant role. One of the most important goals of those studies was to find out the necessary design modifications in such a way that the supplier candidates were able to take them into account in their bids.

6.7. Negative nuclear events

The progress of nuclear power plant projects is very vulnerable to negative events in the nuclear field worldwide. For instance, the Chernobyl accident in 1986 halted the well advanced preparations for a new nuclear power plant unit in Finland. Also, events outside the nuclear field can have an impact. When the handling of the decision in principle application for the OL3 unit was in the most sensitive phase in 2001, the September 11 terrorist act occurred in the USA. The question was immediately raised as to what the consequences could be if the target were to be a nuclear power plant unit. The only possibility to cope with the situation was to revise the requirements on external impacts so that the nuclear power plant unit can also resist the crash of a big passenger airplane without severe consequences to the environment. Those revised requirements were included in the bid inquire specifications for the OL3 unit.

A severe nuclear accident somewhere in the world is one of the biggest risks for the initial decision making, implementation and even operation of a nuclear power plant. It is not easy to be fully protected against the negative impact of those events. One way to decrease that risk is to apply the most modern safety requirements in the design. An example is the requirement to take severe accidents into account in the nuclear power plant design. Another example is to apply passive and inherent design features as much as possible.

6.8. Readiness of detailed design

The construction time is of importance in the competition between nuclear power plant alternatives. The readiness of a detailed design at the construction start has to be high enough in order to achieve a short construction time. A trustworthy schedule for the remaining part of detailed design is also necessary. Those things have to be checked carefully before entering into the delivery contract. In a competitive situation a bidder may give an overly optimistic impression of the actual situation, especially in the case of a first of a kind design.

7. CONCLUSIONS

There were some indisputable facts and arguments that made the start of the nuclear power plant projects attractive in Finland in the 1970s. The implementation of the projects was a challenge for a small country like Finland. The projects were delayed somewhat but not as much as in some other countries. The Finnish nuclear power plant units have had an excellent operating record regarding safety and economics. The successful modernization projects of the units and the firm waste management programme reinforced the general confidence in the nuclear industry. It paved the way for the start of construction of a new unit after a long period without any nuclear power plant projects in Western countries. Additional nuclear power and the increasing use of renewable energy sources are regarded as the best options for the new electricity production capacity in Finland. The strategy based on these options simultaneously takes into account environmental protection, climate policy, economics and security of supply.

REPORT ON JAPAN'S NUCLEAR INTRODUCTION EXPERIENCE

MINISTRY OF ECONOMY, TRADE AND INDUSTRY
Japan

1. BRIEF HISTORY AND CURRENT SITUATION OF NUCLEAR POWER PLANTS

In the aftermath of World War II, Japan's electric power generation infrastructure was in a desperate condition. As the post-war economic recovery got under way, spurring demand for electricity, there was an urgent need to establish large power plants. In view of the country's paucity of natural resources, Japan promoted large scale development of hydroelectric power generation, but this was incapable of satisfying the demand for electricity. Therefore, Japan initiated a study with a view to introducing commercial nuclear power in step with the international trend toward the peaceful use of nuclear power. As a result of the study, it was decided to select the gas cooled reactor (GCR) using natural uranium fuel from the United Kingdom. This decision was based on accumulated experience of GCR operation and the fact that it was relatively easy to procure natural uranium fuel compared with enriched uranium fuel at that time. The start of operation of the GCR reactor (166 MW(e)) of the Tokai power plant unit 1 in 1966 signalled the dawn of the era of commercial nuclear power in Japan.

At about the same time, the light water reactor (LWR) with low enriched uranium fuel was commercialized in the USA. It was decided that the second reactor to be imported would be the LWR because it had become possible to procure low enriched uranium and there was a prospect of scaling up plants in the future with relative ease. Following the second reactor, the LWR, the boiling water reactor (BWR) and the pressurized water reactor (PWR) introduced from the USA started operation around 1970.

Reflecting the fact that nuclear power generation in Japan started shortly after its commercialization in various other advanced countries, there were cases in which nuclear power plants in Japan experienced a decline in their availability factors due to unknown problems and the workers dealing with these problems were exposed to high doses of radiation. From this experience, the importance of ensuring stable operation by improving the existing LWR was recognized. In these circumstances, the first LWR improvement and standardization programme was launched in 1975 for the purpose of achieving enhancement of reliability and a high availability factor and radiation dose reduction for workers, utilizing domestic technologies capitalizing on the experience of LWR construction, operation and maintenance. The results of the improvement and standardization programme were applied to the nuclear power plants that started operation from the 1980s onward. These reactors are still operating well.

The objectives of the third improvement and standardization programme, launched in 1981, were long operating cycle, further improvement of core performance, compact plant and reduction of the construction period. The programme also envisaged development of the advanced boiling water reactor (ABWR) and the advanced pressurized water reactor (APWR). The world's first ABWR started operation in Japan in 1996, and four units of ABWR are in operation as of 2007. Regarding the APWR, the review process regarding the granting of an installation licence is currently under way and it is envisaged that the first unit will start operation around 2016.

As of 2007, 55 LWR units are in operation in Japan. The first imported GCR using natural uranium fuel contributed to the development of nuclear power generation technology and the cultivation of human resources. The GCR, having demonstrated the commercial use of nuclear power, was shut down in 1998. The decommissioning and waste treatment for the GCR, which are under way, will be used to establish the technologies and procedures for future LWR decommissioning and waste treatment.

2. MAIN REASONS FOR THE DECISION TO INTRODUCE NUCLEAR POWER AND TO EXPAND NUCLEAR POWER GENERATION

Given Japan's paucity of domestic energy resources, the country is largely dependent on imports. As electricity demand increased dramatically in line with the post-war economic boom, how to satisfy that demand emerged as an important issue.

In these circumstances, the Atomic Energy Basic Law and the Law of Establishing Atomic Energy Commission of Japan covering the peaceful use of atomic energy came into force in 1955. The Atomic Energy Basic Law embodies three principles governing the peaceful use of atomic energy, namely disclosure, democracy and autonomy. The Atomic Energy Commission was established to formulate policies to promote the peaceful use of atomic energy. The Law Concerning the Regulation of Nuclear Material Substances, Nuclear Fuel Material Substances and Nuclear Reactors came into force in 1957.

The technological feasibility of nuclear power had already been confirmed in various advanced countries by the time Japan decided to introduce nuclear power. Also, the prospect that nuclear power would become economically competitive vis-à-vis fossil fuel fired plants in the near future had become evident.

Therefore, positioning nuclear power as a major energy source for the future, Japan decided on the early introduction of nuclear power, targeting future localization of nuclear technologies through the accumulation of experience in design, construction and operation. The goal of the use of nuclear energy was articulated in the Long-Term Program for Research, Development and Utilization of Nuclear Energy, which was issued by the Atomic Energy Commission in September 1956. In the Long-Term Program, it is stated that: "Research, development and utilization of nuclear energy will not only lead to solutions of Japan's energy supply-demand problems, but also enable rapid development of the industry as well as progress of science and contribute to the welfare of the nation. Therefore, swift commercialization of nuclear energy should be targeted, in particular, domestic manufacturing of the reactor most suitable for the situation in Japan."

The Japan Atomic Power Company, which was established in 1957 to introduce nuclear power to the country, installed the graphite moderated, carbon dioxide gas reactor at the Tokai power plant, and then the BWR at Tsuruga power plant unit 1. Next, the Kansai Electric Power Company was the first electric power utility company to install a reactor, namely, the PWR at Mihama power plant unit 1. Subsequently, Japan promoted nuclear power step by step.

Japan had accumulated experience in the operation of nuclear power plants by the time the oil shocks occurred in the mid-1970s. As Japan depended on oil imports for about 70% of its energy source at that time, the Japanese economy was seriously affected. In light of this experience, a decision was taken to increase the proportion of total electric power generation contributed by nuclear power in order to reduce dependence on oil imports. To accomplish this, Japan launched its third improvement and standardization programme with the objective of harnessing the experience and technological expertise accumulated in the country.

3. MAJOR CONSIDERATIONS REGARDING THE INTRODUCTION OF NUCLEAR POWER, INCLUDING DECISIONS ON REACTOR TYPE, SIZE AND SITE SELECTION

3.1. Major considerations regarding the selection of reactor type

The first reactor Japan introduced was the GCR from the United Kingdom. Next, the LWR using low enriched uranium fuel was introduced from the USA and all subsequent reactors have been LWRs. With a view to accelerating the promotion of nuclear power, the major criteria in the selection of the reactor type were safety, economy, and the trend of nuclear development in advanced countries.

At that time the choice of reactor type for commercial use was limited to GCRs and LWRs. In Japan, a team of experts investigated and evaluated these reactors. It was concluded that there was no significant difference in terms of safety and economy. However, the GCR was already in operation in the United Kingdom and the results were good, whereas the LWR was still under construction in the USA, and, therefore lacked a record of commercial operation.

There was an opinion that the decision should be postponed until the operating results of the LWR in the USA could be confirmed. However, since Japan had an urgent need to introduce nuclear energy to cope with the rapid increase in energy demand, and considering that Japan was already trailing other advanced countries in the development of nuclear technology, it was decided that the GCR, for which operating experience existed, would be the first reactor to be introduced.

Later, in view of the start of operation of the LWR in the USA and its compactness and low construction costs compared with the GCR, as well as its potential for improvement and scale-up, the LWR was selected as the second reactor type to be introduced; the BWR and PWR were introduced from the USA.

Thus, major criteria in selection of reactor types for Japan were (a) operating experience, (b) safety features, (c) economic aspects, and (d) future potential for scale-up.

3.2. Major considerations regarding reactor output

In Japan the major consideration in determining reactor output concerned the requirements of the power distribution network, such as future electricity demand (especially minimum required load), network capacity and margin ratio.

Since the construction cost of a nuclear power plant exceeds that of other types of power plant, greater cost reduction effects can be achieved by scaling up the capacity. Therefore, it is preferable for the output of a nuclear power plant to be as large as the constraints of the power distribution network will allow. On the other hand, if the output of a nuclear power plant exceeds the minimum required load of the power distribution network, it is necessary to lower the output of the nuclear power plant, resulting in a lower availability factor and deterioration of economic performance.

At the time of Japan's introduction of nuclear power, other advanced countries were also at the initial stage of utilizing nuclear power, and therefore the output of a power plant available for introduction was not large and could be accommodated by the power distribution network. So, a nuclear power plant with the maximum available output was selected.

Nowadays, considering the availability of large nuclear power plants with outputs exceeding 1 GW(e), it is important to select the largest possible output within the constraints of the power distribution network, such as the minimum required load, scale and margin ratio.

3.3. Major considerations regarding site selection

The following issues were considered regarding site selection when nuclear power was introduced in Japan: Geological condition;

(a) Cooling and other water requirements;
(b) Distance from the location of demand;
(c) Feasibility of acquiring the necessary land;
(d) Safety related issues such as the possibility of earthquakes and tsunamis;
(e) Evaluation of public dose level in the case of an accident.

In particular, since earthquakes occur frequently in Japan, the evaluation of the possibility of a major earthquake and its impact on the geology were thoroughly investigated.

Aside from the above-mentioned technological and economic considerations, it was also necessary to consider whether or not it would be possible to achieve a public consensus, encompassing local government and local residents, in favour of accepting the siting of a nuclear power plant in the locality. This point remains a major consideration in site selection since suitable sites in Japan with the necessary availability of cooling water are located on the coast where industry is concentrated, the population is dense and commercial fishing is active. In addition, when introducing the first reactor in Japan, which is the only country to have experienced atomic bombing, a site adjacent to the national nuclear research laboratory was selected in order to facilitate achievement of the necessary consensus with local residents.

4. LOCALIZATION EFFORTS AND EXPERIENCE OF TRANSFER FROM ABROAD

In Japan, positioning nuclear power as a major energy source for the future, localization was emphasized based on the experience gained through plant construction and plant operation in the course of introducing nuclear power to Japan.

In order to achieve the above objectives the following conditions were thoroughly considered when selecting a foreign supplier and a contract was concluded with a supplier satisfying those conditions:

(a) Sufficient technical support for design, construction and operation;
(b) Well organized operator training and education programmes;
(c) Involvement of Japanese suppliers in manufacturing and plant construction for technology transfer and development of the nuclear industry in Japan.

In order to enhance the overall technological level of the nuclear industry in Japan and to promote appropriate competition among Japanese suppliers, the scope assigned to each Japanese supplier was changed project by project.

5. LESSONS LEARNED AND SUGGESTIONS, ESPECIALLY DURING KEY PHASES OF THE PROGRAMME

5.1. During the initial decision making process

It was only six years prior to the start of construction of the first reactor introduced to Japan that nuclear power development was included in the national budget, in order to promote the introduction of nuclear power. Meanwhile, there was great controversy among the industrial, academic and governmental parties concerned on the desirability of introducing nuclear power and, if it were to be introduced, how best to accomplish that objective. This was not unexpected as securing energy was one of the most important issues for Japan, a country with a paucity of natural energy resources, in the context of the country's efforts to achieve post-war recovery as an advanced country. Moreover, many Japanese had an antipathy toward nuclear power since Japan was the only country to have experienced atomic bombing. Nevertheless, in the course of these controversies, Japan articulated its future course by establishing three principles governing the development of nuclear power in the country: disclosure, democracy and autonomy.

The introduction and propagation of nuclear power is a major project related to national industrial and energy policies, which requires much time and large financial resources. Consequently, sufficient consultations and discussions should be held among the various organizations concerned, including opinion leaders in the domestic arena, so that policies and attitudes concerning the introduction and development of nuclear power in the country can be articulated domestically and internationally. This process will facilitate the effective use of the resources available within the country, as well as international cooperation, resulting in the high possibility that the project of introducing nuclear power will be successful.

5.2. During the selection (of reactor type and site) and construction phases

Since in the case of nuclear power the construction cost accounts for a higher percentage of the total cost of power generation than in the case of other energy sources, it is important to maintain a high availability factor throughout the service life of a power plant in order to achieve the optimal cost performance.

To maintain a high availability factor of a nuclear power plant, adoption of highly reliable technology is essential, which is confirmed through actual use over a long period of time. Therefore, to ensure a high availability factor it is desirable to select a reactor type for which there is sufficient operating experience in advanced countries.

On the other hand, since various improvements have been implemented in nuclear power plants in light of experience, reactor suppliers are able to propose reactor types offering enhanced safety and reliability by adopting state of the art technologies. If there is no operational experience in advanced countries for a reactor type that is being considered for introduction, it is necessary for the introducing country to take the initiative in solving any problems or malfunctions, which though previously unknown, may emerge and have a negative impact on economic performance and reliability. This is a risk that the country should take into consideration when selecting the reactor type.

Furthermore, in the case of selecting a reactor type that is already in operation in an advanced country, it is essential to carry out a detailed study of its operational performance as well as of the trend of its planned adoption in future. Operation of several reactors of the same type means a higher possibility of operating a nuclear power plant employing that reactor type at a high availability factor and safely because:

(a) Operating experience in other countries can be reflected in the operation and maintenance of the power plants in the country in question;
(b) An increased supply of components and parts ensures their higher availability and better cost performance;
(c) Long term technical support by suppliers is available.

On the contrary, if a reactor type with operating experience in advanced countries but without any plan for adoption in the future is selected, the need to address problems that may emerge following the start of operation may prove to be very time consuming and costly because the level of technical support and parts supply capacity of the reactor supplier will gradually decrease.

In the case of nuclear power, replacement or abolition of equipment is more difficult than in the case of general purpose equipment due to large scale investment and handling of radioactivity. Sufficient consideration should be given to these factors when selecting a reactor for introduction.

Construction of the first reactor to be introduced is an opportunity to establish various procedures and systems associated with construction of a nuclear power plant, including licensing issues. Regarding the establishment of these procedures and systems for construction, it is anticipated that a number of problems, varied in their type and scale, will arise during the process of licensing and construction due to the variation in regulatory regimes and organizations among countries, even though such inconsistencies may have been addressed to a degree in a detailed project plan formulated prior to the taking of the decision to introduce nuclear power. In Japan the addition of new audit items for licensing and regulatory changes, as well as changes in specifications, had an impact on the project process and construction costs. In order to minimize the impact of these factors, strengthening of the relationships among the organizations concerned within the country in question is necessary so that they can make a concerted effort to accomplish the project, in addition to formulating a detailed project plan reflecting the experience of advanced countries. Consequently, discussion among the organizations concerned is necessary from the initial phase of a nuclear power introduction project onward.

5.3. During the startup and operation phase

The startup test and operation of a reactor that is being introduced play a major role in terms of the accumulation of technology in the country and development of its human resources. Currently, startup tests for a reactor are conducted by the reactor supplier in accordance with the full turnkey contract in many cases. In the case of the introduction of the first reactor in Japan, the Commissioning Committee, established shortly after the start of construction of the power plant and comprising the licensee in Japan, overseas consultants and the reactor supplier, discussed test implementation and test result evaluation methods. Furthermore, during the actual test, dispatch of engineers with operating qualification and experience of the same reactor type in advanced countries contributed greatly to the understanding of technological issues as well as to an appreciation of the attitude toward nuclear energy and the reactor design concept.

Accordingly, it is desirable to promote involvement during the startup test phase of a reactor in order to cultivate the human resources essential to support nuclear power in the country.

In addition, in the course of the startup test and subsequent operation it is important to collect and analyze information concerning the operation of various reactor types as well as of the reactor type that is being introduced, as it will contribute to the development of technologies within the country and to the accumulation of safe and stable operating experience for the reactor. This experience will spur the introduction and development of nuclear power.

5.4. During the expansion following the first plant

Many electric power utility companies in Japan vigorously invested their human and financial resources in the introduction of the first reactor, with a view to introducing nuclear power as an activity of their respective companies. While ensuring optimal use of this experience for introducing nuclear power, the electric power utility companies shared their knowledge and experience not only internally but also with each other and with manufacturers in Japan. This approach had a positive influence on the safety and stability of the operation of nuclear power plants in Japan, which, in turn made it easier to secure public acceptance of nuclear power. At the same time, it served as a basis for the improvement and standardization programmes initiated by the government in an effort to expand nuclear power generation in Japan.

In the third improvement and standardization programme, advanced boiling water reactors (ABWR) and advanced pressurized water reactors (APWR) were developed. These ABWRs and APWRs have been developing since the 1970s for the purpose of starting operation from the 1990s. At the start of the ABWR development programme, utilities proposed user requirements reflecting BWR operational performance experiences to the improvement and standardization design targets of government.

Major utilities requirements are as follows:

(a) Further improvement of safety and reliability:

CDF < 1/10 of conventional;

(b) Reduction of radioactive waste:

Quantities of waste drum < 1/8 of conventional;

(c) Radiation dose exposure for worker:

Below one third of conventional;

(d) Improvement of economic efficiency:

—Unit construction cost: approximately 80% of conventional;
—Standard periodic inspection duration: 45 days;
—Standard construction period: 48 months.

As a result of the joint ABWR development project by the united government, electric power utilities and plant makers against a higher development target from user’s point of view, ABWR showed better operational results compared with conventional BWR. APWR development was also carried out in a similar way to ABWR. APWR is now under construction for confirming development technologies.

In expanding nuclear power, it is important to strive for the understanding of the general public by accumulating safe and stable operating experence through the concerted efforts of all the organizations concerned within the country and to reflect this accumulated expertise in nuclear power technology in the design, construction and operation of future nuclear power plants. To achieve these objectives, it is also important to make full use of state of the art technological information and experiences of advanced counties and cultivate human resources on a continuous basis through internships with nuclear power plants overseas, participation in international organizations and so on.

KOREAN EXPERIENCE ON THE DEVELOPMENT AND DEPLOYMENT OF NUCLEAR POWER PLANTS

1. ENERGY SITUATION IN THE REPUBLIC OF KOREA

The primary objective of the Republic of Korea's energy policy has been to secure an economical and stable supply of energy by diversifying energy sources. At present, environment-friendly energy policies have gained ground due largely to a progress in climate change convention negotiations. The impact of the two oil crises in the 1970s on the Korean economy was severe. In response, the government tried to limit the annual increase in energy consumption to about 7~8%. By the 1990s, however, consumption was growing at more than 10% annually.

The total primary energy consumption increased from 12.0 million TOE in 1965 to 233.4 million TOE in 2006. Due to the scarcity of indigenous energy resources, the Republic of Korea is heavily dependent upon imported energy. The overseas energy dependence continuously rises from 47.5% in 1970 to 96.5% in 2006.

As in many other countries that are not endowed with fossil fuel reserves, nuclear power is considered to be the most reliable energy source capable of meeting the soaring energy demand necessary for economic development (i.e. an economic growth rate of some 10% per year). The Republic of Korea has consequently chosen nuclear power as one of its major energy sources.

2. BRIEF HISTORY AND CURRENT SITUATION OF NUCLEAR POWER PLANTS

2.1. Introduction of nuclear power in the 1970s

As early as the late 1950s, the Republic of Korea took a keen interest in the peaceful use of nuclear energy, especially in view of its poor endowment of conventional energy resources. Under a ROK-US agreement on the peaceful use of atomic energy, ground was broken for a project to install a nuclear research reactor (a TRIGA Mark II model made by General Atomics) in 1959, which was completed in 1962. It enabled Korean scientists and engineers to study the basic principles of nuclear power, while also producing isotopes for medical and other applications.

The Republic of Korea launched the full-fledged development of nuclear power production during the early 1970s, with the aim of satisfying the ever-increasing electricity demand arising from the rapid industrialization of the country. With technological capabilities in the first stage of absorption, the country contracted foreign firms to build nuclear power plants on a turnkey basis. Kori nuclear power plant units 1&2 and Wolsong unit 1 were built in that way during the 1970s.

TABLE 1. PRIMARY ENERGY CONSUMPTION IN THE REPUBLIC OF KOREA (UNIT: 1000 toe)

	Coal	Petroleum	LNG	Nuclear	Others	Total
1970	5 829	9 293	—	—	4 566	19 678
1980	13 199	26 830	—	869	3 013	43 911
1990	24 385	50 175	3 023	13 222	2 387	93 192
2000	42 911	100 279	18 924	27 241	3 532	192 887
2002	49096	102 414	23 099	29 776	3 952	208 636
2004	53 128	100 638	28 351	32 679	5 442	220 238
2006	56 687	101 831	32 004	37 187	5 663	233 372

Under this arrangement, a foreign company served as the prime contractor to design and supervise the project and supply most of the necessary equipment. Domestic firms took part on a limited basis in the management of the project and the test operation of the completed power plants, as well as in the civil engineering and installation work, to learn the basics of how to do the job. This was regarded as the first phase of nuclear power development in the Republic of Korea.

2.2. Expansion and self-reliance of nuclear power plants in the 1980s and 1990s

In the next step of absorption, covering the 1980s, KEPCO (Korea Electric Power Corporation) began to act as the manager of nuclear power projects based upon the experience and expertise gained during the previous arrangement. KEPCO contracted both foreign and domestic firms on a ‘component basis’ to build Kori units 3&4, Younggwang units 1&2, and Uljin units 1&2 during the 1980s. Under this arrangement, foreign firms were engaged as the prime contractors to furnish the designs and the core equipment and machinery. Korean companies served as subcontractors to manufacture many of the components, thus increasing their local content. The civil engineering was undertaken by domestic firms primarily on their own responsibility, drawing on their experience during the first phase.

In the late 1980s, the Republic of Korea advanced to the second stage of adaptation in nuclear power technology. Korean firms served as the prime contractors in building Younggwang units 3&4, Uljin units 3&4, Younggwang units 5&6 and Uljin units 5&6. Foreign firms participated in these projects as subcontractors to the Korean prime contractors to provide assistance only in the most sophisticated aspects of the necessary technology. The Republic of Korea thus progressively achieved near total self-reliance in nuclear power technology, becoming able to design, manufacture and construct nuclear power plants almost on its own.

The contract base for Korean nuclear power projects can be summarized as in Table 2.

2.3. Current situation

As of October 2007 a total of twenty nuclear power plants (16 PWRs and 4 CANDU) are in commercial operation and six units (6 PWRs) are under construction: four (Shin-Kori #1&2, 3&4) at Kori and two (Shin-Wolsong #1&2) at the Wolsong site. In addition, two units are scheduled to be constructed by 2020, as shown in Table 3.

In 2006, installed nuclear power capacity was 17.7 GW(e), accounting for 27.0% of the total installed capacity and nuclear power generation was 148.7 TW·h, accounting for 39.4% of total electricity generation. The share of nuclear power capacity and nuclear power generation will be increased to 30.3% and 46.7%, respectively by 2015.

The Republic of Korea has developed an advanced power reactor with capacity of 1400 MW(e), called APR1400, to enhance safety, availability and lifetime and to improve the economics of nuclear power plants. The first unit of APR1400 (Shin-Kori #3) is expected to be in service by 2013.

TABLE 2. CONTRACT BASE OF NUCLEAR POWER PROJECTS IN THE REPUBLIC OF KOREA

Innovation stage	Contract base	Nuclear power plants
Absorption	Turnkey	Kori 1&2, Wolsung 1
	Component approach	Kori 3&4, Younggwang 1&2, Uljin 1&2
Adaptation	Joint design	Younggwang 3&4
	In-house R&D	Korean Standard nuclear power plant (Uljin 3&4, Younggwang 5&6, Uljin 5&6)
Innovation	In-house R&D	APR 1400

TABLE 3. STATUS OF NUCLEAR POWER PLANTS IN THE REPUBLIC OF KOREA

Status	Plant name	Type	Capacity (MW(e)) Gross	Reactor supplier	Turbine supplier	COD year
In operation	Kori 1	PWR	587	WH	GEC	1978
	Kori 2	PWR	650	WH	GEC	1983
	Kori 3	PWR	950	WH	GEC	1985
	Kori 4	PWR	950	WH	GEC	1986
	Wolsung 1	PHWR	679	AECL	HP	1983
	Wolsung 2	PHWR	700	AECL/Hanjung/KAERI	Hanjung/GE	1997
	Wolsung 3	PHWR	700	AECL/Hanjung/KAERI	Hanjung/GE	1998
	Wolsung 4	PHWR	700	AECL/Hanjung/KAERI	Hanjung/GE	1999
	Younggwang 1	PWR	950	WH	WH	1986
	Younggwang 2	PWR	950	WH	WH	1987
	Younggwang 3	PWR	1000	Hanjung/KAERI/CE	Hanjung/GE	1995
	Younggwang 4	PWR	1000	Hanjung/KAERI/CE	Hanjung/GE	1996
	Younggwang 5	PWR	1000	Doojung/KOPEC/CE	Doojung/GE	2002
	Younggwang 6	PWR	1000	Doojung/KOPEC/CE	Doojung/GE	2002
	Uljin 1	PWR	950	Framatome	Alsthom	1988
	Uljin 2	PWR	950	Framatome	Alsthom	1989
	Uljin 3	PWR	1000	Hanjung/KAERI/CE	Hanjung/GE	1998
	Uljin 4	PWR	1000	Hanjung/KAERI/CE	Hanjung/GE	1999
	Uljin 5	PWR	1000	Doojung/KOPEC/CE	Doojung/GE	2004
	Uljin 6	PWR	1000	Doojung/KOPEC/CE	Doojung/GE	2005
Under construction	Shin-Kori 1	PWR	1000	Doojung /KOPEC/CE	Doojung/GE	2010
	Shin-Kori 2	PWR	1000	Doojung /KOPEC/CE	Doojung/GE	2011
	Shin-Wolsung1	PWR	1000	Doojung /KOPEC/CE	Doojung /GE	2011
	Shin-Wolsung2	PWR	1000	Doojung /KOPEC/CE	Doojung /GE	2012
	Shin-Kori 3	APR1400	1400	Doojung /KOPEC/CE	Doojung /GE	2013
	Shin-Kori 4	APR1400	1400	Doojung /KOPEC/CE	Doojung /GE	2014
In planning	Shin-Uljin 1	APR1400	1400			2015
	Shin-Uljin 2	APR1400	1400			2016

WH: Westinghouse Electric, GEC: General Electric, AECL: Atomic Energy of Canada Ltd, HP: Howden Parsons, Hanjung: Korea Heavy Industries and Construction Co., Ltd (Now Doojung).

3. MAIN REASONS FOR INTRODUCING NUCLEAR POWER

The Republic of Korea is an energy resource poor country. There are no significant oil or gas resources and only limited anthracite coal deposits. Consequently, energy security has been one of the prime concerns of the Korean government. A stable energy supply has been a principal consideration in formulating national energy policies to support the drastic economic development in the 1960s and 1970s. At that time, the annual growth rate of electricity demand was in the range of 20–25%.

The domestic uranium deposits identified so far are so low grade and uneconomical, so that their use has never been considered. Because nuclear power could be considered to be a semi-independent energy source as only the uranium had to be imported where the other components of nuclear energy were domestically available and self-reliant in design, manufacturing and construction, the Republic of Korea government chose nuclear power as one of the main sources of its electricity supply. Especially, after experiencing two oil-crises in the 1970s and the following economic crisis in 1979, the Korean government decided to expand nuclear power for a long term steady development of its economy.

4. MAIN CONSIDERATIONS ON INTRODUCING NUCLEAR POWER

4.1. Reactor type

As for the selection of the first nuclear power reactor, initially there was keen competition among UK GCR, US BWR (General Electric) and US PWR (Westinghouse). At first, UK GCR was favoured as many Korean experts were trained there, but later through thoughtful considerations and political and diplomatic interventions, the Korean government chose the US PWR as the final winner of the competition. The decision was made based on through thoughtful consideration of the financial, technical, political and diplomatic aspects of the nation and its national economy and nuclear technology. Some of the main reasons were the easiness of obtaining foreign funds, localization and self-reliance of nuclear fuel technology and the localization of power plant design, component fabrication, and construction technologies.

Later, however, a decision was made to modify the national nuclear energy strategy, leaning toward the US PWR by adding PHWR, namely CANDU, to the nuclear fleet as a complementary type. With the introduction of CANDU, a 2+1 nuclear reactor strategy was envisioned in the Republic of Korea, which means keeping the ratio of PWR to CANDU at 2 to 1.

On the other hand, this strategy can be nothing but a 'spread and thin' drawback of a nation's technological potential if a small country, like the Republic of Korea, launches into the pursuance of two reactor types from the beginning. After much pondering and on in-depth study, the Republic of Korea's nuclear community decided to pursue a one reactor type strategy, that is PWR alone, having terminated the further deployment of CANDU reactors.

The abandonment of the two reactor type strategy was also based on a consideration of the limitations of allocating public funding to localizing two different reactor technologies while the government had to strategically allocate the available funds to the R&D of other strategically important science and technology areas, and industrial areas such as the information technology, automobile, ship building and steel industries.

4.2. Reactor size

At first, in the early 1960s, the initial size of the first nuclear power plant suggested by the Nuclear Power Planning Committee was 150 MW(e), considering the total capacity of electricity generation at that time (around 1000 MW(e)). However, this size did not fit the economics in the commercial sense. In this regard, an argument prevailed that the reactor size could be bigger since the total electricity generating capacity would increase by more than five times after the 6–7 year construction period with the high growth rate of electricity demand (20–25%). Finally, a decision was made that the size of the first nuclear power plant would be 580 MW(e).

After the first unit, PWRs of 600 MW(e) and CANDUs of 700 MW(e) were built. With the total grid size becoming larger, the choice of a larger capacity such as 900 MW(e) like the 3 loop Westinghouse PWRs or its competitors were considered. This partly led the Republic of Korea to choose the CE 1000 MW(e) PWR with other considerations such as an easy technology transfer. For better economic performance, the size of the advanced power reactor (APR1400) was increased to 1400 MW(e).

4.3. Site selection

Around 30 locations were surveyed for the site of the first nuclear power plant, with consideration of various factors such as regional characteristics of population and electricity demand, availability of water for cooling and general use, geological conditions, possibility of earthquakes, climate, transportation, power transmission, availability of land areas, etc. Finally Kori, located on the south-east coast near Busan — the second largest city in the Republic of Korea, was chosen as the site for the first nuclear power plant in the Republic of Korea. Like the first unit, all subsequent nuclear power plants in the Republic of Korea were located in coastal areas.

5. LOCALIZATION EFFORTS

5.1. Localization of CANDU fuel fabrication

KAERI (Korea Atomic Energy Research Institute), with its qualified personnel and research facilities including research reactors, started a CANDU fuel localization project in 1980. A pilot scale nuclear fuel fabrication facility was built and has been operable since 1978 at KAERI. Using this facility, KAERI has carried out fundamental research on CANDU fuel manufacturing technology. In 1981 the government and KEPCO agreed to develop CANDU fuel fabrication technology as a national project. After two years KAERI developed uranium conversion technology and prototype fuel bundles. Out of pile tests to verify the mechanical and material integrity of the fuel were performed at the KAERI facility, which was constructed by domestic industry and designed by KAERI. Subsequent in pile tests for several prototype fuel bundles were carried out successfully at the NRU reactor in Canada with the cooperation of AECL.

Finally, KAERI decided to extend its effort to commercialize CANDU fuel fabrication technology. Thereafter, 408 bundles of fuel were loaded successfully into Wolsong unit 1 with governmental approval from 1984 to 1986. From July 1987, the full core of the Wolsong plant began to be commercially loaded with KAERI made fuel. Through years of efforts to develop CANDU fuel fabrication technology and construction of the commercial scale plant, our self-reliance programme in nuclear power technology could be established with confidence

5.2. Development of the Korean standard nuclear power plant (KSNP)

During the absorption stage (3 turnkey and 6 component approach projects), a significant level of technologies for construction, A/E, and hardware manufacturing could be archived. But it was recognized that software technologies such as NSSS design and engineering were difficult to achieve without an indigenous R&D effort.

Building on the experience and expertise thus gained, the Republic of Korea developed the Korean standard nuclear power plant (KSNP). The project to develop the KSNP was begun in 1984 under the Government's plan for 'technological self-reliance for nuclear power plants' by promoting domestic research and development. The goal was to develop an optimized design for use in constructing a series of additional nuclear power plants in the country that would feature improved economics and safety standards.

The Younggwang units 3&4 project was the first nuclear power project implemented on a component basis by local prime contractors. It was a turning point in Korean nuclear history because domestic involvement was markedly increased by technology transfer. There was a big change in the contract base; that is, Korean companies began to take major responsibilities as shown in Fig. 1.

KEPCO, the owner, designated KOPEC (Korea Power Engineering Company) as the prime contractor/ engineering, HANJUNG for the supply of the nuclear steam and turbine/generator, KNFC (Korea Nuclear Fuel Company) for nuclear fuel manufacturing, and HECC (Hyundai Engineering and Construction Company) for the construction. Procuring the balance of the plant (BOP) was the responsibility of KEPCO as the owner. KAERI was designated as a subcontractor to HANJUNG and KNFC for the design of the NSSS (nuclear steam supply system) and initial core, respectively. These entities subcontracted with foreign companies such as Sargent & Lundy (S&L), General Electric (GE) and AESA Brown Boveri-Combustion Engineering (ABB-CE) for engineering and equipment and related technologies.

The light water reactor system for the KSNP has been developed by modifying and improving on the Asea Brown Bovery-Combustion Engineering's (ABB-CE) System 80 design installed at Younggwang units 3 & 4, whose technical excellence and safety had been well proven at the Palo-Verde nuclear power plant in the USA. Younggwang unit 3 went into commercial operation in March 1995.

The modification and improvement work on the System 80 was aimed, first of all, at reducing its generating capacity of 1300 MW to 1000 MW in consideration of the nation's total grid size. No less important, the KSNP design was based on the codes and standards of 1989, intended especially to more effectively prevent severe accidents, while System 80 was designed according to the US codes and standards of the mid 1970s. Accordingly, the KSNP has many up to date design features not found in System 80. Furthermore, it has incorporated ergonomic features specifically designed to suit Korean operators who are relatively smaller than their Western counterparts. The non-nuclear parts of the KSNP have been designed entirely by Korean engineers to constitute a balanced and well functioning whole with the other parts.

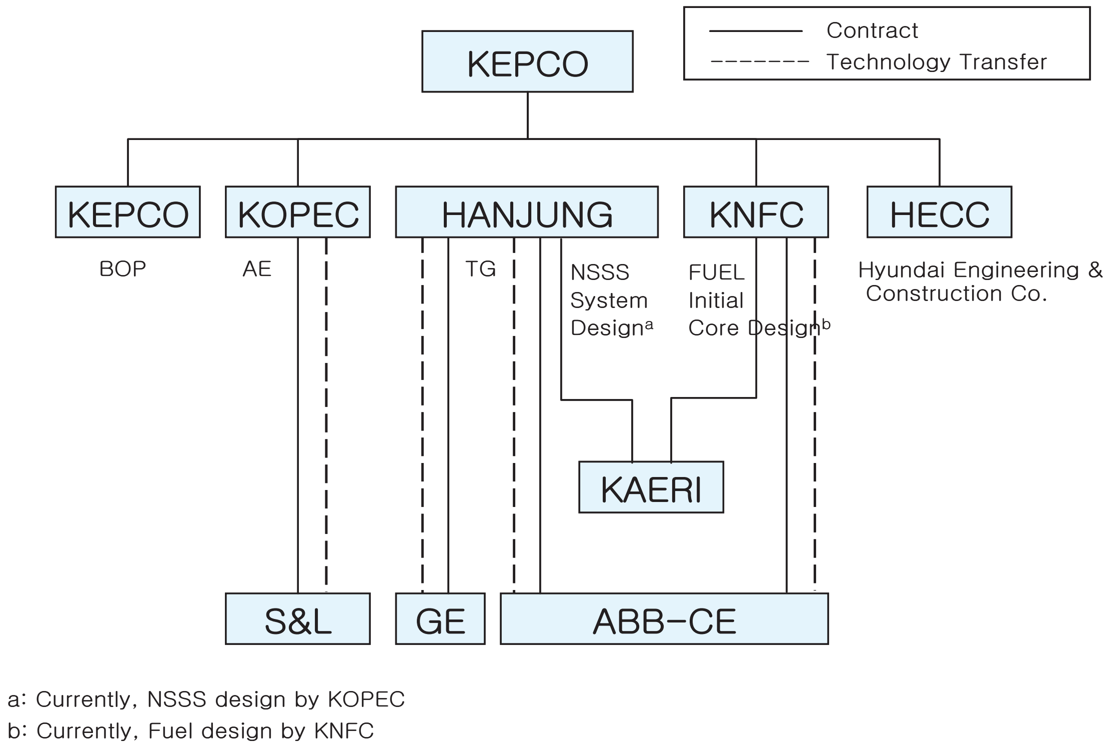


FIG. 1. Contractual hierarchy of the Younggwang 3&4 projects.

Other improvements include the simplification of operational procedures, enhancement of plant economics and increased plant availability, especially by minimizing the downtime needed for maintenance. The Korean engineers fully utilized computer aided engineering in developing the KSNP, and they also independently developed the necessary computer codes needed to develop and verify the final design. Younggwang units 3 & 4, the reference plants for the KSNP, were constructed with about 100 modifications to the Westinghouse design.

As a result of the implementation of the Younggwang 3 & 4 project, domestic nuclear industries became prime contractors with the support licensed technology transfer from the foreign subcontractors for Younggwang 3 & 4. The Republic of Korea aimed at achieving an overall self-reliance level of 95% by the end of 1995.

The successful and continuous self-reliance effort for nuclear technology was completed earlier than expected and created the country's own KSNP. The first KSNP, Uljin 3, was scheduled to start commercial operation in 1998.

The KSNP design has been applied in the building of additional nuclear power plants such as Uljin units 5 & 6 and Younggwang units 5 & 6. Efforts have been continued to further improve on it through close examination of Uljin units 3 & 4 after they went into actual operation and through continuing research and development. Currently, the Republic of Korea's rate of self-reliance in nuclear technology is estimated at 95% overall. The KSNP has already begun to attract interest from other Asian countries that are also seeking to develop nuclear power.

5.3. PWR fuel technology development

In 1985, upon the success of CANDU fuel design and fabrication at KAERI, the Korean government decided to localize PWR fuel technologies by using KAERI's experience and capabilities. Thereby, KAERI has been assigned for PWR fuel design and engineering while KNFC for fuel manufacturing.

To expedite self-reliance in PWR fuel technology development, two technology inducement contracts were made in August 1985. One for fuel design technology transfer, between Kraftwerk Union (KWU) of the

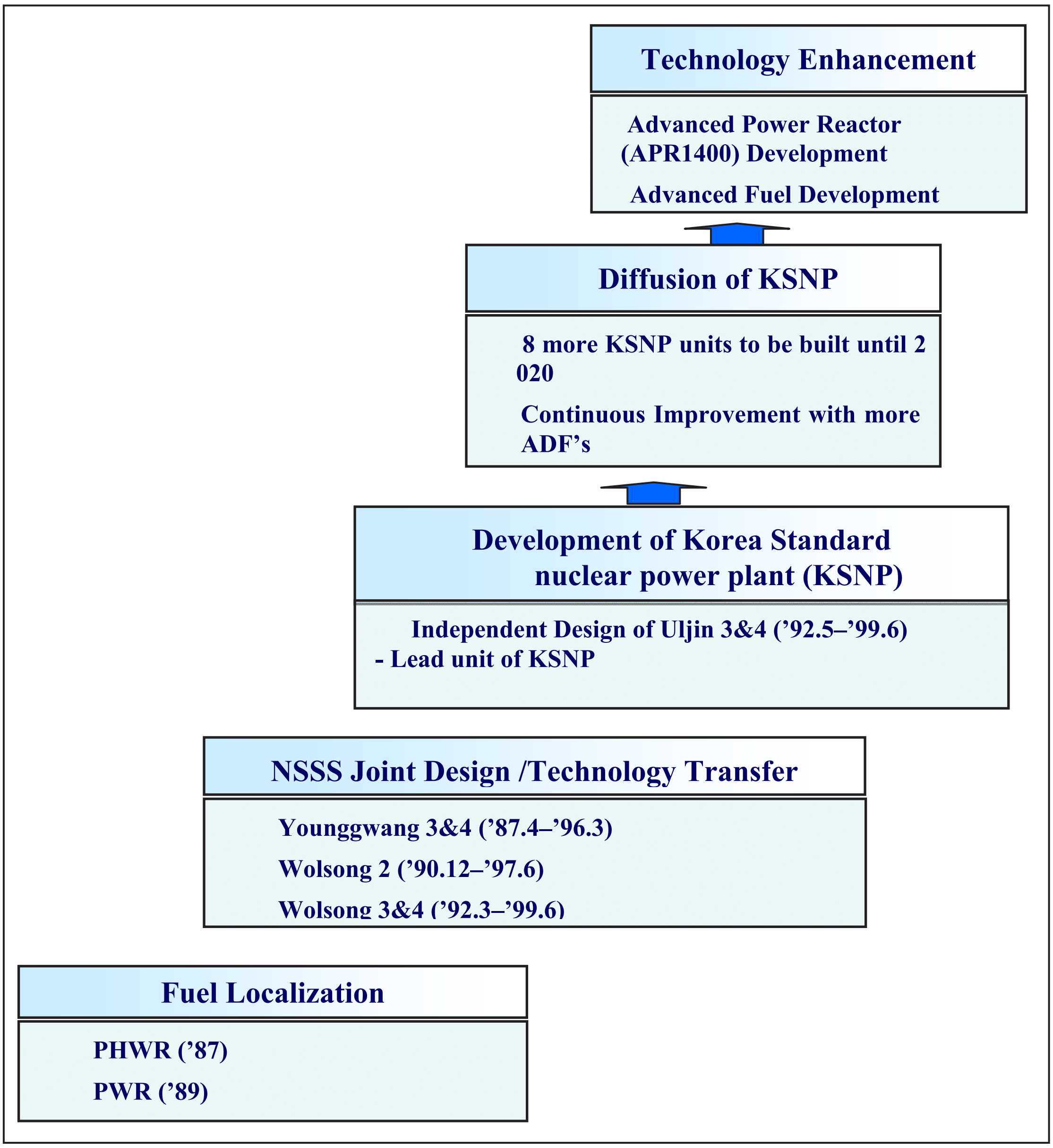


FIG. 2. Vertical path of technological learning in the Republic of Korea.

Federal Republic of Germany and KAERI, and the other for fuel fabrication technology transfer between KWU and KNFC.

For the design of fuel itself, a joint effort with KWU was made in two steps. The first step is called preliminary joint design, whose activities are defined as generation of manufacturing related documents and licensing reports. The second step is the final design, which is the design of the reload core using the fuel that was determined during the preliminary design stage. From May 1986 until March 1988, preliminary design activities for reload fuel assemblies to be fabricated during 1989 were successfully completed by a joint effort of KWU and KAERI engineers. The final design was begun in November 1987 in a stepwise manner for Kori unit 2.

At present, KNFC supplies all the necessary CANDU and PWR fuels in the Republic of Korea. Just recently KNFC decided to localize Zircaloy tubes, which accounts for more than one-third of the nuclear fuel fabrication cost.

5.4. Development of APR1400

Based on the technological capabilities accumulated in the course of the KSNP project, the advanced PWR reactor 1400 MW class (APR1400) has been developed as the Korean next generation reactor when work started on the project in 1992. APR1400 is designed to meet the future need for electric power in a cheaper, more efficient and reliable manner. Korean engineers have upgraded safety and economic aspects compared to the previous reactors by implementing advanced design features such as the extension of the plant design life span from 40 to 60 years, upgrading of the safe shutdown earthquake value from 0.2 to 0.3g and the like. The cost is expected to be US $1400 per kilowatt, falling to US $1200/kW in subsequent units. Two units of APR1400 are scheduled for construction at the Shin-Kori site next to Shin-Kori units 1&2, with target completion years of 2013 and 2014, respectively.

6. KEY LESSONS LEARNED

6.1. Lessons from the deployment of nuclear power plants

6.1.1. Long term planning and its implementation

In the Republic of Korea, the long term nuclear power development programme was drawn up in the early 1960s when electric power was in short supply and the nation's total electric grid was too small to accommodate even the smallest unit of nuclear power plants. But there was a consensus among the ruling elite, as well as among the public, that the dire power shortage had to be tackled by whatever measures were necessary, and nuclear power was considered a break-through solution.

Over the years the original development plan was modified a number of times to be consistent with the progress of reactor commercialization in advanced countries. In time, the Republic of Korea's role underwent a flip from technology recipient to supplier of nuclear technology. The remarkable transformation took three decades of toil, sweat, brainpower, and mobilization of many dedicated people in the industry.

6.1.2. Continued training of good quality manpower

Relevant and creative staffs are necessary to introduce nuclear power in a developing country. The most active nuclear training centre is the one that was established at KAERI, and it has been the delivery clinic, incubator, nursery and kindergarten for Korean nuclear personnel, as well as for those from abroad. In the year 2005 KAERI's nuclear training centre offered 36 domestic courses to 1580 persons and 9 international courses to 116 foreign individuals, and it managed one international seminar attended by 122 participants.

The nuclear training centre of KHNP is well furnished and well equipped, and it is sometimes open to international courses. In addition, each power plant has its own training centre furnished with respective simulators and experienced faculty members.

6.1.3. Technical backup by R&D

The nuclear sector being a knowledge based industry, the technical problems encountered usually call for technical expertise for resolution. When problems arise the quickest solution is to resort to foreign consultants and engineering companies. This approach, however, can be costly, time consuming and above all it will not engender a local accumulation and accretion of technical expertise that should result from working on various problems and issues.

Given all this, it is best to adopt a 'do it yourself' approach, wherein a technical group is empowered to tackle various problems that will inevitably arise. This technical group, however, can only succeed if there is an effective R&D backup that can be called in to help address the most intractable of problems. Again, dedicated and high quality research manpower is a prerequisite for the success of the local go it alone approach.

All the nuclear related organizations in the Republic of Korea operate in-house training centres and research centres for their employees and new recruits. Some organizations offer evening classes on specific topics to their members either by inviting outside experts or professors and/or senior in-house professionals. In the case of reactor operators, one of six shifts is always sent to a training centre, while another shift is deployed to a technical evaluation maintenance group at the site.

6.1.4. Fund raising from favourable sources and capital cost

Inasmuch as a nuclear power plant is an engineering project, it is also an economic project. It must make economic sense to be viable and the bottom line is what matters ultimately.

Access to favourable financing terms and obtaining favourable interest rates on funding will determine to a large degree the long term success of a nuclear power plant project. This is especially true since a nuclear power plant is a capital intensive investment and power plant construction takes place over several years, which means that the discount rate used to evaluate a project can have a huge bearing on whether the project is viable or not over its designed lifespan.

Because of the heavy burden of discount rate and capital cost, a nuclear power plant must be operated as much and as long as possible. It must be borne in mind that fuel cost consists of 70% of the total power generating cost for gas fired plants, whereas capital costs make up 70% of the total power generating cost in nuclear plants.

6.1.5. Construction management

The Republic of Korea's first and second nuclear power projects were undertaken on a turnkey contract basis. The suppliers were fully responsible from design to test operation and the projects were completed on schedule and within budget. Korean engineers and technicians were involved in every step of the process and they were eager to learn and absorb the tangible know-how from the foreign suppliers. The deployment of Korean personnel in every aspect of the project meant, too, that the suppliers could realize a savings in their personnel expenses.

In short, it was a win–win situation for both parties: the supplier could save in personnel development while the buyer's personnel could become proficient in the new technology through on the project participation. This on the job learning gave us not only new knowledge but also fomented within us a determined self-confidence necessary for confronting the subsequent projects which we, for the most part, carried out on our own.

After completion of the first two turnkey projects of the nuclear power plants in the Republic of Korea, the construction company dispatched many of its engineers to KAERI for the training on the nuclear basics and concept of quality control & quality assurance systems. Needless to say this construction company has been the most successful bidder in the public bidding for many subsequent nuclear power plant construction projects. This firm has grown to be one of the top notch construction/engineering companies in the world market in terms of work progress, quality and contracted amount.

6.1.6. Measures for winning public acceptance

Ardent supporters for national nuclear projects can be found in any society, as can activists agitating against them. The general public, for the most part, remains unperturbed, neutral and non-biased.

What we have learned is that in order to win wide pubic acceptance of nuclear power we must focus on the unthinking general public in the middle, for example the housewives, students, children and, especially, those in the mass media, rather than waste our time wrestling with incorrigible activists. A winning campaign will require our total commitment for the long haul, with lots of patience, sincerity and, of course, incontestable facts and data with which to present our claims.

Using straightforward and simple language, we must appeal to reason and common sense and make a case for how nuclear technology can ensure environmental conservation and at the same time provide a stable energy supply for now and for future generations.

6.2. Lessons from the localization effort

6.2.1. Technology self-reliance programme

Embarking on a nuclear programme is an important step in the industrial development of a country. Since the programme requires a vast amount of initial investment, strong support with a firm commitment to the programme and leadership by the government are crucial in the implementation of the programme. Energy independence requires the ability to operate a plant throughout its lifetime with a minimum need for imported expertise and materials. The value of self-reliance lies in the fact that it could reduce energy dependence on foreign countries. A national self-reliance programme for nuclear energy should be established to maximize the role of local industries and to reach its goal in the most efficient and economical manner.

6.2.2. Scope of technical self-reliance and localization

The scope of technical self-reliance and localization of nuclear technology should be determined based on the number of nuclear power plants to be considered. However, for pursuing technical self-reliance and localization in the areas of maintenance and operation the scope of technical self-reliance and localization of nuclear technology should be determined based on the number of nuclear power plants to be constructed. However, pursuing technical self-reliance and localization in the areas of maintenance and operation technology is recommended regardless of the number of plants, since these activities should be performed for the entire plant lifetime and relatively small investment is required.

The total cost of a nuclear power plant's construction consists of civil costs and installations of BOP and NSSS with turbine generators, each of which requires approximately one third of the total cost. Among them, localization of manufacturing of major NSSS equipment and turbine generators requires large amounts of capital investment. Should a relatively large number of plants be constructed in series, extending the scope to the construction and manufacturing of major components can be considered. Whereas if only a few sporadic construction programmes are planned it is not economical to extend the scope to the manufacturing of large equipment. In this case it is recommended that the scope be determined in the area of civil work and part of the BOP equipment by considering the spin-off effect of the technologies to be localized and national infrastructures.

6.2.3. Technology transfer

A basic approach to reaching technology self-reliance is to combine a nuclear power plant construction contract with a separate technology transfer contract. In establishing a long term national plan for technology self-reliance it is extremely important to set up a master plan incorporating all the nuclear industries related to the project, including the utility. The master plan should include the type of contract, the scope, the field of technology transfer and a priority by considering the manpower resources, work performance capabilities, and facilities of the related nuclear industries.

Legal rights to the transferred technologies such as intellectual property rights, propriety rights, and copyrights should be carefully reviewed and negotiated when writing a technology transfer contract. Future needs for the application of the technologies should be foreseen and considered in the contract.

6.2.4. Evolutionary development

There are a lot of benefits in using an evolutionary development plan as the Republic of Korea did when deploying nuclear power plants in series. When introducing the first unit the use of proven technologies is recommended. Using proven technologies demonstrated by previous construction and operations will significantly reduce the risks associated with a construction programme. In addition, use of a proven tcchno1ogy enhances the licensability of a plant.

For the follow-up units it is highly recommended to develop a standardized design as early as possible by referring to the first unit and implementing improved design features. Standardization ensures cost savings for the follow-up units. For example after three further construction projects since the construction of YGN 3&4 in the Republic of Korea, the construction cost of SKN l&2 was reduced by more than 20%. Once a sufficient technical basis is prepared from continued development, construction and operation of nuclear power plants, innovation in a design can be achieved by utilizing the state of the art technologies proven in other nuclear or industrial plants.

6.2.5. Distribution of the division of responsibilities

The division of responsibilities has to be clearly defined and carefully distributed among the related participating organizations. During the technology learning phase the division of responsibilities does not affect the project much. However, after the technology reaches a certain level and if it is necessary to advance the technology, e.g. developing a new system, the process could become ineffective depending on the distributed division of responsibilities. Consider a case where responsibilities for very closely related technologies are distributed among several entities. There will be unnecessary interfaces between the entities and sometimes the interests of the entities may conflict, which can hinder the progress of technology advancement.

Examples are the initial core design, the NSSS system design and a component design. These design areas are so closely related to and dependent on each other that it is not a good practice to distribute the division of responsibilities for these design areas among several organizations. For better performance and effective implementation of a development programme it is recommended that these three design areas at least be carried out by one lead organization.

7. FINAL REMARKS

The Korean experiences over the last thirty years offer many lessons to developing countries which intend to develop nuclear power technologies by technology transfer from advanced countries in the future. The Korean experiences described so far might be regarded as a good model case for the developing countries in terms of implementing strategies, management systems, self-reliance policies and manpower training, etc.

However, the success of a nuclear technology development programme greatly depends on country specific factors such as infrastructure, economic level, manpower quality and energy resources. Therefore, developing countries pursuing nuclear technology development should consider all the country specific factors including international relations with advanced countries.

Now the Republic of Korea is taking a step torward advanced nuclear technology. The basic strategy to acquire advanced technologies is to perform the national long term nuclear R&D programme and the continuous expansion of nuclear power plants. It is hoped to achieve the development of advanced nuclear technologies in the near future through feedback of nuclear power plant projects and an R&D programme.

OVERVIEW OF INTRODUCTION AND DEVELOPMENT OF NUCLEAR POWER IN CANADA

1. INTRODUCTION

This paper provides an overview of the introduction and development of Canada's nuclear power programme. Our experience with nuclear power dates back to the dawn of the nuclear age. As a country, we have a rich history of nuclear power research and development, including the successful commercialization of the uniquely Canadian CANDU reactor. This paper highlights the history in the development and introduction of nuclear power in Canada, and gives an overview of the structure of the Canadian nuclear industry. Some 'lessons-learned' based on the Canadian experience are also presented.

2. HISTORICAL DEVELOPMENT

Canada's first experimental reactor facility, ZEEP (Zero Energy Experimental Pile), started operating at the Government's Chalk River Laboratories (CRL) in 1945. This signalled the first systematic effort by Canadian scientists and engineers to study the possibility of using nuclear energy to generate electricity. As part of this effort, NRX (National Research Experimental) reactor began operating in 1947 at Chalk River Laboratories and became one of the highest flux reactors in the world.

The effort by the Canadian nuclear scientists and engineers was matched by the strong interest of the Canadian federal government, which was well aware of the potential for industrial and technological developments that came with the use of nuclear technologies for peaceful purposes. Consequently, in 1952 it decided to establish Atomic Energy of Canada Limited (AECL) as a federal Crown corporation having responsibility for research and development in nuclear energy. One of AECL's prime objectives was the development of Canada's nuclear power programme.

A concrete step for the Canadian nuclear power programme was taken in the early 1950s with an industry-wide cooperation to design a 20 MW(e) demonstration reactor called NPD (nuclear power demonstration). At this time, Canada's central province, Ontario, was anticipating, planning and forecasting a major growth in electricity demand driven by its expanding industrial sector. The provincial electrical utility, Ontario Hydro, anticipated an exhaustion of hydroelectric sites and the use of uranium, mined in Ontario, seemed preferable to the use of coal, which would need to be imported from the USA. In 1954 AECL, Ontario Hydro and Canadian industry (represented by Canadian General Electric) joined together to undertake the design and construction of the NPD at Rolphton, Ontario, close to the Chalk River site.

The NPD reactor was designed to use heavy water and natural uranium fuel. The choices were based largely on Canadian experience at Chalk River with design, construction and operation of the NRX research reactor, and, at that time, the design and construction of the larger National Research Universal (NRU) research reactor (which entered into service in 1957 and remains in service today as a valuable research and medical isotope production reactor). Also, it was recognized that Canada did not have the financial or technical resources to develop several different nuclear power reactor systems based on different technologies, as was then the case in the USA.

The use of heavy water and natural uranium fuel, however, did impose a challenge for Canadian designers; namely, to achieve neutron economy — to make the best use of every neutron from the fissioning of natural uranium fuel. This required close collaboration between scientists and engineers, which to this day remains a hallmark of the Canadian programme.

The unique design feature of the Canadian reactor was added in 1957, when it was decided to use pressure tubes to contain the fuel and heavy water coolant with the pressure tubes contained horizontally in a low-pressure calandria vessel, which contains the heavy water moderator and necessary control assemblies. With this arrangement, the heavy water moderator is separate from the fuel and heavy water coolant. This arrangement allows for on-line at full power refueling (necessary due to very low excess reactivity with natural uranium fuel). It also resulted in a reactor design that was within the capability of Canadian industry to manufacture since it did not require heavy engineering capability such as that required to manufacture PWR and BWR reactor pressure vessels.

Even before NPD was completed, plans were under way to design and construct a full scale 200 MW(e) nuclear power plant at Douglas Point (in Ontario, at what is now the Bruce site). On this project a power reactor design capability was established at AECL. Construction of the Douglas Point CANDU (Canada-deuterium-uranium) was approved in 1959.

Only two years after NPD became operational in 1962, and three years before Douglas Point went critical in 1967, Ontario Hydro announced in August 1964 that it was going ahead with the first two of four 500 MW(e) CANDU units at its Pickering site near Toronto. The beginning of the Canadian commercial nuclear power programme was remarkably speedy as it took only ten years from starting of a prototype reactor to announcing a full size commercial reactor programme. All together, eight units were subsequently built at the Pickering site and went in-service from 1971 to 1986.

In the mid 1960s, Canada provided India and Pakistan with CANDU units. The Kanupp reactor in Pakistan and the RAPS-1 in India began operating in the early 1970s.

The CANDU design, which is optimized to burn natural uranium, was subsequently refined and introduced to other provinces and overseas. In 1968, Ontario Hydro committed four 745 MW(e) units at the Bruce Station, which came on-line from 1976 to 1979. Four more units at 860 MW(e) each were added at the Bruce site in the mid 1980s. Meanwhile, AECL developed the standard CANDU 6 (net capacity was initially around 630 MW(e), and is currently uprated to slightly less than 700 MW(e)) design. The first four CANDU 6 units were built in the province of Quebec, Province of New Brunswick, Argentina and the Republic of Korea, which went critical from 1982 to 1983. Currently there are eleven CANDU 6 units operating in the world, including additional units in Romania, the Republic of Korea and China. With the success of the Bruce design, Ontario Hydro subsequently developed a further refined version of the design. Four units of this design, with 880 MW(e) each, were built at the Darlington site and went into service in early 1990.

AECL has also developed a smaller version of the natural uranium based CANDU design, the CANDU 3, with its 450 MW(e) rating, and a larger version which is CANDU 9. The natural uranium based CANDU 9 has a net capacity of about 880 MW(e). Using slight enriched uranium fuel, CANDU 9's capacity rating is about 1000 MW(e).

At the turn of 21st century, AECL was developing its advanced CANDU reactor (ACR). With the aim of cost competitiveness, ACR is optimized with the use of a D_2O moderator, H_2O coolant and enriched uranium fuel. AECL is also developing one of the Generation IV designs, a fuel channel type supercritical water reactor. Table 1 provides a list of all Canadian supplied CANDU reactors in the world.

3. CANADIAN NUCLEAR INDUSTRY

An important point about the structure of Canada's nuclear industry is that AECL, as the CANDU designer, is both an engineering organization and a research and development organization. However, AECL is not a nuclear equipment manufacturer. Rather, there are about 150 companies in Canada that manufacture and supply CANDU nuclear reactor components based on AECL design requirements and specifications.

Overall, the Canadian nuclear industry consists of the following:

(a) **Engineering and R&D:** Atomic Energy of Canada Limited is the designer and vendor of CANDU reactors and is responsible for nuclear energy research and development in Canada. AECL is a Crown corporation owned by the Canadian government. AECL reports to the Canadian Parliament through the Federal Minister of Natural Resources.

(b) **Utilities**: Ontario Power Generation, Hydro Quebec, and New Brunswick Power are the provincial public sector utilities that own and operate CANDU nuclear power plants. Bruce Power is a private sector company that operates the CANDU reactors at the Bruce site in Ontario.

(c) **Suppliers**: There are about 150 companies in Canada that manufacture and supply CANDU reactor components as well as uranium mining, refining, conversion and CANDU fuel manufacture.

(d) **Regulatory Authority**: The Canadian Nuclear Safety Commission is the federal authority responsible for nuclear power safety regulation in Canada.

TABLE 1. LIST OF ALL CANADIAN SUPPLIED CANDU REACTORS

Unit		Location	Gross output	In-service year
NPD		Ontario, Canada	22 MW(e)	1962
Douglas Point		Ontario, Canada	220 MW(e)	1967
Pickering A	1	Ontario, Canada	540 MW(e)	1971
	2	Ontario, Canada	540 MW(e)	1971
	3	Ontario, Canada	540 MW(e)	1972
	4	Ontario, Canada	540 MW(e)	1973
RAPP	1	India	220 MW(e)	1972
	2	India	220 MW(e)	1981
KANUPP		Pakistan	140 MW(e)	1972
Bruce A	1	Ontario, Canada	800 MW(e)	1976
	2	Ontario, Canada	800 MW(e)	1977
	3	Ontario, Canada	800 MW(e)	1978
	4	Ontario, Canada	800 MW(e)	1979
Gentily	2	Quebec, Canada	675 MW(e)	1983
Embalse		Argentina	650 MW(e)	1984
Pickering B	1	Ontario, Canada	540 MW(e)	1983
	2	Ontario, Canada	540 MW(e)	1984
	3	Ontario, Canada	540 MW(e)	1985
	4	Ontario, Canada	540 MW(e)	1986
Point Lepreau		New Brunswick, Canada	680 MW(e)	1983
Bruce B	1	Ontario, Canada	920 MW(e)	1984
	2	Ontario, Canada	920 MW(e)	1985
	3	Ontario, Canada	920 MW(e)	1986
	4	Ontario, Canada	920 MW(e)	1987
Wolsong	1	Republic of Korea	680 MW(e)	1983
	2	Republic of Korea	715 MW(e)	1997
	3	Republic of Korea	715 MW(e)	1998
	4	Republic of Korea	715 MW(e)	1999
Darlington	1	Ontario, Canada	935 MW(e)	1992
	2	Ontario, Canada	935 MW(e)	1990
	3	Ontario, Canada	935 MW(e)	1993
	4	Ontario, Canada	935 MW(e)	1993
Cernavoda	1	Romania	710 MW(e)	1996
	2	Romania	710 MW(e)	2007
	3	Romania	710 MW(e)	(2013)
Qinshan Phase 3	1	China	730 MW(e)	2002
	2	China	730 MW(e)	2003

4. DECISION MAKING RESPONSIBILITIES

In Canada, the Provincial Governments have constitutional responsibility for electricity supply. In the nuclear power field, the Federal Government has responsibility for nuclear regulation. The Federal Minister of Natural Resources has responsibility under federal law to prepare for the use of nuclear power, including undertaking research and development on nuclear power (this is implemented via the Federal Crown Corporation, AECL).

Within this structure, the Provincial Governments and their utilities are responsible for deciding on the introduction and use of nuclear power. Decisions have been taken on the basis of considerations regarding resource availability and utilization, economic competitiveness of nuclear power, and development and support of provincial industrial sectors.

The non-polluting characteristic of nuclear power is an important consideration in recent decisions to refurbish CANDU reactors in Ontario and New Brunswick. Going forward, a key consideration for new reactor construction and existing reactor refurbishment is the requirement to manage financial and technical risk.

5. LESSONS LEARNED

(a) Need for strong and sustained governmental support to initiate and implement a nuclear power programme;
(b) Need for a close relationship between the reactor designer, owner, operator and manufacturers;
(c) Need for utilities to focus their efforts on core competencies related to operational aspects;
(d) Need for strong and continuous research and development capability and infrastructure both to support current reactor operations and to undertake necessary R&D for advanced reactors and fuel cycles;
(e) Need for strategic planning of long term R&D focus and programmes;
(f) Need for public confidence and broad based support to help inform and enable policy decisions;
(g) Need for a combination of strong scientific and technical leadership, as well as industrial/utility leadership, to make a case for the introduction of a nuclear power programme and to provide policy advice and programme direction;
(h) Need for high level of technical, managerial and policy competence in programme planning and implementation;
(i) Need for effective and active international collaborations to ensure and facilitate all levels of information exchange and experience sharing, such as that facilitated and fostered by the IAEA.

GLOSSARY

The definitions and explanations proposed in this glossary are based on the IAEA Safety Glossary — 2007 Edition. They are not always alphabetical order as sometimes it was considered more practical to keep some words close to each other.

Base construction costs. The sum of the direct and indirect costs, and a part of the total capital investment costs (TCIC). In some evaluations, the owner's costs are included in the base construction costs.

Decommissioning. 'Decommissioning' is the administrative and technical action taken to allow the removal of some or all of the regulatory controls from a facility. Decommissioning typically includes dismantling of the facility, but in the IAEA's usage this need not be the case. A facility could be decommissioned without dismantling and the existing structure subsequently put to another use (after decontamination).

Design. 'Design' is the process and the result of developing a concept, detailed plans, supporting calculations and specifications for a facility and its parts.

Design life. 'Design life' is the period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.

Grace period. 'Grace period' is the period of time during which a safety function is ensured in an event with no necessity for action by personnel. The grace period may be achieved by means of automation of actuations, the adoption of passive systems or the inherent characteristics of a material (such as the heat capacity of the containment structure), or by any combination of these.

Interest during construction (IDC). The accumulated money disbursed to pay off interest on the capital invested in the plant during construction. Associated with every project are financial costs related to the use of capital. Money borrowed or committed for project implementation must eventually be paid back or recovered, with interest.

Levelized discounted electricity generating costs (LDEGC). Costs calculated by assuming that the present worth value of all revenues produced by the electricity generated (price at the levelized cost of the kilowatt-hour) equals the present worth value of all expenditures incurred in the implementation and operation of a plant.

Modular design. An engineering technique that builds larger systems by combining smaller subsystems

Nuclear power plant system. 'Nuclear power plant system' is understood as the element of a nuclear energy system that produces electricity and/or provides power for non-electrical application. Nuclear power plant system therefore does not include fuel cycle facilities nor waste storage or disposal facilities.

Operation. 'Operation' is defined as all activities that are performed to achieve the purpose for which a facility was constructed. For a nuclear power plant, this is intended to include maintenance, refuelling, in-service inspection and other associated activities. However, in this publication, for clarification purpose, the terms maintenance and operation are differentiated.

Overnight costs. The overnight construction costs of a power generation facility, including all direct and indirect costs, owner's capital investment and services costs, and commissioning expenses, spare parts and contingencies. These costs exclude escalation and interest charges.

Regulatory Body. An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, radioactive waste and transport safety. The regulatory body can also have the legal authority to grant licences and to regulate the siting, design, construction, commissioning, operation or decommissioning of nuclear installations.

Reliability. 'Reliability' is the probability that a system or component will meet its minimum performance requirements when called upon to do so.

Availability. 'Availability' is the fraction of time for which a system is capable of fulfilling its intended purpose.

Repository/Disposal. 'Repository' is defined as a nuclear facility where waste is emplaced *for disposal (with no intent to retrieve).* A geological repository is located underground (usually several hundreds of meters or more below the surface) in a geological formation to provide long term isolation of radionuclides from the biosphere, whereas a near surface repository is located at or within a few tens of meters or the Earth's surface.

Storage. 'Storage' is defined as the holding of radioactive sources, spent fuel or radioactive waste in a facility that provides for their/its containment, *with the intent of retrieval.* Storage is by definition an interim measure.

Requirement. 'Requirement' is defined as something required by (national or international) law or regulations, or by the IAEA Safety Fundamentals or Safety Requirements. In IAEA publications, 'requirement' should be used in this sense only. The more general sense of something that is necessary should be expressed using other words. As a consequence, in this report, the expression 'desired features' was adopted instead of the word 'requirement' that was originally chosen by the experts of the technology user countries who participated in the CUC activity.

Standardization. The process of developing and agreeing upon technical standards. A standard is a document that establishes uniform engineering or technical specifications, criteria, methods, processes, or practices.

Waste. 'Waste' is defined as material for which no further use is foreseen. Spent fuel is nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form (because of depletion of fissile material, poison buildup or radiation damage). Spent fuel is usually distinguished from waste unless it is declared a waste.

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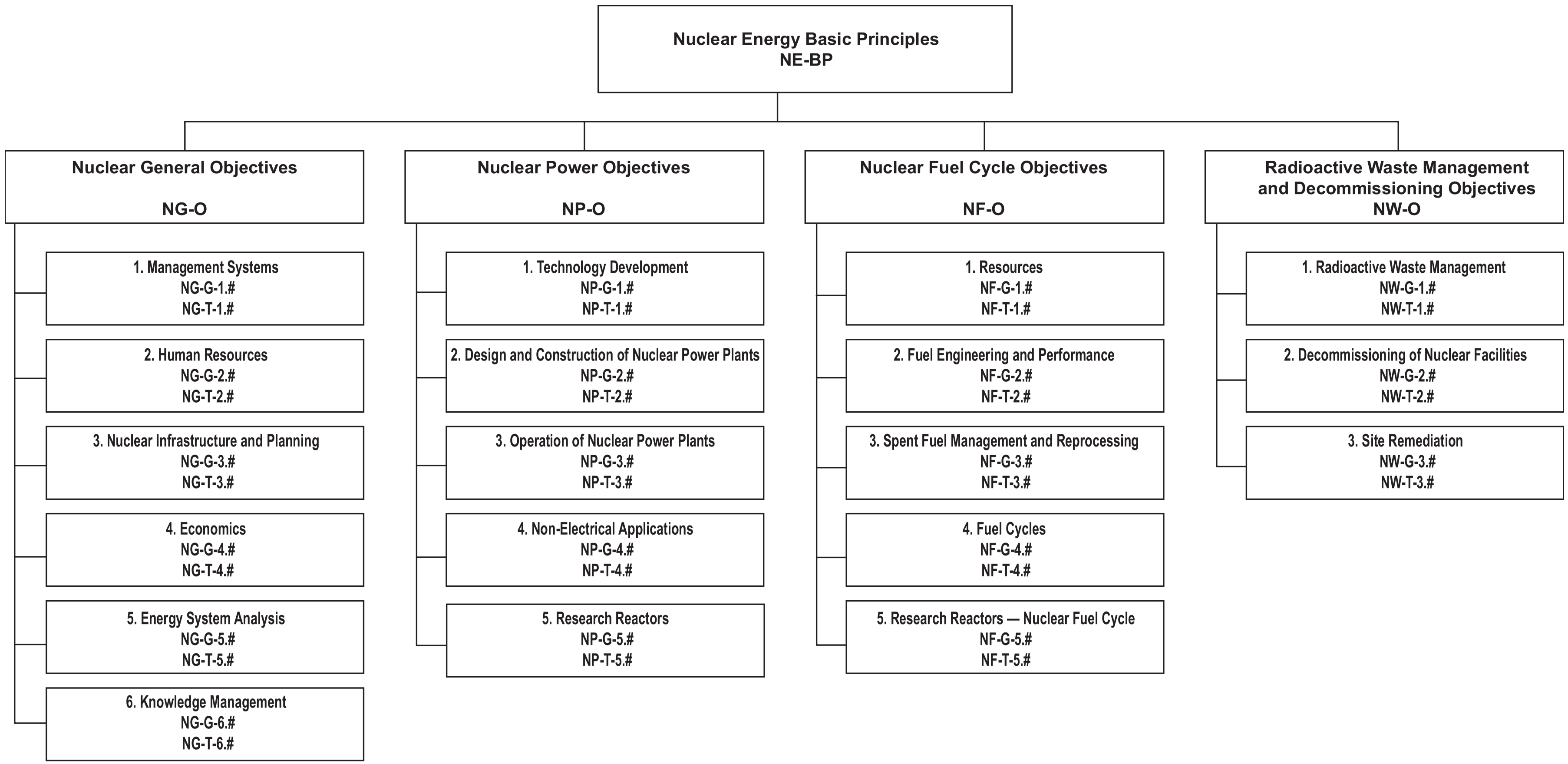

Key

BP: Basic Principles
O: Objectives
G: Guides
T: Technical Reports
Nos. 1-6: Topic designations
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Examples

NG-G-3.1: Nuclear General (**NG**), **G**uide, Nuclear Infrastructure and Planning (topic **3**), **#1**
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NF-T-3.6: Nuclear Fuel (**NF**), Report (**T**), Spent Fuel Management and Reprocessing, **#6**
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