Nuclear power in developing countries

by H.J. Laue, L.L. Bennett, and R. Skjoeldebrand*

Nuclear energy now contributes more than 12% to total electricity generation in industrialized countries, including those in Europe which have centrally-planned economies [1]. However, it still plays a minor rôle as an energy source in developing countries. As shown in Figure 1, at the end of 1983 only six developing countries which are Member States of the IAEA (Argentina, Brazil, India, the Republic of Korea, Pakistan, and Yugoslavia) had nuclear power plants in operation – a total of 13, with a combined capacity of around 5100 MWe, accounting for less than 2% of developing countries' total electricity production. In addition, 18 plants with a total capacity of about 11 000 MWe were under construction, in these six countries and in Cuba, Mexico, and the Philippines. In at least four other countries (People's Republic of China, Egypt, Libyan Arab Jamahiriya and Turkey) plants are in the final planning stage.

In the year 2000, the total nuclear capacity in developing countries might be 50 GWe, providing about 7% of their total electrical energy. The corresponding figures for industrialized countries are expected to be between 500 and 700 GWe, supplying about 30% of their total electrical energy. However, if prevailing constraints can be overcome, up to ten additional developing countries have the potential to start construction of nuclear power plants before the end of the century. Given that the lead time for plant construction in most countries is 10 to 15 years, those intending to launch programmes must take early decisions. Such decisions need to be based on careful assessment of future energy supply and demand, economic and financial implications, and requirements for infrastructure and technology transfer.

Experience indicates clearly that most developing countries actively planning and implementing a nuclear power programme require broad-scope assistance if their use of nuclear technology is to be safe, economic, and reliable. This is normally assured by bilateral co-operation, the most important channel for the transfer of nuclear technology. Argentina and Brazil are good examples of countries which have received assistance through successful bilateral co-operation, and have developed the necessary industrial infrastructure. However, other sources of assistance are needed in the preparatory phase of a nuclear power programme, before bilateral agreements can function. Assistance is also needed to establish the necessary support and surveillance structures.

The Agency's assistance is therefore directed both to general planning, and to the development of supporting structures; and is based on an assessment of needs which cannot be satisfied by other means. The Agency's Division of Nuclear Power has the technical background and tools to support a comprehensive programme of assistance in nuclear power assessment, planning, and implementation. Assistance can be provided on request either as a complete package, or as selected components.

The overall objective of such a programme is to help strengthen national capabilities of executing the following tasks:

- Analysis of overall energy and electricity demand and supply projections;
- Planning the possible rôle of nuclear power in electricity supply, through determining the economically optimal extent and schedule for the introduction of nuclear power plants;
- Assessing the available infrastructures and the need, constraints, and possibilities for their development; and
- Developing master schedules, programmes, and recommendations for action.

Proposed programmes must be reviewed periodically, and one of the Agency's aims is to ensure that national competence to carry out such reviews exists or can be developed. Training of local staff is therefore one of the most important objectives.

The Agency's comprehensive programme is addressed mainly to two categories of developing Member States: those which are in the early stage of nuclear programme planning; and those which are considering or have just taken a decision to launch a nuclear power programme. Countries which have well-established nuclear programmes have a good understanding of their requirements, and generally request assistance in specific subject areas such as the establishment of coherent quality assurance (QA) programmes (the Republic of Korea); or specific aspects of manpower development, such as high-level nuclear

* Mr Laue is Director of the Agency's Division of Nuclear Power. Mr Bennett is Head of the Economic Studies Section, and Mr Skjoeldebrand Head of the Reactor Engineering Section, of that Division.

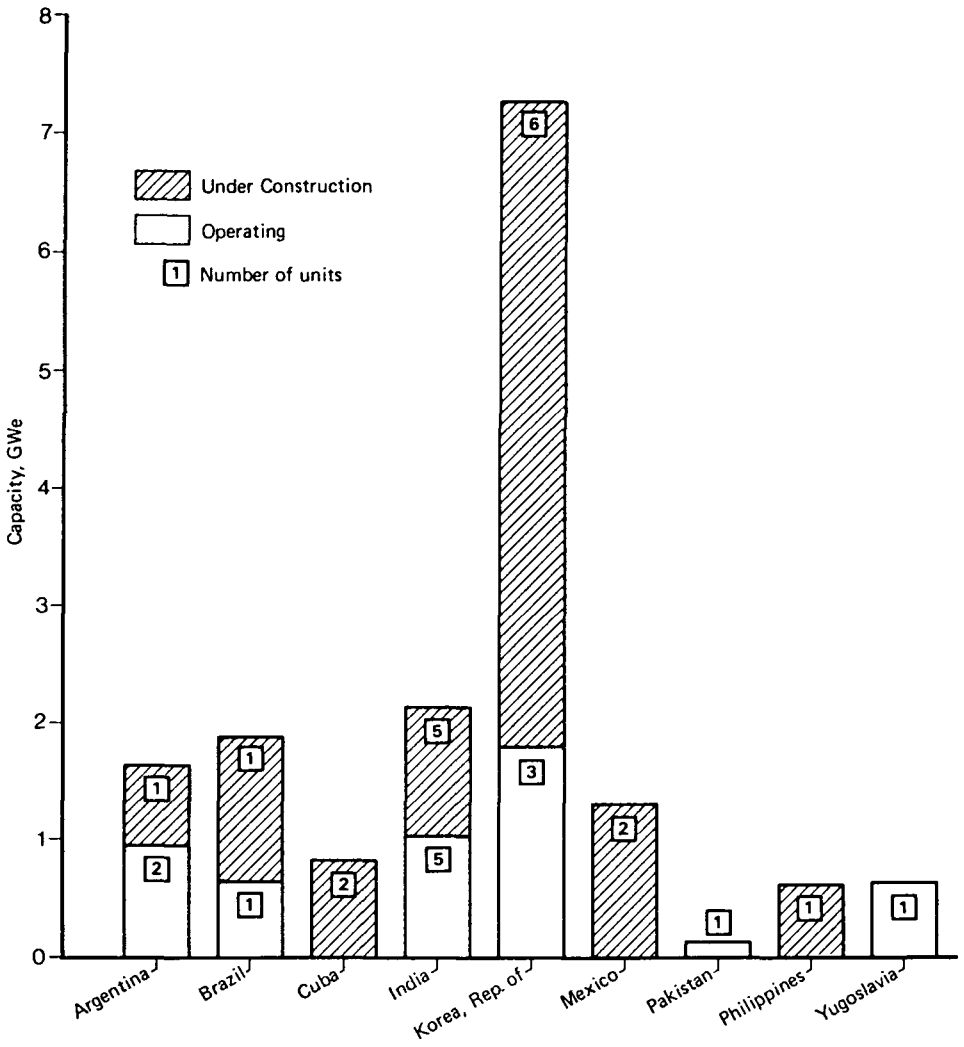

Figure 1a.
Status of nuclear power programmes in developing countries, as of December 1983.

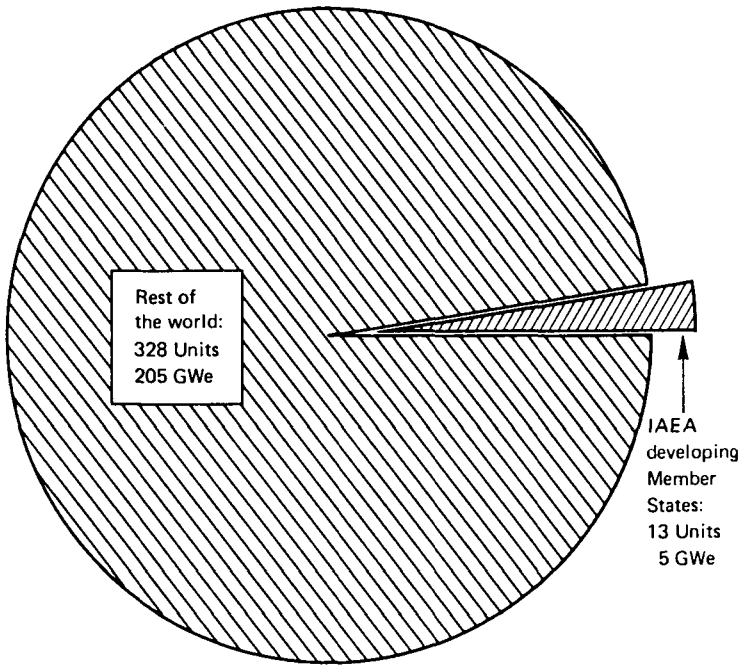

Figure 1b. Power reactors in operation, as of December 1983.

engineering education (Argentina) or manpower qualification (simulator centre in Brazil).

The Agency's Technical Assistance and Co-operation programme is and will remain the major source of funds. All the traditional means of technical co-operation such as advisory missions, expert services, fellowships and training courses are used. A steadily increasing portion of the regular budget of the Division of Nuclear Power is used as well, however, to give substantial support to technical co-operation activities. Since 1970, the staff of the Division have given a total of about 100 man-years' direct assistance to developing countries in nuclear power planning and implementation. In 1983, 70% of staff time and more than 50% of the budget of the Division were directly or indirectly devoted to the assistance programme. The Division executes each year about 40 individual technical assistance projects and four training courses directly related to specific components of the comprehensive programme, accounting for more than US$ 1 million of technical assistance funds in 1983.

Nuclear power planning

Nuclear technology is only one among many means which may be used to supply electricity and heat, and national energy planners should assess the various types and forms of energy requirements and evaluate all supply options. They should consider also the country's general planning for economic development, a long-range undertaking requiring constant review, additions, and improvement.

The Agency's assistance to developing Member States has the important objective of helping them to improve their own nuclear power planning capabilities. The Agency can make available to them proven methodologies for use in their planning of future electric power systems, including the assessment of the rôle appropriate for nuclear energy. However, the Agency cannot act as a substitute for national energy experts, who must take the final responsibility for planning the development of national energy supplies.

The Agency gives individual developing Member States direct assistance, on request, with the aim of helping them to carry out studies of their future energy and electricity requirements, and to determine the economically optimal rôle of nuclear power in the supply plan. General guidance in the complex and interrelated tasks of nuclear power planning is also given, with the objective of developing and making available guidebooks, methodologies, training courses, information, and data which are useful to all developing countries interested in upgrading their capabilities.

Direct assistance. A Member State may request an Energy and Nuclear Power Planning (ENPP) study, to be carried out jointly with the Agency [2]. The objective of such a study is to assist the Member State in making detailed economic analyses, and to determine the need and rôle appropriate for nuclear energy within the national energy plan. The Agency's analytical methodologies MAED and WASP [3] are used – improved or changed as necessary – and are released to the country during the study.

An ENPP study for Algeria, initiated in April 1980 and completed in April 1982, may be taken as a typical example. This study, which required approximately seven to eight man-years' work by Agency and Algerian experts, produced a detailed report [4] on Algeria's future energy and electricity needs and the economically optimal rôle of nuclear power. It also resulted in the development of an in-depth energy data base for Algeria, and the formation of a highly qualified expert group of energy and electricity planning specialists within the national electric utility (SONELGAZ), who are now able to use the Agency methodologies for nuclear power planning.

The Algerian study illustrates the two specific objectives of the Agency's assistance in ENPP studies. The first is to work with the requesting Member State to quantify future energy requirements, consistent with both national economic development plans and the expected share of electrical energy within the overall energy needs; and to outline an economically optimal electrical system expansion plan, including an assessment of the need for and rôle of nuclear power. Secondly, conducting the study provides on-the-job training to a local team of engineers and economists; and the country receives the Agency's computer models so that its national experts can use proven methodologies to carry out further energy planning studies.

The Agency's experience and broad capabilities have been recognized not only by its Member States, but within the United Nations system and by other international organizations. The Agency and the International Bank for Reconstruction and Development (IBRD), for example, co-ordinate their assistance activities in the electric power sector. The Agency has participated in some IBRD electric power sector assessment missions in developing countries (for example, in Jordan in October 1982 and in Turkey in February 1983). The results of such missions serve as a basis for co-ordinated follow-up technical assistance activities.

Training in nuclear power planning. The Agency conducts each year two inter-regional courses to train specialists from developing Member States to strengthen the expertise available to them to make their own supply and demand projections and to plan for electric system expansion.

The major objective of the four-week training course "Energy planning in developing countries with special attention to nuclear energy" is to familiarize energy specialists in developing countries with elements fundamental to comprehensive national energy planning, including an understanding of the rôle appropriate for

nuclear energy. The aim is to improve a country's ability to make a careful and objective choice among the various available energy options. The Agency has developed a textbook [5] for this course which contains extensive information on basic planning concepts and methods, and on the principal technological options for energy supply.

Between 1978 and 1983 more than 170 senior-level engineer-economists from 55 different countries were trained in energy planning. This course has been very successful, largely because Member States have always nominated highly-qualified participants, and also because the contributing countries and organizations have given strong support.

The second training course, on "Electric System Expansion Planning" (ESEP), has as its objective the training of specialists in planning the expansion of an electricity generation system. The course emphasizes giving realistic planning experience, through case studies which the trainees carry out during the course, using the Agency's WASP methodology to analyse their own national situation. After completion of this nine-week course, the trainee should be fully competent to carry out studies to determine economically optimal expansion programmes including, in particular, the economically optimal share of nuclear power.

An Agency Guidebook on "Expansion Planning for Electrical Generating Systems" [6] is used as a textbook in this course, and also to give general guidance to developing countries.

Including those who received training at IAEA headquarters from 1975 to 1977, and five sessions of the ESEP training course during the period 1978 to 1983, more than 160 senior engineers and power system planners from 50 countries have been trained in the use of the various versions of WASP.

The Agency's WASP methodology has gained widespread acceptance, among both Member States and financing organizations, as a sound basis for optimizing the investment requirements of electricity generation system expansion. By mid-1983, the Agency had transferred the WASP package to 45 requesting countries and five international organizations. To date, these countries report having used WASP in about 60 ESEP studies, with plans for an additional 30 or more.

Nuclear power introduction

The practical introduction of nuclear power, however, poses specific requirements and demands on national infrastructures which go beyond those which arise in general industrial and energy development planning. Recognizing that weaknesses in this area may become a primary constraint on nuclear power development, the IAEA has since the mid-1970s developed a systematic approach to assessment and development of infrastructures, categorized under the following main headings:

- qualified manpower
- organizational structures
- industrial support
- electricity grid size and structure.

One common objective in the strengthening of these structures is to assure a level of quality that will guarantee a high level of safety and reliability in all phases of a project and plant operation.

Qualified manpower. Nuclear technology is usually acquired from a more advanced country. For technology transfer to be successful, the recipient country must be capable of absorbing the technology, and the key to this is the availability of qualified manpower.

In many developing countries the need for nuclear scientists and research-oriented personnel has often been over-estimated, while the need for highly qualified and experienced practically-oriented engineers, technicians and craftsmen has been very much under-estimated. In most cases the major staffing problems have concerned engineers and technicians at all levels with practical experience for project execution and operation.

The Agency's assistance usually begins with an assessment of the need for a manpower development programme. This reviews the staffing experience of the existing organizations, and national educational institutions at all levels, and takes into account the number of graduates, their disciplines, and the levels of qualification attained. IAEA missions for assessment of manpower availability and required manpower development programmes have been performed in Egypt, the Republic of Korea, the Libyan Arab Jamahiriya, Mexico, the Philippines, and Yugoslavia.

Following such assessments, comprehensive manpower development programmes have been established with Agency assistance in the Republic of Korea and the Philippines, and in specific sectors of education in Argentina, Brazil, and Egypt. In addition, significant United Nations Development Programme (UNDP) projects (shown in Table 1) have been or are being executed in Argentina, Brazil, the Philippines and Yugoslavia. In the latter case a major project valued at more than US$ 3 million over five years helped to establish manpower qualification and a simulator training centre. It is certainly desirable that manpower development programmes take the form of multi-year technical co-operation (Yugoslavia) or UNDP projects, as they require continuity and more funds than are normally available under the Agency's regular Technical Co-operation programme.

Technician education and training for nuclear power remains a difficult problem. It is not, however, one of education and training only; it is also one of social tradition and of recognition of the technician level.

Table 1. UNDP projects related to nuclear power 1973–1983

		US$
Argentina	National centre for non-destructive testing and quality control	1 024 000
	Nuclear engineering education	2 316 000
Brazil	Nuclear manpower qualification and training	2 671 000
Chile	Support to the nuclear power programme	998 000
Peru	Nuclear power (Phases 1 and 2)	3 611 000
Philippines	Feasibility study for a nuclear power plant in Luzon	122 000
	Philippine nuclear power manpower development programme	1 114 000
Romania	Establishment of an institute of nuclear technology (Phases 1 and 2)	2 075 000
	Assistance for nuclear power stations	700 000

Only a few countries, notably Brazil, have approached it systematically, through both a UNDP project and now a project under the Agency's regular programme.

In addition to giving direct assistance to Member States, the Agency provides indirect assistance in manpower development for nuclear power, as a result of two important early decisions. The first was the launching of a nuclear power training course programme in 1975. The first series of courses were general in nature, dealing with the management problems of planning and executing a nuclear power plant project. These courses were organized in response to a perceived lack of practical experience at the management level in developing countries, and aimed at transferring experience. Planning and project managers were used as lecturers and trainers. France, the Federal Republic of Germany, and the USA offered to host training courses, and these three countries were later joined by Spain and Argentina. General courses have since 1978 been followed by more specialized courses on such subjects as quality assurance, project management tools and methods, control and instrumentation, fuel cycle management, and several safety-related topics. In total more than 450 trainees have participated in the general courses and more than 1000 in the specialized ones.

The second decision was to develop and publish a guidebook on "Manpower development for nuclear power" (TR-200, 1980). Not only has this become a much cited general guidance for Member States; it also serves as a yardstick for all assessments in Agency expert missions, as it discusses manpower requirements in both quantitative and qualitative terms in such a manner that it can be adapted to individual country situations. In this way it has also become a model for other guidebooks. The authorities of the Republic of Korea have translated it into Korean for national use.

Organizational structures. No single, optimal organizational framework designed to assure the independence of the regulatory function can be recommended equally to every country. Developing countries have in the past adopted differing organizational frameworks, all of which have worked. In some countries, for example Argentina, India, and Pakistan, nuclear power plants have been planned, built and operated by national atomic energy commissions or authorities, the regulatory authority being a separate department within the same organization. In other countries, such as the Republic of Korea and Mexico, and in most industrialized countries, the utility has been placed in charge of programme planning and project execution, and the regulatory authority has been set up as a separate organization. In Brazil a new organization was created to plan the nuclear power programme, be responsible for technology transfer, and construct the plants; operation is the responsibility of the utilities, and the regulatory body is the national atomic energy commission.

Organizational requirements are discussed in general terms in the "Guidebook on the introduction of nuclear power" (TR-217), published in 1982 (Table 2). The Agency has been asked several times for assistance in resolving detailed questions, for example in project management and execution, and in the establishment and organization of QA programmes. To provide more general advice on such questions, an international course

Table 2. Guidebooks on nuclear power

Published

Economic evaluation of bids for nuclear power plants (TR-175, 1976, being revised)

Manpower development for nuclear power (TR-200, 1980)

Technical evaluation of bids for nuclear power plants (TR-204, 1981)

Guidebook on the introduction of nuclear power (TR-217, 1982)

Interaction of grid characteristics with design and performance of nuclear power plants (TR-224, 1983)

In preparation

Nuclear power project management (1984)

Expansion planning for electrical generation systems (1984)

Qualification and training of operations personnel (1984)

Electricity grid requirements for nuclear power (1985)

Industrial support for nuclear power (1985)

Nuclear engineering education (1985)

on project management tools and methods was held in 1983. This is to be repeated, and a guidebook on the subject is to be published in 1984. A first national course on project management is to be held in Egypt in 1984. QA programmes and organizations, which are in any case indispensable to both project and operations management, are also normally required by regulatory bodies and are subject to regulatory controls. Increasing efforts are now being made to create an awareness of the importance of QA in project execution and operation, and of the plant owner's responsibility to set up the corresponding organization.

Industrial support. Competence in the construction and erection industries and in operational and maintenance capabilities is a basic requirement if a country is to introduce nuclear power. The industrial infrastructure which is already available will probably not have all the necessary technology and know-how and will not be of a sufficiently high quality to support a nuclear power programme: the requirement for high quality is likely to be new. Bilateral agreements and contracts for transfer of technology have played a decisive rôle in development of support industries. Argentina, Brazil, and the Republic of Korea are clear examples of countries where participation in nuclear power programmes has benefited local industries, as a result of their adoption of generally improved product QA schemes and more advanced production techniques.

It is necessary, however, to assess carefully the possibility of national industrial participation in a nuclear power project, and to assign clear priorities to efforts to increase such participation. First priority should be given to industries which can produce the equipment required with no or only reasonable additional effort; and to the development of engineering competence, which is essential for expanded participation in future. It is important to bear in mind both the cost-benefit ratio of the development of new industrial capability, which can be small for some of the major components, and the size of the future assured market for new production capacity.

In several cases the Agency has advised on particular industrial efforts, and has supported development and demonstration institutes, for example, in welding and quality control. A guidebook on industrial support requirements, for publication in 1985, is now being developed. Assistance given has concentrated mainly on establishing the required QA levels in the industry, both through education and training and through the advice of field experts at nuclear power projects.

It is expected that the Agency's advice will be sought increasingly. Experience has shown that problems which arise in the course of a project often have their roots in deficient QA programmes. The Agency's QA programme was established in the early 1970s. QA codes and guides, part of the Agency's Nuclear Safety Standards (NUSS) programme, have essentially been completed, and attention has now turned towards providing assistance in their application. Some 150 engineers have been trained in QA for design, construction, and operation. Several advisory missions have been sent to developing countries, and courses have been held nationally (in the Republic of Korea in 1980 and 1982, and in Egypt in 1983) to train local staff in QA requirements and practices. The Agency is now preparing to expand its assistance to Member States in this area, primarily by giving advice on the implementation of QA codes and guides in the field, through a series of manuals and by local training of inspection personnel; and by performing QA programme audits and inspections upon request.

Electricity grid size and structure. In many developing countries, this is an important factor limiting the introduction of nuclear power: the grid is often too small and fragmented to permit introduction of the fairly large nuclear power plants which are commercially available. The stability and reliability of the grid and its interaction with nuclear power plants also poses specific problems which have only recently been recognized clearly. In severe cases, grid-induced plant cycling may ultimately limit the safe lifetime of a plant.

An Agency guidebook on the problems of grid-plant interaction (TR-224, 1983) was the first summary of the technical aspects of this potentially important problem area. However, no standard approach has been developed to assess the adequacy of an electric grid for introduction of a nuclear power plant, and the Agency has not yet been asked for assistance in this area. Any technical assessment of grid adequacy to accommodate a specific nuclear plant will be a very complex task.

The experience of India is relevant. The structures of the grids in that country were adequate in size for the first nuclear power plants, but they did not meet the reliability requirements; nor did they permit high plant utilization. Substantial improvements were achieved when the interfaces between plants and the grid were carefully analysed, and the requirements placed upon the nuclear plant during network transients taken into account in the central system load dispatching. It must be expected that in the future Agency advice will be sought on how improvements can be achieved in such situations.

References

[1] Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, Romania, and the USSR.
[2] See also "An assessment of nuclear energy in developing countries: how the Agency can help", IAEA Bulletin, Vol. 24, No.3, September 1982, page 3.
[3] MAED – Model for Analysis of Energy Demand; WASP – Wien (Vienna) Automatic System Planning.
[4] In press.
[5] To be published during 1984.
[6] To be published during 1984.