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Developing Industrial Infrastructures to Support a Programme of Nuclear Power

A Guidebook

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1988

DEVELOPING INDUSTRIAL INFRASTRUCTURES TO SUPPORT A PROGRAMME OF NUCLEAR POWER

A Guidebook

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FOREWORD

For several decades the electric power industry has been steadily expanding to respond to an ever increasing demand for dependable electricity. All over the world hydro and fossil fuel thermal power stations have been and still are being built to provide the required central electricity generating capacity.

The construction of nuclear power generating plants began in the late 1950s. Presently there are 374 such plants in operation around the world. In 1958 these plants generated some 1400 TW·h of electricity or about 15% of the total world generated electric power. Over the past two decades, the number of both developed and developing countries initiating nuclear power programmes has increased, although at different paces.

However, when compared with the early forecasts, the growth of nuclear power in the developing countries has been lower than anticipated. A close analysis of this downward revision in the extent of nuclear power in those countries reveals that despite their needs, a number of developing nations could not make any headway in going nuclear. A lack of the necessary infrastructures prevented them from being able to manage an increasing control over and participation in the execution of a nuclear power programme.

This Guidebook, then, is intended to offer assistance in the many considerations and decisions involved in preparing the national industry for participation in a nuclear power programme. The heavy financial investment, the setting up of certain infrastructures many years ahead of plant construction, plus the high level of technology involved require early and systematic planning.

A further purpose of this Guidebook is to serve particularly those decision makers and planners in the various governmental authorities, the technological institutions and in the industries likely to be involved in a nuclear project. These industries include the services of the national engineering resources, the domestic design and manufacturing groups as well as the civil construction companies. These will be responsible for plant erection, testing and commissioning and most of all for the establishment of a framework for quality assurance. All of these are the components of an essential infrastructure necessary to raise the standards of the national industry and to displace increasingly foreign suppliers to the extent possible.

In addition, this Guidebook should help to show some of the implications, consequences and options involved in a nuclear power programme. It does not consider the basic decisions for going nuclear, nor does it review the choice of the technology or nuclear process selected for the programme. Instead, it limits itself to a consideration of the nuclear power plant and its essential cycle activities.

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CONTENTS

INTRODUCTION

The successful execution of a nation's nuclear power programme is dependent on the presence of a network of industrial infrastructures within that country. These infrastructures, covering a wide range of activities, basically include the capabilities:

— to plan, administer and regulate the execution of a nuclear power project
— to operate a reliable and adequate electric power generation and transmission system and to implement its timely and necessary expansion
— to staff both public and private organizations and industries with qualified personnel at all levels
— to provide the required R&D supporting services for technological development
— to foster adequate support by the national industry so that the targeted level of participation in the execution of power projects is attained
— to procure adequate financing for the necessary investments.

This Guidebook will focus mainly on the demands placed on the capabilities of the national industries in order to permit a viable development of the nuclear power project. The other infrastructures mentioned above will be discussed to the extent that they influence the response of the national industry. The role of the government, therefore, will be presented mainly as that of creating incentives for the involvement of potential national suppliers. Its promotional role will include creating a climate of confidence regarding programme continuity, as well as organizing a legal regime to protect the interests of the domestic industry. The government is also responsible for ensuring a positive aptitude for and close monitoring of the transfer of relevant technologies to the national suppliers.

A further concern of this Guidebook is to examine the objectives, methods, schedules and personnel resources necessary if the nuclear power programme is to be carried out in the optimum conditions. Thus a full appreciation is needed of the importance of:

— organizing the preparatory activities efficiently
— being realistic about national involvement
— participating positively in the execution of the project.

As is evident from the discussions in this Guidebook, it is not economical to build only one nuclear plant. This Guidebook assumes, then, that the nuclear programme envisages several power plants even if the timing of the project is extended. Another assumption is that the country embarking on a nuclear programme will resort to a transfer of technology irrespective of the time necessary for this process.

Many of the tasks to be completed prior to the nuclear project decision involve an audit of the country's industrial and human resources and an appraisal of the steps necessary to carry out such a major project with maximum efficiency and optimum spin-off to the country. Those audits or appraisals and their subsequent analysis can be of immense help to the nation even if the programme were to be delayed.

The audit results in this latter case would not be wasted, but would, on the contrary, permit the country to plan for the industrialization and upgrading of the human resources necessary for industrial advancement. The subsequent carrying out of a major project (nuclear or non-nuclear) would then be executed more efficiently in less time and with less cost.

Several International Atomic Energy Agency publications deal extensively with these basic infrastructure issues and provide detailed information on these aspects of a nuclear power programme. They include:

— Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217, IAEA, Vienna (1982)
— Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants: A Guidebook, Technical Reports Series No. 224, IAEA, Vienna (1983)
— Manpower Development for Nuclear Power: A Guidebook, Technical Reports Series No. 200, IAEA, Vienna (1980).

CHAPTER 1

AN EXECUTIVE OVERVIEW

1.1. INTRODUCTION

It must be recognized that in support of a nation's industrial infrastructures there must be other general infrastructures within which the industries can operate successfully. These supporting infrastructures have a direct influence on the response of the national industries to the requirements of the nuclear technology. They can be positive if they function well or negative if they are not adequately developed or do not interact with each other in an efficient and co-ordinated manner. For example the industrial sector cannot develop if there are not qualified personnel to staff the necessary functions both in the workshops and engineering offices. Thus an educational infrastructure must be established to provide the relevant academic technology and management training. Similarly, the industry cannot operate without a legal regime setting up regulatory directives with respect to the applicable codes and standards, licensing and quality assurance (QA) enforcement. In addition, communications and transportation are vital to industries as are the R&D infrastructures and a legal system which regulates the mercantile sector.

The total infrastructure of a nation can be viewed as a set of components which interact with each other to various degrees (see Fig. 1). The infrastructures under direct government control are not the objective of this Guidebook. However, since they reflect indirectly on the industrial infrastructures, it is appropriate to discuss briefly to what extent the promotional role of the government in all sectors is essential to industrial development and to note the important role played by the government through its direct and indirect influence.

1.2. THE GOVERNMENTAL FUNCTIONS

The one component of the total infrastructure that is central to the implementation of a new and large endeavour is undoubtedly the government as represented by all its departments and political structures. The government provides a focus and is a source for major movements towards new commitments. It also represents the formal link between domestic intentions and external countries and agencies. In this respect, whether in the context of the broad national level or for setting details in specific areas of the infrastructures, a planning process is essential.

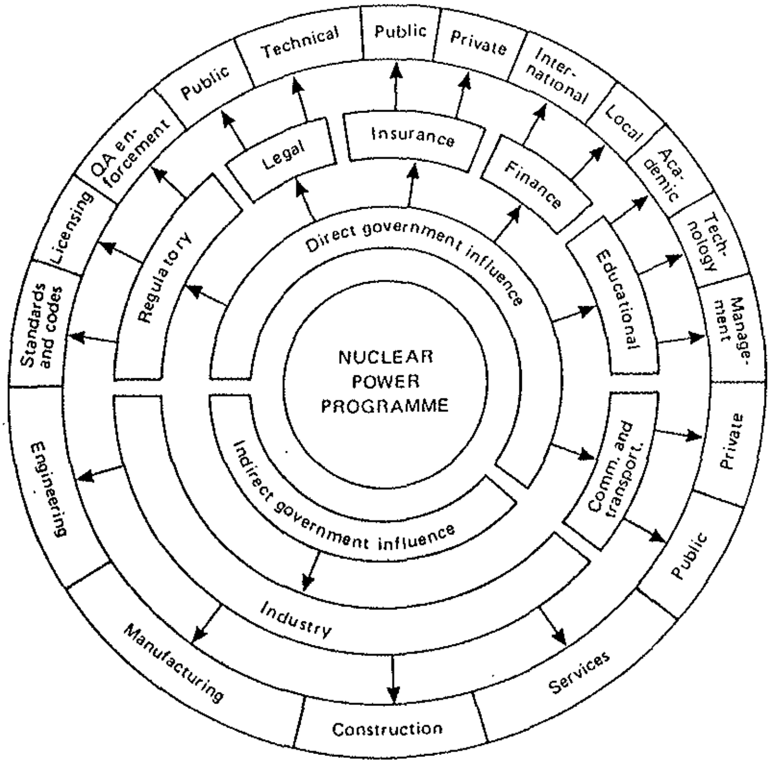


FIG. 1. Basic infrastructures to a nuclear power programme.

1.2.1. Planning for the infrastructure

National planning led by the government is an essential element in exploring options available to a country and in assessing associated costs and benefits. The government can help to determine whether a major programme, such as an NPP, is a viable option, when it should be implemented and what agencies should be involved. It is also the role of the government to discuss what priorities are to be emphasized regarding job creation, foreign exchange demand, scheduling and other aspects of the nuclear power project.

The planning process will recognize those existing policies which influence or determine national activities and lead to recommendations for new policies. These policies may include taking positions on such issues as public versus private enterprise, resource allocation, trade and tariff barriers, and the degree of encouragement of foreign investment or other participation. Government policy identifies the jurisdictional control over education, health and safety measures and will be reflected in laws and regulations on matters such as technology transfer and foreign ownership.

Four major assessments are sought from the planning process; it is necessary to determine:

(1) What range of domestic participation is currently possible and what levels are desired;
(2) What investment in resources (money and people) is necessary to achieve the desired domestic participation;
(3) What foreign assistance is required and available;
(4) What is the timing of the entire process.

To be effective, the planning process requires the analysis of data and objectives relating to the increase in population, mechanization and automation of industry. Advances in transportation and mining activities as well as general economic growth are additional areas to be studied.

Specifically, the distribution of energy can require the planning of a progressive improvement in local isolated grids with development of links to form a national or international interconnected system. The planning process and supporting analysis are possibly the most important elements in developing the infrastructure to support a nuclear programme. During this phase a decision must be made regarding the contractual regime under which the first NPP is to be procured. This decision is important as it will condition the required supporting industrial infrastructures.

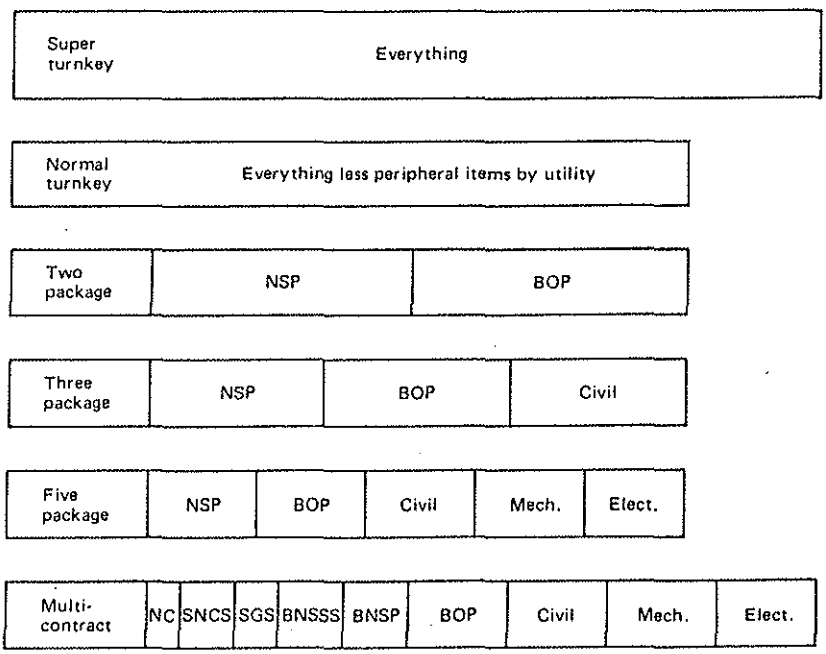


FIG. 2. Types of contract approaches for nuclear power stations.

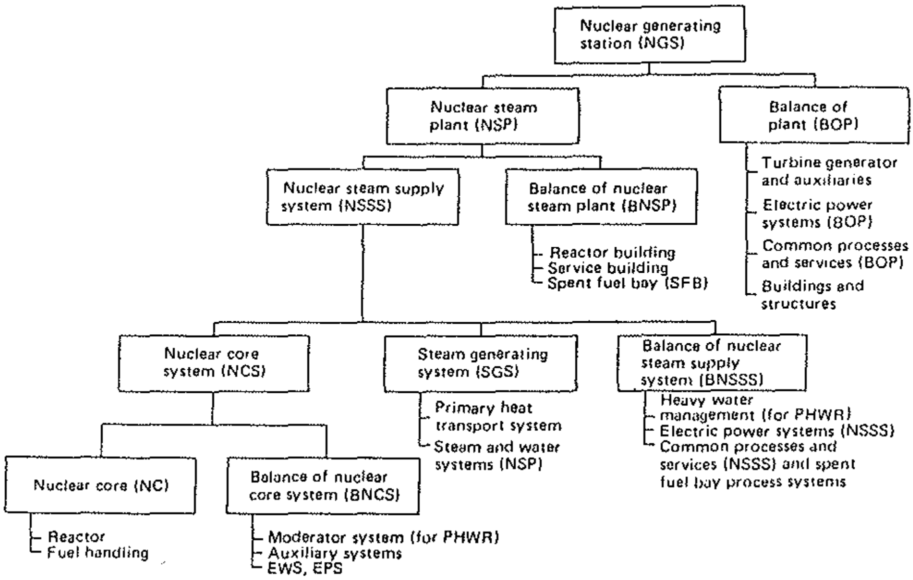


FIG. 3. Component parts of the plant.

Local industry should be surveyed during the preparatory phase to identify companies potentially capable of participating in a nuclear power programme. The survey should recognize the role of industry in the nuclear power programme and should lead to the identification of suitable firms and an assessment of their potential involvement.

Often a nation when first starting a nuclear power programme will choose the single responsibility turnkey approach because the utility has limited resources and experience. The responsibility for total performance including design, construction and commissioning is then placed upon the foreign contractor and less involvement is required by the utility in influencing or approving the design. Thus a simpler agreement can be achieved.

After acquiring experience, a nation may choose situations where the plant is built under a few contractual packages. Split package approaches require a greater involvement by the utility than turnkey jobs because the utility must evaluate and control complex interfaces and hence take an approval role in design. The split package approach may be chosen by nations seeking to develop a measure of self-sufficiency by acting as their own prime contractors.

The different contractual approaches which are normally used are schematically illustrated in Fig. 2 and are based on the component parts of the plant as shown in Fig. 3.

1.2.2. Supporting the national industry

The local involvement is not only in plant operation and maintenance, but also in civil construction, mechanical and electrical installation and equipment manufacture. While some areas of work, both nuclear and non-nuclear, have a high technological content and stringent quality requirements, other parts of the programme such as the construction of miscellaneous buildings, minor civil works and fencing will involve no more than normal engineering practices. Also, there may be local firms already capable of manufacturing much of the construction equipment and the less critical components of the system.

In addition to meeting technical requirements, local industries must be aware that both cost and management present serious challenges. The products of local companies may be more expensive than those from foreign competitors who have extensive experience in manufacturing the particular products required and already have standard designs and procedures. The foreign companies will likely have a larger production, so overheads will be correspondingly less. Also the foreign suppliers may have much stronger managerial resources to control the manufacturing process and to meet schedule deadlines.

The support that can help local manufacturers, however, is derived from a combination of political, technical and organizational factors within the infrastructure. Whether or not local manufacturers are given protection will depend on the benefit seen accruing to the country. Before making a decision it is necessary to evaluate if investment, whether directly through subsidies or indirectly through tariffs or import control, will lead to stronger companies able to compete later in further nuclear or other allied high technology projects that are planned without subsidies. The implication, if the evaluation is positive, is that the main contract for the nuclear power plant could require that bids must be obtained from local companies where local involvement is possible.

However, much more is involved. If local companies do not understand properly the technical and commercial conditions in the bid documents, they may increase their prices higher than necessary out of an unjustified anxiety. Also, they may not appreciate how tough foreign competition can be and, even with government protection, include too much profit. At the same time, it is too much of a burden on the foreign contractor to insist that every local supplier be given the chance to renegotiate every time its price is too high.

In most cases, extensive transfer of technology will be necessary if local participation is to increase as the nuclear power programme progresses. Once the local participant has been identified, adequate resources must be provided to absorb and to use the technology. The participants will have to invest a large amount of the time of some of their best personnel. They will also perhaps have to spend great effort in development and testing facilities, and so will need to be given the confidence that the effort is justified. Such investment requires a consideration of the

TABLE I. HANDLING OF HEAVY EQUIPMENT (1300 MW, PWR unit)

	Weight (t)	Diameter (m)	Length (m)
EQUIPMENT WHICH CANNOT BE SHIPPED BY RAIL			
Reactor vessel	320	4.50	10.20
Vessel lid	80	4.20	3.35
Pressurizer	117	2.80	13.80
Reactor internal equipment			
— Upper	46	4.30	4.40
— Lower	115	4.30	10.13
Steam generator			
— Lower	300	3.75	14.65
— Upper	135	5.00	8.05

needs of individual industries and of the broader needs of the infrastructure. Government support and co-ordination are essential for this assessment phase.

1.2.3. Transportation

When a major project, such as a petrochemical plant, a mine or a nuclear plant, is implemented, improvements or extensions in the transportation sector may be essential. New roads or ports with heavier load capability may be necessary for delivery of equipment and material. However, there are further implications. For each method of transportation, there must be an assessment of whether the routes are suitable for delivery from foreign suppliers and from domestic manufacturers to the project site. For example, the suitability of a method of transportation must consider the weight and dimensions of the large components involved. A turbine generator rotor can weigh several hundred tonnes; a reactor vessel or a steam generator may have a length of the order of 15 m. Bridges and culverts have to be checked to ensure load carrying capability, and obstructions such as tunnels and transmission lines need to be considered. In most cases, even with a well developed transportation sector, a new project site for a nuclear plant may require some extension of the existing facilities. This may be a major project in itself with its own impact on aspects like foreign exchange and long term debt. Table I gives an idea of the problems involved in the handling of some heavy components.

The choices then that have to be made in terms of which existing forms of transportation can be used, or what new developments must be implemented, have implications on schedules and domestic participation. A mode of transportation too slow or subject to disruption from weather conditions can result in extended delivery times and schedule delays.

Planning and assessment in the transportation sector are vital ingredients in the implementation of a major national project. If it is not well planned, the penalties can be large enough to hurt seriously the economic benefit of the project. However, good planning can bring benefits which extend to many other sectors of the economy.

1.2.4. Communications

The ability to transmit data and information is essential to the effective operation of all components in the infrastructure of a nation. The communications network is the neurological system of a nation. This system links sources of data measuring results, such as trade and industry, to organizations using information to make decisions, such as a ministry, a bank or other sectors of business and government.

The physical attributes of these systems will determine how well they can serve the communication needs. Obsolete equipment or poorly maintained systems will result in poor performance in the exchange of information with attendant delays and increased costs for any project which must depend on efficient communications.

In summary, the communications requirements for a project must be reviewed in relation to the facilities available within the existing infrastructure. New development and investment in the communications sector may be required both to ensure that delays do not jeopardize the value of the project and to help increase domestic participation.

1.2.5. Education and training

The balance of benefit and cost derived from science and technology must be adequately weighed in the planning process. Because an NPP programme can have large implications on all aspects of the nation, the educational system should train people able to judge these implications from a sufficiently broad collective perspective. Hence, while a nuclear programme will recruit scientists and technologists from the educational system, making the correct decisions with respect to technology options also requires that the system provide skills across a broad spectrum of disciplines.

For the domestic industry to develop and attain the targets set forth by the national participation policies, a large number of technicians and craftsmen must be available and training centres equipped to give the trainers the necessary initial hands-on experience. The technical education system of a country produces the engineers, scientists, technicians and craftsmen to work in industry. Clearly, there is an interaction between what the industry needs and what the system produces, but the interaction is often weak and there may be delays in providing new types of education required for new industrial technologies.

One important reason for such delays is that the system serves other groups besides industry and the objectives of the technical education system may not be the same as the objectives of industry. These factors can create difficult interfaces between industry and the education systems. Further, because the output of the education system is used by all sectors of the nation, the system is usually directed by government; industry is seldom involved and universities especially often enjoy a degree of autonomy. Industry itself may therefore have to make good any deficiencies in the technical education system by providing specific nuclear training and operating industrial apprenticeship programmes.

The adequacy of the education system is fundamental to successful technology transfer, which requires personnel with the capacity to absorb as well as practise the technology. Evaluation, and upgrading if necessary, of the technical education system should be a priority for a nation embarking on a nuclear power programme and should be done well in advance of the first nuclear power project.

The evaluation should cover these questions:

(a) Does the system offer qualifications at the three levels of training: craftsman, technician and professional engineer/scientist in disciplines relevant to the industries of the country and to the nuclear power industry?

(b) Are the content and the standards of courses leading to these qualifications appropriate for the nuclear power industry?

(c) Are courses available, at each of the three levels, which are practically oriented and which include work experience appropriate to employment in the industry?

In addition to evaluating the system providing initial education, post-experience education given to people who have spent several years in employment since completing their initial education should be considered. The objective of post-experience education is to bring a person's knowledge up to date, and to extend his/her capabilities. In a period of rapid technological change, the demands for updating technical knowledge is clear. Similarly, the need to extend capabilities results from the demands of new or developing technologies.

For example, engineers filling positions in a nuclear power programme may require updating of classical engineering subjects, such as thermal hydraulics; people concerned with nuclear fuel performance may need increased knowledge of materials' behaviour; individuals responsible for technical supervision and other roles may need to improve managerial techniques.

The problems of preparing the manpower required by a nuclear power programme are treated extensively in the following publications:

- Manpower Development for Nuclear Power: A Guidebook, Technical Reports Series, No. 200, IAEA, Vienna (1980).
- Engineering and Science Education for Nuclear Power: A Guidebook, Technical Reports Series, No. 266, IAEA, Vienna (1986).

1.2.6. Financing

The nuclear power programme requires the provision of capital funds to many sectors. Table II shows a typical distribution of the costs associated with such a programme, and Table III presents a quantitative structure of the owner's capital costs.

Typical sources of financing include:

- Local sources: own resources (rare), debt capital, etc.
- Foreign sources: international markets, export credit agencies, suppliers, international development organizations
- Countertrading (less frequent, practical for relatively small amounts and difficult for larger amounts).

The financial infrastructure may involve adjustments to the country's national budget in order to provide some of the funds. The financing plan for the procurement of the plant will probably involve a number of sources, the sum of which needs careful management since long term commitments, in some cases extending up to 20–25 years, are involved.

Whichever financial infrastructure and plans are adopted, they have to be realistic and inspire confidence in the lenders and participants. Thus, it would be reassuring if the country embarking on a nuclear programme itself provided some finance as a sign both of governmental determination and confidence in the success of its own programme. Equally, when international financing sources are necessary, it is always reassuring to the foreign lenders to be shown that the nuclear programme does satisfy a realistic forecast energy need, that the infrastructures and the nuclear programme have been well thought out and that a maximum of the relevant experience of other nuclear programmes has been injected into the overall plan. In addition, the use of well experienced nuclear contractors and vendors for the execution phase is a further comfort to the lenders.

The key participants in the nuclear programme and the future owner of the nuclear plants will evaluate as best as possible the likely costs of the various components of the nuclear programme, not forgetting to include provisions for contingencies. Then, the various options for raising the finances required and establishing the modes for repayment of the loans are designed and assessed for their merits. These options will require developing future scenarios on such factors as: cash flow, revenues, interest rates, inflation and exchange rates.

TABLE II. TYPICAL COST MAKE-UP OF A NUCLEAR PROGRAMME

Plant owner's capital costs		Engineering, procurement and construction of plant
		Site temporary facilities, land acquisition, etc. Fuel (first load) Spares
Plant owner's other costs	Services	Consultants, site investigation, etc. Know-how acquisition and updating of operator training, simulator facilities etc. Regulatory and licensing (owner's costs) Own engineering and management (incl. site activities)
	Equipment	Owner's supplied materials and equipment Site temporary facilities (for owner's use)
	Other	Insurance and legal Interest, escalation, exchange rates (if applicable) Modification to transmission network Contingencies
Additional costs		Establishment of regulatory body Education, training, technology transfer R & D facilities Legal and insurance dispositions Environmental measures Transportation, communications, etc. Industrial development and technology transfer Financing costs (interest and debt services, inflation, etc.)

These analyses converge in a recommendation accompanied by a list of risks that the implementation of the recommendation will incur, especially regarding bank interest rates, inflation, exchange rates and extra costs. This whole exercise is best carried out under the leadership of a single authority. In view of the high costs involved, it is common practice to have an adequately experienced outside organization carry out a similar exercise or at least check thoroughly the basic data, the method and the results of the initial exercise.

The transfer of technology may require assurances on payment for equipment, royalty fees and the cost of training. The payment of construction forces and local manufacturers will require banking and financial services which are appropriate to the needs of the programme.

It is most likely that the funds to be raised will involve international contributions especially with respect to the procurement of the plant. This may in turn require the government to intervene directly or indirectly, for example, in guaranteeing any loans or prepayments.

Government is a prime player in the economic structure and decision making process of the whole framework; the banking and financial community in a country is an important tool for assuring that major economic and programme intentions can be achieved.

1.2.7. Legal system

The legal system of a country must provide a framework within which various sectors of the industrial infrastructure can operate while providing safeguards for the interests of individuals and companies. Such a system includes laws covering contracts between companies, both local and foreign, regulations concerned with employment of labour, and professional practices.

TABLE III. CAPITAL COST STRUCTURE BY ACTIVITIES (TYPICAL VALUES)

Percentage	Activity	%	
15	Engineering design and management (Incl. site management)	• 50	Nuclear engineering
		• 10	Civil engineering
		• 23	Mechanical engineering
		• 17	Electrical engineering, instrumentation and controls
50	Material and equipment (incl. transp. insurance and spares)	• 26	Nuclear steam supply system
		• 30	Balance of nuclear island
		• 12	Turbine generator
		• 32	Balance of conventional island
35	Construction and startup (incl. site procured materials and site temporary facilities)	• 62	Civil
		• 28	Mechanical
		• 10	Electrical, controls, instrumentation
100	Total plant cost (incl. contingencies by suppliers)		

Early in the planning for a nuclear programme, laws and regulations appropriate to this technology should be put in place. These may be new laws and legal processes involving in some cases the creation of new agencies or structures such as a regulatory authority for licensing facilities and control of radioactive materials. However, existing laws and structures may be sufficient or require little modification. An established system of laws and regulations relating to intellectual property is particularly important for technology transfer and should cover such matters as patents, trade marks, and licensing.

Established laws and regulations are important because they provide protection and security to both foreign and local organizations involved in the nuclear power programme and in technology transfer. A foreign company could be reluctant to participate in a nuclear programme if the legal system of the country did not provide a fair framework for that company's commercial activities and protection for its business interests and personnel.

1.2.8. Regulations, standards and testing

Certain agencies, defined by law, should exist within a country to carry out regulatory mandates such as ensuring conformance with building construction codes, pressure vessel design guides, construction practice requirements and radiological protection guides.

The regulatory bodies require personnel with appropriate knowledge of the features of the technology and the applicable standards so that proper judgements can be made concerning the validity of the design, manufacture, construction and operation of the plants.

Regulations controlling the use of ionizing radiation and experience in regulating the use of X-rays, gamma rays and radioactive materials in medicine and research may already exist. While this provides a base of relevant experience, regulation of the activities of a nuclear power programme is more complex and calls for a very wide range of engineering and scientific expertise.

In general the supplier will make use of a combination of its own national standards and international standards in designing and specifying the nuclear power plant. Some standards dealing with specialized aspects of the power plant have been prepared by only a few countries in the world. Many more standards will relate to common industrial practices.

The use of different sets of standards in the same technical area is a potential source of confusion and error. It is therefore desirable to reduce the number of duplicated standards which are referred to for a project. Such a reduction can be effected by adopting standards identical to the supplier's or by using existing national standards. However, it must be recognized that there are major schedule and cost implications which are sensitive to what is chosen.

Formation of a national standards organization should be given high priority. There will be suppliers of other technologies who may use different standards and as the country's industry develops, both the manufacturers and the major buyers of industrial goods will tend to set their own standards. In the absence of a national body to impose some uniformity, the nation may find itself with a multiplicity of duplicating standards. As time goes on, it can become increasingly difficult to rationalize the situation because the buyers, and to a lesser extent the manufacturers, will find it takes considerable effort and expense to change from the particular standard with which they have been working. It is better therefore to establish national standards from the beginning.

Since components will be manufactured to drawings and specifications, checking that the component conforms to the intention of the designer requires measurements, most frequently of dimension, but also of weight, temperature and chemical composition. Checking that the fabrication has been done properly will involve both destructive and non-destructive tests, using techniques such as radiography, ultrasonics, eddy current, dye penetrant, toughness and impact testing, tensile strength and microscopic examination of metallurgical sections.

There is a need to calibrate all measuring instruments against accurately known quantities by using gauges or other devices which are stable and calibrated against quantities which can be traced to the international standards. Test laboratories and services, therefore, are an essential component of the infrastructure whether set up as national facilities or within individual manufacturing organizations.

The final test that the regulation process, the application of appropriate standards and suitable testing have been properly carried out is seen in the performance of the programme. For a nuclear programme this will mean that construction schedules are achieved, plant performance is amply demonstrated, costs are controlled, and the safety of the workers and the public is ensured.

1.2.9. Research and development

In the context of introducing a new and major development, such as a nuclear programme, the status of existing R&D in the country may be viewed in terms of how it can support the new programme. An alternative view is that quite separately from any major industrial or energy programme, conducting basic research in even a few key fields is comparable to retaining membership in a club; nations which do not pay their dues are excluded. By contrast, countries which develop research strength in even a few fields can have entry to many sectors which provide an opportunity to enlarge the knowledge base and methodologies available to many parts of the economy.

R&D covers a range of activities including:

— Basic science research to improve and extend knowledge of fundamental mechanisms, often undertaken without any particular application in mind;
— Applied technology development, usually undertaken to support a specific and real industrial objective.

The following list shows some basic science research areas with relevance to a nuclear power programme as well as a few of the many applied technology topics which could be supported by each research activity.

BASIC SCIENCE	*APPLIED TECHNOLOGY*
Geology, Hydrology, Soil Science	Stability of soil, foundations Fluid dispersion in soils
Thermal hydraulics	Atmospheric dispersion Flow and temperature in plant system under normal and abnormal conditions
Structural analysis	Plant and component design Behaviour under stress and temperature
Statistical theory, Mathematics	System reliability & safety consequences of operating defects Probability of accidents
System analysis and Control theory	I & C system design Computer programs
Electronics	Instrument design, measuring techniques
Interaction of radiation with matter	Irradiation of human tissue Shielding materials Radiography Nuclear fuel performance
Materials science	Nuclear fuel design Power plant water chemistry Welding, Non-destructive testing Bulk & surface treatments, e.g. heat treatment, surface hardening

There are two important points to note. First, nuclear power encompasses very broad ranging technologies. Secondly, although not listed explicitly, there is usually more than one basic science research activity relevant to any applied technology development. For example, electronics, as well as control theory, is relevant to control system design; materials science, as well as the interaction of radiation with matter, is relevant to nuclear fuel performance.

A national R&D programme is beneficial to many sectors. Engineering, construction, manufacturing and plant operating groups, quality assurance agencies and regulatory bodies are examples of organizations which will have vital interests in the results of both basic science and applied technology research. The relevance of the R&D infrastructure to industrial development is apparent.

1.3. THE INDUSTRIAL INFRASTRUCTURE

Developing the industrial infrastructure involves the arrangement or rearrangement of a number of industries in the country whether for services, materials supply and fabrication or construction, so that optimum participation is achieved by these industries. In this way the best industrial support is provided to the nuclear programme and the maximum of positive spin-off is obtained by the industries.

In order to establish this infrastructure, the following key questions have to be considered:

(i) To what degree does the country wish to be independent with respect to the execution of the programme, the operation of the plants and their maintenance?

(ii) To what degree is it feasible for the present industries to meet these objectives and participate with their existing know-how, and what new technology and facilities are needed? To make up for any deficiencies is the transfer process that would be provided compatible with the timing of the nuclear programme?

(iii) What investment is required in setting up the planned industrial infrastructure and is that investment economically viable?

(iv) Will the new infrastructure open up to new non-nuclear work and will it help to make the existing industries more competitive?

(v) Will the human resources be able to meet the additional load implied by participation in the nuclear programme?

(vi) How firm is the nuclear programme and is it likely to change along the way?

In other words to what degree should the country's industrial resources participate in the programme so that the participation is economically sound and yet is able to meet certain politically strategic needs? In all cases, if an industrial infrastructure is to be a real success, it should be first economically viable so that it may provide a maximum of motivation to the participating industries.

TABLE IV. PREVIOUS RELEVANT EXPERIENCE

Industrial infrastructures	Minimum role/participation	Useful previous experience
Engineering companies	— Design and engineering of utilities	Participation in the BOP engineering of: thermal power plants, chemical plants, refineries, etc.
Manufacturing industries	— Bulk material production	Production of rebar, small piping, cables, painting, cement, etc.
	— Fabrication of equipment	Fabrication of low pressure tanks and valves, heat exchangers, ventilation equipment, pumps, switchboards, instruments, etc.
Constructors	— Construction in civil works (non-nuclear)	Participation in ports, complex buildings, airports, hydro projects, etc.
	— Erection (up to 400 t lifts)	
	— Management of • Project execution • Cost/schedule control • Quality assurance	Companies in engineering and construction management, quantity surveyors, cost and schedule management and high standard quality controls in important projects

The nuclear features that have a particular impact on the industrial infrastructure include:

- the need for advanced technology
- the high quality standards required
- the use of unusual materials such as titanium and zirconium
- the unique design and the scarcity of some of the equipment
- the unusually large size and weight of some of the equipment
- the long term schedules which are critical in many areas
- the need for costs to be competitive.

Sometimes, the subsequent exporting of 'nuclear' or nuclear associated equipment is thought of as a possibility and therefore as a justification for investment in the industrial infrastructure. In that case, the questions of economics, delivery schedule, meeting the standards of the buying country and competition must be thoroughly considered. In export, the competition is severe; the nuclear programmes of prospective buyer countries can fall behind schedule or change in size and even in technology. Furthermore the import regulations of the buying country may eventually be a hurdle. Thus all export considerations need to be carefully checked into and given the weight they merit when decisions are being made on the industrial infrastructure. In the best of situations nuclear export possibilities are in general very limited.

The industries involved are those directly implicated in the programme such as engineering companies doing engineering and project management work, the suppliers of equipment and materials, and the construction contractors for site work. There are also the indirectly associated industries such as the testing laboratories, subvendors and subcontractors, training centres, the maintenance services and transportation. About 300 to 500 companies may participate. Table IV shows the previous relevant experience necessary to qualify as national subcontractors.

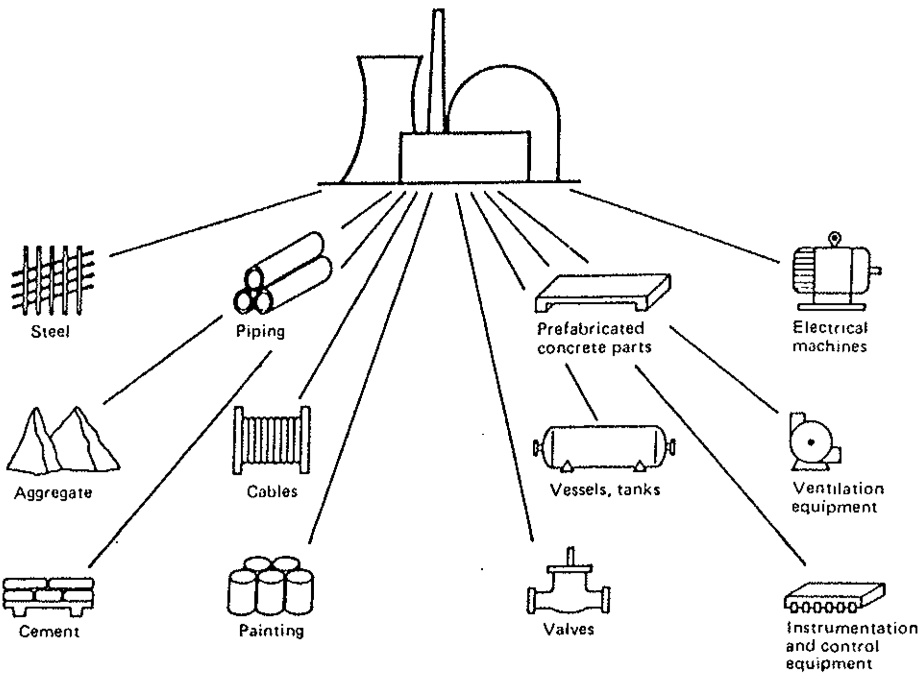


FIG. 4. Typical supplies of material and equipment.

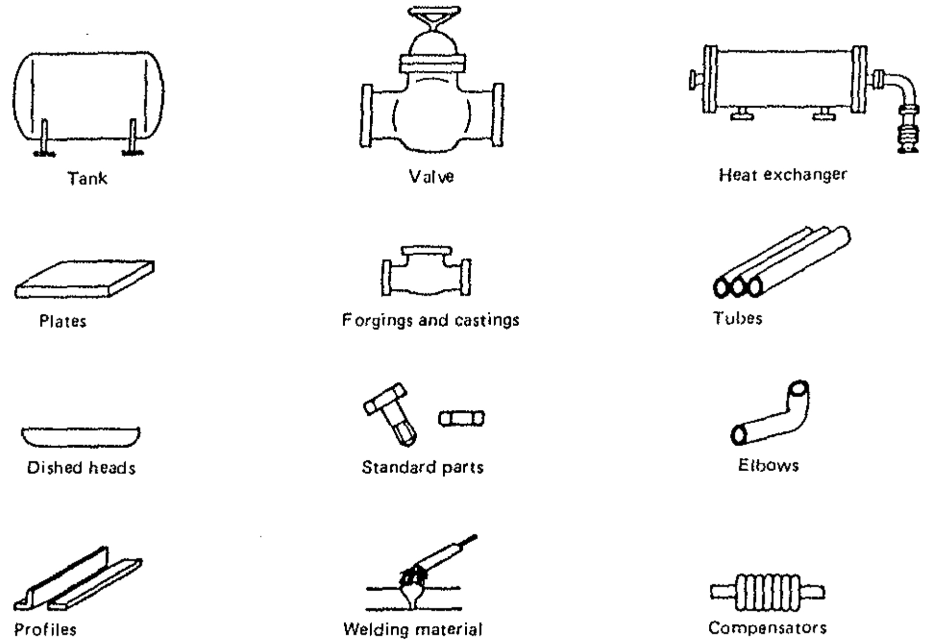


FIG. 5. Typical semifinished products for mechanical components.

The industries can also be divided in another way: those involved with the nuclear services, equipment and construction and those associated with the non-nuclear items of the nuclear plants.

Figure 4 depicts the typical supplies of material and equipment needed for the construction of a nuclear power plant, and Fig. 5 presents the semifinished products for three typical mechanical components employed in large quantity. The non-nuclear quality applicable and the ordinary good engineering practices required place them within, or close to, the normal capability of many industries which could profitably participate in the plant construction.

Table V reports some typical quantities of hardware involved in the construction of a nuclear power plant and Table VI shows the order of magnitude of the human resources required for the construction of a nuclear power plant.

The fabrication of the heavy components for a nuclear power plant is similar to the mechanical processes employed in heavy mechanical industries involved with shipbuilding, heavy lifting equipment, pressure vessels, large valves and large pipework used in high pressure chemical plants.

Chemical plants and thermal power plants have several features in common. Both types of plants have ancillary systems connected to the main system by pipe

TABLE V. SOME QUANTITIES OF HARDWARE IN 1000 MW NPP (PWR) (TYPICAL VALUES, SOURCE: KRAFTWERK UNION)

CIVIL	
Cement	60 000 t
Aggregate	200 000 m^3
Concrete	200 000 m^3
Formwork	350 000 m^2
Reinforcement	20 000 t
Embedded parts	2 000 t
High tension steel	500 t
Decontamination paint	200 000 m^2
MECHANICAL	
Supports	400 t
Pipes	60 000 m
Welds	50 000 m
Pumps	280
Vessels/tanks	260
Heat exchangers	250
Valves	12 650
Hand operated	10 600 (150 different types)
Motor operated	450 (25 different types
Valves for measuring circuits	1 600
ELECTRICAL	
Drives	900
Large transformers	21
Cables	430 000 m
High voltage	20 000 m
Low voltage	410 000 m
CONTROL AND INSTRUMENTATION	
Video display units	8
Recorder	60
Indicators	500
Alarm windows	1 000
Cubicles	200
Modules	16 000
Instrumentation cable	1 500 000 m

TABLE VI. TYPICAL MANPOWER RESOURCES INVOLVED (1000 MW SINGLE UNIT)

Engineering and project management (utility)	2 500 000 man-hours
Construction	
Engineering and project management (main contractor)	4 500 000 man-hours
Civil	7 600 000 man-hours
Mechanical/electrical	5 500 000 man-hours
QA/QC	500 000 man-hours
Startup	300 000 man-hours
Typical manpower peaks	
Regulatory function	50 people
Engineering and management (main contractor)	500 people
Construction	2 500 people
Startup	200 people
QA/QC	100 people
Operation and maintenance	220 people

(Equipment manufacturing not included)

and cable runs that are perhaps long and complex; they may also have extensive sophisticated instrumentation. Experience with designing the layout as well as with the construction of chemical plants and fossil fuel power plants provides background knowledge relevant to the corresponding activities in the building of nuclear power plants. One must bear in mind, however, the special features of nuclear plants. In the same way, experience in the design and building of large civil structures, such as dams and complex multistorey buildings, will provide relevant expertise for civil contractors participating in nuclear plant construction.

The industries likely to be involved in a nuclear industry are shown in the list which follows.

Raw materials — Civil — aggregate, sand, timber, cement, etc.
— Metals — iron and steel plates/ingots, rods, wires, etc.
— Chemicals — petroleum and coal products, rubber, plastic, etc.
— Unusual material — zirconium, titanium, special alloy steel.

Material products Piping (CS and SS), supports, joints anchors, rebars, structural steel, plates, ducting, nuts, bolts, screws, fencing, gates, etc.

Machinery and Equipment	Pumps, blowers, filters, valves, strainers, low pressure vessel/tank, heat exchangers, condensers, heating and ventilation equipment, water treatment plants, lifting equipment, elevators.
Electrical and Electronics	Cables, insulators, conduits, earthing, trays, switchgears, transformers, electrical drives, activators, recorders, indicators, controllers, control panels, etc.
Scientific/Industrial Instruments	Laboratory and field testing instruments, fault detectors, measuring and calibration instruments, meteorological instruments, water and soil quality testing.
Transportation	Trucks, railcars, heavy and long load carrying equipment, marine handling and transportation, barge roll on-off, etc.
Construction	Earth moving machines, batching plants, concrete pumps, cranes, rebar workshops, testing, trucks, graders, trenchers, forklift trucks, scaffolding, etc.
Erection	Piping, heavy lifts, field welding, prefabrication, heating and ventilation, scaffolding, testing equipment.
Services	Warehousing — Buildings, shelves, forklift truck lifting, bins, etc. Offices — Office equipment and materials Others — Canteen, cleaning, security, industrial safety, fire fighting.
Engineering and Management	Engineering design, procurement, site management.
Utilities	Water, electricity, drainage, transportation and communications.

To determine the degree of participation, industrial surveys have to be carried out which highlight the projects's positive and negative aspects, the latter usually expressed as deficiencies. Figure 6 shows schematically what a typical survey would identify. When planners are making the final decision as to the extent of local participation, the involvement cannot be below a certain minimum if plant realization and operation of the complete plant are not to be jeopardized.

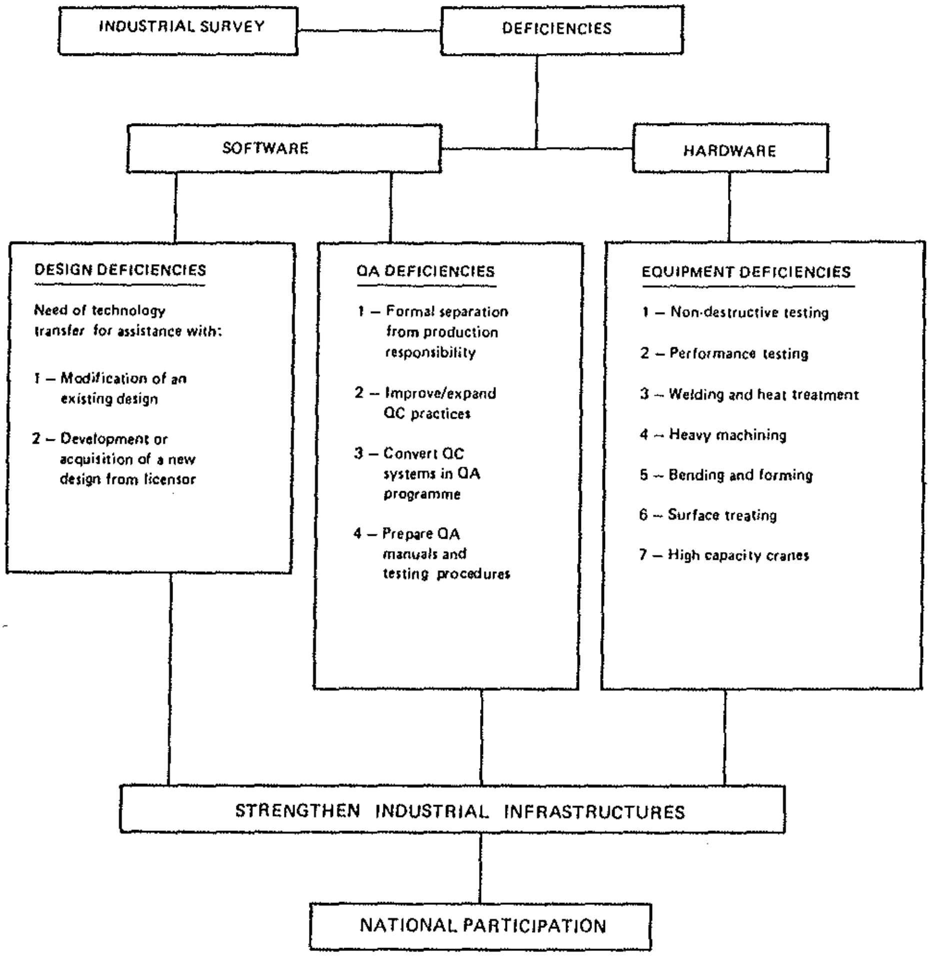


FIG. 6. Typical industrial survey conclusion for manufacturing and industry.

1.4. SOME TIMING ASPECTS

A notable characteristic of a nuclear power plant programme is the long period, more than ten years, which elapses from the decision 'to go nuclear' to the commercial operation date (COD) of the first nuclear plant. A typical time span is illustrated in Fig. 7.

It can be said that on a given project, establishing a realistic plan and schedule can be one of the most decisive means for controlling, indirectly or directly, the costs, scope and satisfactory completion of the project.

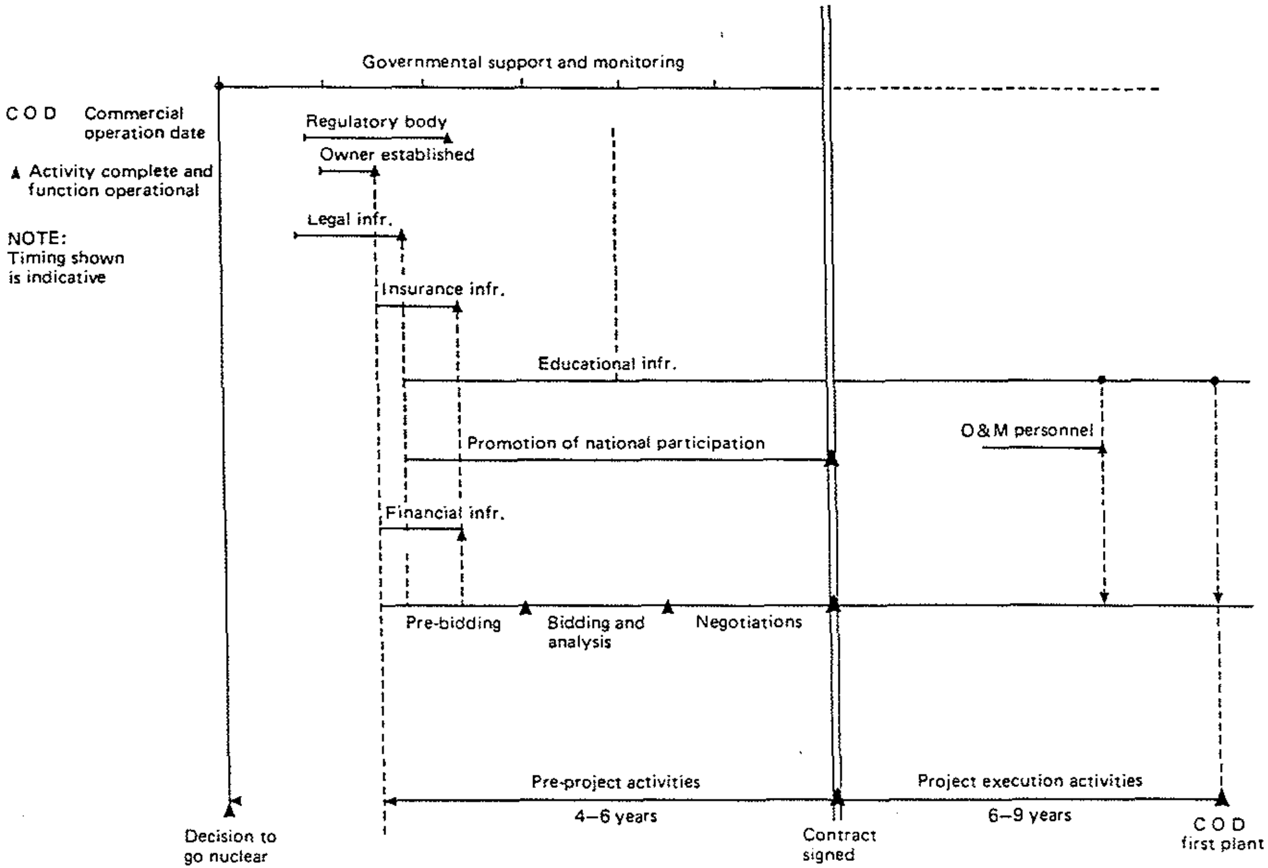


FIG. 7. *Typical time-span of a nuclear programme.*

The experience of a number of countries which have established nuclear power programmes has shown that though the process is relatively long, the viability and success of the programme are largely based on the schedule's being met. If there is slippage, the programme budget will be overrun according to the principle that time costs money. As many major activities have to be maintained simultaneously during a nuclear programme and because of the high costs inherent in any nuclear project, schedule slippage will automatically involve high cost overruns either because of the extension of the original schedule or because of the costs of the catch-up measures needed to get back on schedule.

When the costs of a nuclear programme are looked at, schedule verifications must be detailed and studied carefully as each single day late represents a loss of the sale of electricity by the utility. Usually this sum is far above the costs of the effort that could have been extended in order to be on schedule.

Another consequence of the long periods involved in completing a programme is that an owner has to commit himself to a particular plant design about ten years ahead of its COD. In addition, the design committed to will be based on an operating plant whose design was fixed prior to the new owner's commitment. The owner is therefore buying a plant whose basic design was fixed a considerable period before its COD. This situation however is compensated for by the backfitting process applied almost continuously to take advantage of design improvements and operational experience.

Keeping the design of a completed nuclear plant up to date depends not only upon the technology but also upon the discipline involved. Thus, civil design could be one to two years out of date, whereas the other disciplines could be much more outmoded. Therefore in a nuclear plant, the different parts have different ageing periods; the instrumentation becomes outmoded much more quickly than the civil work.

Another outstanding feature of a nuclear programme is the nuclear quality to which certain parts of the plant must be constructed. The basic principle in the design and construction of a nuclear plant is that on no account may nuclear quality suffer; the quality assurance programme is, in part, designed to ensure this. However, it is not infrequent that the initial planners, especially with respect to the project execution schedule, sometimes underestimate the time and effort necessary in order that quality is not put at risk. This conflict between time and quality needs careful monitoring. Usually the optimum solution is to have a schedule which takes into account the requirements of a realistic quality assurance programme.

A further typical feature of the timing aspect of a nuclear programme is having the right system to monitor the planning progress. In this process, there should be built-in facilities for highlighting exceptions and trends, as well as an alarm system warning of impending problems. The reporting system should satisfy also the needs of the different levels of people who need to know. For example, the higher the level of the receiver of the progress report, the more concise it should be, concentrating only on key and major items and exceptions. This monitoring process should give information that will give the receiver an opportunity to take appropriate action and respond to any criticality or major deviation from the approved plan.

Of necessity, a nuclear power programme is based on a number of imagined scenarios: industrial, economic, social and political, covering not only the ten years' period but extending well beyond that period both before and after. There is, thus, a continuous need during the programme to backcheck a number of major assumptions and decisions made either prior to the establishment of the nuclear programme or during the first phase of the execution of the programme. These backchecks have to be made at certain points so that any change detected on the original assumptions can be taken into account by corresponding changes to the programme.

The unduly long period required for completion of a nuclear programme poses a particular problem of crystalball gazing for those whose concern is finance, money and countertrade. Finance has to be provided from the signing of the commitment to the COD of each plant, a period covering 8 to 10 years. Repayment of the loans is usually made over the next 15 years with perhaps a franchise of 5 years. Since the financing plan was probably designed 2 to 3 years before commitment, the financing experts of the owner and those of the contractors have to design or accept a financial plan which has a span of around 25 to 30 years with a centre of gravity of between 10 to 15 years after project commitment. The difficulties of forecasting rates of interest, rates of inflation and currency exchange rates on an international basis are evident, but they become even more difficult when countertrading operations are included.

If precautions are not taken, the longevity of a nuclear programme can erode the responsibility felt not only by the people involved directly in the project, but also by some of the decision makers. This human reaction has to be compensated for to ensure the right level of responsibility and personal involvement. Equally the long period of execution can have a negative effect on the performance of the project if not taken care of beforehand. The project people, for example, may lose interest if kept too long on it or may become battle weary and though they are still motivated, the quality of their work and decisions may slip.

A factor which can reduce the total duration of completion is the standardization of the plants making up the nuclear programme. Experience has shown that with standardization one to three years can be saved compared with the time taken normally for each plant built to a continuously changing design. Figure 8 illustrates the French experience. Here time reduction because of standardization stems from a number of factors such as:

— A single learning curve for most of the participants in the programme,
— Increased efficiency with all project operations from design through startup
— Shorter delivery periods for the subsequent same materials,
— More expeditious licensing proceedings after completion of the first plant.

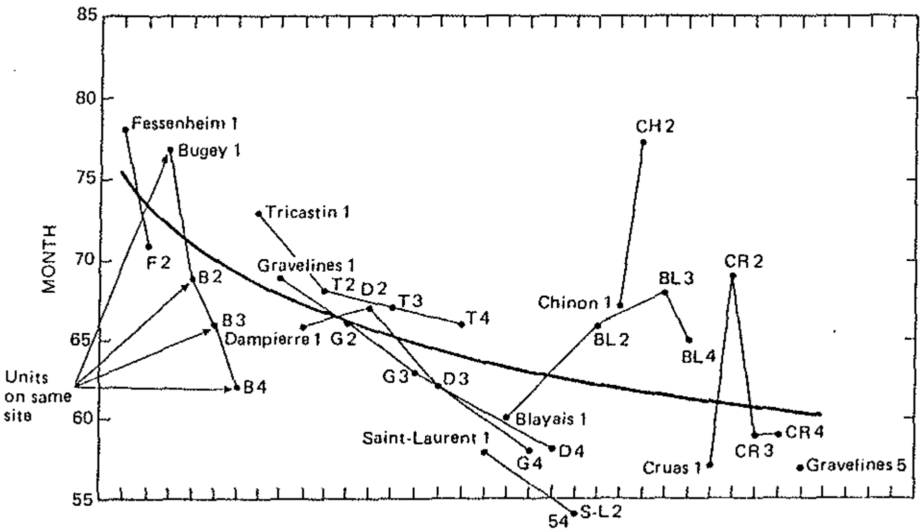


FIG. 8. Time reduction between commitment for reactor unit and connection to grid for standardized 900 MW plant.

However, standardization is only valid if the programme has a certain minimum number of plants realized at a minimum frequency. These minima are specific to each country.

In view of the extensive costs, the large number and complexity of major simultaneous activities, as well as the long completion period of the project, time management is a must to keep the nuclear programme on its planned schedule. The appreciation of the need for the setting-up of an effective time management plan needs careful attention right from the start of the programme.

In addition, drastic change in the political, social or economic climate domestically or internationally can result in a major impact on the timing of the programme. Politics, whether internal to the country or external to it, can have a decided influence on a nuclear programme, even after the decision to go nuclear. The areas where politics can have a serious impact, good or bad, include the selection of the contractors to build the power plants, the extent of local participation for services or equipment, the pricing, the financing, the extent of countertrade and the guarantees or warranties.

A final consequence of the long duration of the nuclear programme is the collection of risks that the project can involve. It is a fact that the longer the project schedule, the more the project is exposed to risks. Over a period of 15 years, many major risks can arise such as:

- a change in power consumption needs
- the discovery of a serious generic design or fabrication error
- the devaluation or the re-evaluation of the currency
- the failure of the owner or a contractor to remain financially viable
- a change in the political regime or in the government
- a change in the nuclear policy.

If any of these risks materializes, the effect on the project can be most serious.

For example, the idea may prevail that major decisions may be delayed since there is plenty of time in which to correct any negative schedule repercussions resulting from poor early phase planning or delayed and incomplete decisions. Another erroneous belief is that the project management information reports can be issued once every six months rather than on a monthly basis as is normally the case with well managed engineering companies. Finally, there is the thinking that with any time lost by the owner or the authorities during negotiations or at any other time, the contractors and system suppliers can make up for it.

These misconceptions (and there are others) can be most hurtful to the successful implementation of a programme, in terms of time, money, quality and finally the public image. Those participating directly in the programme can suffer as well from such planning and management errors.

Many countries which have gone through or initiated a nuclear power programme have had teething problems of all kinds. This experience can be precious to those thinking of planning a programme and can be obtained directly from the other country's authorities or utilities. Alternatively, a consultant can be hired to provide an account of this experience and to offer his advice as to the practicality and pertinence of the experience of others. This latter function is most important.

CHAPTER 2

THE NUCLEAR POWER TECHNOLOGY

2.1. INTRODUCTION

To describe nuclear technology is not the purpose of this Guidebook as the subject is well covered by many excellent publications. However as background it is useful to be aware of certain distinguishing features of the nuclear power technology. These specific features not only mark the differences between classical thermal and nuclear power plants but also the reasons for the special approach having to be adopted in the procurement, construction and operation of an NPP. The consequences resulting from the differences are then described to explain more fully the unique features of nuclear power technology.

2.2. SIMILARITIES

The similarities between the technology used in an NPP and that in a classical thermal power plant are basically that:

(1) Both develop heat as the prime result of the process;
(2) Both processes use the heat developed to generate steam which passes through a turbogenerator unit and generates the electric power;
(3) Both types of power plants are connected to and interact with the national electric power generation and distribution system in a similar manner.

2.3. DIFFERENCES

Radioactivity

Heat energy in an NPP is generated by the fission chain reaction. This fact automatically results in the presence of radioactivity within the power plant. Because the need of ensuring the integrity of its containment is a paramount requirement, unprecedented safety measures are required. Industrial standards, codes of practice and comprehensive programmes for quality assurance applicable to safety related plant equipment and systems therefore are much higher and stricter in an NPP than in a fossil fuelled power station. They are also enforced by regulatory mandates.

Working environment

The combined effect of temperature, pressure, and irradiation on structural materials and substances constitutes a plant operating environment vastly different from the classical thermal plant and more demanding on the designers, equipment suppliers, constructors and plant operators. To prevent radiation assisted corrosion/erosion, more unusual materials and larger quantities of stainless steel have to be used in an NPP than in a fossil fuelled power plant. Also more accurate water chemistry regimes are required in an NPP than in a fossil fuelled plant.

Heat sink

When shutting down an NPP there is considerable residual heat in the reactor core and a highly reliable heat sink must be available at all times. Additional engineering, equipment and instrumentation are thus necessary as well as appropriate redundancy to ensure satisfactory reliability (see Ultimate Heat Sink and Directly Associated Heat Transport Systems for Nuclear Power Plants: A Safety Guide, Safety Series No. 50-SG-D6, IAEA, Vienna (1981)).

Auxiliary power supply

Both classical plants and NPPs need an auxiliary power supply in order to assist plant operation and obviate undesirable consequences during abnormal operation conditions. However, as a direct consequence of the heat sink, for an NPP, the need to have an auxiliary emergency power supply fully independent of the plant is greater and more critical because of demands for crush cooling and heat decay removal (see Emergency Power Systems at Nuclear Power Plants: A Safety Guide, Safety Series No. 50-SG-D7, IAEA, Vienna (1982)).

Fuel cycle

Nuclear fuel requires a more complex and delicate technology than fossil fuels. Special processes are required to fabricate the nuclear fuel elements which involve unusual materials, special facilities, comprehensive QA programmes with extensive QC and auditing techniques, and skilled personnel. The in-core fuel cycle management requires complex fuel handling and computer assisted burnup optimizations by experienced personnel.

It must be observed, however, that a 1000 MW(e) fossil fuelled power station at 65% average capacity factor would use in one year:

- 1.8 million tonnes of coal, or
- 7.7 million barrels of oil, or
- 1350 million cubic metres of gas.

An NPP of the same capacity would use 125 tonnes of uranium. This consumption requires the mining of about 65 000 tonnes of ore (at 0.2% concentrate). Thus the material handling infrastructure is considerably less for the nuclear fuel than for the classical fuels of a conventional power plant.

Spent fuel, waste conditioning and removal

The irradiated nature of the spent fuel and other waste requires stringent conditioning and handling, poses special transportation problems and needs adequate facilities for permanent disposal (see Fuel Handling and Storage Systems in Nuclear Power Plants: A Safety Guide, Safety Series No. 50-SG-D10, IAEA, Vienna (1984)). If the decision is made to reprocess the spent fuel, a dedicated reprocessing plant is required to deal with the additional problems of the conditioning, handling and final disposal of the associated wastes.

International implications

The strategic nature of the nuclear fuel, the handling of the wastes, the transboundary consequences of an accident in an NPP have international aspects which require the establishment of and compliance with international, bilateral and/or regional agreements. An international safeguards regime has been established to deal with material accountancy and surveillance in order to promptly detect any material unaccounted for and to prevent unauthorized uses of such material. (For a complete treatment of these problems, see the Guidebook on the Introduction of Nuclear Power, Technical Reports Series No. 217, IAEA, Vienna (1982).)

2.4. CONSEQUENCES

The differences from a classical thermal power plant require taking into account certain items or measures which are specific to an NPP. Some of the notable consequences include the design, siting, third party liability as well as management operations, quality assurance and finally emergencies.

Design

The inherent high degree of the safety level necessary in an NPP requires that appropriate engineered safety systems be considered as an integral part of the plant design (see Design for Safety of Nuclear Power Plants: A Code of Practice, Safety Series No. 50-C-D, IAEA, Vienna (1978) and relevant Safety Guides). Because these systems must be of the highest standard possible, they add noticeably to the plant capital costs and make NPPs heavily influenced by the economy of scale.

The plant design and its engineering must provide for the maximum protection of personnel, particularly the maintenance personnel, having access to sensitive areas. In addition the design of certain equipment and its layout must be such that there is inherent maximum protection against accidental damages (see Protection Against Internally Generated Missiles and Their Secondary Effects in Nuclear Power Plants: A Safety Guide, Safety Series NO. 50-SG-D4, IAEA, Vienna (1980) and External Man-Induced Events in Relation to Nuclear Power Plant Design: A Safety Guide, Safety Series No. 50-SG-D5, IAEA, Vienna (1982)).

Because of the heavier implications of the wear and tear of the critical equipment and materials in an NPP, there is a high proportion of redundancy in equipment and in the instrumentation and control aspects. The I&C systems and their degree of automation are more extensive and more demand is put on their reliability (see Nuclear Power Plant Instrumentation and Control: A Guidebook, Technical Reports Series No. 239, IAEA, Vienna (1984)).

Siting

Siting of an NPP requires a much more complex analysis than for a fossil fuelled power station. Correct siting must minimize the impact of the site characteristics on the safe operation of the plant and the consequences of the plant operation to the public and the environment both in normal and accident conditions (see Safety in Nuclear Power Plant Siting: A Code of Practice, Safety Series No. 50-C-S, IAEA, Vienna (1978) and relevant Safety Guides).

Third party liability

Another consequence resulting from an NPP is that the compensation for damage to or loss of property as a direct or indirect result of an accident may go beyond the NPP owner's financial capability. Thus provisions of a special liability regime are required.

Management

Because an NPP involves an extensive labour force and large amounts of materials, it needs a higher number of contractors for special services than a fossil fuelled plant and requires higher investments and longer construction times. The need for strict cost, schedule and quality control is evident. Thus more skill and experience are required to perform NPP project management and engineering functions than to manage and operate a fossil fuelled power plant. A Guidebook on project management is under preparation.

Operation

The economical operation of an NPP requires maximum plant availability. While this holds true also for conventional plants, it is all the more important for an NPP where higher capital costs can be only offset by maximum generation. Thus the following aspects demand much more consideration in an NPP than in a conventional power plant:

(a) Extensive operator training to minimize human errors and ensure correct operator action in normal and abnormal conditions. Particular ability of the operations staff is required for handling situations which might involve exposure to radioactivity.
(b) Care in ensuring high performance and efficient maintenance of critical equipment so that it operates satisfactorily, minimizes plant downtimes and assures high plant availability. Thus more stringent and accurate surveillance and inspection programmes are necessary.
(c) Convenience to extend QA programmes to those plant equipment systems which, although not prescribed by regulatory mandate, are, however, critical for continued maximum plant output.
(d) Good maintenance capability, preventive maintenance programmes and optimum spare parts management which are important to minimize loss of plant output.

Unlike a fossil fuelled power plant, an NPP requires that a continuing monitoring system be set up inside the plant in order to prevent overexposure to the operations staff and outside the plant to provide environmental surveillance. During plant operation wastes accumulate as either solids, liquids or gases. One of the special requirements of an NPP is that these wastes be handled, conditioned and then stored in specially designed repositiories under continuing control. It is also necessary to release them with time delay and dilution so as to have an insignificant effect on the environment.

Quality

QA and QC are much more important for an NPP than for a conventional power plant. In fact it is a paramount requirement for an NPP that quality be enforced and monitored in all phases of the programme and throughout the operational life of the plant. The IAEA Nuclear Safety Series (NUSS) Documents for QA provide a thorough treatment of this very important aspect of nuclear technology. (See Quality Assurance for Safety in Nuclear Power Plants: A Code of Practice, Safety Series No. 50-C-QA, IAEA, Vienna (1978) and relevant Safety Guides).

Emergencies

Because of the consequences of accidents in an NPP, special crisis plans must be developed in which many parties besides the utility have a role to play in order to mitigate critical situations. For these situations expert help must be made available on short notice and an appropriate escalation threshold, i.e. plant emergency, must be defined which requires notification outside the shift operating teams. This notification should first reach the safety engineering team which is stationed at the site and reachable by communication lines open 24 hours a day. This team should consist of professionals with a thorough knowledge of systems, operations and accident analysis.

The preparation of plans and procedures and the preparedness to cover emergency situations transcending the power plant's limits are also essential and involve local and national organizations and authorities in addition to the utility and the regulatory body.

2.5. NUCLEAR TECHNOLOGY MANAGEMENT

A country's decision to go nuclear involves the automatic acquisition of a minimum of nuclear technology, theoretical and applied as well as nuclear know-how. This acquisition in turn implies automatically the maintenance of this newly acquired knowledge so that it is constantly up to date and complete. Because of this and of the complex nature of the technology, management on a national level is necessary.

The management process would first of all define precisely the minimum technology in terms of depths or levels to be acquired in each area so that the NPP programme can be executed under optimum conditions of efficiency and safety. This definition will also recognize that the minimum is a variable with time and experience. It will take into account any ambition by the country or the utility to go beyond the strict minimum.

Management would thus determine how this technology is acquired, usually partly by technology transfer and partly by in-house learning process. This will then entail the definition, planning and setting up of training facilities in academic and industrial centres. Some of these will involve close co-operation between public and private organizations. If research work is chosen as a means for technology acquisition, research facilities or even a research reactor may have to be built.

The acquisition process would also entail the establishment of bilateral agreements between donor and receiver countries and donor and receiver entities such as universities, utilities, engineering companies or manufacturers. These numerous agreements have to be seen as part of a whole complex of agreements. It is part of the technology management process to ensure that these agreements are coherent and mutually supporting. Another feature of the nuclear power technology which needs good management is the importance of documentation. The basic objective of the documentation is to show and have on record sufficient and retrievable evidence so that the plant equipment and systems can be proven to have been safely and correctly designed, erected, inspected and operated. This results in a complex and in-depth documentation procedure which in turn produces several tonnes of paper per nuclear plant throughout the life of the plant. The following list gives an indication of the typical paperload processed by project personnel for an NPP:

— *Mail*	(Letters, memos, etc. ...)	— 250 000
	Copies distributed	— more than 1 000 000
— *Drawings*		— 40 000 Initial issue
	Average No. revisions 5	— 200 000 Issued
— *Specifications*		— 1 250 Initial
	Average No. revisions 4	— 5 000 Issued
— *Procedures*		— 3 000 Initial
	Average No. revisions 4	— 12 000 Issued

Excluded:

- Governmental and local authorities' documents
- Manufacturers' and construction contractors' own working documents
- Transfer of technology documents

The maintenance and upgrading of the acquired nuclear technology also require management in a broad manner and should ensure coherence among the quality levels of the know-how acquired in different areas. Good nuclear technology management therefore ensures not only how best to acquire and maintain new technology but also how that acquisition process can proceed at a rate compatible with the nuclear power programme and its objectives.

CHAPTER 3

ROLE OF THE UTILITY IN PROJECT IMPLEMENTATION

3.1. INTRODUCTION

The purpose of building a nuclear power plant is to produce and distribute electricity as realiably and cheaply as possible. The role of the utility, the plant owner, in ensuring successful transition from project inception to power generation is a vital one.

In the NPP programme the utility is one of the key 'players' around whom many activities that contribute to project success revolve. The utility bears full responsibility for all aspects of the project, as stipulated by nuclear regulations governing quality assurance and safety requirements.

3.2. TYPES OF UTILITIES

The world's power industry offers a wide variety of utility organizations, ranging from small power companies that must combine their resources to purchase and operate even a single power plant to giant utilities that assure these functions for a large number of plants.

Regardless of the utility's size, for any given power project it is expected that the owner is usually the operator. And if the owner is acting as a prime contractor, he may either assume this latter responsibility directly or delegate it totally or partially to engineers, contractors or vendors, depending on his capabilities.

The main construction tasks of a power plant in which the utility is often directly involved are:

(1) Defining a project master plan that describes plant characteristics and sets forth project options and objectives;
(2) Submitting basic project engineering, some site specific design and drafting of general layout drawings, certain basic specifications and flow diagrams;
(3) Applying for conventional as well as those permits and licences specific to the nuclear industry (e.g. for plant operation and release of radioactive materials in effluents);
(4) Establishing a project realization plan and a work breakdown system and setting up administration contracts and acceptance of work;
(5) Co-ordinating, planning and scheduling overall project activities and cost control;
(6) Organizing general project administration;

(7) Reviewing system and integrated systems testing: commissioning, startup and power buildup;
(8) Providing operation maintenance spares and fuel procurement;
(9) Establishing public relations, communication and interaction with the local community.

Though only a rough breakdown, this list does illustrate the diversity of services that a utility must itself provide or obtain through engineers and contractors in building a nuclear power plant.

The project tasks listed above may be classified according to the functions performed by the four major participants in a power project:

(a) the *owner* who has actual title to the plant and, as such, assumes overall responsibility for the project;
(b) the *prime contractor* who plays the role of architect–engineer and project co-ordinator. This function includes project engineering and project management;
(c) the *vendors and contractors* who design, manufacture and often erect, construct, and start up their equipment or facilities;
(d) the *operator* who operates, manages and ensures maintenance of the plant after participating in, and, in some cases also co-ordinating, plant commissioning and startup operations.

This classification is, of course, somewhat arbitrary, since work allocations are dependent on the capabilities of these main participants. For example, equipment design may either be included in the scope of the prime contractor or assigned to vendors.

Given the wide range of capabilities that may be available from one utility to another and the large number of more or less logical combinations of assignable project tasks, it is not surprising that utility project organizations take many different forms.

Several overriding trends can, however, be observed:

- Owner and operator functions are increasingly performed by a single company, known as the 'utility';
- As part of its overall project responsibilities, the utility takes responsibility for award of prime contracting, construction and supply by its own internal departments or outside contractors or vendors.

This may be done in any number of ways, but the most frequently encountered schemes are:

At one extreme:

- the *turnkey approach*, whereby contractor and vendor functions are grouped together and a single responsibility prime contract is awarded for engineering, equipment supply, construction and project management;

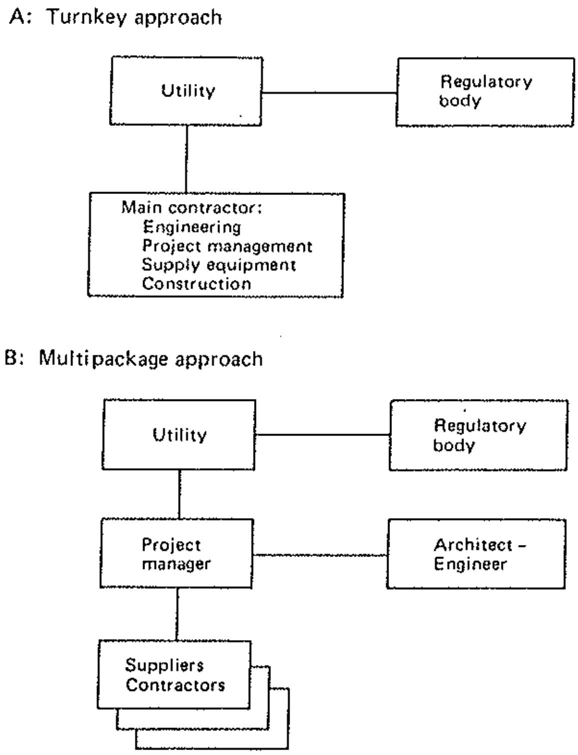


FIG. 9. Typical basic organizations for a nuclear power project.

At the other extreme:

— the *multipackage system,* which involves splitting up the prime contractor/vendor responsibilities. Under this system, the number of contractors may range from a few (e.g. for nuclear island, conventional island and related equipment) to several hundreds. Project engineering and project management functions are not assigned to the contractors and vendors, but are performed instead by the utility, using in-house resources or outside engineering contractors.

Figure 9 shows these two approaches. Between these two extremes, there are a variety of others in which the utility plays a more or less dominant role dependent on the scheme adopted. Therefore, whatever the size or the inherent capabilities of the power utility, it is more or less seen as the pivot for the total project organization.

3.3. ROLE AND RESPONSIBILITIES OF THE UTILITY IN THE PRE-PROJECT PHASE

This section describes the activities and responsibilities of the utility during the phase of the project that precedes the awarding of the main engineering construction contracts.

3.3.1. Defining a nuclear power project

Utilities usually think of multiplant programmes rather than of single plant projects, since the investment in material and human resources required to build and operate one nuclear plant is often difficult to justify. As a consequence, a country's nuclear power programme is usually defined within the broader framework of a national energy programme. This implies formal planning, i.e. the forecasting of the future energy demand based on economic development goals and the choice of the reactor technologies best suited to meeting this demand.

Success can only be achieved through a forceful and clearly oriented energy policy, with well defined medium and long term goals. The vital and growing role played by utility companies in the development of national energy programmes is becoming more evident and indispensable.

3.3.2. Integration of nuclear power plants into an existing electric energy network

Once energy planners and utilities have determined the inclusion of nuclear power within the national energy policy, a clear definition of the future plant construction programme is necessary.

The utility must then take into account factors such as:

— The future power needs: baseload and peak power demand, existing generation facilities, kW·h cost by type and size of power plant and the sequencing of putting the future plants on line;
— Existing transmission and distribution: location of major user points, central generating stations and regional interchanges.

An examination of these factors enables the utility to determine the size of future nuclear units and to be able to draft a schedule for their construction. There are two points that should be kept in mind:

— The cost of nuclear energy usually decreases as plant size increases if factors such as plant availability and efficiency are equal.
— The plant size must not be out of proportion with grid demand (see Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants: A Guidebook, Technical Reports Series No. 224, IAEA, Vienna (1983)).

The reliability of the network connecting the plants should also be considered, since off-site power is needed for essential plant auxiliary systems in case of reactor trip. Also grid power failures of any kind can have a negative effect on plant availability. Normally the first units of a nuclear power programme are usually baseloaded, but, if the share of nuclear power generation in the overall energy supply increases, nuclear plants should also be capable of operating in load following conditions.

3.3.3. Defining an implementation policy

After the decision to build one or more nuclear power plants of a given size, the utility must answer a number of questions related to the implementation policy:

(i) *What type of plant technology is preferable?* Different nuclear reactor designs have been developed, each having its own characteristics in respect to fuel, moderator, etc. Different reactor technologies have different levels of reliability. Even for the same type of reactor, different designs by different suppliers have accumulated different amounts of operating experience.

(ii) *Which regulations will apply?* In most cases, the design proposed by the reactor vendor is based on that of a reference facility existing in his country of origin. This facility is designed to a specific set of requirements, and, if full advantage is to be taken of the reference, the utility must incorporate these in its own set of regulations.

(iii) *How should the project be executed?* Should it be turnkey supply, a multipackage type arrangement or a mix? How much local participation and how much transfer of technology? Often the utility's approach evolves along with the evolution of its nuclear power programme. After having constructed the first units on a turnkey basis, it progresses towards multipackage contracting which allows for greater direct involvement but also gives the utility greater project responsibility for successful completion.

(iv) *How should the contracts be let?* Should they be offered through public of private bidding, or by direct negotiations, e.g. in the framework of bilateral international agreements? What type of financing is available?

The answers to these questions and some others may be based on decisions made at the governmental level, with input from both the public authorities and the utility. Typical contractual approaches and their scope of supply and their consequences are schematically indicated in Chapter 1, An Executive Overview.

3.3.4. Site selection

Plant siting is a vital step in undertaking any nuclear power programme. There are many plant siting criteria, especially those related to safety, which are absolute imperatives. For example, the choice of site must take into account the geology, the earthquake history and tectonics of the area, its local hydrology and climatic conditions. Location of neighbouring industrial establishments and population, possible risks to the plant from the outside environment, as well as radiation and contamination hazards and environmental impact from the plant itself are also important site considerations.

These criteria, in principle, serve as grounds for acceptance or rejection of a site, and also determine the extent to which basic process design or standard plant design has to be modified. In the final analysis, the technicalities of site selection are the domain of siting engineers who must seek a compromise between the potential advantages and drawbacks of the site.

There is one area in which the utility needs to be extremely vigilant: that of public reaction to the plant and acceptance of the project by local authorities and elected officials. Public acceptance or rejection of the project often hinges on irrational factors to which a very subtle attitude must be adopted. The utility must view such acceptance as a necessary condition to obtaining project approval and must therefore act accordingly in providing information and communicating with the public, elected officials as well as local interest groups. The important role of the media must be reckoned with in devising an information strategy for the project and the utility must obtain full support of all relevant authorities.

Government authorities will not grant the necessary licences for plant construction and operation unless they are convinced of the project's usefulness and its medium and long range compatibility with regional development programmes. Generally speaking, responsibility for selecting a site and for reconciling technical requirements with the need for public acceptance and certain political considerations lies with the utility which must ensure a presence in and develop good relationships with the local community. This work should be started as early in the project schedule as possible.

3.3.5. Feasibility studies and basic design

The basic design of a given power plant involves adaptation of the standard plant design to the characteristics of the site chosen for the project.

The matching of the standard design to the site characteristics entails a thorough study of foundation requirements, water intake and outfall structures, means of access to the plant, connection to the existing power grid, environmental impact and plant building layout. The utility is involved in this work and depending on its in-house capabilities will assume some of or delegate to others the following items:

(1) Planning of major project phases including definition and duration, i.e. preliminary work, procurement, equipment manufacture, shipment, erection, testing and startup,
(2) Designing a site infrastructure including water and power utilities, community centre, bulk materials supply sources and heavy transport facilities,
(3) Arranging a project financing scheme and definition of payment schedule,
(4) Developing a programme for hiring and training of operating and maintenance personnel.

All of the above must be co-ordinated by the utility who must collate the data from interested engineers, vendors and contractors. This work will enable the utility to:

— Assess project feasibility,
— Prepare certain or all of the technical specifications,
— Draw a basic plan for quality assurance,
— Draft applications for permits and licences,
— Establish the project management tools, methods and information systems.

The quality and success of the NPP programme depend largely on good definition of the scope of each project task, effective organization and thorough execution planning.

3.4. ROLE AND RESPONSIBILITIES OF THE UTILITY DURING PROJECT EXECUTION

As many as six to nine years may have elapsed from the time a utility formally confirms its decision to build a nuclear power plant (by letter of intent or award of contract), and the start of commercial operation that marks the takeover of the completed plant. During this period, the utility will be deeply involved in four important project functions: quality assurance, nuclear safety, cost, and schedule control for the execution activities.

As the utility has the ultimate responsibility for the overall plant life (e.g. 30 years), nuclear safety is the prime role during this phase. The utility is also responsible for quality control which will ensure full reliability of nuclear and conventional islands. The utility is also involved directly with certain activities not specific to nuclear plants. Some of these include: grid expansions needed to accommodate additional plants, large site organization policy, obtaining authorizations such as construction permits, water intake and discharge licences, as well as fly-over rights.

3.4.1. Defining quality assurance policy

This section considers the importance of the utility's involvement in quality assurance. The topic of quality assurance as a whole is discussed later in this Guidebook.

In accordance with nuclear regulations and, in many cases, as imposed by law, the utility is responsible for implementing the measures necessary to ensure plant safety. The quality of plant installations, i.e. their ability to function satisfactorily, is a fundamental prerequisite for safety. Since the utility is vested with primary safety responsibility, it is also held responsible for the effectiveness of job quality and quality assurance. Naturally the utility delegates part of these responsibilities to suppliers. Purchase orders and contracts let by the utility must clearly state required quality levels and quality control requirements, together with quality assurance obligations.

Effective quality control is guaranteed first and foremost by writing good contracts. But this is not enough; throughout project execution, the utility must directly or indirectly supervise compliance with quality requirements. It must also verify, through appropriate auditing, that supplier quality assurance programmes are being implemented, are effective and provide for suitable corrective action in the event of discrepancies and non-compliances.

In addition to the above measures, which aim at assuring suitable levels of quality equipment, the utility is responsible for the coherence and completeness of overall quality control strategy. Every link in the complex chain that makes up a nuclear power plant must be perfectly co-ordinated, contract by contract, into a programme of quality assurance that is defined and implemented under the utility's own jurisdiction.

The utility *must* exercise total control of the quality. This quality assurance is more than just a mere formality; it is also an essential aid for organizing, defining and controlling all activities involved in project execution. This approach is not specific to nuclear power projects. It is valid for all types of complex projects requiring particularly high levels of plant performance.

3.4.2. Nuclear safety and licensing

The utility is responsible for all the interaction with safety authorities. In this role, it prepares applications for all the permits and operating licences, submits them to the relevant authorities and supplies any additional information required.

At the start of the project, the utility, together with the architect–engineer, drafts a preliminary safety report (PSAR) which provides a detailed description of the plant. This report is intended to demonstrate the plant's compliance with applicable safety regulations. Following review and approval of the report by the safety authorities, the utility is granted a construction permit.

Thereafter, and throughout the detail design, manufacturing and plant erection phases of the project, the utility co-operates with the engineers, the equipment suppliers and contractors in compiling additional safety related information. These data are incorporated into the final safety report (FSAR), which is submitted on completion of the plant to demonstrate compliance of plant components and structures with nuclear regulations and quality assurance requirements. Any significant discrepancies observed during design, construction, erection or testing must be reported in writing, together with the type of corrective action proposed in each case.

Only after review of the FSAR, follow-up and inspection of various project activities, and analysis of test results can safety officials authorize the utility to load the core, bring the reactor to criticality and escalate to full power. The licensing process generates constant dialogue between the utility and safety authorities. It is thus essential for the utility to be fully cognizant of all safety related matters.

3.4.3. Planning and scheduling

Planning and scheduling are probably the best tools available to ensure the success of any project. They are an indispensable part of the co-ordination of the project activities of all the participants. Therefore the utility has to set up its own means of planning and scheduling irrespective of the degree of direct involvement in the project.

In complex projects like nuclear power plants, the risk of reaching completion behind schedule is high. Countries with a long history of nuclear projects have often registered large delays, particularly on the first plants constructed, usually due to the learning curve effect. Experience gained in the course of a nuclear programme is probably the best protection against time loss. Where experience is lacking, the utility can at least take the necessary measures to ensure that the targets are clear and that work progress is carefully monitored and controlled and that the future trends are evident.

Good planning and scheduling require the utility to have:

(a) Set a clear definition of the scope of each single project task, defining their interrelationships and estimating the time required to complete them;
(b) Identified key decisions to be made and set deadlines for making them;
(c) Defined targets to which the utility itself is committed with respect to its suppliers (e.g. deadlines for obtaining permits and licences, release of premises, notification of contract awards and issuing of authorizations to proceed);
(d) Set milestone targets for engineers, vendors and contractors;
(e) Provided an adequately phased supply of fuel (normally the first fuel load is supplied with the NPP by the NSSS or plant vendor for performance guarantee reasons).

The utility and all participants must provide contingencies for unforeseeable events and foreseeable risks. In addition, the utility's role is to plan for a prompt reaction on its part when such a risk occurs.

3.4.4. Cost control

Staying within budget is as vitally important to project success as meeting completion deadlines. The utility has a significant role to play in this area. There are many reasons why cost targets are exceeded. The following partial list gives some of the most important ones:

- scope errors or omissions in plant definition
- poor scoping or negotiation of contracts
- selecting the wrong type of contract (lump sum, cost plus etc.)
- unequal distribution of risks between utility and suppliers
- unforeseeable events or insufficient cost contingencies
- changes in progress
- extension of deadlines, work suspensions
- economic fluctuations affecting manpower, equipment and construction costs.

Several of these can be directly influenced by the utility through actions or strategies adopted. Others are dependent on the experience and ability of the participants to cope with difficult or unexpected circumstances. Because delays in completion inevitably result in price mark-ups, reasonable extra cost to limit or prevent delays is usually warranted. Only the utility can decide on this aspect of cost control, however.

Major purchase orders and contracts ideally should provide room for incentive and should allow a balanced distribution of risks between the utility and the vendor or contractor. If all the risks are assumed by the suppliers and contractors, prices will be high and conflicts will be frequent. If, on the other hand, the risks are borne in a large measure by the utility, the latter must be fully capable of controlling costs. This reasoning applies to lump sum as well as to cost plus contracts. The utility must also refrain from erratic change in activities and make only those changes that are absolutely unavoidable. Finally, to complete good cost control, the utility must have an efficient financial management strategy.

3.5. ROLE AND RESPONSIBILITIES OF THE UTILITY DURING PLANT STARTUP

Regardless of the type of supply contract used, the utility is always actively involved in plant testing and startup. The startup phase is important because it is the transition between the end of construction and start of operation. The utility in this phase will participate in:

(i) Verifying compliance of the completed plant with specifications and ensuring correct operation of the equipment;
(ii) Confirming performance and capabilities of systems, structures and equipment under normal and transient operating conditions, as well as during simulated incidents;
(iii) Confirming the suitability of operating procedures, operating manuals and maintenance procedures both for normal and upset conditions.

During this phase, the utility also becomes directly responsible for ensuring plant safety. The commissioning and startup process includes:

- Construction and pre-operational testing which cover the entire pre-loading period;
- Startup tests which run from core loading to commencement of commercial operation.

Equipment tests (construction tests) are the normal conclusion of the plant erection phase. They begin early on in the project, about three years before the COD for electrical and handling equipment. System and integrated system tests (pre-operational tests) begin some one and one-half years before COD. This long term test effort requires careful, methodical planning on the part of the utility. The utility's share in startup responsibility means that it must participate in test preparation and ensure that qualified personnel are available well in advance of plant startup.

The utility's safety commitment begins with core loading when the utility becomes accountable to national safety authorities. All pre-operational testing must be completed before loading. This process includes verification, as well as the adjustment and functional testing required to ensure that core loading, criticality and low power testing will take place under fully safe conditions.

Throughout the startup test period, the utility must ensure close co-operation with the relevant safety authorities. Because the process of plant startup and safety checks is gradual, permission to begin a new phase of testing is only granted if results of the previous phase justify it. Testing can proceed in several stages, including:

- cold testing
- delivery and acceptance of fuel
- core loading
- pre-critical hot functional testing
- criticality and step by step increments to 90% full power
- full power operation.

CHAPTER 4
NATIONAL PARTICIPATION

4.1. INTRODUCTION

Local participation if well framed within a realistic plan can be a strong positive stimulant to the economy and industry of the country. On the other hand, if poorly carried out, local participation can cause an unbalanced industrial structure, considerable waste of money and time as well as damage to the NPP programmes. Local participation needs therefore great care in the definition of the objectives (which should preferably be justifiable on grounds other than just pure political independence), as well as definition of the plan of action and rigorous monitoring.

Local participation in the execution of a nuclear power plant would mean the use of material and manpower resources within the country. A vital decision when going nuclear is based on the degree to which independence is sought by the country or alternatively to what degree the country is prepared to be dependent on one or more other countries. This matter has both financial and technical implications. A certain dependence is almost unavoidable with most countries. In any case there is an obligation to have a certain minimum local participation.

It is logical that a country entering nuclear technology will consider local participation while formulating a nuclear power programme. The extent of participation may vary from country to country and will depend largely on the availability of resources needed for the nuclear power programme. Economics will more certainly govern the decision for local participation. Such local participation is not only desirable and feasible, but it can be considered indispensable if necessary skills are to be built up for subsequent operation and maintenance of nuclear power plants. Domestic industrial participation reduces the foreign exchange content of the overall costs of the plant, provides encouragement and employment to the local people and also gradually upgrades the quality of industry. With each successive nuclear power plant built, the level of local industrial expertise increases and can reach a point where virtually total expertise will become available within the country to design, construct, commission and operate the plants.

It must be recognized that an increasing participation in the nuclear programme is in the interest of both technology exporting and technology receiving countries, though for different reasons as shown below. For supplier countries more local participation permits:

(1) Successful competition among other bidders and the easing of the sale of future NPPs,
(2) Development of a long term industrial relationship with the receiving country,

(3) Creation of new markets in importer's neighbouring countries and consolidation of the supplier's position in the region.

At the same time more participation helps receiving countries to:

(a) limit the need for foreign loans,
(b) improve industrial competitiveness and the country's self-sufficiency,
(c) increase local employment,
(d) raise national engineering capability,
(e) develop the ability to use new technology and acquire know-how,
(f) strengthen independent capability to train local manpower.

Obviously supply packages including a larger share of domestic participation are an important element in the selection of the supplies. However, there is a point beyond which any further increase of national participation might expose the project to risks and not be in the interest of the technology receiving country. Thus utmost consideration must be given to selecting the extent of the national participation.

4.2. EXTENT OF NATIONAL PARTICIPATION

There is a minimum level of nuclear know-how and of experienced personnel that the country must have available if plant operation and maintenance are to be carried out efficiently and safely.

There is also an optimum level which can evolve with time and experience and which will fit best the infrastructure already in place. The industrial and nuclear objectives established and the capability of improving the infrastructure and enhancing the resources of the country will also benefit from such extensive involvement.

Around the optimum level, the country can find itself in a situation which does not take all the economic, industrial and technological advantages of the opportunities that an NPP programme can offer. This can occur by being overambitious in the objectives of participation or by not giving the participation plan the importance and attention that it should receive.

When there is national participation, it must not hurt the quality and safety aspects of the plant nor jeopardize the schedule of the project execution. Thus the limitations of the national participation must be considered fully.

There are *technical limitations* which may result from the:

(i) Ability of local suppliers to meet delivery schedule
(ii) Ability to meet stringent quality requirements
(iii) Availability of qualified manpower
(iv) Availability of relevant technology and know-how.

There are *financial and economic limitations* which are linked to the:

(1) Availability of funds for expanding the factory facilities and machinery which would permit acquisition of new technologies;
(2) Adequacy of the market size to justify the investments required for the items to be produced domestically;
(3) Actual total cost of the items to be produced domestically as compared with cost on the international market.

An important consideration governing the extent of national participation is the size of the nuclear power programme which must be sufficiently large to be attractive to the local participants. They then can make the necessary investments of effort and money to obtain special equipment and to create a pool of skilled manpower.

All the participating industries, if new to nuclear related work, most probably will have to modify their facilities or methods of work in order to satisfy the nuclear requirements. These modifications may also involve seeking some technology transfer. In all cases, retraining of some personnel and management will be necessary. These modifications will depend upon the industries in question and their respective involvement. Relevant considerations include whether:

(a) The utility is involved in all phases throughout the programme;
(b) Engineering companies (civil, mechanical and electrical engineering contractors) are involved in the construction/erection phase and can supply services related to maintenance and backfitting during the operating phase;
(c) Manufacturing companies are involved in the construction phase in providing components and equipment and similarly in the operating phase for the supply of replacement parts and components;
(d) Suppliers of metals, chemicals and plastics are involved in all phases;
(e) Construction companies covering civil, mechanical, electrical and instrumentation work are involved during the construction/erection phase;
(f) Professional services are required throughout the phases to provide specialized experts whom other participating organizations may not normally provide;
(g) Companies in the chemical industry are involved in the operating phase depending on the nature of the fuel cycle activities that the country decides to undertake.

4.2.1. Minimum and desirable levels of participation

The technology involved in the construction of a nuclear power plant is similar in many respects to that required for building fossil fuelled power plants, chemical process industries and cement manufacturing plants, although there are areas where specialized technologies have to be introduced. These include the manufacture of reactor components, fuel assemblies, reactor control devices and computerized control systems.

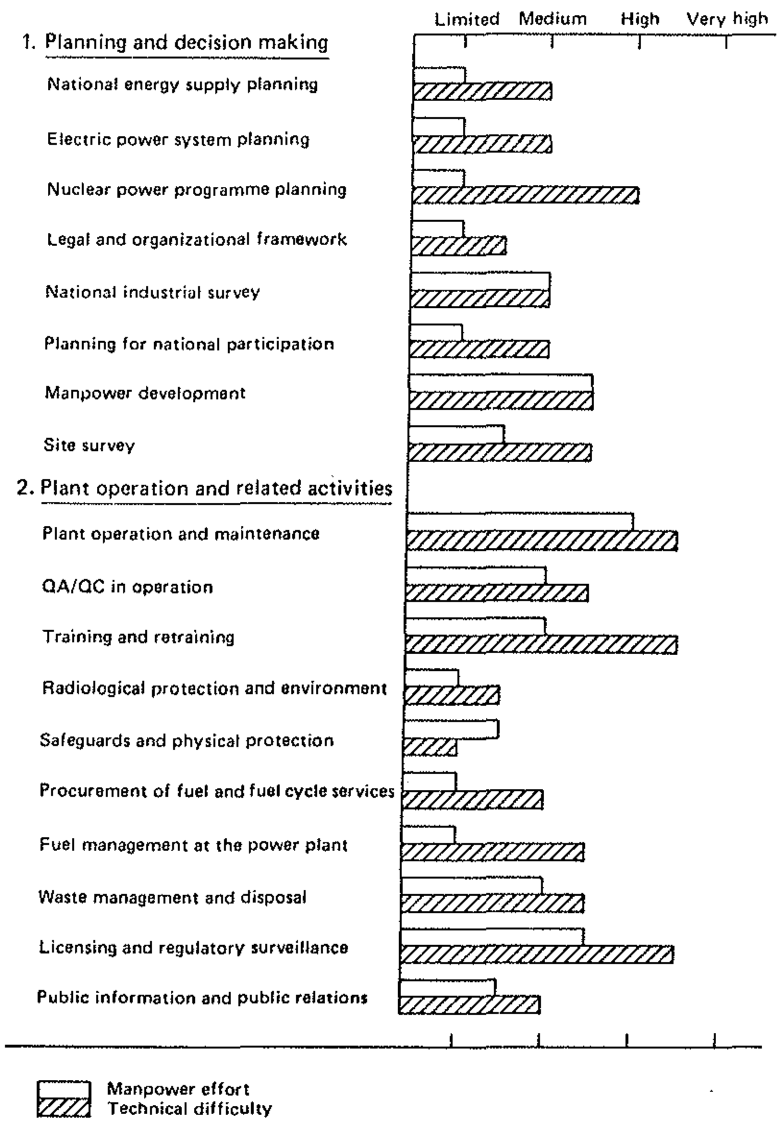


FIG. 10. Minimum participation.

It is difficult to quantify the unavoidable minimum of local industrial support since the conditions are bound to vary in different countries. However, for meaningful local participation, the existence of a medium and heavy engineering industry experienced in the manufacture of cement, steel or chemicals and a well developed civil construction industry should be considered the minimum of industrial capability. These facilities should be in place before a nuclear power programme with a meaningful chance of success can be conceived.

When making a final decision on the extent of local participation, planners need to recognize that industrial capability cannot be below a certain minimum if the plant's construction and operation are not to be jeopardized.

Figure 10 shows the minimum national participation in the execution of a nuclear power programme and the degree of difficulty involved in the related activities.

To carry out the minimum activities the country must possess a certain competence in the following areas:

- Site selection
- Civil design and civil construction
- Design review (sufficient to monitor the engineering work)
- Quality assurance and control
- Fabrication of some equipment in the balance of conventional island
- A minimum of erection capability to cope later with certain modifications and with maintenance
- Testing of equipment, systems and plant acceptance
- Specialized manpower training
- Certain management activities (especially in project execution, plant operation and technology transfer)

Further, for a minimum involvement, even with the first plant, the local engineering companies and industries should participate to a reasonable extent in the following activities:

(i) The detailed engineering of conventional activities such as civil and architectural work,
(ii) The supply and manufacture of basic common materials, e.g. bulk materials for civil, mechanical and electrical work,
(iii) The completion of construction work especially in civil, mechanical and electrical work in balance of plant and in some conventional areas, to the extent possible.

The above participation does not need too great an adaptation to nuclearization, yet the contribution to local economy may be highly beneficial.

In addition to this minimum, Fig. 11 shows other activities that although not strictly necessary, would increase noticeably the success of the project if they were to be executed by domestic resources.

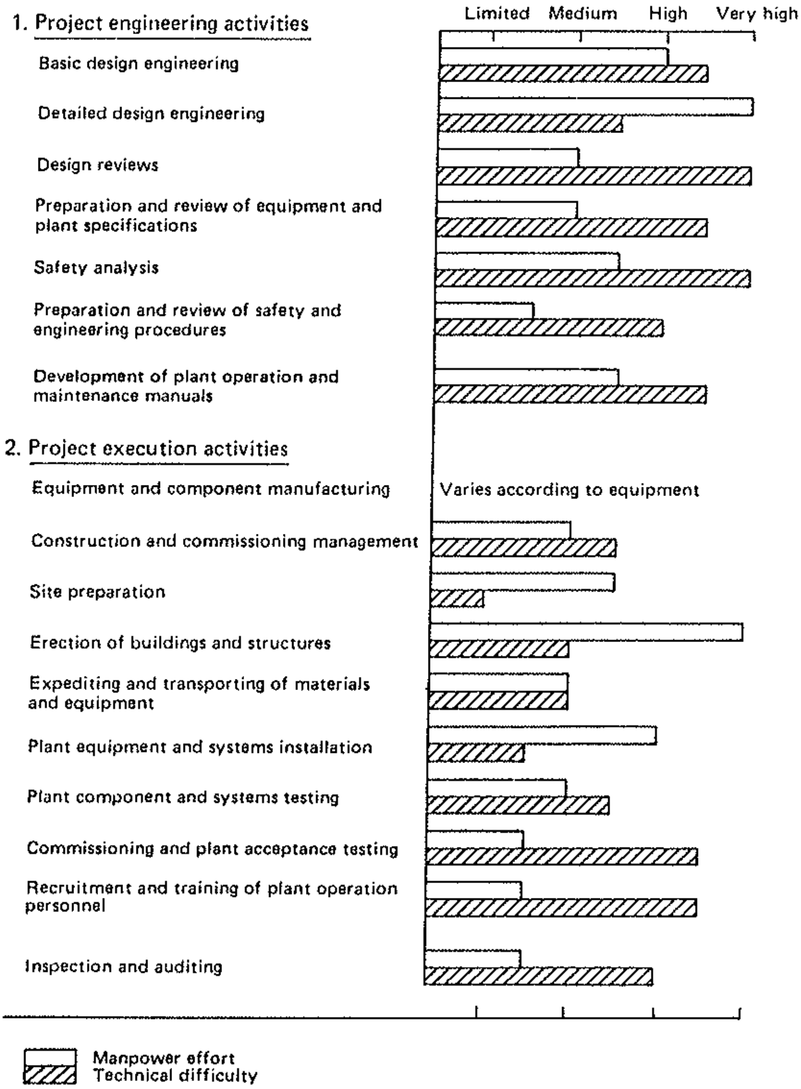


FIG. 11. Desirable participation depending on technical capability and resources.

In order to encourage participation of the domestic industry, planners may have to take promotional actions which motivate and ensure a meaningful participation. The following steps can guarantee a positive and efficient evolution of the national participation:

(1) Establishing a plan of nuclear power plant programmes and matching it with the required expansion of interested industries that wish to participate;
(2) Performing periodic analyses of local industrial potential and balancing the requirements of the nuclear power programme with those of other industrial sectors;
(3) Issuing periodic special reports giving details of product groups and local industries which have demonstrated their capabilities in the various product groups;
(4) Supporting potential domestic suppliers having the basic capability for manufacturing a product, but requiring some additional equipment and technical know-how;
(5) Transferring technical knowledge of complex equipment to places where manufacturing know-how is not fully available. This transfer can be accomplished through suitable technical assistance or technology transfer agreements from experienced technology suppliers and by organizing suitable training for manufacturers under such agreements;
(6) Obtaining prototypes and 'development orders' initially to create the industrial capability needed whenever precision components have to be produced on a repetitive basis;
(7) Adopting a standardized design which will make repetitive manufacture possible thereby cutting down the cost and time progressively.

When setting targets for the national participation, planners should consider evolutionary aspects of local involvement. The general guideline below lists a series of progressive levels of local participation that a country could achieve after experience is acquired and involvement increased.

Level 1. As a minimum, local labour and some construction materials are used for on-site non-specialized purposes, especially for the civil engineering work.

Level 2. Local contracting firms take full or partial responsibility for the civil work, possibly including some design work.

Level 3. Locally manufactured components from existing factories are used for non-critical parts of the balance of plant.

Level 4. Local manufacturers extend their normal product line to incorporate nuclear designs and standards.

Level 5. Special factories are set up locally to manufacture heavy and specialized nuclear components.

In any one country, the potential to contribute to a nuclear project will vary between a pessimistically low and an optimistically high percentage. Too frequently one hears the call for *maximum* participation but really the objective should be *optimum* participation. Excessive local participation not backed by proven experience may involve appreciable risks in terms of schedule delays, cost overruns and poor performance.

4.2.2. Optimum levels of participation

If a policy decision has been made by the country to implement a long range nuclear programme, it follows that an appraisal has been made of the available resources in the country. Also it infers that a policy has been framed regarding the demands projected to meet the shortfalls. The country must also take into account to what degree it is feasible for the present industries with their existing know-how to meet the objectives of the national participation. It is also necessary to know what new technology and facilities would be needed to achieve the envisaged local participation. The time-frame for making available the necessary skills must be consistent with the nuclear power programme schedule. Penalties resulting from cost overruns and delivery delays are almost inevitable in the initial stages of the programme so the country's policy makers would necessarily have to take these into account.

These schedule overruns will decrease progressively, however, as fabrication is repeated and experience acquired. Figure 12 shows that one country's experience

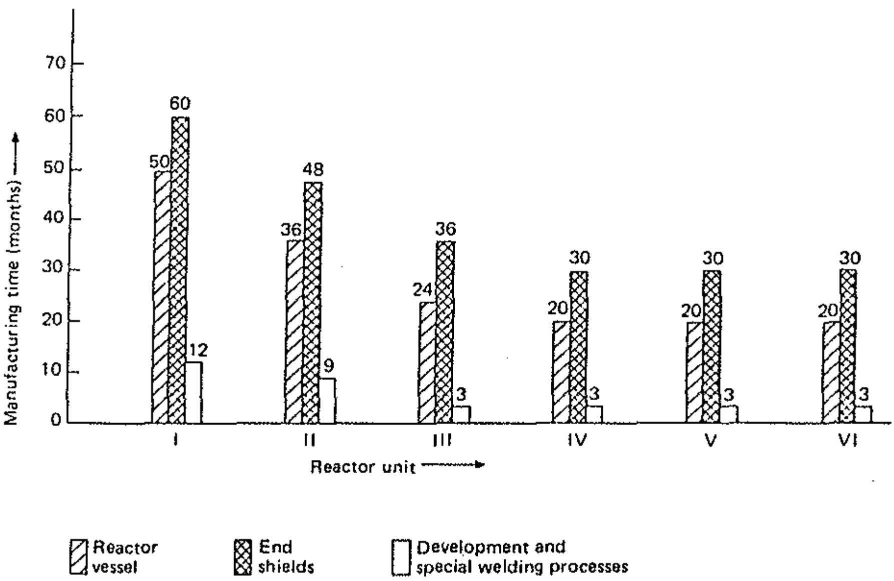


FIG. 12. Manufacturing cycle time of nuclear reactor components.

in manufacturing nuclear power plant components led to the reduction of manufacturing time when fabrication was repeated for subsequent units. It is important to recognize that a realistic approach to national participation is an important element for success since overambitious targets may lead to disappointment and disillusionment which must be avoided if the continuity of the nuclear programme is to be preserved.

In assessing the targets for optimum participation of national suppliers of plant items, planners must pay attention both to the weak and strong points of individual companies, so that efforts are made to eliminate the weaknesses and to make effective use of the strengths. The assessment of the suppliers' existing manufacturing capabilities is fundamental and should be therefore of the highest quality because it is the foundation on which the modifications and additions to the present industrial capabilities will have to be made.

Such an assessment will generate important information regarding the strategy for optimum national participation. The following example shows the type of results that a national industrial survey would produce in the case that, for example, a major pump shaft be the item envisaged for prospective domestic manufacturing;

Design	Impossible for national industry
Fabrication	
• *casting*	Easy
• *rough machinery*	Normal
• *finishing machining*	Difficult
NDT	Difficult
Transportation	Easy

This actual situation could change if certain modifications were made to the existing facilities and manpower. Thus in the example above, finishing machining can change from diffficult to normal and the viability of making those modifications must be assessed accordingly on cost-benefit considerations.

In selecting those items whose domestic manufacture is considered to be a part of optimum participation, the following considerations would be relevant. Typically there is some equipment which is specially nuclear and whose manufacture would require installation of new factories and the introduction of unfamiliar fabrication processes. Obviously such manufacturing would be advisable as second stage participation and only if the country's policy involved a large commitment to nuclear technology. Much of the equipment required, however, is not nuclear specific, presents only moderate technological difficulty and has a large application outside the nuclear technology. Moreover, many items in this category of equipment may be within the actual capability of the national manufacturing industry. Since this is, apparently, the right starting point for optimum national participation, initial attention must be concentrated on items which:

(a) are already currently manufactured event if at a lower quality level than needed, thus requiring moderate efforts for upgrading shop floor capability and organization;
(b) already have an internal market, whose planned expansion would justify the required investments in view of the expected turnover of sales;
(c) are not in the critical path of the plant construction.

4.2.3. Criteria governing national participation

When determining the types of equipment envisaged for local manufacturing, planners must consider the limiting factors as discussed in Section 4.2. Moreover, for viable participation, some prerequisite conditions must be met by the national industry. The ability to fulfil those conditions governs the extent of the national participation.

Prerequisite conditions for national participation basically require that the industry be able to meet delivery schedule and quality specifications while keeping overall production costs competitive. Thus a national manufacturer may be regarded as a potential supplier of selected equipment if:

(i) Investments have been made or are available to adequately strengthen and organize the workshop capability to permit the planned manufacturing;
(ii) Materials specifications, shop drawings, manufacturing documentation and procedures are complete, adapted to the workshop conditions and approved;
(iii) Qualified personnel are available as
- supervisory personnel
- technicians with adequate capability for material procurement, manufacturing process and non-destructive evaluation (NDE) techniques
- skilled workers with welding and precision machining capabilities

(iv) Testing of the prototypes of particular items to be manufactured has been satisfactory;
(v) Effective QA organization has been established.

Prior to entrusting a prospective national supplier with an actual order, its workshop must be accredited. The manufacturer has to demonstrate that he possesses the technology for the required fabrication process and is able to apply it according to quality specifications. Thus he must have:

(1) A complete programme for QA, including QA manuals and procedures designed according to the quality category of the equipment to be manufactured;

(2) The technical and technological capability to manufacture the specific equipment, i.e. he must have the process technology, the necessary manufacturing and control equipment, adequate testing facilities and qualified personnel.

To obtain workshop accreditation, the supplier must undergo audits conducted to verify the above points. These audits may take 10 to 24 months to complete depending on the complexity of the technological process involved. They may also require testing of prototypes which have been manufactured as development orders when precision components have to be produced in large quantities. The accreditation is not permanent and must be confirmed by periodic audits.

4.3. AREAS FOR NATIONAL PARTICIPATION

A nuclear power project encompasses many activities which require the country's important and long term involvement with financial, industrial and human resources. These activities include planning and decision making during the pre-project phase. The activities that occur during the project's execution, operation and maintenance phases are project management and engineering, equipment fabrication, plant construction and erection and plant commissioning. As stated before, some of these activities represent an unavoidable minimum of domestic participation as the responsibility rests with the country no matter what type of contract has been selected.

Conversely, although desirable, national participation is not mandatory in the major part of the activities carried over in project engineering and equipment manufacturing. These activities will be performed to the extent possible depending on the country's financial, industrial and human resources.

4.3.1. Categories of equipment

Non-nuclear constituents represent an extensive part of the NPP. These materials and equipment production capabilitities are found in a wide range of conventional industries. This means that with no additional technical know-how, local industries can make a substantial contribution to an NPP programme. Moreover, because of the large quantities of non-nuclear materials needed, it is possible that the local industries may wish to invest in order to increase their existing capacities.

Generally speaking the types of equipment used in an NPP include:

(a) Mechanical equipment whose fabrication basically requires casting, forging and machining capabilities. Included are pumps, valves and compressors.
(b) Fabricated equipment whose production mainly requires bending, forming and welding capabilities. Included are tanks, heat exchangers, vessels, filters and demineralizers.

(c) Electrical equipment. Included are control systems, relays, instruments, motors, transformers, cable and switch-yards.

To produce a given type of equipment, the national industry must possess the required technology, have the capability to finance the necessary expansions of its facilities and organization and find an adequate market for the product. This expertise will also depend on the technical difficulty of the fabrication process both in the shop and on the site as well as on the complexity of engineering the equipment within the plant system. Thus there are technological as well as economic limitations beyond which domestic manufacturing may not be advisable.

4.3.2. Prospective participation of the manufacturing industry

To illustrate the concepts expressed above, Fig. 13 reports a qualitative estimate with respect to the technical difficulty of and required investments for the manufacturing of some major NPP components which are mainly nuclear.

It is apparent that developing a domestic manufacturing capability for such equipment must be regarded as beyond the scope of national participation unless the country is committed to an important nuclear programme and has the required industrial infrastructure already established and available.

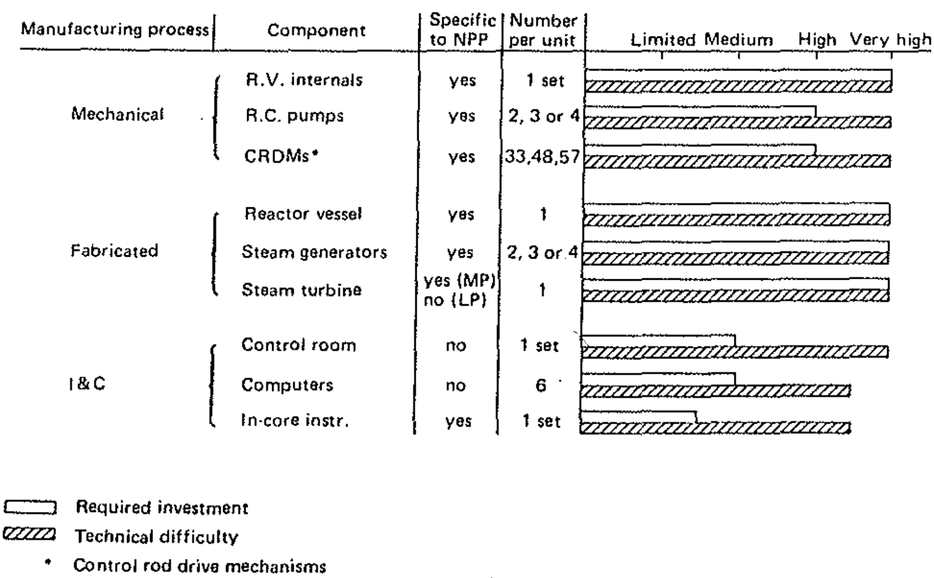


FIG. 13. Main NPP equipment (1000 MW PWR).

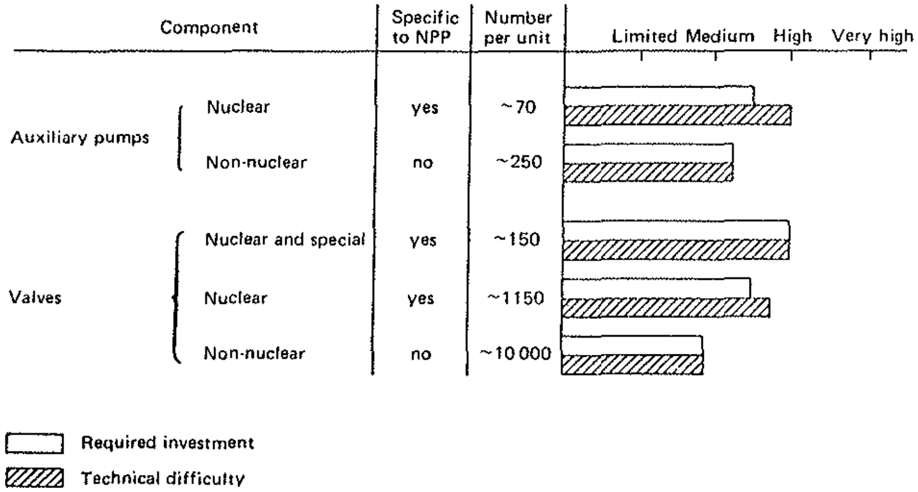


FIG. 14. NPP equipment whose local manufacture may be considered.

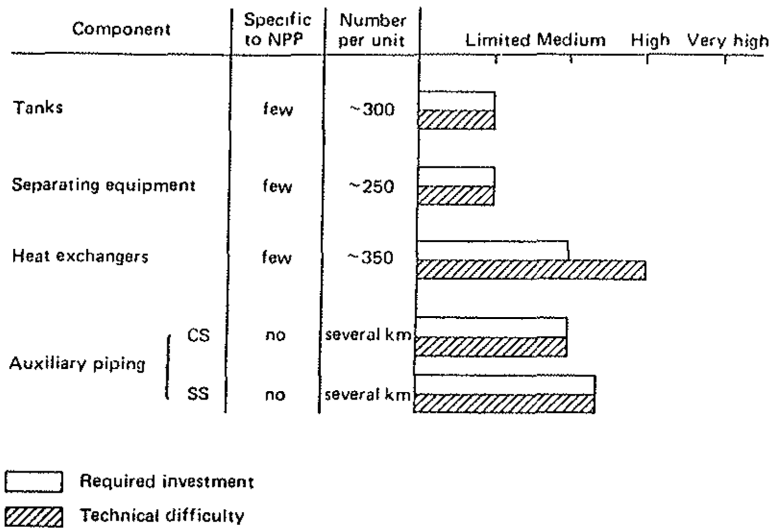


FIG. 15. NPP fabricated equipment whose local manufacture may be considered.

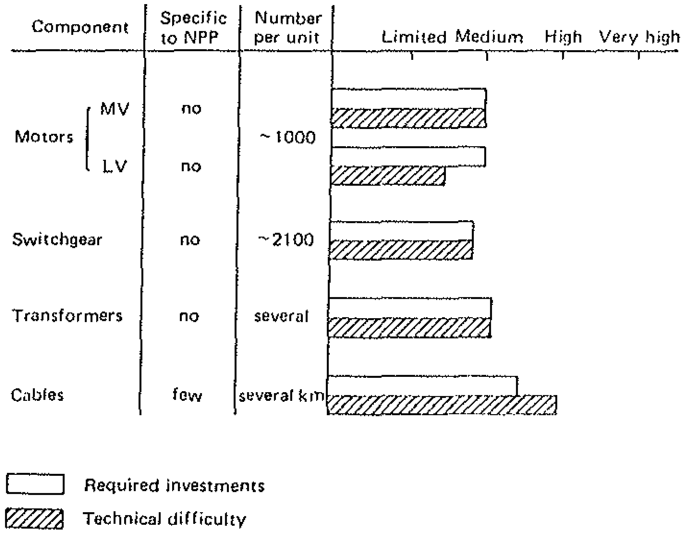


FIG. 16. NPP electrical equipment whose local manufacture may be considered.

A more accurate cost–benefit analysis may be necessary to decide whether or not a domestic capability should be developed for the I&C equipment. Although the technical difficulty of I&C design and fabrication is high, the investments required to qualify a domestic production are moderate. Moreover not being nuclear specific, I&C equipment can be employed in a large number of other industrial uses. Such production capability, if acquired, will certainly generate a vast spin-off effect on the national industrial production at large. Thus, under special circumstances, a dedicated effort to develop a national industry for I&C equipment might be justified.

Figures 14, 15 and 16 give examples of nuclear and conventional equipment whose fabrication requires lower investments and a generally moderate degree of technical difficulty. This equipment can be used in non-nuclear applications and may have a sizeable market. It might be noted that out of some 300 pumps in a 1000 MW PWR unit, about half require very difficult manufacturing; the others present only moderate difficulty. Similarly out of some 12 000 valves, only 150 have special nuclear requirements and involve difficult fabrication. These kinds of equipment, then, clearly represent areas in which development of national capabilities may be sought profitably.

In the area of fabricated equipment, a majority of items can be manufactured with moderate difficulty. These include:

- low pressure tanks
- separating equipment such as filters, demineralizers, degasifiers, separators, mixers and ion exchangers

- heat exchange equipment including heaters, coolers, steam separators, condensers and depressurizers.

This equipment should be considered for local production all the more because of its widespread use in non-nuclear applications.

The selection of equipment for prospective domestic fabrication should start with equipment of a non-classified quality level whose delayed delivery does not disrupt the plant construction schedule. This equipment should require only moderate modifications in the already existing manufacturing industry and adequate sales turnover of investment.

Thus, subject to unconstrained delivery schedule, adequate shop qualification and accreditation and availability of financial and human resources, suggested equipment for initial domestic participation may include:

- light fabricated equipment (initially in carbon steel (CS) and later in stainless steel (SS) outside critical paths of plant construction
- ventilation ducts and later more complex ventilation equipment
- cable trays
- CS anchoring elements and embedded plates
- CS structures for handling equipment
- non-classified quality level CS piping.

The following list of items suggests typical areas where domestic participation could be expanded:

Civil works

— General site earthworks
— Site facilities, access, upgrading communication structures
— Special foundations
— Water circulation conduits
— Water structures (intake and discharge galleries or channels)
— Main civil works
— Fuel and reactor building pool linings
— Structural steelwork, ironwork (external handling gantries, nuclear island and machine room structural steelwork, cladding, special doors, secondary steelwork, metal doors and windows)
— Lifting and handling plant (turbine haul overhead crane, operating trolleys, various overhead cranes, lifts and freight elevators)
— Preparation and ventilation of non-contaminable rooms
— Annexed buildings (administrative buildings, canteen, workshops, stores, etc.)
— Finishes and miscellaneous (tiling, paint work, floor finishes, sanitary appliances, etc.)

Conventional mechanical engineering

— Condensers, heaters, depressurizing equipment
— Pumps (extraction pumps, dewatering pumps, miscellaneous)
— Feedwater treatment
— Production of auxiliary fluids (compressed air, auxiliary steam supply, demineralized water)
— Filtration and water treatment equipment
— Pipework (main ducting, MP–LP pipework, miscellaneous pipework, lagging)
— Pipe fitting (taps, valves)
— Tanks and exchangers
— Fixed fire detection and fighting equipment

Electrical engineering

— HV transformers (main transformer, letdown and auxiliary transformer)
— HV connections (6.6. kV connectors, HV equipment, HV switch-yard)
— LV transformers and electrical boards (6.6 kV board, 380 V board, LV cabinets)
— 6.6. kV motors
— Backup and monitoring power (generator set, batteries, chargers)
— General electrical installations
— Centralized data processing
— Site electrical installations
— Site lighting
— Telecommunications

CHAPTER 5
THE TRANSFER OF TECHNOLOGY

5.1. INTRODUCTION

Transfer of technology (TT) which at one time was often an appendage now is becoming a more and more important part of a supply contract and can no longer be treated as a side issue. Equally it is now realized that the very process of TT is an expertise at par with other management expertise.

In a large project, such as an NPP, the drawings, specifications and other documents, which explain how things are made and how they are operated, are not the technology but only a description of it. When an organization practising the technology (a supplier organization) passes these documents to another organization (the receiver) the technology is not transferred. Only when the receiver is able to make the articles and operate the plants can it be said that the technology has been transferred. Technology transfer requires that the receiver acquire information, absorb the information and act on the basis of the information. In other words the receiver must not only acquire information, but must learn how to use it.

5.2 TRANSFERRING THE TECHNOLOGY

The complexity of nuclear technology requires a relatively high financial investment as well as a commitment of human resources. Since there will be serious consequences if TT is poorly executed, it is wiser to develop a master plan for the totality of the TT to be achieved. This will mean that various independent participants in the NPP programme will need to get together to ensure a certain coherence in the know-how to be acquired and a coherent phasing of the actual acquisition of this know-how.

Technology transfer is a learning process which is only successful when knowledge, skill and experience have been imparted to people in the receiver organization; it is not enough to transfer documents and equipment. If the receiver does not practise the technolgy, he will forget what he has learned, and the technology will no longer be transferred. The receiver, then, must have sufficient prior knowledge to enable him to understand the new information he is to learn, and sufficient experience and skills to enable him to practise the new techniques of the transferred technology. Like all learning processes, technology transfer takes time; if well managed, TT can be a benefit to both the supplier and the receiver of technology.

Viewed from the point of view of the donor of the technology, TT will achieve the following:

(1) The opportunity to establish a long term relationship with the receiving country and its industries. Such a relationship usually is commercially positive for both parties;
(2) The development of a new market in nuclear and nuclear related industries;
(3) An improvement in the donor's international image and in its export capacity;
(4) An advancement in existing technology which can benefit both the donor and receiver when TT is used on specific R&D projects;
(5) The successful winning of a contract which is more attractive to the receiver because of the TT package offered.

Viewed from the receiving country, TT will permit:

(a) The acquisition of the know-how developed by others in a shorter time and at lesser cost;
(b) The development of capabilities which can be transferred to other industries by spin-off;
(c) The achieving of more independence by better control within and management of the execution of the nuclear programme as well as through a buildup of increasing national participation in the future projects;
(d) The raising of the standards of the technological education and training.

Finally a factor that can lead to a better definition of TT is the realization by both the donor and the receiver of what TT is not. For example:

(i) It is not a simple mechanical process, but a complex teaching process and does not produce instantaneous results.
(ii) It is also not a process that is cheap either to the donor or receiver if they provide all the conditions necessary for a successful transfer of technology.
(iii) The transfer of technology is not a magic solution to any problem.
(iv) TT will not provide immediately all the benefits that technology will eventually produce.
(v) The newly acquired technology will not automatically be a key to entering export nuclear markets.

5.2.1. Kinds of technology to be transferred

Within the nuclear context there are three basic technologies that can be transferred:

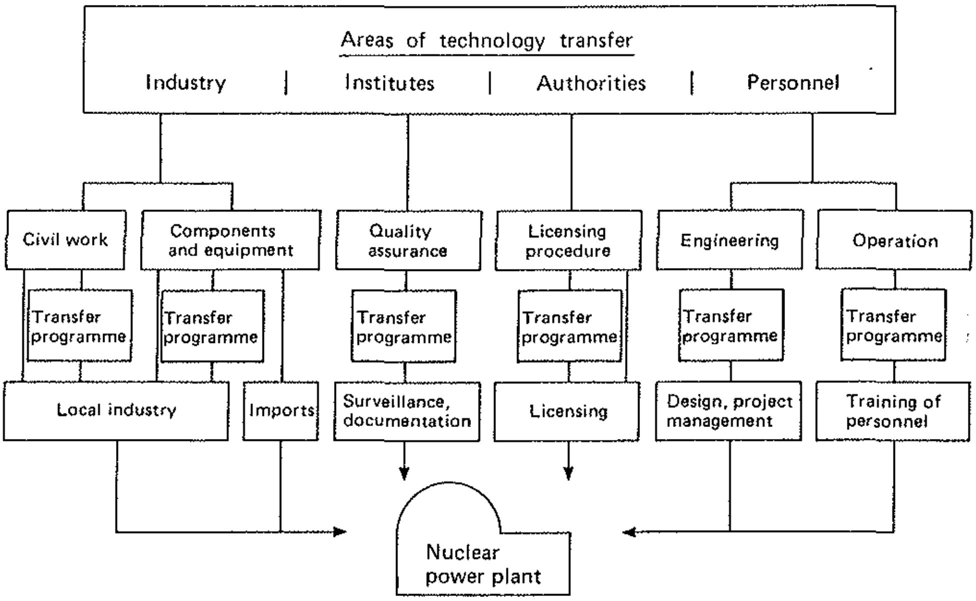


FIG. 17. Areas of technology transfer for nuclear power plants.

Design technology	This can start at the R&D stage and continue right up to final process design of all the systems making up a nuclear plant.
Manufacturing and construction technology	This includes the design of nuclear equipment and extends through the special manufacturing techniques and QA methods to the construction techniques of a nuclear plant.
Project engineering and management	This deals with the software work necessary for the successful execution of a nuclear power project. It includes both the home office and site activities and covers partly the pre-project period as well.

Typical technological areas in which capabilities are usually transferred include:

— nuclear island design, supply and construction
— nuclear steam supply system design and supply

— subsystems design and supply
— component supply
— fuel supply
— licensing support
— project engineering and management
— site management
— quality control and quality assurance.

Each technology and area requires a different approach and method for successful technology transfer. Figure 17 shows the different areas and how they relate to the NPP programme.

5.2.2. The main stages of technology transfer

There are several stages of achievement of technology transfer. There is the first level or stage which is the *copying or initiating phase*. At this level, the plant and equipment are specified and provided by the supplier while the receiver operates the process according to the supplier's specifications and instructions. The receiver's personnel are trained to undertake the necessary tasks, but they have not the technical capacity to understand the process. The receiver can operate the process and maintain the equipment in normal conditions, but requires technical support from the supplier for dealing with abnormal conditions.

The next stage or level may be called the *selective stage;* it is characterized by the receivers' increased technical understanding which enables him to be selective in his choice of process, equipment and foreign suppliers. He may also be selective in operational and maintenance methods and techniques, but remains dependent on the supplier for technical support in the more difficult situations.

The *adaptive stage* follows wherein the receiver with the help of the supplier's assistance modifies the supplier's technology to adapt it to the specific local conditions. Adjusting to local conditions involves usually the introduction of site specific conditions into the engineering. It also requires modifying specifications and processes to accommodate the components of local manufacture, the materials available locally and the abilities of the local labour force.

The highest level that can be reached is the *mastery stage*. At that level the receiver has such a good command of the technology acquired that he can now modify it at will to suit his own objectives and policies. Modifying a technology is a creative activity which must be based on a thorough knowledge of process and technology. The activity is creative because a solution has to be invented to satisfy a new need. Also a thorough understanding is essential to ensure that the product is not affected adversely by the modification and that there are no undesirable side effects.

Understanding the process of technology transfer requires that the receiver has personnel at a higher level of technical education than is needed for the first two stages of an NPP. The creative activity requires personnel capable of original thinking. Once the receiver has personnel of this quality contributing to the technology, it is only a matter of application and time for the receiver to master the technology.

To make this significant step, the receiver must also have, or develop, the more sophisticated management skills required to guide technological change to integrate technology, personnel, finance and the market into a successful corporate achievement.

There is no clear dividing line between each stage as all four stages are part of a continuum in which the growing experience of the receiver results in the acquisition of knowledge and increasing competence. The transfer of all aspects of a technology need not take place at the same speed; indeed, they are unlikely to do so when a complex technology is being transferred. For example, some civil engineering activities may be adapted to the use of local materials and labour practices at an early stage in nuclear technology transfer; in contrast, the materials and the fabrication techniques used for the manufacture of key components are likely to remain unchanged for some time.

5.2.3. Methods of transferring technology

Any country starting to operate a nuclear power programme is immediately involved in technology transfer to a range of institutions. The utility requires the capability of managing, operating and maintaining a nuclear power plant while engineering companies require the capability of constructing nuclear power plants, including undertaking the design which is specific to the local plant. The manufacturing industry requires the capability to manufacture to nuclear standards, while the regulatory body needs to be able to devise regulations and supervise their implementation. There is a need also for technology transfer to activities which are not purely nuclear, such as standardization, testing and R&D.

Methods of transferring technology can be any one or a combination of the following:

- *Off-the-job training or education* in universities or educational institutions, industrial classroom training within receiver or donor organizations, field observations and briefings;
- *On-the-job training or education* in home offices or site offices concerned with an ongoing NPP project, in manufacturing shops or construction facilities involved with an actual NPP project, or in technical assistance programmes either in the offices, sites or factories.

In both approaches there will be customized and standard courses.

In the transfer approaches and methods employed, documentation will be an important item. This documentation at the end of an extensive TT may reach several tonnes. The contents, the format, the distribution and the control of this documentation is therefore important. The cost angle of this apparent minor item of TT can be an important non-negligible amount. In one example of TT, in the first year, a selection of more than 10 000 technical reports and engineering documents was transmitted and in five years this total increased to 55 000. In addition 125 computer programs were furnished.

The language employed for TT can be a vital factor in the process. The ideal is that the TT be conducted in the receiver's language, but this is not always practical for a number of reasons such as:

(a) The difficulty the donor's personnel experience in acquiring the new language quickly,
(b) The need to expand the receiver's language to include the new technology,
(c) The fact that producing the documentation, video films and computer programs in the receiver's language is a long term project on its own.

5.3. THE STRUCTURES OF THE TECHNOLOGY TRANSFER

It is evident that a comprehensive technology transfer will involve several organizations in both the receiver and the donor countries. It might be thought desirable to simplify the interfaces and strengthen control by channelling all the technology transfer through one organization. For example, one government department could receive all the technology and then pass it on to the various organizations in the country who would use it.

If technology were transmitted by passing packets of documents such as patents, drawings and specifications, centralization of transfer in this way might be feasible. However, the point has already been made that transfer of technology is not like the transfer of goods; a technology is only transferred when people practise it. Because successful practice must build on similar technological experience, the transfer must be between similar organizations. A natural corollary is that each organization should make a separate agreement with its opposite number in the other country.

The far-reaching nature of nuclear technology transfer, the number of organizations involved and the time-scale over which the transfer must continue to take place indicate strongly the desirability of the individual transfer agreements being effected under the cover of a general intergovernmental agreement.

5.3.1. Intergovernmental agreements

Intergovernmental agreements are probably necessary and certainly desirable for countries participating in TT. They indicate an intent on the part of each country

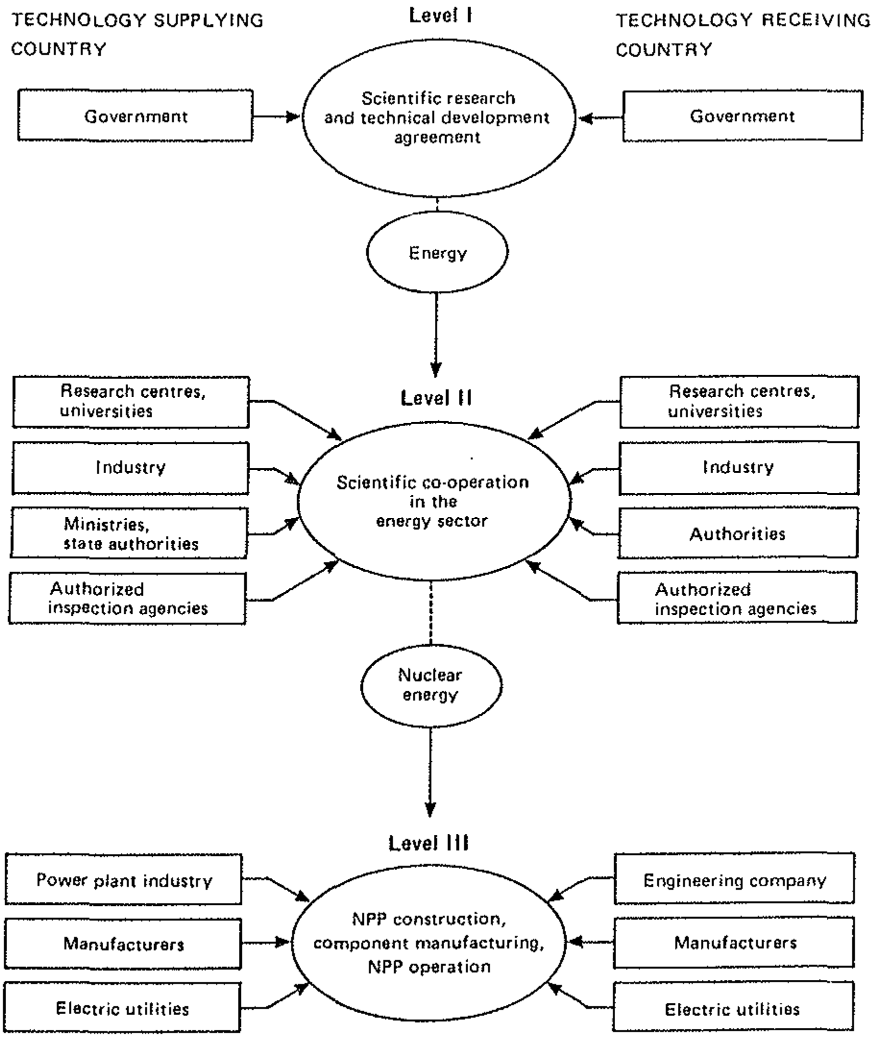


FIG. 18. Structure of an agreement for the transfer of nuclear technology.

to respond to the requests of the other in the area covered by the agreement. They also provide a framework for the separate technology transfer agreements between the technical organizations of the two countries. Typical levels of bilateral agreements — governments, scientific institutions, industry — are illustrated as examples in Fig. 18.

Intergovernmental agreements are particularly desirable in the pre-project phase when a country is exploring the technical and commercial aspects of a nuclear power programme. One result of an intergovernmental agreement is that it does indeed provide a framework; the individual working agreements for transferring the technology and providing the plants, equipment and services can be drawn up and agreed to rapidly since they conform to an already established and accepted method of working between the two countries.

The agreements between specific organizations under the general cover of the intergovernmental agreement need not be limited to companies in the nuclear power industry. If both parties wish, the contract can be written to include detailed agreements among research and development organizations, standards institutes, government departments and educational institutions.

5.3.2. Company agreements

The agreements between individual companies and organizations are of basic importance because technology is transferred between these companies and organizations. Of particular importance for these working level agreements is the definition of the technology to be transferred, and the level of competence which the receiver is to achieve. There must also be a clear definition of how the competence is to be established. The type and nature of documents which will be transferred, the formal training which will be given, the on-the-job training in the supplier's facilities and the secondment of supplier's personnel to the receiver's organization should all be covered.

5.3.3. Characteristics of various agreements

They are many types of agreement under which technology can be transferred. The form of agreement suitable in particular conditions is determined by the technical competence of the receiver and by the way the supplier and the receiver intend to use the technology after the transfer. In the following discussion, the characteristics of some distinct types of agreements and the conditions for which they are more appropriate are described.

(1) *The licensing agreement*

Definition of the technology and the technical services is of fundamental importance to a successful agreement. This is not only a question of defining the scope of the technology to be transferred. It also is necessary to be specific about the scope and nature of technical services and technical assistance to be provided and especially of being clear about the end product and the know-how involved. In practice, differences regarding expectations are a common cause of difficulty in technology transfer; the perceptions of the receiver and the supplier may differ on the technology to be transferred, the capability to be achieved by the receiver and the relative importance of documentation and training in achieving this capability. Misunderstandings of this sort can be avoided by full discussion and careful documentation of the technology transfer process and its scope.

The agreement should provide that the receiver have *access to improvements in the technology.* If it does not, the receiver will have bought a static technology and will only be able to keep a place in the market by improving the technology himself or by making a further agreement with a supplier. Another reason for defining the technology clearly is to ensure that there is no dispute about what constitutes a change in the technology, although it may still be difficult to distinguish between improvements and the development of new techniques.

Guarantees by the licensor should ensure:

— that the technology is suitable for the products covered by the agreement,
— that the know-how transferred belongs to the licensor,
— that the technology is capable of achieving the level of production which is specified,
— that the content of the technology transferred is full and complete,
— that the delivery of drawings, specifications and materials is completed within the specified period.

The *restrictions on the licensee* depend on the relative bargaining strength of supplier and receiver. In addition to restrictions on the territory of sales and the purchase of specified materials and items, suppliers may wish to impose restrictions on items such as pricing, production, and obtaining know-how from others.

Inspection and reporting concerns the right of the supplier to have access to the plants, records and books of the receiving company. It assumes special importance when the receiver makes payments related to the use of the technology to the supplier in the form of royalties.

Since a technology is only transferred when the people of the receiver organization are able to practise the technology, the importance of *training* cannot be overemphasized. The agreement should specify the training to be given and the level of competence the trainees are to achieve.

The *language* of the authentic text of the agreement is a matter of great concern to the lawyers. When entering into contractual agreements, suppliers will only accept contracts written in their own language or in a language common to both parties.

With this situation there is a potential for misunderstandings which could cause serious problems and perhaps lead to litigation. The language used for transferring the technology for all documentation including drawings, specifications and official communications is of more general concern and can also have wide implications.

(2) *Technical co-operation agreements*

The term technical co-operation agreement is used here to cover a wide spectrum of technology transfer agreements in which the supplier's efforts to transfer the technology go beyond handing over documents. However, the intention of these agreements is the same as a licensing agreement, namely that when the transfer of technology is completed, each party will continue as before to pursue its business independently and perhaps competitively. The word co-operation is used in recognition of the close working together necessary for successful technology transfer.

The number of documents, such as drawings, specifications, codes of practice, materials lists, reports, and computer codes, involved in transfer of nuclear technology can be very large. The work required for identifying and cataloguing can be considerable, and in addition the supplier must take further steps to ensure that the material is understood and used correctly. These steps include training and consultancy, which may involve formal training sessions in which the receiver's personnel work in the supplier's shops and offices. At the same time the supplier's personnel may work with the receiver's staff during the execution of the project in both the supplier's and the receiver's countries.

The agreement may be prepared in several ways related to three distinct aspects of the transfer process:

— *Setting up the agreement:* the supplier provides information on what may be transferred, on defining the scope of the technology to be transferred and on the methods and administration of transfer. With this process, the supplier runs the risk that his proprietary knowledge may be disclosed without the protection of an agreement. These costs and risk are often covered by an initial fee or down payment.
— *Implementing the transfer:* the supplier expends effort in preparing documents, transferring documents, providing consultancy services and training receiver personnel. The receiver usually pays for these services on a normal cost plus basis.
— *Licensing the technology transferred:* when the technology has been transferred according to the terms of the agreement, the supplier and receiver are in the position of licensor and licensee; the technical co-operation agreement must make provision for the continued use of the technology by both parties. The provisions will usually include royalties or similar payments from the receiver based on his use of the technology.

The agreement will also normally contain provisions defining the way the receiver uses the technology, and the markets in which supplier and receiver will operate after the technology has been transferred; provisions of this nature will have to be discussed in due time. Since there is no absolute way of calculating the value of technology, the amount of the initial down payment and of the royalty type payments on subsequent use of the technology can only be determined by negotiation and bargaining between the supplier and receiver. The payment for services given by the supplier during the transfer are usually charged at cost plus and are thus not subject to the same type of negotiation.

(3) *Joint ventures*

The joint venture is distinguished from licensing and co-operation agreements by the arrangement existing after the technology has been transferred. In a joint venture, the supplier and receiver agree at the beginning that the association established for transferring the technology will be maintained in the future; there will also be a continuing relationship between the parties through the phase of transfer into the phase of exploitation.

The organization and administration of the transfer, and the payment by the receiver for services from the supplier, need not be any different from a technical co-operation agreement. But the considerations affecting an initial fee, and the commercial relationship after the technology is transferred, must be judged from a different perspective.

The joint venture implies an identical interest in the outcome of the transfer and in the continuing association. This in turn implies that both parties will continue to commit resources to the venture after the initial transfer is complete. The definition of these commitments in practical terms is usually a must. Thus the donor and receiver code-sign and co-produce the products resulting from the TT. The agreement should provide that the receiver have access to improvements in the technology within a time-frame and under specified conditions.

(4) *Technical assistance*

This is an agreement usually on a very limited scope of TT in which the receiver is performing work with the technical assistance of the donor. This agreement, which automatically involves an on-the-job-training situation, is used particularly in the manufacturing and construction sectors. In this type of agreement the donor has a fairly dominant and leading role and in principle the receiver follows the instructions of the donor.

(5) *Consultancy*

This type of agreement provides a limited TT and the donor plays a relatively passive role in contrast to that played in the other agreements. In principle, the donor advises but does not instruct the receiver on how a particular work should be done or how a particular situation should be handled. This can be a good means for transferring software type of technologies or skills.

5.4. PROTECTING THE TECHNOLOGY

The establishment of a technology transfer agreement will be facilitated if the legal system in the receiver country recognizes the ownership of intellectual as well as physical property and also gives technology transfer contracts the same legal protection as any lawfully constituted contract. For example, the undertakings of both parties should be legally enforceable and both should be protected against a third party's having access to the information transferred when that party is not a participant in the transfer agreement.

Similarly, there should be provisions special to technology transfer which allow the supplier to receive fair and reasonable compensation for the technology transfers and to be protected against unreasonable exploitation. The legislation must reflect a proper balance between the rights and interests of the supplier and those of the receiver; when this is achieved, responsible organizations will be able to reach agreement within the legal framework.

5.4.1. Legal framework for agreements

The function of a legal framework is to facilitate technology transfer by establishing conditions which afford protection of the legitimate rights of the donor and receiver. Thus the framework should enable technology transfer agreements to be made which include the following features:

(a) The handing over of specifications, drawings, designs, samples and models as appropriate to the agreed scope of transfer,
(b) The provision for training the receiver's personnel to enable the receiver to acquire the technology up to the desired level of transfer,
(c) An agreement on a sufficient duration to enable the receiver to practise the acquired technology,
(d) The fair and reasonable use and exploitation by the receiver of the technology transferred,
(e) Protection against abuse of the information transferred and its unauthorized exploitation by third parties,

(f) The establishment of licence fees, royalties and other forms of payment which give the donor fair compensation.

Similar methods are used for protecting intellectual property in various countries. In these, the laws provide for registration of designs and trademarks, for patenting of inventions and for copyright of documents and recordings. The law can be invoked to prevent or stop the unauthorized use of intellectual property thus protected.

Designs, patents and copyrights apply to distinct and relatively easily identifiable types of intellectual property and therefore can be described and registered. There is much intellectual property covered by the general term know-how which does not fall into any of these definitions and for these the owner must rely on secrecy for protection. The major content of nuclear technology transfer agreements is concerned with intellectual property of this type; a relatively small proportion of the information transferred will have been described in patents and other published documents.

5.4.2. Some commercial considerations/the price of technology

The supplier has developed his mastery of the technology at high cost and risk usually over a long period. In addition he will probably expend considerable effort in transferring it. Reasonably, he will want compensation when he transfers his technology and will seek payment in some form because technology is bought and sold like any commodity.

One fact, however, complicates the establishment of a fair price for the value of the technology transferred. This is because of the receiver's usual lack of experience in and appreciation of the degree of complexity of the technology in question. Therefore the receiver has difficulty appreciating or quantifying the investment in effort and money made by the supplier in developing the technology. To this can be added the difference in costs of resources used as perceived in the supplier's country and in the receiver's country.

Nevertheless, the technology market has one aspect in common with other markets: transfer of technology will only be successful when both the supplier and the receiver perceive that they will benefit from the transaction.

For a TT to be successful both parties must feel that the agreement is profitable. In arriving at the price for transferring the technology, the aspects to be taken into account are:

(i) An assessment of the cost to the donor of developing the technology and of continuing that development after transfer since the receiver usually wishes to be kept up to date on the technology passed on;

(ii) The nature of the technology and the level of effort necessary to master it;
(iii) The value of using a sales linked agreement (e.g. sale of a nuclear power plant);
(iv) The possibility that the donor, in spreading knowledge of his technology, is risking its unauthorized dissemination and consequent loss of competitiveness;
(v) The limitations on markets, prices and materials which are incorporated into the agreements;
(vi) An assessment of the extra business in the new technology which will accrue to the receiver; relevant factors include the size of the receiver's domestic market, the cost of local labour, and the trading relations with other countries;
(vii) An assessment of the royalty income accruing to the donor (following from the receiver's business in the new technology) and additional business for the donor, e.g. through access to new markets in countries with which the receiver has special relationships.

5.5. THE EXPERIENCE OF OTHERS

The following is a brief account of the experience of some developing countries which have successfully transferred the nuclear technology and have presently an active ongoing nuclear power programme.

5.5.1. Requirements for effective technology transfer

A strong commitment to the construction of more than one unit within a specified time-frame is an important condition for the introduction of the nuclear technology. The execution of an actual project is also recognized as an essential condition to promote the transfer effectively. The importance of making the success of the first project a necessary step for any further development limits initially the national participation. In all countries, the procurement of the first nuclear power plant was essentially a turnkey job with extensive supplier's supervision and reduced technology transfer playing a major role.

In all countries a group of professionals with extensive industrial experience and previous exposure to basic nuclear physics and research reactor operations are essential for making the fundamental technological choices and for building up the initial nuclear architect-engineer functions. Also, common features at the outset of the technology transfer include a developed civil construction industry with the capability to execute civil works for dams and hydro projects and to procure bulk construction materials. Typical industrial infrastructures in all countries include chemical process plants, petrochemical industry, carbon steel making capability though limited in size for casting and forging. It is also necessary to have an electrical industry for switch-yard, cabling, motor and transformer assembly and testing, a mechanical industry for limited piping works, erection works and some manufacturing capability for heat exchangers, tanks, low pressure valves and other minor items in the balance of plant of thermal power stations.

Some engineering capability must be domestically available to perform architect-engineering functions under supervision of the suppliers, not adequate however to act as an independent nuclear architect-engineer. An early commitment to a selected type of technology and reactor size is reported as an important condition to attain standardization and thus accelerate the learning process and stimulate the progressive involvement of the manufacturing industry.

All countries recognize the necessity of the participation of the national industry in the execution of the project and the need for providing that technology transfer be included in the scope of procurement. In all countries the establishment of a dedicated organization with strong government support to take the lead in the transferring of technology to the national suppliers proved necessary and effective.

5.5.2. Methods of transferring the technology

Methods of transferring technology depended on what was to be transferred and how as well as on the industrial development attained by the receiving country. Thus different countries adopted different methods which were equally successful. Typically the transfer was framed within a general agreement with the supplier of the technology who also was the supplier of the first nuclear power project. At one extreme, the outright purchase of blueprints, shop drawings and technical specifications was adopted for review, modification and approval by the receiving organization under the supplier's supervision. At the other extreme a long term partnership with the supplier was aimed at and thus joint ventures were established.

Intermediate cases were also reported with licensor/licensee contracts for acquiring specific manufacturing processes and joint venture type of agreements for increasing responsibility in project management and engineering. Different methods had equal merits and proved satisfactory although the first one was more demanding on the ability of the recipient organization to make the correct technological choices.

In all countries an important step in preparing for the transfer was the assessment of the country's industrial capabilities, either as an internal appraisal or with independent outside assistance. Such an evaluation served to identify the scope and extent of the transfer which would be necessary to attain the targeted level of national participation. In all cases a clear definition of the type of transfer and its content was negotiated and contracted for as an integral part of the equipment procurement. However, different methods were followed in different countries.

Method A. In one case the development of the nuclear technology was undertaken in parallel with the broader scope of an overall industrialization process. No nuclear specific industries were developed at an early stage. The promotional organization identified a restricted number of national industries already existing in the country and assisted them in upgrading their production to include nuclear equipment. Shop drawings and technical specifications purchased from the supplier were adjusted to local manufacturing. Standards and QA procedures were developed with initial supplier's assistance and accreditation with the national R&D infrastructure providing the necessary support for testing and validation.

Training of national manufacturers' personnel was organized at the supplier's shop during fabrication of the equipment procured for the first unit. The order for the second unit was timely placed so as to engage the trained staff in the same jobs soon after the training was completed. More than one national manufacturer was involved to stimulate competition and permit the selection of the national suppliers through open bidding. This was not regarded as a dispersion of resources since the requested capabilities were just an improvement of the already existing capabilities. In the long run involving more than one manufacturer proved beneficial in raising the standards of the overall industrial sector and in reducing the risk of exposing subsequent projects to cost and schedule overruns which could occur in the case of failure of a single national supplier.

Method B. In another country from an early start a nuclear specific industry was set up for large components for which the local manufacturers did not accept the risk. Thus, an industrial consortium was created as a joint venture with the technology supplier. This approach expanded the national participation but was reported as a cause of delay at an early stage when the one supplier could not meet the nuclear quality requirements within the expected delivery schedule. Other countries took the intermediate approach of upgrading the manufacturing capability of their existing industries to include some nuclear equipment while developing a special nuclear industry for key items such as fuel and zirconium technologies. Documentation and training were instruments for transferring this technology.

For good results the receiving organizations had to play an active role in ensuring the relevance and quality of the transmitted documentation. These organizations were directly involved in a joint effort with the supplier of the technology and co-operated in identifying the appropriate documentation to be released, its adaptation and prompt transmission to the relevant receiving industries as well as its proper storage and retrieval. In the countries' experience two types of documentation proved relevant:

- *Technical documents* referring to specific project scopes. They normally included: as-built drawings' applicable standards, material specifications, shop drawings, QA manuals and relevant software.

- *Reference documents* covering a broader scope. They normally included working reports, organization reports and experience reports.

The transfer of this documentation and its completeness was not always an automatic process. All countries recommended that the receiving organizations keep an active role in monitoring the transferred documents for quality, relevance and completeness. Particularly their relevance might have to be reassessed periodically.

A detailed joint training plan was drawn up with the supplier and individual training curricula worked out both in the receiving country and at the supplier's technical offices and shops. Careful selection of trainees who were competent and experienced was an important element for success. Also important was a systematic follow-up of the results achieved by consistently monitoring and documenting the trainees' progress in performing the jobs for which they were being trained.

Method C. One country reported on the positive results achieved from early involvement of the national staff in the design, construction and commissioning, in the supplier's country, of the plant considered to be a reference plant for the first unit to be procured. In this particular case two groups were staffed with personnel who accumulated many years of experience in nuclear R&D activities:

- The *design group* who acted later as architect–engineer for the domestic project under the supplier's supervision;
- The *site group* for commissioning and operation who participated in the actual commissioning of the reference plant.

Soon after this training, civil works for the first unit started in the country and the site group took over the site management. Plant construction and commissioning was a domestic effort with the supplier supervising and retaining the final responsibility.

The final safety report and the operation manuals were prepared by the site group, reviewed by the supplier and finally approved by the design group and the national licensing authority. In parallel, during fabrication of the equipment for the first unit, the country's inspectors performed quality control (QC) audits with the supervision of the supplier. Also, national manufacturers sent their staffs to watch manufacturing at the supplier shops. Follow-up manufacturing for the second unit and quality surveillance were part of a national effort with the supplier acting as chief inspector for acceptance. Finally some staff in the design group with core physics and thermohydraulics competence evolved training programmes and started building a national training centre.

This experience showed how an initial nucleus of qualified professionals, a well co-ordinated schedule and a good response by the national industry were able to transfer technology with effective results and short lead times.

5.5.3. Managing the technology transfer

For the technology transfer to be successful, the capability of the recipient country to plan, monitor and control the transfer was a prerequisite condition. Technology transfer was not a passive process and careful management had to be established from its very outset. Because experience in all countries was very similar, the same type of management tools were developed and used. In the first place a good capability to make correct choices was present in all countries. A group of senior professionals took the lead in advising the government on nuclear matters within the scope of the overall industrial development of the country.

An ad hoc national organization was entrusted with the task of promoting the transfer of the nuclear technology. This organization was developed at a research centre when a nuclear R&D infrastructure was already available. In other cases it emerged as an industrial consortium or was created under direct government mandate. In all countries there was the early recognition that the nuclear technology cannot be viably developed without the direct support of the national industry. Thus a strategy for increasing the national participation in the nuclear programme was formulated which established a time-frame for interim and final targets. The selection of the technology to be transferred and developed was an important choice which affected the method of transferring the technology.

Basic criteria governing this choice included: the degree of desired independence, the availability of materials as natural resources and production capability, initial development of the manufacturing industry and a correct appreciation of its future response. Also under consideration was the availability of resources to develop, at an early stage, some nuclear captive industries as well as the existence of the personnel to staff the necessary functions.

The selection of the technology supplier followed next and involved the capability to negotiate an agreement for the technology transfer. Provisions for a certain degree of flexibility were recommended as many problems which are likely to occur along the line may be overlooked at an early stage. A mechanism for controlling the transfer of information had to be set up. This involved the signing of a technical information contract governing the access by the recipient organization to all the documentation associated with the transfer. Included were the technical documents and the reference documents. An efficient databank for systematic classification, filing, storage and retrieval of the information was set up together with an expeditious distribution system to the relevant national counterparts. Another important function of the management of the transfer was the maintaining of a continuing open dialogue with the supplier so that questions and answers could be exchanged at all working levels.

Reportedly an important management tool to achieve this was the establishment of the design review procedures consisting of systematic checks of jobs performed by the recipient staff for review and approval by the supplier counterparts. These procedures were aimed at progressively transferring the total responsibility for a specific job to the receiving staff. They proved useful in assessing the progress and completeness of the transfer.

Training of the recipient staff at the supplier's premises was closely controlled by the management of the transfer. The opening of field offices with resident engineers acting as liaison between trainees and supplier instructors was very effective. Training plans were tailored to specific trainees' requirements; the quality of the supplier's instructors was continually monitored and if necessary promptly corrected. A systematic follow-up of the training against the achieved results was also effected so that all shortcomings could be efficiently removed and corrected. The importance of this management tool and its relevance to a successful transfer must be stressed.

Controlling the cost of the technology transfer was another important task of the management. As with any commodity, the acquisition of a technology had a price which was stipulated contractually. Good management had to establish stage payments based upon submission of a given documentation or equipment delivery. Payments for transferring functional capabilities were due when responsibility for the execution of a specific job was transferred fully to the technology receiving staff. Provisions for guarantees were also made to cover extra costs from unforeseen delays and/or lower response by the receiving organizations.

5.5.4. Problems in transferring technology

Reportedly the major problems experienced in the nuclear technology transfer were of an organizational, industrial, financial and political nature.

(1) *Organizational.* A centralized responsibility for and control over the nuclear technology transfer was reported as a prerequisite condition for success. Poor results were achieved when the promotion of transfer was left to individual organizations and industries. It was reported that in one country poor co-ordination prompted some industries to enter licence agreements with foreign suppliers for the acquisition of particular manufacturing capabilities to meet their corporate objectives. The capabilities were acquired successfully, but the production was exported and not used in support of the national nuclear programme. Moreover in the absence of a centralized organization, there was no clear responsibility and thus no adequate budget allocated. Hence long term decisions could not be made nor continuity assured.

(2) *Industrial.* Experience in several countries indicated that transfer of manufacturing capabilities to industry was in general successful. Conversely problems were experienced in transferring capabilities in the engineering industry and in the utility project management. In some countries, initial deficiencies in the engineering industry impaired noticeably the technology transfer. All participants reported that the

response of their national industries was not without problems. The enforcement of a discipline for quality was particularly difficult until the concept of QA and its benefits was understood by the industry fully.

(3) *Financial.* Adequate funds were of course a necessity. Equally important was the funding continuity. In some receiving countries, the lack of a well established financial policy, inadequate financing resources or the reduction of financing caused delays in the transfer and reduction in the scope of the project transfer.

(4) *Political.* Equally disruptive to the successful nuclear technology transfer were changes in the nuclear energy policy of the country. An unfavourable political climate always introduced delays in the nuclear programme with a consequent negative impact on the technology transfer because of a loss of acquired skills and the attrition of qualified personnel. An NPP can develop successfully only in a constantly favourable political climate. The reaction and support of the public are largely influenced by constant government support. Therefore both financial and political underwriting are necessary so that the resources committed to a nuclear programme are not wasted but rather are fully developed.

CHAPTER 6
QUALITY ASSURANCE

6.1. INTRODUCTION

It is essential that a country embarking on the implementation of its first nuclear power project give serious consideration to the various activities necessary for the assurance of the required quality of equipment, materials and services through all the phases of the nuclear power project. It is important to have full recognition of the scope of QA activities incorporated into a consistent programme and to prepare the necessary number of qualified engineers and inspection personnel for the establishment, execution and supervision of an effective QA programme.

Contemporary regulations for nuclear power plant construction and operation based on a set of safety requirements contained in safety criteria, standards, procedures, drawings, specifications and associated engineering requirements must also be available. It is necessary to be certain that the plant is designed, constructed, installed, tested and operated satisfactorily. This assurance will be possible if all participants in the nuclear power project are obliged to plan, perform, control and document their work in a systematic and consistent manner. The management system which ensures that all activities affecting safety and quality of the plant are performed in a planned, systematic and controlled manner is the QA system.

Basically, the QA system consists of:

(1) Planning, management and documentation of systematic action which will provide adequate confidence that an item processed or facilitating will perform satisfactorily in service. This includes such activities as quality assurance programme formulation and co-ordination, review and approval of procedures, preparation and performance of QA audits.

(2) QC activities which provide a means to control and measure the characteristics of an item, process or facility to established requirements. These include such actions as inspections, testing, surveillance or monitoring of items, processes and services.

6.2. SETTING UP A QA PROGRAMME

The total activities established and implemented to assure quality together constitute the quality assurance programme. For a QA system to function efficiently there has to be a coherent organizational structure consisting of several levels:

Government	A regulatory body establishes the requirements and reviews, inspects and enforces their implementation.
Owner/operator	The owner/operator has to set up an internal organization to ensure compliance with the regulatory body's rules and requests.
Contractors/engineers	Each participant in the NPP construction has to set up its own QA organization in order to satisfy the utility's requirements.
Subcontractors, subvendors	These entities also have to set up a special QA organization so as to satisfy all QA obligations defined by the contractors or engineering company with whom they have a committment.

Depending on the structure, those assigned to perform QA functions may form a single unit or several units covering separate quality assurance functions. For simplicity, they are usually referred to as the quality assurance unit or department. The QA department has a position in an organization equivalent to and completely independent of other departments such as engineering and procurement.

Three components are required to assure the necessary quality:

(a) A production organization capable of achieving the required quality in such basic activities as design, construction, manufacturing or operation;
(b) A quality control staff which controls and verifies the conformance of the output of the production organization to the pre-established requirements;
(c) A quality assurance department or unit responsible for the monitoring of quality control activities and the auditing of the quality assurance programme.

The organization of programme activities and their assignment to programme participants for implementation through their constituent programmes are described in Quality Assurance Organization for Nuclear Power Plants: A Safety Guide, Safety Series No. 50-SG-QA7, IAEA, Vienna (1983).

In the process of identifying the requirements of a quality assurance programme it may be advantageous to develop a classification system such as the following by which items and services may be characterized and the appropriate quality assurance activities identified. Such a system would include:

Classification of plant items and services

The classification system for items and services should be based on the safety implications of a malfunction of the item or of an error in the performance of a service (for guidance refer to Safety Functions and Component Classification for BWR, PWR and PTR: A Safety Guide, Safety Series No. 50-SG-D1, IAEA, Vienna (1979)).

Identification of appropriate quality assurance activities

It may be advantageous to develop a set of graded specifications which define specific programme activities that are generally applicable to each class of item and service. The selection of programme activities to be applied to each class should involve consideration of the following:

- Extent and form of procedure and instructions
- Methods of verification
- Extent of verification
- System of audits
- Quality assurance records

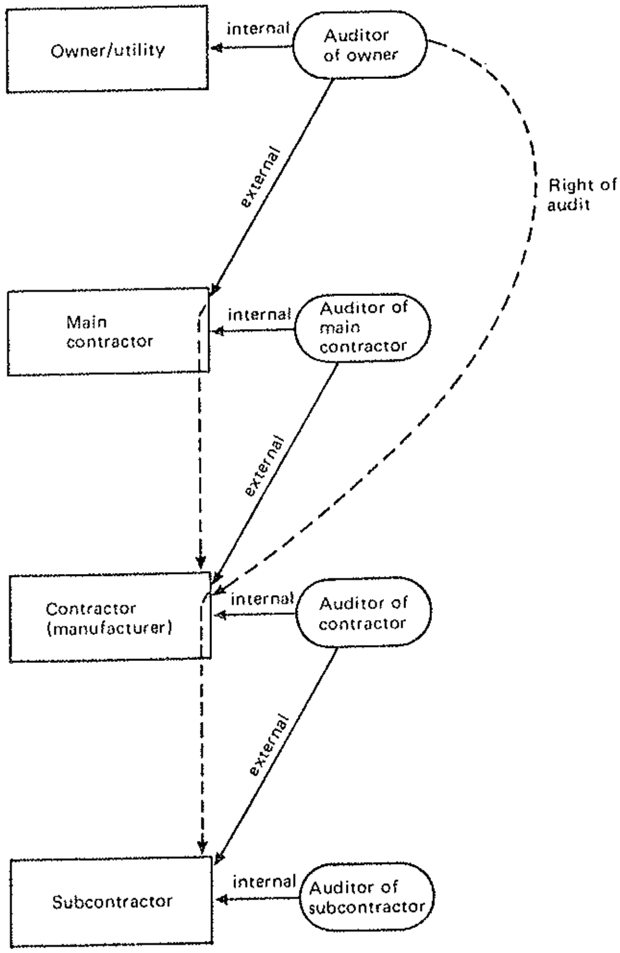


FIG. 19. The auditing system.

Organizational structure

The plant owner is ultimately responsible for the effectiveness of all QA programme activities; therefore he must perform overall QA programme management. Each organization participating in a nuclear power project is required to implement only those activities of the quality assurance programme that apply to its scope of assigned work. The co-ordination of the quality assurance activities of all participants is the responsibility of the owner who performs surveillance through his auditing system as shown in Fig. 19.

The organizational structure and the functional assignments of a quality assurance programme shall take into account the fact that execution of a quality assurance programme requires both performers and verifiers. The organizational structure and the functional assignments shall be such that:

(i) Attainment of quality objectives is accomplished by those who have been assigned responsibility for performing the work; this may include examinations, checks and inspections of the work by the individual performing the work.
(ii) When verification of conformance to established requirements is necessary, it is carried out by whose who do not have direct responsibility for performing the work.
(iii) In each participating organization, one or more key positions shall be established for the quality assurance functions. Such an arrangement will ensure that an appropriate quality assurance programme is established and effectively implemented and will verify that activities have been correctly performed.

6.3. QA AS A MANAGEMENT CONTROL SYSTEM

A formal management control system that is required in nuclear power project activities to be established and used by the management in implementing control over technical aspects of the project is the system of quality assurance. This system should be used by the management in the attainment of organizational goals and objectives which define a nuclear project as a safe, reliable and economic electricity generator. These ultimate goals and objectives should be achieved by implementing the following quality assurance functions:

(1) Achieving quality objectives of equipment and activities through identifying and prescribing the quality and safety standards, and by imposing their implementation by qualified personnel under rigorous management control.

(2) Verification of achieved quality through a series of complementary or independent methods such as inspection, testing, surveillance, auditing and reviews as well as assessment and generation of objective evidence of achieved quality.
(3) Ensuring feedback of information to the management on identified deficiencies and their causes as well as the initiation of corrective actions to eliminate root causes of quality related problems.

Identifying the QA as a management control system implies that it will have all the elements of a management control system and be based on a defined organizational structure with assigned autonomy, responsibility and authority. The organizational units and each person in the organization perform delegated functions that are prescribed by a documented QA programme. As a basis for establishment of this programme, regulatory requirements and applicable industrial standards are used. A broad scope and orientation to both the achieving of quality and quality verifications require that the QA programme be implemented by all personnel performing quality related activities. QA is, therefore, not a responsibility of a single group that may be formally identified as a QA unit, but is a responsibility to be shared by all performers and verifiers in project activities.

QA should be used by the management at all levels as a closed loop system of management control. The management itself will determine the extent of the efficiency of this system. Inability or failure of some management to implement the QA system efficiently can have severe consequences on the quality of equipment and activities related to the construction and operation of nuclear power plants.

Constituent elements of this system include:

Organization: In an organization with an established QA system, a documented organizational structure should be established with clearly defined functional responsibilities as well as levels of authority and lines of internal and external communications for management, direction, and execution of project activities. Implementation of the QA programme is the responsibility of all individuals and groups participating in activities. However as a general rule, establishing and supervising the QA system are assigned to a specialized group of personnel, usually named the QA unit, who report to the management. The verifications, including quality control functions, are performed by individuals or groups who have not directly participated in the activities being examined.

QA programme: The goals, objectives and functions of the QA system are defined and documented in the QA programme. For a nuclear power project an overall QA programme will be established by the plant owner and will consist of constituent QA programmes of all those project participants performing activities affecting the quality of the plant. The overall QA programme will define all those items and activities to be subject to control and verification.

Establishment and documentation of the QA programme are among the first functions of an organization's management after the decision is made to perform activities related to a nuclear power project. This task includes:

- A thorough analysis of the work to be performed and an identification of all items and activities influencing the safety and performance of the nuclear power plant;
- The development and qualification of procedures and instructions for performing activities affecting the quality of these items;
- The creation of inspection and test plans as a constituent part of the manufacturing, construction and installation plans;
- The development of inspection and test procedures and the specification of acceptance criteria;
- The arranging of training and qualification programmes for all personnel performing quality related activities.

The QA programme is documented in programme description and QA procedures, as well as in inspection and test plans which include procedures and instructions for performing and verifying activities. The QA manual is a document containing policies and procedures that prescribe the functioning of the QA system.

QA system functions: All participants in a nuclear power project should perform their QA functions according to the requirements set down in the QA programme. These functions are managerial or administrative as well as technical. Through implementation of these functions, the management control system is exercising necessary controls over activities affecting the quality of a nuclear power plant.

The IAEA Code of Practice on QA and other similar documents elaborate on the function of the QA system in the form of QA requirements or criteria. These requirements shall be implemented in all activities related to quality of all items and activities covered by the QA programme. However, the intensity or the level of programme implementation will depend much on safety classification of items and other relevant factors.

The following QA functions are specified in Quality Assurance for Safety in Nuclear Power Plants: A Code of Practice, Safety Series No. 50-C-QA, IAEA, Vienna (1978):

(a) *Document control*

Document preparation, review, approval, issues and distribution are subject to control. Control measures shall ensure that only correct and approved documents are used in activities.

(b) *Design control*

Design process and design documents are subject to control and verification to ensure that applicable regulatory requirements, codes and standards are correctly translated into specifications, drawings, procedures and instructions.

(c) *Procurement control*

The procurement process shall be controlled. Contracts shall be awarded only to qualified suppliers with an established QA programme. Procurement shall be controlled through verification of manufacturing processes and products using inspections, tests, surveillance and audits.

(d) *Control of purchased material and equipment*

Purchased material and equipment shall conform to quality requirements specified in procurement documents. Control measures shall include both the examination of products upon delivery and the examination of objective evidence concerning quality during the process of procurement, source evaluation and surveillance.

(e) *Control of processes*

Processes such as welding, heat treatment and non-destructive examination shall be accomplished by qualified personnel under controlled conditions and procedures.

(f) *Inspection and test control*

As a part of quality control activities, inspection and testing of items shall also be subject to control to assure that these activities have been administered adequately.

(g) *Identification and control of materials, parts and components*

Identification and control of items shall be ensured through appropriate markings on the items, or on the records traceable to the items. These measures should also provide means for tracing items back to the materials and ahead to their location within an assembly.

(h) *Non-conformance control*

Non-conforming materials and activities should be subject to control to prevent their inadvertent use or installation. Each non-conforming item shall be evaluated and marked as 'reject', 'repair', 'remove', or 'use as is'.

(i) *Corrective actions*

Conditions identified as adverse to quality shall be corrected and appropriate measures taken to prevent recurrence.

(j) *Quality assurance system audits*

Regular and unscheduled internal audits of the quality assurance programme, within the organization, and external audits of suppliers and other contractors shall provide confidence in the efficiency and adequacy of the established QA programme.

The basic methods of implementing the above QA functions include the:

(i) Performance of activities affecting quality on the basis of established and qualified procedures and instructions;
(ii) Performance of activities under controlled conditions by qualified personnel;
(iii) Verification of conformance to established requirements and to prescribed quality characteristics through a series of complementary verifications such as inspections, tests, surveillance of activities or QA and programme audits;
(iv) Control of non-conformance and implementation of corrective actions to eliminate the root causes of unsatisfactory conditions.

6.4. MANPOWER REQUIREMENTS AND QUALIFICATIONS

Manpower requirements for QA depend on the scope of the QA programme within an organization. In principle the work-load for QA/QC will be proportional to the work activities directly related to the manufacturing, installation and construction of the nuclear power plant. For the work on the nuclear power plant site related to construction and installation of equipment, the ratio of craft workers to inspection and test personnel (QC staff) is approximately 10 to 1. For typical QA functions, QA programme preparation and maintenance, evaluation of procedures and auditing, the ratio in some situations can be 50 to 1.

In the manufacturing industries, manpower requirements for QA/QC will very much depend on the type of product, its safety relevance, complexity, and the degree of automatization of the production. A highly automated process, such as fuel fabrication, will need a large quality control staff in relation to the production staff; for other technological processes, this ratio may be the opposite. For a nuclear power project the overall QA programme will be the responsibility of the utility (plant owner). QA organization of a plant owner may vary widely depending on how many of the QA programme activities the owner delegates to other organizations and how many it retains for itself. As a minimum, a utility must retain actitivties related to the overall supervision of the work. In this case the plant owner is normally establishing two organizational units to perform the QA actitivies, i.e. the home office and the site QA organization with a total number of approximately ten engineers who are responsible for the following QA functions:

The *home office:* Development of the overall QA programme including procedures, quality plans and work schedules, as well as review and approval of procurement documents and equipment specifications, auditing of all major suppliers, constructors and installers.

The *site unit:* Surveillance and audits of construction actitivies and review and approval of construction and installation procedures, as well as the witnessing of all important inspections and tests and initiation of corrective actions.

Usually, some of the QA functions of the plant owner are delegated to an architect–engineer organization or to consultants. The QA organization of an architect–engineer is usually structured in a way similar to that of the plant owner, i.e. home office and site unit. These functions are mainly oriented to control of the technical aspects of plant design and construction. The home office of an architect–engineer is responsible for QA during the design of the nuclear power plant and for review and approval of design specifications and surveillance of all important vendors. The site unit is engaged in surveillance of constructors, nuclear steam supply system (NSSS) suppliers and the inspection and test activities of the installers. This unit also establishes co-ordination between site and home office actitivies. The number of QA/QC specialists whom an architect–engineer may engage in a nuclear power project will be 10–20. In addition, this organization should establish all technical supports at the site such as laboratories, storage, handling and management of QA records.

Various organizations involved in plant construction and installation of equipment will have their QA/QC units. Their functions will be mainly the planning and performance of first line inspections and after installation testing of equipment. To implement these responsibilities, inspection and test personnel with specialized qualification in the inspection of mechanical equipment, electrical equipment or civil structures will be needed. The ability to perform various techniques in non-destructive examination will also be necessary for implementation of these functions. Manpower requirements for this staff will vary during the plant construction period and at the peak of construction actitivies may consist of 80–100 inspection and test specialists qualified in various engineering disciplines and inspection techniques.

It is customary to classify QA staff into two broad groups, i.e. QA engineering personnel and inspection and test personnel. QA engineering personnel responsible for performing QA programme operation preparation and management should be educated in some of the engineering disciplines, and qualified in QA/QC methodology and techniques.

Their education must include knowledge of QA requirements, methods of surveillance and audits, and skill in planning and documenting such QA actitivies as inspection and test planning, audit planning and scheduling. Inspection and test personnel should be specialized in engineering disciplines and in examination and test techniques. These staff members are usually categorized according to several levels of qualification, where the lowest level represents qualification in performing specific examinations and tests and documenting the results. At this level they do not have authorization for acceptance or rejection of items or actitivies. Higher levels are qualified in performance of examinations and tests as well as for acceptance or rejection of work.

6.5. MEASURING AND TEST EQUIPMENT REQUIREMENTS

Implementation of quality assurance functions, particularly in the area of verification of achieved quality, demands use of equipment which can measure the quality characteristic with the required precision. Taking into account that the list of quality characteristics to be measured and verified is rather large, there is a whole range of measuring and test equipment that must be purchased and/or developed for satisfactory implementation of the QA functions. The equipment may be termed generally as quality information equipment because its main role is in providing information on quality characteristics to be used in product or process analysis and control. The increasing importance of such equipment can be demonstrated by the fact that in some industries up to 25% of the industrial plant investment can be assigned to quality control equipment. One should take into account that the equipment used directly for measurements and tests should be supplemented in many cases with digital data evaluation equipment that provides on-line analysis and facilitates the decision making on acceptance or rejection. In the process of development of a quality assurance system, development and supply of measuring and test equipment should be performed in a systematic way which includes the following steps:

(a) *Equipment specification planning:* Taking into account various industrial branches and specialization in manufacturing of specific products or performance of services, it will be necessary to establish specific information on the quality of the equipment required both by the quality assurance progamme of the organization and by the inspection and test plan for specific products. This process should include specification of the required type of equipment as well as the necessary precision, automation and data processing equipment.

(b) *Design and procurement:* Not all the necessary equipment will be commercially available. Some will have to be designed and will require detailed design and operational requirements, accuracy and calibration. Information input and data processing as well as information output will be needed. For the equipment which is commercially available, the selection of the supplier should be based on the quality characteristics of the equipment, the supplier's records in providing quality products and testing of samples of the equipment.

(c) *Installation, check-out and calibration:* Before use, the procured equipment should be subject to verification of its application and operation. This includes the preparation of instructions for operation, maintenance and calibration. Training of operation personnel in equipment use should be considered as an additional requirement to the general training of inspection and test personnel.

For performing specific quality verification functions during plant construction, an organization participating in a nuclear power project should be equipped with necessary quality information equipment corresponding to the scope of its activity and the methods to be used in verification.

During plant construction, the first line inspections and after-installation testing are normally performed by inspection groups (QC group) of the organization performing the work. These groups should be equipped with basic inspection tools specific for the type of activity (mechanical, electrical, civil) and adequate for field use. It would be impossible to list all required measuring and test equipment needed for each type of inspection activity. Generally they may be grouped under headings which specify quality characteristics to be measured or tested.

(d) *Measuring of dimensions:* This equipment includes a range of types based on mechanical, optical or electrical principles. It may include simple tools such as calipers or gauges as well as complicated optical systems such as optical comparative stereo microscopes.

(e) *Measuring of plant system parameters:* In this group of equipment belongs all temperature, pressure, level or flow measuring equipment.

(f) *Surface examination:* This includes non-destructive examination equipment used for visual examination (gauges, telescopes, borescopes, photo or video cameras, etc.) as well as magnetic particle and liquid penentrant examination equipment.

(g) *Volume examination:* The whole volume examination for defects in pressure retaining components needs NDE equipment for radiography, ultrasonic or eddy current (thin wall components) equipment. A number of components specially designed for a given application are commercially available.

(h) *Leak testing:* This type of testing includes various methods and requires a special type of equipment for each method. Simple pressure change detection instruments can be sufficient for some application, but for others halogen detection or mass spectrometer types of leak testing equipment may be needed.

(i) *Hydrostatic testing:* This testing requires a set of pressure gauges and pressure relief devices as well as specific leak measure devices.

(j) *Electrical measurements:* For inspection and testing of electrical equipment, instrumentation and control devices, instruments and measuring devices are needed such as voltage testers, ammeters, ohmmeters, resistance bridges, breaker testers, probes, cable pull testers, tension meters.

(k) *Laboratory testing:* An equipped laboratory will be needed at the construction site to perform all laboratory testing related to construction activities such as testing of soils, rocks and concrete. Standard types of laboratory test equipment for chemical and mechanical testing will be needed.

(l) *Calibration laboratory:* An organization responsible for measuring and test activities should have a calibration laboratory with all necessary standards to implement QA requirements on the control of inspection and test equipment. The standard in the laboratory shall be traceable to well recognized national standards.

To the list of required inspection and test equipment one should add equipment for storing and processing information that may be located centrally in the organization, or that might be associated with the specific inspection or test group. This equipment can be of importance for data recording, processing information, analysis and decision making. Also, this processing equipment will be necessary for the retention and handling of integrated quality information important to the nuclear power plant quality database.

6.6. QA SPIN-OFF

A country embarking on its first nuclear power project will probably face the QA methodology for the first time. Strict quality assurance requirements for equipment and actitivies emphasized by safety considerations for nuclear power plants will be unique for a country without much experience in manufacturing of high quality products. However, the QA identified as a management control system is not exclusively designed for nuclear power plants. The design, manufacture and installation of each quality product will require elements of control of quality related activities to ensure achievement of those characteristics that determine the product's performance. Traditional quality control methods that are used in most industries concentrate almost exclusively on manufacturing and serve to reduce imperfections in the product and eliminate the bad products from the lot.

Nuclear QA, however, introduces a concept of total product control, both by the quality achieving process and verification of achieved quality of products. Implementation of QA will be necessary in all high technology industries where performance characteristics must be identified and strictly maintained.

Quality consciousness established during the nuclear power programme will facilitate the acceptance and development of quality technology in conventional industry. Manpower qualified in a nuclear power project will represent a nucleus of personnel to introduce quality technology and to increase the quality standards in developing countries. However, although QA systems in both nuclear and conventional industry will have the same elements, different goals and objectives should be established in each specific case.

In a nuclear power project, the first objective of a QA system is safety. In conventional industries, the QA system should be oriented both to quality and cost control and to the achievement of minimal life cycle costs of a product. This control will be implemented from the stage of design and manufacture to the use and maintenance of the product. Quality characteristics such as reliability and the ability to be manufactured and maintained efficiently, as well as other cost related parameters will be evaluated. These economic objectives will require the QA programme to be cost effective. Cost–benefit considerations, not entirely applicable to the nuclear QA, will be used in establishing and evaluating the QA programme's effectiveness in conventional industries.

Experience from a nuclear power project can be transferred to other industries either through direct involvement of an industrial organization in nuclear power activities, or indirectly through the acceptance of QA methods and the recruitment of trained QA personnel. To participate in nuclear power activities, an industrial organization will be obliged to establish and implement the QA programme which will satisfy regulatory and contractual requirements. Once the QA programme is established, it may be used also in activities which are outside of its nuclear power contract, although in a modified form. Indirect transfer of QA practices will always be based on good examples of the effective use of the QA programme in nuclear industry.

Experience acquired in the nuclear power project on the use of QA as a management control system is likely to become the fundamental approach to quality technology in the industrial progress of a developing country. A QA system will allow the integration of efforts of various groups and individuals who are in those modern industries related to the creation, building and maintenance of product quality.

CHAPTER 7

ENGINEERING AND PROJECT MANAGEMENT

7.1. INTRODUCTION

The term engineering and project management (E&PM), as used in this Guidebook, covers all the engineering, procurement, quality assurance and construction activities necessary to implement a nuclear power project. These actitivies, though of a software nature, usually generate and manage hardware actitivies such as the production of engineering documents, the fabrication of equipment, and site construction work.

This chapter will somewhat broadbrush these activities as the IAEA Guidebook on Nuclear Power Project Management goes into much more detail on this subject. The quality assurance function is handled specifically in Chapter 6 of this Guidebook and therefore will only be referred to in this chapter. However, this chapter will look at the salient features of E&PM and certain aspects and factors having a major effect on it.

The cost engineering and project management functions of an NPP amount to between 15 and 20% of the total cost of a plant. This sum will include the E&PM activities carried out by the suppliers of the nuclear and turbo-generator systems and those supplied by the industrial architect. It will also cover the services rendered by subcontractors engaged in engineering types of activities and the utility's own project services. This total, excluding the utility, can represent approximately 3–4.5 million man-hours of which about 2–3 million are spent off the site and about 1–1.5 million at the site. The on-site figure, however, excludes the various subcontractors' own site engineering and management. At the peak effort of the project, the engineering and project management function can be equivalent to about 400 engineers and technicians for home office activities and about 200 for the site. About 80% of the engineering personnel would have the equivalent of an engineering degree.

7.2. SCOPE DEFINITIONS

The term engineering usually covers the activities of basic and detail design, project engineering, procurement, construction support at the home office, quality assurance and quality control as well as site management. The latter normally includes field engineering, field procurement, construction and startup activities. Additionally, transfer of technology and localization of any of these activities may be part of engineering and can take place either in the home office and other locations

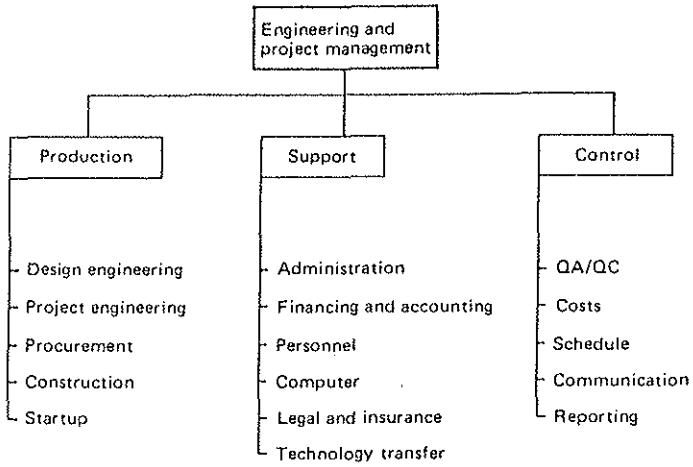


FIG. 20. Scope of engineering and project management.

off the site or on the site. The sum of these actitivies can be considered as the production part of engineering activities.

Project engineering is a term often used to describe general engineering work, such as layouts and general specifications. It includes, in particular, co-ordinating and expediting the various engineering disciplines so that these integrate efficiently and coherently.

The term project management includes the management of the various activities just described as well as the administrative functions that the project execution activities require for support such as personnel, finance and accounting. Project management will also cover all of the management controls and information that the total project requires so that the various project targets and plans are correctly established and efficiently met. The scope of E&PM is seen in Fig. 20.

Typical end products of the engineering design functions are the drawings and specifications to which the project is to be built and the requisitions against which the equipment and materials are purchased. Typical procurement end products are the bid requests, bid analyses, purchase orders and subcontracts to cover all the services and materials to be provided on the project. Construction support activities at the home office usually produce drawings and specifications to define how construction will be carried out and what site support and temporary facilities are needed. Other vital end products within the construction support actitivies are the construction plans and the outline draft of the various construction contracts.

Tables VII, VIII and IX give an indication of the typical design work carried out in the civil, mechanical and electrical engineering aspects of the project.

TABLE VII. CIVIL WORK ENGINEERING OF A NUCLEAR POWER PLANT PROJECT

PRINCIPAL ACTIVITIES OF BASIC DESIGN	PRINCIPAL ACTIVITIES OF DETAIL DESIGN
— Plan layout of buildings and systems	— Detailed structural analysis including seismic and dynamic calculations
— General arrangement of every building	— Detailed design of structures
— Site studies	— Floor response spectra evaluation for components seismic analysis
— Structural design criteria: overall description, materials, design loads and allowable stresses	— General drawings
— Materials and operations specifications	— As-built drawings and equipment layout
— Data for preliminary safety analysis report (PSAR)	— Reinforcing steel detailed drawings
— Conceptual design of structures: critical stresses, sizes and reinforcing steel calculations	— Steel structure drawings
— Architecture and landscaping	— Drawings of elements such as piping, supports, etc.
	— Architectural drawings: fire prevention and others
	— Materials lists
	— Field engineering

End products coming within the project management function include documents stating the policies as well as the procedures defining how each project activity will be carried out. These documents will cover also the support activities such as accounting, insurance, personnel and communications.

Further end products include the various management control reports on scheduling, costs, quality, use of resources and the production of the finished products needed by the project personnel in order to control and manage the project

TABLE VIII. MECHANICAL ENGINEERING OF A NUCLEAR POWER PLANT PROJECT

PRINCIPAL ACTIVITIES OF BASIC DESIGN	PRINCIPAL ACTIVITIES OF DETAIL DESIGN
— General layout of equipment and components	— Layout drawings
— Mechanical and chemical equipment	— General technical requirements
— HVAC	— System specifications
— Piping stress analysis	— Flow diagrams
— Mechanics	— Process diagrams
— Design criteria	— Equipment specifications
— Design review	— Calculations and analysis
— Components and systems classification	— Equipment and materials lists
— Applicable codes and standards	— HVAC drawings
— Seismic design	— Field engineering
— Stress calculations	

efficiently. Finally, there are the management information reports outlining the project performance needed inside and outside the project in order to have an accurate appreciation of the status of the project, the past and future trends, and other critical items.

7.3. THE PRINCIPAL PARTICIPANTS

The engineering and project management activities are shared among a number of principal partners. The number of participants and the depth and range of their activities depend on the extent of previous nuclear experience within the country, particularly in the utility and the local engineering companies. The degree of confidence felt by the utility in its ability to manage construction works is a further factor affecting participation.

The usual main NPP participants with their typical engineering and project management roles include:

TABLE IX. ELECTRICAL SYSTEMS ENGINEERING OF A NUCLEAR POWER PLANT

PRINCIPAL ACTIVITIES OF BASIC DESIGN	PRINCIPAL ACTIVITIES OF DETAIL DESIGN
Activities	*1. Electrical systems*
— Design criteria manual	— One-line diagrams
— Standards and guides manual	— Short-circuit calculations
— Detailed design manual	— Voltage drop study
— Voltage and power stability studies	— Busbar and cable calculations
— Systems classification	— Diesel generators and batteries
— Electrical protections	— Earthing, lighting, surge arrestor calculations
— General one-line diagrams	— Electrical wiring diagrams
— Electrical equipment layout	— Systems manuals (specific criteria summary; description and lists of equipment and components of every system)
— Planning of electrical raceways (trays, conduits, etc.)	*2. Electrical equipment* (Transformers, motors and switchgears)
	— Equipment specifications
	— Equipment data sheets
	— Equipment sizing
	— Suppliers' document reviews
	3. Field engineering
	— Equipment layout
	— Electrical raceway drawings
	— Field cabling
	— Earthing drawings, surge arrestor drawings
	4. Materials list

(1) *The utility*

The activities of the utility are divided between those involved in preparation and those necessary for the execution of the project. For some of these functions, the utility may be assisted by one of several consultants in specific tasks such as site survey, preparation of bid requests, and bid analysis.

Pre-project activities include the:

- feasibility study
- site survey and site selection studies
- outline definition of project (scope, schedule and costs)
- project execution plan (including QA requirements)
- processing the pre-qualifications (if any)
- preparation of the bid requests
- analysis and negotiations of the retained bids
- project financing plan
- operation and maintenance personnel planning.

Project activities cover:

- Application to the regulatory body for site and construction permits and for licensing of the plant;
- Monitoring the project and the performance of the main contractors and subcontractors;
- Surveillance functions for QA/QC;
- Monitoring conformance to environmental regulations;
- Taking care of any interfaces created by the project construction plan and not handled by the contractors themselves;
- Checking that all required as-built documents are obtained.

(2) *The main contractor*

The company acting as a single main contractor will construct all or almost all of the power plant. In this role, the contractor performs virtually all of the engineering and project management functions including:

— the development of design criteria, basic and detailed engineering, procurement of material and equipment which will include purchasing, expediting and inspection;
— the carrying out of all quality assurance and quality control actitivies during construction, startup services and site management;
— the preparation of the documentation the utility requires for the construction permit, PSAR and FSAR with licensing support and any environmental requirements.

(3) *System supplier*

In the case where the construction plan provides for separate suppliers of NSSS, or nuclear island, or turbo-generators, or conventional island, the company providing any one of these items is usually referred to as the system supplier. In this context, the system supplier will be responsible for a substantial portion of the engineering and project management activities described under the main contractor role outlined above. Management of the overall project may or may not be part of one of the system supplier's scope.

(4) *Architect–engineer*

When he is included in the project execution plan, the architect–engineer provides all the engineering and project management activities not covered by the system suppliers or the utility. In addition, the architect–engineer can supply certain specific services usually in the balance of plant area. In some cases, the architect–engineer is retained by the utility as a consultant providing services such as monitoring the project performance of the main participants.

(5) *Equipment vendor*

In the E&PM field, each vendor:

- — Designs and fabricates equipment acccording to criteria and specifications included in the purchase order;
- — Implements his own quality assurance and quality control measures;
- — Provides input data for erection, startup, operation and maintenance;
- — May at times carry out equipment erection as a subcontractor.

(6) *Contractor*

Each contractor carries out all the construction and often the startup activities in his scope of supply. These usually include:

- — Detailed drawings and specifications for the civil works and the procurement of civil engineering materials;
- — Procurement of all site related materials and erection of mechanical, electrical and instrumentation material and equipment;
- — The supply of all site engineering and management services to cover his work;
- — The performance of all quality assurance and quality control activities related to his work.

(7) *Consultants*

In terms of man-hours or manpower supplied to the E&PM function, the consultants usually employed on an NPP project play a quantitatively minor role. However, in qualitative terms, their role can be critical and vital.

Their activities can provide:

- Special technical expertise in areas such as:
  - Site surveys and site selection
  - Hydrology, geology, soil mechanics, seismology and environmental studies
  - Personnel training
- A second opinion on some critical project item such as:
  - Special site related problems
  - Project execution plan
  - Risk management plan
  - Project controls
- An audit on such items as:
  - Project performance progress
  - Project management function
  - The information processing system.

7.4. THE CONTRACTUAL ENVIRONMENT

The contractual environment within which engineering and project management activities are carried out is most varied and will depend on factors such as:

- The project execution plan
- The nature and extent of guarantees looked for by the utility
- The degree of competence, technical and managerial, on the part of the utility
- The extent of packaging the execution of the project
- The degree of localization
- The extent of the technology transfer.

Owing to the software nature of the E&PM functions, the end results to be provided in quantitative and qualitative terms, and thus the guarantees of good performance, need particular care in defining. The contractual conditions for E&PM functions are therefore critical if optimum results are to be expected.

When there is question of providing technical end products such as drawings, specifications or reports, relatively simple contracts almost of a turnkey nature, can be used. At the other extreme, a cost-plus approach can be used and be especially effective when the scope of the work is not clear, when the conditions under which the E&PM functions are supplied cannot precisely be determined or when the utility wants to save time. However this approach demands a very careful selection of the company which provides these services.

In between these two extremes, there are contractual variants adapted best to a particular situation. For example, targets and key milestones are often employed in these cases. Targets will be established between the utility and the main contractor (or architect-engineer) regarding the man-hours or cost of the services to be supplied. If there is an overrun, it may be at the total or partial cost of the contractor. If there is an underrun, benefit may be shared between the utility and the contractor. Key milestones are usually employed in order to monitor and motivate progress. A payment by the utility is usually linked to some or all of the milestones; however, in such instances, if the contractual targets and milestones are not well defined and well monitored, they can be sources of misunderstanding and conflict.

Ideally the contract should be as simple as possible to avoid problems in interpretation. It should be worded in clear language rather than in words which could cause possible double interpretations. The formulation of a good software contract merits the use of considerable experience and expertise and the major key to a successful contract is the selection of a good contractor who can be trusted because of his expertise and not because of a host of clauses protecting the utility in theory.

A typical software services contract will define clearly such key items as:

- Scope
- Timing
- Responsibilities of each party
- Guarantees expected
- Prices and payment.

The responsibilities allocated by the utility to the other parties have to be simple and clear. The utility should bear in mind that the more responsibilities given, the more independent the other parties should be in order to be able to meet these responsibilities correctly.

Equally, the expected guarantees should be feasible and verifiable in a concrete and almost physical manner. The more guarantees there are, the more freedom the other parties should have to face up to meeting these guarantees.

Typical items that these responsibilities and guarantees cover are the:

— Scope of services, its completeness and technical quality
— Timing and sufficiency of resources to meet schedule and scope
— Co-ordination and interfacing between the two parties and among any other groups
— Independence of the party supplying services
— Extent of review and control by the utility
— Progress reporting on the work performed by the supplying party.

7.5. NATIONAL PARTICIPATION

Whenever engineering and project management activities are concerned, provision is always made for a certain degree of national participation. When a country or a utility embarks on a nuclear power plant for the first time or has little experience in nuclear technology, this participation will be greater in scope and more easily attainable in the non-nuclear actitivities of the engineering and project management and in the non-nuclear areas of the power plant. Therefore, a foreign main contractor or systems supplier has to envisage the participation of local engineering and project management companies in the conventional island, the balance of plant and some participation in the balance of nuclear island. If however, the country or the utility additionally requests transfer of nuclear technology, then further provisions have to be made within the engineering and project management organization and activities so that this transfer takes place under optimum conditions without hurting the project schedule and the quality of the transfer process.

The country may also wish to provide material and equipment usually in those areas involving non-nuclear types of equipment. It is therefore usual, during the bidding stage, for the utility to specify a minimum of localization of services and of equipment as a guide to the bidders. The bidding contractors can then identify those services that they believe are best performed locally with a minimum of risk to the project or to the contractors. In principle, both the utility and the bidders expect this localization not to add extra cost to the bid or extend the schedule of the project. Though the utility often expects a lower cost, this is often not the case.

If transfer of technology is also required, then the areas, the levels, the range and timing of this transfer of technology are specified in the bid request. The bidders can then check how this can be best done within the various constraints specified by the utility.

Local participation in E&PM may concern areas such as:

- Production activities: engineering and procurement
- Support activities: administration, finance and accounting
- Control activities: planning and schedule, cost and quality control
- Co-ordination and supervision activities: of some or all of the E&PM functions.

The manner in which local participation is managed is important as it affects the coherence and efficiency of all of the E&PM functions and the responsibilities and guarantees allocated to the various participants in the NPP project. Inadequate attention to this aspect can result in potential conflicts and unnecessary risks within the project.

There are two basic approaches to local participation that are practised with variants situated between these two. There is the integrated approach wherein the local participation is integrated within the E&PM activities and responsibilities of the main NPP participants. In practical terms, this approach gives total immersion to the local personnel and gives opportunities for the transfer of know-how without this having been necessarily specified. Care, however, must be exercised in the integrated approach so as not to affect the responsibilities assumed and guarantees offered by the donor. Another advantage of integration is that the unwritten know-how is transmitted more effectively.

The other extreme approach is the task force method. In this situation, the local personnel are organized as a team working alongside the rest of the E&PM staff. The group is given certain E&PM tasks and quality and scheduling responsibilities. Know-how is transferred so that the team can carry out its work according to an agreed plan. This approach has the particular advantage of allocating responsibilities to the local personnel who are more motivated and more likely to succeed in this local participation.

In this task force arrangement all know-how acquired must be constantly updated so that the upgraded people do not lose it by disuse. It is also prudent that local personnel, who are now more highly competent and experienced to pass on this know-how to others, avoid the danger of allowing the knowledge to be concentrated in a few people or of permitting the know-how to get lost.

7.6. ORGANIZATIONAL ASPECTS

Four basic factors determine the manner in which the E&PM activities are organized and carried out:

- the pre-project or project implementation
- the execution plan of the project and packaging of the work
- the contractual environment
- the extent of transfer of technology and localization of activities.

In all cases, the organizations initially adopted will evolve with the evolution of the project. The organization is dynamic and flexible but based on a constantly stable fundamental plan which involves two phases, the pre-project period and the implementation period:

Pre-project period

During pre-project, the engineering and project management activities are organized on the utility's side and have the following objectives:

- the definition of project, scope, schedule and costs
- the determination of the project execution plan
- the selection of the main contractors and participants in the project
- the preparation of requests for bids, analysis of the bids and negotiations.

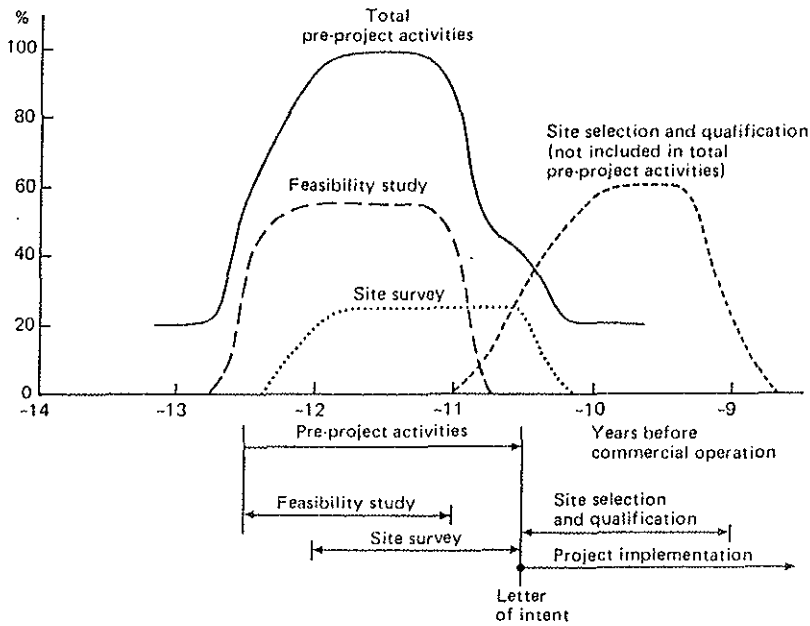


FIG. 21. Engineering and project management manpower (mostly by the utility).

During this same period, the principal contractor's engineering and project management organization will concentrate on:

- responding to bid requests and carrying out all design and pre-procurement activities to prepare a competitive bid
- answering the utility's questions on bids submitted
- supporting negotiations between utility and contractor.

The various engineering and project management activities on the utility's side, during this pre-project phase, do not require any large or complex organization. However, for expediency and continuity, it is usual at this stage for the utility to create a task force for the future project. Once the contracts are let, this force becomes the project team which will manage the project work.

Figure 21 shows the evolution of the effort expended by the E&PM personnel during the pre-project period. On the utility's side, it is not unusual for the task force to be helped and advised by external consultants.

On the contractors' and the suppliers' sides, the engineering and project management organizations will concentrate on the following activities:

- Analysis of the bid request
- Development of a design sufficient to define what will be offered to the utility

- Arranging pre-procurement activities for certain key pieces of equipment and giving information on costs, availability and delivery period of that equipment
- Determining the feasibility and the extent of the localization of services, equipment and construction
- Arranging the schedule
- Estimating the bid prices
- Giving support to the contract negotiations with the owner.

For the pre-project activities, the various contractors will each set up a task force which will have to take into account the possibilities of being awarded the contract or failing to win it. If localization is involved, this process might include setting up joint ventures with local entities. Then the contractor's task force may be modified to take into account local participation in the engineering and project management activities necessary for the preparation of the bid. It is prudent that a special inquiry team investigate the existing services, equipment and construction capability within the country. Such an investigation could measure the service possibilities during the execution of the project with or without technology transfer. It could also include determining the contractual context within which localization can best take place.

With both the utility and the contractors, the organization of the task force and the assignment of the key people during this pre-project period are such that when

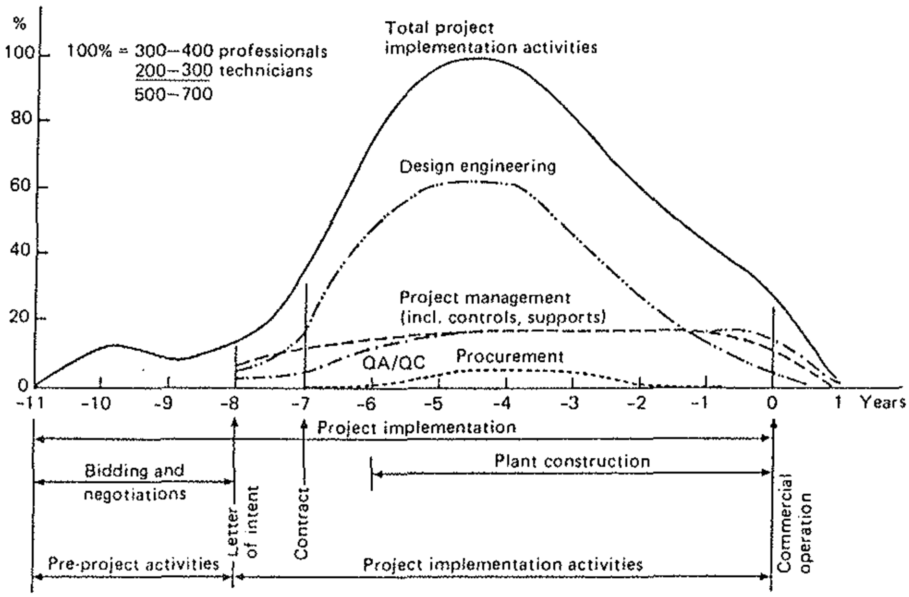


FIG. 22. Engineering and project management manpower (mostly by the main contractor).

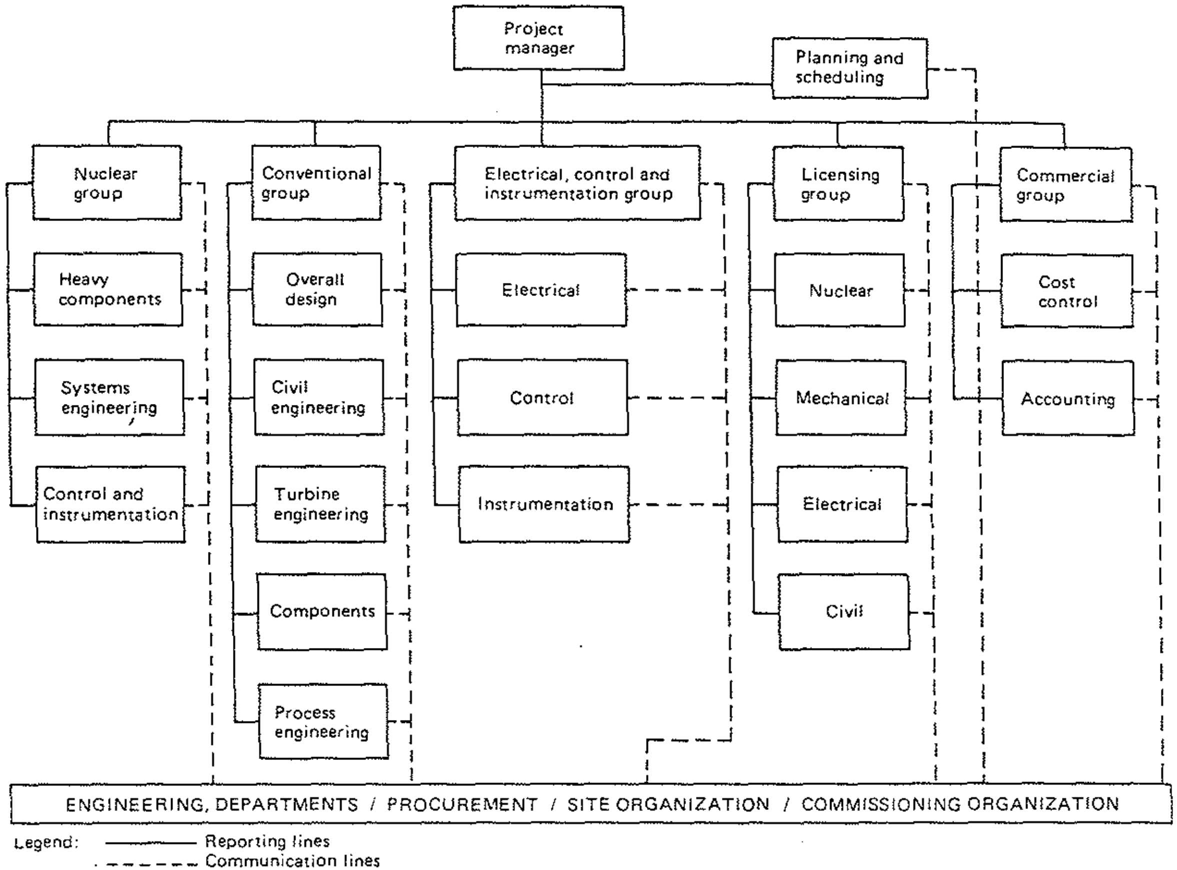


FIG. 23. Organizational structure of main contractor project management.

the project's execution starts, there is a maximum continuity and a minimum number of risks in the transition.

Implementation period

During this period, the manner in which the engineering and project management activities are organized involves the following objectives:

- Execution of the project within the quality, time and cost parameters agreed to by the utility and the contractors;
- Optimization of any possible transfer of technology in the engineering and project management domain;
- Staff project organization using the most competent people to maximize personnel development and to foresee replacements, both planned and unexpected.

Therefore, on the utility's side, the organization of engineering and project management will be biased to maximize the management, monitoring, and control capabilities since basically it is the contractors who will carry out most of the project production activities. The project plan and contractual context will determine the extent of engineering capability that the utility will provide.

The project policies and procedures adopted by the utility will be conceived to interface with the various contractors who will provide the best visibility and maximum opportunity of transfer of technology, even if transfer of technology is not a specific contractual requirement. The utility and the contractors will also set up a personnel replacement plan, kept up to date periodically, so that the project team members are replaced in a planned manner and the majority of the utility's project people can participate in the ongoing project and thus gain experience and expertise.

Since the utility's basic concern is to ensure that the contractors carry out their activities according to an approved plan and within approved objectives, the project team will also develop adequate project management tools and reports. These will ensure that at all times the utility is aware of where the project stands, where it should be according to the project plan and where it might be in the future according to past trends. Therefore the utility's project team will have a strong project control and information section.

The utility also has a prime responsibility which cannot be delegated to comply with all the licensing requirements. In this particular activity, it will be helped and supported by the contractor although the utility's project team interfaces directly with the regulatory body. This licensing activity requires a relatively high level of technical competence which, though temporary, will be reflected in the make-up of the project team.

Other participants, such as the main contractors, system suppliers and architect-engineer, will be organized along virtually the same principles as those

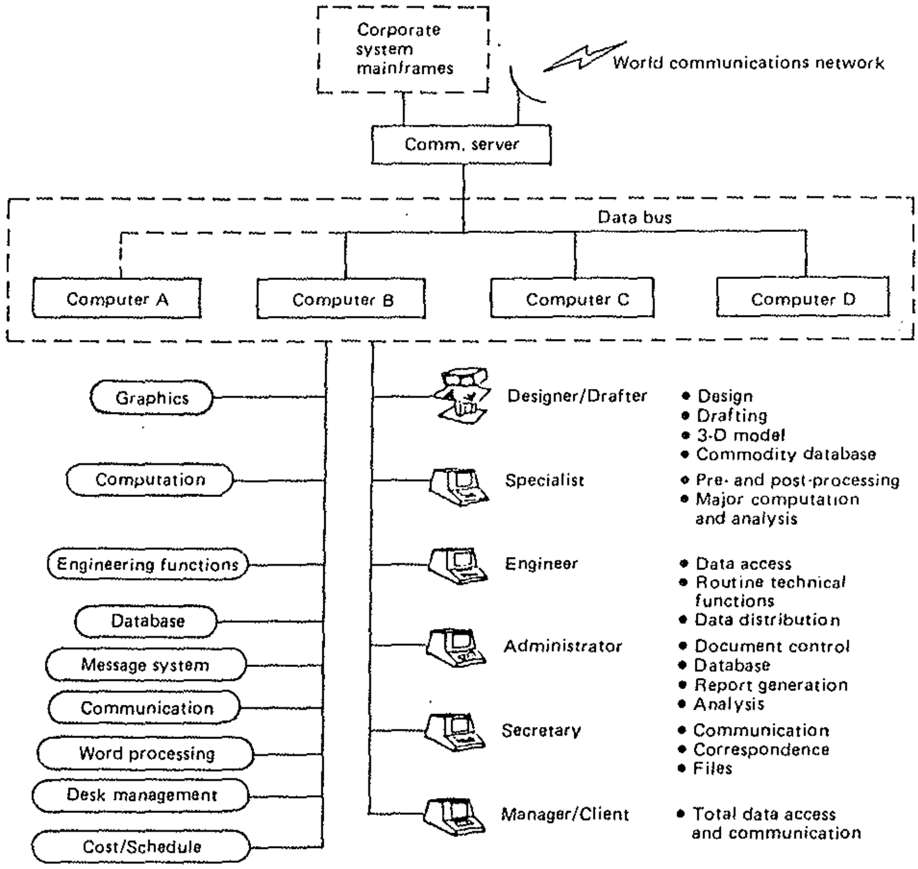


FIG. 24. Typical computerization of engineering and project management.

adopted by the utilities described earlier on. The main difference will probably be a question of the resources used. With the utility, the human resources mobilized are relatively modest in numbers since the utility's basic service is to produce and sell power and not to carry out engineering and project management activities. In contrast, each of the other participants will have to mobilize directly and indirectly (if subcontracting) large numbers of highly skilled personnel so that the scope of the work can be carried out within the time and quality standards adopted.

Figure 22 shows the evolution with time of the effort expended by the E&PM staff and Fig. 23 is an example of organizations for NPP project execution.

7.7. DOCUMENTATION ASPECTS

Documentation is often not given the attention it merits though the failure to document could be the cause of poor quality work, schedule faillures and poor relationships among the main participants in the programme.

The basic sources of NPP documents and papers are:

— bid and later contract documents
— commitment documents such as purchase orders and subcontractor agreements
— engineering design, procurement, construction and quality assurance papers
— communications — internal and external.

In addition, the need to issue document revisions and to make numerous copies of project papers can result in the generation of 8–10 million pages of documents per project. Generating all of this paper requires office staff and equipment to produce and store the documents and allow for later retrieval. Some of the key documents have to be stored for a period between 10–30 years so microfilming and computer storage are ways to resolve some of the storage difficulties.

Another aspect of the documentation of the NPP is the extensive number of communication systems which are becoming more and more electronic with automatic printing at various end points. The different time zones that exist among the various participants in an NPP often lead to constraining windows for oral communication. However, electronic communications have neutralized this window constraint, and equipment, such as the telefax, has shown its 24 hour usefulness.

There is the question of the reliability of these electronic communications which can vary depending on the quality and network of the telephone systems as well as on the use of satellites. The confidentiality of certain oral or written communications is also an important consideration. Special precautions such as coding are used in such situations though they can be a complicating constraint.

There are also situations, although some have not yet been tested in the courts, where the legality of the written communication transmitted and received electronically can be questioned. With basic legal documents such as a contract, hard copies are transmitted by the usual postal means or by companies specializing in courier services. However, often other communications giving contractual instructions or information are electronically transmitted, but they carry no written signature of course. In such cases, the telefax is used at it does show a manuscript signature on the receiving end. However, the full legality of this can be a problem in some countries.

Other facets of the NPP also involve electronic communications. The E&PM production activities are increasingly computer assisted. Calculations, drawings, and procurement documents can be computerized with hard copies only at the end of the completed function. This is also the case with the management controls such as planning and cost control which can be almost totally computerized on a typical NPP. Figure 24 shows an approach to an extensive computerization of the engineering and project management activities control.

CHAPTER 8

EQUIPMENT MANUFACTURING AND MATERIALS SUPPLY

8.1. INTRODUCTION

The equipment, components and special materials which are required in the construction of a nuclear power plant represent approximately 40–50% of the overall cost of the plant. The proportion of these items that can be manufactured economically by a country embarking on a nuclear power programme will depend to a large extent on the facilities and abilities of the existing manufacturing industry and supportive industrial infrastructure within that country. While it is possible for a country to establish a capability to manufacture a large fraction of the nuclear related equipment through appropriate technology transfer, the considerable investment in the facilities, skilled personnel and capital needed suggests that this capability can only be achieved over a long period of time encompassing several nuclear power plant projects.

This chapter reviews, in general terms, the types of components and materials used in typical nuclear plants as well as some of the key factors which must be addressed in their manufacture. Finally, the role of technology transfer in acquiring the necessary manufacturing capability will be considered together with some comments on the priorities which may be assigned to individual components or materials.

An NPP feature that is often underestimated is the documentation required on nuclear related equipment. It is one of the basic requisites in quality assurance and control that at all times it should be possible to have the appropriate documentation on the materials used, the manufacturing techniques employed and the testing methods applied on each piece of equipment and each distinct component of this equipment. The documentation should identify precisely the sources of the materials used, including consumables such as welding rods and the various stages of manufacturing and controls. Each item, therefore, has to have a historical set of documents so that in the event of a malfunction or a modification, it is possible to trace accurately the piece of equipment to the origins of the prime materials. This requirement, then, demands a factory organization with procedures sufficient to produce this documentation in a timely fashion.

8.2. EQUIPMENT AND MATERIALS

The equipment and materials used in the construction of a nuclear power plant cover a wide range of complexity and required quality. Although much is conventional power plant equipment, in many cases the standard of quality exceeds normal requirements. Some equipment is, however, only applicable to a nuclear power plant; this is particularly true of the components directly related to the reactor core. The materials used in a nuclear power plant range from conventional rebar steel to specialized steels and from high nickel alloys to zirconium alloys. In the case of heavy water reactors, the heavy water is used as moderator and coolant.

In general terms, equipment can be separated into that used in the nuclear steam plant, that related to the turbine generator and that contained in the rest of the plant. The total value of equipment in a PHWR nuclear power plant represents approximately 40% of the total cost of that station. This cost can be broken down further as 50% related to the nuclear steam plant, 15% to the turbine generator system and 35% for the rest of the plant including transformers and switch-yards. In the case of an LWR nuclear power plant, the equipment cost is approximately 50% of the cost of the station This amount can be further allocated as 60% for the nuclear steam plant, 18% for the turbine generator system and 22% for the rest of the plant.

Virtually every segment of industry has some role to play in producing either equipment or materials for the nuclear plant. The metal and metal forming industries will provide the basic steels and speciality alloys needed as raw materials or as finished products such as pipe and tubing, cable trays, hangers, sheets and plates. The chemical or petrochemical industry will provide the chemicals, oils, lubricants and gases used in manufacture and operation and, in the case of heavy water reactors, the heavy water used as a moderator and coolant. The electrical and electronic segments of industry will produce the many kilometres of cable required, the electric motors, transformers and switch-yard gear, the computers, simulators and other electronic products. Industry related to scientific and industrial instrumentation will produce the many sensing and measuring devices so essential to the satisfactory operation of the plant. These factories will also provide the laboratory and other instrumentation required for the extensive quality control programmes. Finally, the manufacturing industry will fabricate the heat exchangers, pumps, valves, pressure vessels and other components required for the plant.

8.2.1. Manufacturing and quality requirements

A substantial portion of the components and materials used in a nuclear power plant is manufactured to stringent specifications. These standards have been developed through many years of experience in the nuclear industry as well as in the power generation and aerospace industries which also demand high manufacturing standards. As a result, components manufactured to such standards have been well proven and tested.

Many countries have developed standards specific to their needs but all have the same basic goals of quality and conformity. Typical examples of standards developed in the United States of America include those of the American National Standards Institute (ANSI standards), the American Society of Mechanical Engineers

(ASME codes), the American Society of Testing and Materials (ASTM standards), the Institute of Electrical and Electronic Engineers (IEEE standards) and the American Society of Nondestructive Testing (ASNT standards).

Any manufacturer entering the nuclear component manufacturing field must conform to these or equivalent standards and, in most instances, institute rigorous quality assurance procedures and quality control programmes. It is sufficient to note here that manufacturing of nuclear components to the required standard and quality will impose significant demands over and above those normally experienced in the manufacture of similar components for other industries. However, once the techniques and procedures have been mastered, their use in other segments of industry will result in a significant increase in the quality and reliability of the product and ultimately in its competitiveness.

8.2.2. Manufacturing of major components

Since it is impossible to cover, even briefly, the manufacture of the vast number of components used in the nuclear power plant, this chapter will concentrate on the cost or critical nature of the principal components or groups of components. These include the reactor vessel, steam generator, pumps and valves, the turbine generator, instrumentation and the electronic or electrical equipment.

(1) *Reactor vessel*

(a) PWR/BWR systems

The reactor pressure vessel of a PWR or BWR type of nuclear power plant is the most massive and critical of any of the pressure vessels in either plant. The vessel typically weighs approximately 350 tonnes and is about 14 m high with a diameter of about 4.5 m and a wall thickness of 0.2 m.

While the principles involved in the design and manufacture of the reactor pressure vessel are similar to those used in all pressure vessels, the actual manufacturing technology used is considerably different. The vessel requires high integrity welds in alloy steels at wall thicknesses of 0.2 m and involves special welding techniques and heat treatments. In addition, large forged nozzles must be welded to the body of the vessel to permit connection to the primary coolant circuit.

Production of the reactor vessel also involves overlaying of the inner surface of the alloy steel vessel with stainless steel to a thickness of approximately 6 mm and machining of the internal surface to close tolerances. The stainless steel overlay is produced by a continuous and automatic welding process.

The factory facilities needed for the production of such vessels are large and require special machines capable of handling large and heavy loads during welding and machining. The factory must also have extensive destructive and non-destructive laboratory equipment. The building would have a floor area of 10 000 m^2 or more with a height of at least 20 m and a crane with a capacity of 250 to 500 tonnes is required. Ready access to an adequate transportation system is also essential.

The cost of providing such facilities and equipment is high, perhaps of the order of US $50 million (1985). While other pressure vessels can be made in the facility, the factory's primary use will be limited to producing heavy equipment for nuclear power plants since the techniques and equipment have few applications in other industries. As a result, the companies in several countries of the world capable of manufacturing heavy nuclear components found little alternative equipment to manufacture in their factories when nuclear business declined. Currently, the world capacity for manufacturing heavy nuclear components is well in excess of the demand. Thus commercial considerations would not favour establishing a local manufacturing capability for such heavy nuclear components.

(b) PHWR systems

The equivalent to the reactor pressure vessel in the PWR or BWR plants is the calandria. The CANDU 600 calandria, which contains the heavy water moderator, together with its end shields is a vessel some 8 m in diameter and 6 m long. It weighs approximately 150 tonnes.

The calandria vessel itself is made from stainless steel plates and sheets and is completed by insertion of the 380 Zircaloy-2 thin walled calandria tubes. Fabrication involves high integrity welds yet involves dealing with much thinner walls than the PWR or BWR vessel since the contained pressure is far less, approximately 1 bar. The high integrity is required to preclude heavy water leakage rather than to provide pressure retention. The end plates forming the calandria must be precision machined and drilled to very close tolerances. The same is true for the carbon steel plates used to form the end shields. The high accuracy is required to permit the insertion of the calandria tubes. A high integrity seal between the Zircaloy calandria tubes and the steel end plates is produced by a roll expanding process in much the same manner as that used in the tubing of steam generators.

A facility capable of producing two complete calandria vessels per year would require an investment of approximately US $10 million (1985). It would include the necessary welding and precision machining equipment as well as the non-destructive test equipment required for quality control. As is the case with the PWR or BWR reactor vessel, such a facility would not be commercially viable in the absence of a continuing nuclear power programme.

(2) *Steam generator*

Manufacture of steam generators requires several technologies including those associated with the fabrication of pressure vessels from carbon steel and, in the case of light water reactors, the technology involved in the overlay of stainless steel on those surfaces which contact the primary coolant. In any event, the primary side of the tube sheet must be overlayed with a material compatible with the tubing material.

Since most steam generators are now tubed with Inconel 600 or Incoloy 800, the compatible material is a high nickel alloy. The tube sheet is then precision gun drilled with the required number of holes, typically of the order of 7000, to accommodate the tubes. The tubes are sealed into the tube sheet, first by roll expanding and then by seal welding.

The steam generators are nuclear class 1 components and are manufactured to the highest standards of quality with strict quality assurance and control. Much of the final assembly of the steam generator, e.g. the tubing and seal welding, is done under clean-room conditions. A steam generator manufacturing facility, which also included the required equipment, could involve an investment of some US $8 million to $10 million (1985). This estimate assumes that the basic materials such as plates, forgings and tubing are produced elsewhere. The facility would employ some 150 to 180 skilled personnel.

There are about 250 heat exchangers in a PWR plant, in the nuclear steam plant, in the turbine generator system and in the rest of the plant. Although all heat exchangers must be made to strict specifications and standards, those which provide the interface between the reactor's primary coolant and the secondary system are the most critical and demand the highest standards of quality. The most significant and costly heat exchangers are the steam generators which provide the interface between the primary coolant and the secondary coolant circuits feeding the turbine generator.

The other heat exchangers involved are less complex and serve a variety of functions. One that deserves special mention is the turbine condenser which is not a particularly high pressure component but is often subjected to corrosive factors, particularly when the plant is located on a coastal site. In this case, the necessity for an increasing use of titanium alloys as tubing material brings an added criticality to the manufacturing process.

(3) *Pumps*

There are about 300 pumps in a PWR plant. These range from the large nuclear quality primary coolant circulating pumps to the relatively simple metering pumps or circulating pumps commonly used in the chemical or petrochemical industries.

The number of primary coolant circulating pumps required in any single nuclear power plant is small. These nuclear class 1 pumps are large, about 8.5 m high when the driving motor is attached; they weigh about 100 tonnes. Their manufacture requires the availability of large radiographically inspected castings in which no significant defects are permitted. While the repair of defects is possible, the techniques used are complex and are not always successful even though they require highly trained personnel. The motor drives are also large, of the order of 7 to 9 MW.

A facility manufacturing the primary pumps would require an initial investment of some US $8 million (1985) and an additional $2 million (1985) would be required to develop an adequate test loop capability. Much of the technology involved has no other application in other industries. The remaining nuclear steam plant pumps are smaller yet still require nuclear class quality. A facility producing these pumps would cost approximately $5 million (1985) and a test loop would also be required. Once this facility is in place, it could also produce non-nuclear class pumps for both the nuclear and non-nuclear industries.

If a pump manufacturing facility already exists in the country, it is probable that many of the non-nuclear class pumps could be produced there. The major requirement, then, would be the upgrading of existing procedures to meet the necessary standards and quality assurance requirements.

(4) *Valves*

The total number of valves used in a nuclear plant is well above 10 000. The range of valves covers all types, e.g. check, globe, gate, relief and needle type valves and, as with pumps and other components, includes both nuclear and non-nuclear class valves. Clearly, many of the valves are similar to those used in other process industries. Therefore a manufacturing plant producing non-nuclear class valves should have a wide market potential. There are some valves, however, where the application is so specific to the nuclear industry that the total world market of the industry to date has been satisfied by a single company.

The technologies involved in valve manufacture include the production of castings of high quality, particularly when used for nuclear quality valves. The application of appropriate hard facing materials by weld deposition on sliding surfaces and the production of packing materials and systems to minimize leakage or the use of bellows as a method of sealing where leakage is not permitted also demand quality production. The assimilation of these technologies takes time and involves difficulty. It is probably appropriate for a country first entering the field to concentrate on the valves used in the balance of plant where experience in the basic manufacturing techniques can be obtained without the complications of the stringent quality required of valves used in the nuclear steam plant.

(5) *Turbine generators*

Turbine generators used in nuclear power plants are modifications of similar units used in conventional power plants. Much of the technology of large turbine generators is vested in a small number of turbine manufacturers who together supply the world's needs for coal, oil or nuclear power plants. The number of manufacturers has decreased in recent years so that careful market analysis is required before a decision can be made to invest in a manufacturing plant.

For turbine manufacture, buildings will be required to cover heavy component manufacture and to have considerable 'lay down' space, as well as large cranes and substantial foundations for the heavy precision machine tools. The building size will need to be about 180 m long by 50 m wide for the stationary parts, and 150 m by 30 m for the rotating parts. The work has to be done to close tolerances as the rotors weigh 150 tonnes and will have to run without any vibration at 1500, 1800 or 3600 rev./min depending on the electrical system in use and the design of the generator. The seals around the blades have to be to a close tolerance for efficent operation. This requires that the inner cylinders are machined when assembled with a horizontal stub bar boring machine that compensates for the deflection of the rotor due to gravity when the turbine is in operation.

About 80 machine tools, ranging from small conventional engine lathes to large numerically controlled lathes, will be needed to cover all the manufacturing operations for this facility. It is advisable to use numerically controlled multipurpose machinery centres in a climate controlled building to manufacture the large low pressure cylinders so that all the operations of milling, drilling and boring in a single manufacturing process give the required accuracy and reduce the manufacturing time of the operation.

Test equipment is capital intensive, costing around US $5 million (1985); a further $1 million for measuring and gauging equipment will also be needed. The cost of the facility would be of the order of $55 million and, if the manufacture of the turbine blades is also undertaken, an additional $45 million of additional equipment would be required.

The generator is also a specialized component. It produces the full power of the station at 20–30 kV and is a large machine, operated at close to its design limits. Any shortcomings in design or manufacture are likely to result in months of downtime of the whole plant because:

- The stator core uses some quarter of a million laminations and deterioration of the insulation between the laminations can cause catastrophic failure in service;
- The generator has to be constructed to reduce the risk of moisture leaks from the coolers which can promote stress corrosion cracking of austenitic steel rotor end rings and can penetrate end winding insulation and cause a flashover;
- End winding vibrations can cause fatigue cracking of the conductors and failure of the insulation.

(6) *Instrumentation and electronic equipment*

The rate of change of the technology of an NPP is so rapid that the instrumentation and control systems as well as the equipment in some plants have had to be renewed, simply because replacement components have become obsolete. The new technology differs from the old in the way the information from the sensors is handled. Microprocessors, logic systems and larger computers give great flexibility in the use that can be made of the primary information.

A reliable computer system will be required to aid the operators by displaying information about the plant condition, by activating alarms when abnormal conditions arise and by recording information for historical and diagnostic purposes. (In the CANDU nuclear plant, computers are also used for direct control of the reactor and turbine generator systems.) Since data will be supplied from a larger number of sources, the computer must have the adequate capacity to handle the data and execute the associated programmes.

Electronic systems and computers meeting required specifications are available from several countries. The manufacture of chips and microcircuits is an advanced technology requiring substantial investment and large sales to recover the investment; it is in this area that technical change is most rapid. A nuclear power programme would not in itself justify setting up an electronic/computer industry. A competence in designing, maintaining and modifying computer programs is much more valuable.

In an NPP, the process instruments, except for those measuring radioactivity, are basically the same as instruments used in many process industries although a higher quality and reliability requirement may exist in some cases. The higher quality instruments are those used for measuring pressures, flow rates and temperatures in the plant operation. They also include devices for transmitting the measurement signals to the control room, and for operating control valves and switches to modify the process when instructions are transmitted from the computer or operators. The smooth running of the plant depends to a large extent on the reliability of these instruments and control devices.

The sensing instruments are often manufactured by small speciality firms and could be considered for local manufacture. However, those that have to be inserted into critical lines of instrumentation and plant systems must comply with the full regulations for that line or plant item. Supportive testing facilities to assure performance capability in the plant will be required.

The sensors which detect and measure nuclear parameters such as neutron flux and gamma radiation have very little application outside the nuclear industry. The high degree of specialization, the relatively small numbers needed and the limited application suggest it is better to import these than to set up facilities for local manufacture at the start of a nuclear power programme.

(7) *Electrical equipment*

In general, conventional fossil fired power plant electrical equipment, or adaptations of it, is used in nuclear power plants. Equipment such as transformers, switchgear, motors and storage batteries are widely used in all types of industry so any investment in manufacturing facilities should not be considered on the basis of a nuclear power programme alone for an NPP would be a small proportion of the total market.

Some of the components which can be used in several industries include:

- station switch-yard gear and transformers
- plant distribution systems with circuit breakers, motor control centres and relays

— diesel generator units in the 5 to 6 MW size range
— a low voltage power supply provided by static invertors or rotating convertors from a battery system
— a DC power system composed of batteries and associated chargers
— electric drives ranging from fractional kW motors to up to 10 MW motors
— several thousand kilometres of power cable and instrument cable.

The electrical systems serving safety related systems of the plant must be of high quality. The cabling and electrical components for these systems have to be manufactured to stringent and unique standards which may require significant capital investment and which can cause difficulties in production. Nevertheless, over half of the electrical equipment is used in systems where conventional industrial standards are adequate. Thus there is a wide variety of electrical equipment which could almost certainly be supplied by domestic manufacturers in a country with a sufficient electrical load to justify a nuclear power programme. However, if the electrical manufacturing industries in some countries are less well developed, these countries could begin the manufacture of the smaller and less critical NPP items. All countries could take advantage of their nuclear power programme to expand the range and to upgrade the quality of electrical items manufactured locally.

8.2.3. Materials supply

Some of the basic materials used in construction of the nuclear power plant will be supplied locally. These include aggregates, cement and other civil construction materials. Other materials such as the steels, special alloys and the heavy water required for PHWR plants would not normally be produced by many countries entering a nuclear power programme. Some of these special materials used include Zr-2.5 Nb, 403 mastonsitic SS, 304 L austenitic SS, Incoloy 800, Zircaloy-2 and titanium.

(1) *Standard steels*

The amount of carbon steel required by a nuclear power plant, though a significant quantity, is small in relation to the output of a steel works or a tube mill. For instance, the weight of structural steel is of the order of 4000 tonnes; and there will also be several kilometres of piping, electrical conduit and cable trays required. These quantities would provide a welcome addition to the demands on any existing manufacturer, but would not in themselves justify the installation of a steel works.

(2) *Special steels*

The majority of the critical components are made of special steels. The nuclear steam supply system demands materials controlled to the ASME code, ASTM standards or an equivalent code. All forms of material, whether plate, pipe, forgings or castings, must be traceable to the initial ingot and must meet exacting standards of chemical composition, mechanical properties and integrity.

The major materials of the turbine are low carbon steels for the stationary parts and high alloy steels for the rotating parts. The forgings for the high and low pressure rotors have gross weights of 70 and 170 tonnes respectively.

The total amount of special steels used in a nuclear power plant is about 4500 tonnes, but divided among over 20 different types of steel and in the forms of plates, forgings, castings, bars, sheets and tubes. These quantities do not justify installing a new facility for this use alone.

(3) *Special alloy tubing*

Tubing requirements will vary with the specific design of the plant, but common demands are for Inconel 600 or Incoloy 800 high nickel alloy tubing and for the steam generators and Zircaloy tubing for the fuel cladding.

This high precision, thin walled tubing is generally produced by a cold pilgering process from a basic extruded ingot. The performance of the material is often strongly influenced by contamination, particularly so in the case of Zircaloy or other zirconium alloys; as a result, separate buildings and equipment are required to handle both basic types of materials.

The equipment commonly used in producing the finished tubing from the thick walled extrusion includes:

— cold pilger machines
— hydrogen atmosphere and vacuum furnaces
— tube straightening and polishing equipment
— a degreasing and pickling plant
— tube testing equipment
— a tube bending plant
— handling and storage facilities

A facility for producing either high nickel alloy tubing or Zircaloy tubing would require an investment of several million dollars. With an output of several hundred thousand metres of tube per year, a committed programme of several nuclear power plants would be required to justify a plant producing Inconel or Incoloy tubing which has limited application elsewhere. However, since Zircaloy tubing is an ongoing requirement, a plant producing this material may warrant more serious consideration.

(4) *Heavy water*

Heavy water is an essential ingredient in pressurized heavy water reactor plants. The initial charge of heavy water to both moderator and primary coolant systems of the CANDU 600 nuclear power plant requires 450 tonnes. There is also an ongoing requirement for heavy water to replace any operating losses. However, this make-up requirement is small, less than 1% of the total inventory per year, i.e. less than 5 tonnes per year.

Several processes are available for producing heavy water of the required quality, in excess of 99% D_2O. Since ordinary hydrogen contains of the order of 0.015% deuterium, large quantities of water or other hydrogen bearing compounds must be processed to recover sufficient heavy water. The available processes are based on multiple exchanges using the differences in the chemical and physical properties of hydrogen and deuterium. The processes include electrolysis and distillation of water, exchange between H_2 and NH_3 or its derivatives and exchange between H_2O and H_2S.

The present world production of heavy water, spread among five countries, amounts to some 1000 tonnes per year. Most of the capacity is derived from the current commercial process which is based on the exchange of hydrogen and deuterium between water and hydrogen sulphide. The hydrogen sulphide is alternately absorbed and desorbed in countercurrent streams of water, the light hydrogen transferring slightly faster than the heavy deuterium at each exchange, leading to enriched streams. Typically the exchange is carried out in large diameter columns, carrying trays of bubble caps similar to petroleum distillation units. The hydrogen sulphide is moved about by large conventional blowers but the extreme toxicity of hydrogen sulphide places strict requirements on leak tightness. Hydrogen sulphide creates corrosive conditions and therefore special steels have to be used.

The technology of heavy water production is a special variant of basic chemical engineering technology. The main concern is process optimization to minimize energy use, to reduce leaks from enriched heavy water streams and, whenever needed, to minimize toxic hazards. Overall, the technology is not much more difficult than that of a modern oil refinery and, in principle, is commercially available.

Commercially viable heavy water production plants have capacities well in excess of 100 tonnes per year. This volume is far more than is required for make-up purposes and thus a significant nuclear power programme would be required to justify a heavy water production plant, particularly since there is currently an oversupply of this product.

8.3. CONSIDERATIONS FOR LOCAL PARTICIPATION

Many countries entering a nuclear power programme wish to achieve the highest levels of local participation. While there are several examples of countries which have successfully increased the proportion of national participation in each successive plant in an ongoing nuclear power programme, opportunities for a substantial local involvement in the first plant are few. The most significant opportunities in the manufacturing area are likely to occur first with the non-nuclear, more conventional items of equipment and material.

In the first nuclear power plant, the extent of local participation will depend on the country's existing manufacturing capabilities particularly those that can be readily upgraded to the required standards of quality. Even so, a significant level of local participation could be achieved in most countries.

It is probable that, to achieve any degree of local participation in the manufacture of nuclear components, an intensive programme of technology transfer will be required. The programme will require significant investment of both human and financial resources on a national scale. Training of the personnel required, at the professional, technical or skilled trades level, will take a considerable time since the nation's total production of skilled personnel cannot and should not be solely directed toward the development of nuclear power. Similarly, the financial resources of the country must be assigned to meet the overall goals of the nation. It follows then that the development of the manufacturing sector, like other sectors of the nuclear industry, should take place in an orderly fashion and be phased in over a programme of several nuclear units.

Ideally, the initial entry into the manufacturing of components for the nuclear plant should concentrate on less complex and less demanding equipment so that an appreciation can be gained of the standards of work and the quality assurance aspects required. For example, simple tanks may be fabricated as precursors to pressure vessels or small heat exchangers may be produced before tackling the major, more critical condenser or steam generator.

Before undertaking the investment which will be required, several questions should be asked first by the country and then by the individual manufacturer. These questions are:

What is the present industrial base in the country and how can its capabilities be used in manufacturing components and supplying material?

Answering this question requires a thorough survey of the present industry by those who have had experience with the standards and qualities required and the technologies to be assimilated. This survey can be conducted by employing consultants to work with local manufacturers or by seeking help from experienced manufacturers of nuclear components. The survey can also identify those existing companies which would be the most appropriate to take part in the technology transfer programme and can estimate the investments of both financial and human resources which would be required.

What products should be given priority?

The answer can only be determined by the nation itself, since it will depend on both the political and economic aims of the country. In general terms, the products selected first should be those which will have a large volume of production, preferably with applications in other industries. Those products should be considered which will provide a high employment potential as well as maximum domestic content for the minimum capital investment. In the case of volume of production, only the domestic market should be considered as a firm market. With the present oversupply situation in nuclear component manufacturing, competition for foreign sales is fierce and a new, unproven supplier is not likely to have much credibility or success. In the case of return of capital investment, the more simple, large volume items, such as small valves or pumps which have applications elsewhere, would have significant advantages over a facility to produce the reactor pressure vessel or a heavy water production plant.

How quickly can the technology be assimilated and local production achieved?

Before the manufacturing technology can be assimilated, trained personnel must be available and the facilities in place. If these do not already exist, a significant delay will occur. Even so, the acquisition of a new technology, particularly one with the stringent quality requirements associated with nuclear components, takes a considerable time.

The fact that the successful assimilation of technology takes time is perhaps best illustrated by considering a specific example. Consider the technology associated with the manufacture of nuclear quality steam generators. Steam generators are good candidates for technology transfer as the manufacturing skills needed to build steam generators and heat exchangers are widely applicable in producing goods for other industrial market areas such as refining and chemical processing.

In the local participation programme, the local manufacturer would begin by assembling the product from the supplier's components, while it assimilated the design and manufacturing technology and began to build some of its own steam generator components. As the programme proceeded, the local manufacturer would build up sufficient design and manufacturing capability to become fully responsible for steam generator supply. This process could take 5–6 years.

Once a technology transfer agreement has been signed with a supplier, documentation including quality assurance policies, a quality control procedures manual, vessel qualification reports (stress, vibration and seismic analyses), technical specifications, reliability and safety reports, shop tool information, manufacturing procedures and material specifications could be transferred to the local factory and the process of familiarization with the product could begin.

A training programme, both through courses given by the suppliers at the local facility and through attachment of the local staff to the supplier's factory, would be a vital component of the technology transfer process. In the first stages of training, conducted over 12 to 14 months, general fabrication techniques, quality assurance requirements and manufacturing skills including sub-arc welding, plate rolling, layout and plate cutting would be reviewed. The extent of these courses would, of course, depend upon the level of skills already possessed by the local company.

The second level training, taking about 12 months, would be directed towards more advanced procedures, including tubesheet overlay and gun drilling as well as tube bundle assembly, expansion and seal welding and advanced testing procedures. Up to thirty-six major technologies involved in steam generator manufacture would be covered in these training programmes so that the local manufacturer could develop the skills necessary to build the steam generators and heat exchangers once it has the necessary production facilities and in-house quality assurance processes in operation.

The supplier would also expect to offer long term assistance to the local company by placing consultants in its facilities to help ensure that the equipment is produced to the design specification and schedule, and that questions which arise during the manufacturing of the first few products are quickly answered. In particular, this assistance in the areas of project engineering, fabrication methods and quality assurance should help to ensure that the supplier's technology is assimilated in the most efficient and least expensive manner.

What is a disadvantage of local participation?

Most countries entering a nuclear power programme for the first time have found that considerable delays in the project can result from local participation in areas where previous experience did not exist. Therefore, scheduling is perhaps the greatest problem arising from the initial stages of local participation.

8.4. MANPOWER QUALIFICATIONS

Once a manufacturing shop is operational, manpower is required for the following activities:

- understanding the client's technical specifications/drawings and preparation of detailed design, shop drawings/tooling drawings for the manufacture of the equipment
- preparation of detailed manufacturing procedures
- setting up quality assurance and control procedures
- materials planning and procurement
- control of schedules and costs
- documentation.

Since the manufacture of nuclear components is covered by stringent quality requirements, it is essential that the methodology of design and manufacture is identified and documented in advance. The preparation of drawings, tooling design and manufacturing procedures require engineering graduates with adequate experience. These engineers are assisted by draughtsmen in the preparation of drawings.

Experienced engineers are also needed for materials planning. The flow of material is to be controlled from the time it enters the shop until it leaves, to ensure no mix-up and no delay. Engineers chosen for this function should have enough experience in procuring materials from the right sources and controlling them at the shop. These engineers may have to be assisted in these duties by technicians.

In order to plan and control schedule and cost of manufacture, suitably trained engineers with knowledge of management techniques combined with an industrial engineering background are chosen. These engineers also are supported by technical assistants.

When orders are given for the manufacture of equipment like pumps and heat exchangers, the tender request may give only reference design or performance requirements. The detailed design of the equipment, then, is to be done by the manufacturer. In such cases, the manufacturer requires competent postgraduate and graduate design engineers who have relevant specialization skills.

The types of manpower required for such production include:

— several machine tool operators for both light and heavy machines
— skilled workers such as fitters, machinists and other fabrication workers
— assembly workers
— technicians to run the heat treatment furnaces, foundry and forging shops.

These workers must be trained in special areas like welding and heat treatment. They must also be judged as qualified by competent personnel and also certified to the requirements of the codes. At the supervisory level, personnel with enough experience and training in production work are chosen. These personnel should be thoroughly conversant with the production techniques and be able to guide skilled workers. They should also be able to deal with labour in a motivating and positive manner in line with good industrial relations practised in the country.

Quality control and inspection is yet another important and vital discipline in the manufacture of components and equipment. Since nuclear components/equipment have serious nuclear safety implications, step by step quality control and inspection are necessary to ensure that the final product is meeting the desired specification. Personnel are required to conduct non-destructive testing. They are needed on three levels. At the first level, technicians with sufficient training and experience to perform the necessary tests are needed. At the second level, manpower of a supervisory level are needed to direct and carry out tests according to approved methods. They must be able also to set up and calibrate equipment, read and interpret indications and evaluate them with reference to specifications. They shall also be familiar with limitations of any technique employed and be able to organize and report non-destructive testing. At the third level, engineers are to organize the entire function of non-destructive testing. Such level 3 personnel shall be able to train and qualify level 1 and level 2 personnel as mentioned above. They shall be engineering graduates with adequate practical experience in all the non-destructive techniques. They should be certified by standard non-destructive testing societies. As mentioned above, manpower for ultrasonic, radiographic, magnetic particle, helium leak and other tests need also to be trained.

Having the manpower to organize and run the testing laboratory is important. The laboratory activities will involve tensile testing, hardness testing and impact testing. Skilled operators trained in the operation of the above machines are needed. They should be able to do the test according to approved procedures. Supervisory personnel in this field should be able to interpret the specification and organize the testing. They should also be able to calibrate the machines periodically to satisfy the required codes.

Skilled personnel to conduct chemical analysis and spectroscopic analysis of various samples are also needed. Technicians must prepare metallographic samples according to specification requirements for micrographic/macrographic analysis, assessment of electroplating quality and other such metallurgical studies. The testing laboratory could be under the charge of an adequately experienced metallurgist who has to direct all the required mechanical testing and metallography. Further he can also direct the entire metallurgical evaluation and heat treatment operations including calibration of furnaces and instruments that may be required. The services of this laboratory would be used by inspection engineers during the process of inspection of equipment/components and during the development of new technologies.

Dimensional inspection of components and equipment during intermediate or final stages is to be completed. Technicians with experience in handling all types of gauges and measuring devices are required, as are technicians capable of handling optical instruments for surveys of large size equipment. There will be a need to conduct functional testing of components and equipment in many cases. Supervisory personnel with enough experience in such areas as metrology, measuring techniques, use of optical instruments and functional testing have to direct the above work.

Quality assurance is another important need for the industry manufacturing nuclear components. While engineers in this discipline will not be involved in day to day quality control and inspection, they will be responsible for organizing an overall quality assurance programme for the manufacturing activities of the company. Procedures for personnel qualification and training, document control, procurement control, identification control and measuring equipment calibration are to be standardized. Professional engineers with specialization in these areas have to organize this function.

Quite often, the manufacturer also assumes erection and commissioning responsibility for certain equipment. Such erection activities call for erection engineers, erection supervisors and skilled workmen and require overseeing by the field design engineering staff to ensure fulfilment of the design intent.

Whenever the manufacture of new equipment or the establishment of a special technical procedure is required, development efforts involving trial manufacture are necessary. Well qualified engineers with experience in the relevant field supported by adequate technicians are also needed for such development. The established manufacturing techniques are also reviewed by this team for improvement.

The maintenance of plant machinery in the various industries requires personnel at engineer, supervisory and skilled workmen levels. They are expected to have a clear understanding of the details of the machinery and equipment as well as of the service instructions, preventive maintenance, breakdown maintenance and replacement parts.

In addition, proper storage of materials is called for before, during and after manufacture. Incoming materials are to be stored with proper precautions to prevent spoilage and finished components are to be stored with due care. All materials are to be properly identified and the right materials are to be released for manufacture. If the client has supplied materials as free issue items, there will be a need to account for the materials to the client. Inventory levels of continuously moving items are to be controlled. Movement of various types of equipment may have to be organized and all finished components are to be dealt with with proper care. Critically machined components are to be packed by approved methods and boxes for packing, rust preventives to be applied and overall arrangements of packing need to be looked into in detail. For this function, manpower at the technician level and a supervisory staff are needed and are expected to work in close co-ordination with planning engineers.

CHAPTER 9

PLANT CONSTRUCTION, ERECTION AND COMMISSIONING

9.1. INTRODUCTION

A nuclear power plant requires an investment from the utility in the order of a few billion US $.[1] Between 20 and 35% of the total order value of the power plant is spent on the site for the construction which encompasses the civil work, the erection of the systems with the mechanical and electrical components and the startup or commissioning of the plant.

Success in performing the construction, erection and the commissioning of a nuclear power plant depends to a large extent on the efficient management and co-ordination of a well qualified work-force and the astute use of the local resources and construction approach and methods.

The total construction of a nuclear power plant covers a period of six or more years and requires special attention during the implementation of the whole project. These activities represent the deliveries, the co-ordination and the assembly of thousands of individual pieces for a single unit. Each element or component is tested and accepted prior to its installation on site; however, when put together with the adjacent elements, they have to fulfil their functional operation for the first time.

The construction schedule requires overlapping of many individual activities with site preparation and installation, formwork and finishing work, erection and commissioning. Because of the overlap, a correspondingly large number of site personnel (engineers, technicians, labour, auxiliary personnel) is required. Figure 25 indicates the overlapping of the four main activities. The maximum number of personnel (about 2500) lies between the third and fourth year in the six year construction period. Figure 26 gives a typical site manpower loading. The typical percentages of work categories and the number of the participating companies are shown in Fig. 27.

It is worth while to mention that the most intensive package of work on the site is the piping erection that represents approximately 20% of the whole site activity or about 60% of the mechanical erection.

For the efficient co-operation of such a large number of persons who are recruited at peak from a diversity of over 100 companies, several prerequisites must be fulfilled. These are mainly organizational and supportive in nature, the site management being organizational while the site installations are supportive. Quality assurance and control is another function vital to the successful completion of construction. This is also the case for local participation and transfer of technology which can also have a major influence on the success of construction.

[1] A billion = 10^9 US $.

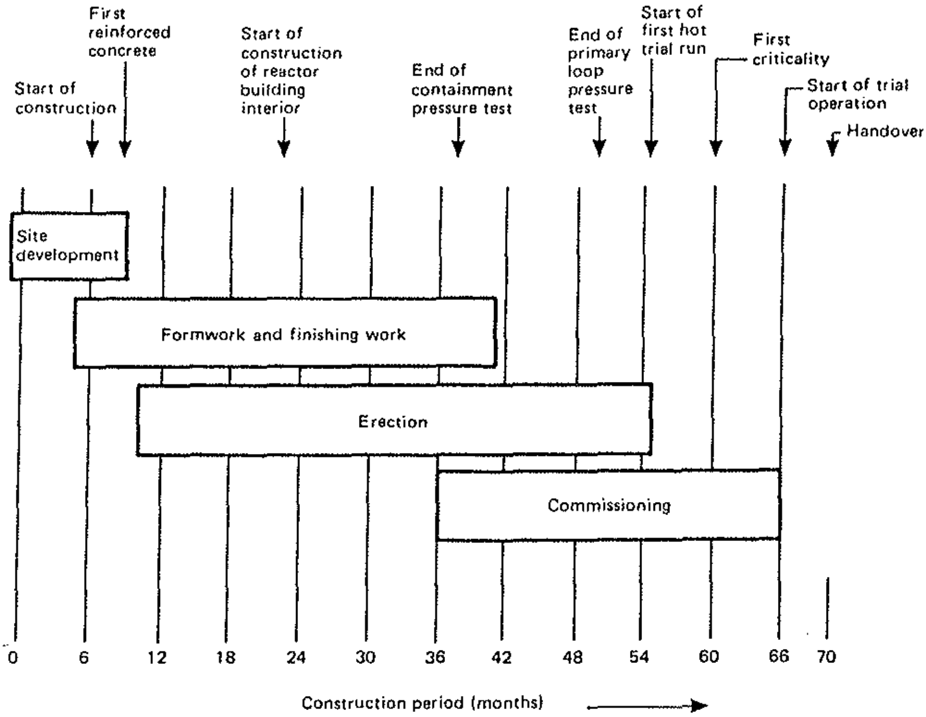


FIG. 25. Construction phases and milestones.

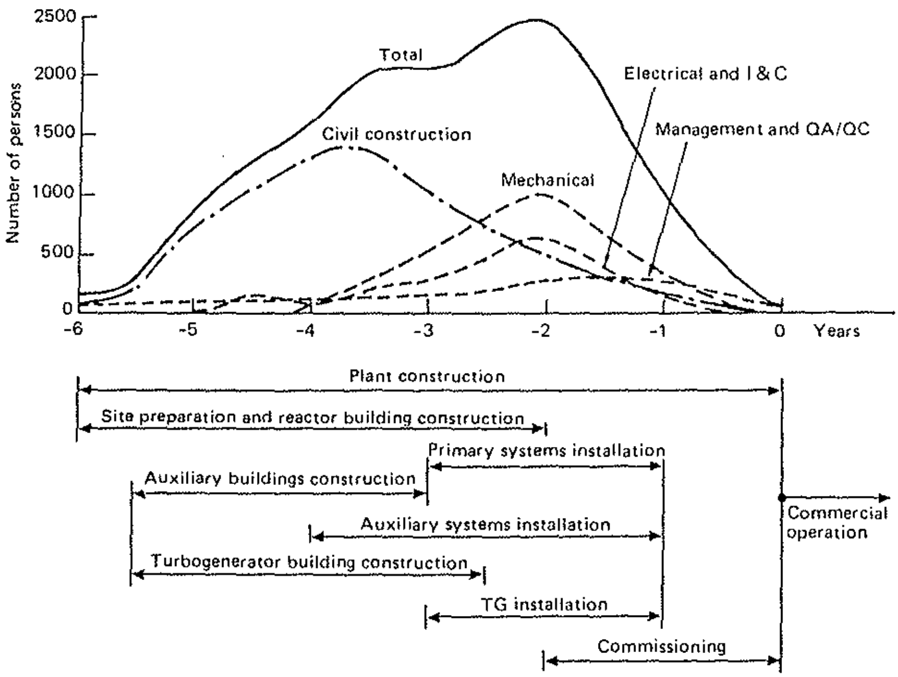
9.2. SITE ORGANIZATION

The co-ordination, control and supervision of over 100 contractors and more than 2000 labourers are performed by the site management. Depending on the contractual strucure of the NPP construction work, this site management can be built up by the main contractor (if this is the case), or by different contractors, each having its site superintendent. To respond best to the evolution of the site activities, in quantity and nature, the site management structure has to evolve as well. The job structures of the management therefore vary between the start of work on the site to the handing over of the plant to the utility.

The composition and profile of the site supervision personnel correlate therefore to the main construction phases such as the carcass work, site improvement and structural work and mechanical and electro-instrumentation erection. The organization of all of these phases is headed by the site manager.

An example of this type of site management is shown in Fig. 28 which refers to practice in the Federal Republic of Germany. The organization during commissioning and handing over to the utility is shown in Fig. 29. This unit is headed by the commissioning manager.

Owing to the shifting of the focuses of the tasks when the civil work and erection phase overlap with the commissioning phase, the total responsibility on the site lies in the hands of the site manager from start of work to the beginning of the hot test. The commissioning manager bears the overall responsibility from beginning of the hot tests until the handing over of the plant to the utility. Smooth transition between these two basic site activities is assured because both managers report to the project director who is ultimately responsible for the successful execution of the NPP. The roles of these various managers are described below.



300 professionals:	Civil, mechanical, electrical engineers
300 technicians:	Mechanical, electrical, civil technicians
1900 craftsmen:	Concrete workers, iron workers, heavy equipment operators, pipe fitters, welders, electricians, painters

FIG. 26. Manpower loading for plant construction (typical figures).

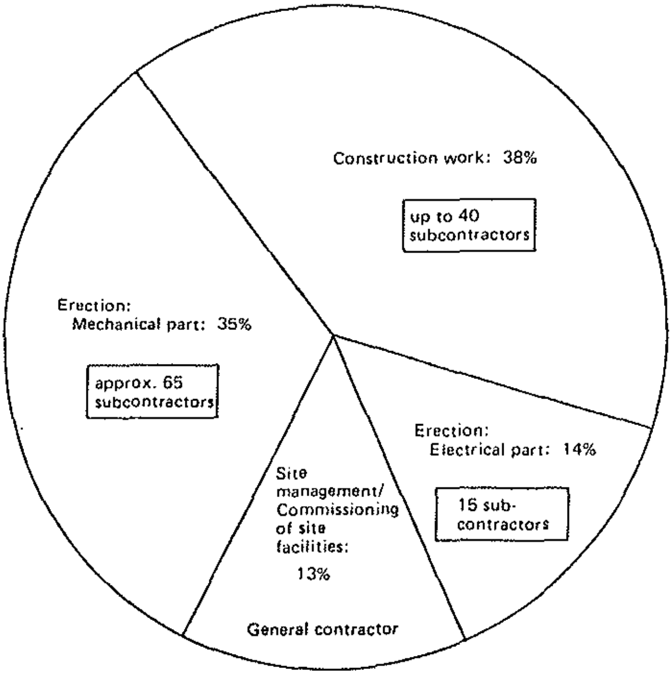


FIG. 27. Distribution of work.

The site manager

The site manager is entrusted with all responsibilities and authority necessary so that the site activities are realized with success, safety and with the maximum motivation of the site people. It is possible that in some country the law impacts somewhat on the scope of his responsibility. Yet, in all cases he supervises:

— the co-ordination and supervision of the civil work and erection work
— the conformance of the site operation to the rules and duties stipulated by the regulations and the local authorities of the country
— the execution of all work in accordance with the contract specifications, time schedules and plan targets, technical requirements and costs
— the periodic reporting on the status of the work
— the timely detection of critical situations and the application of remedial measures to deal with these.

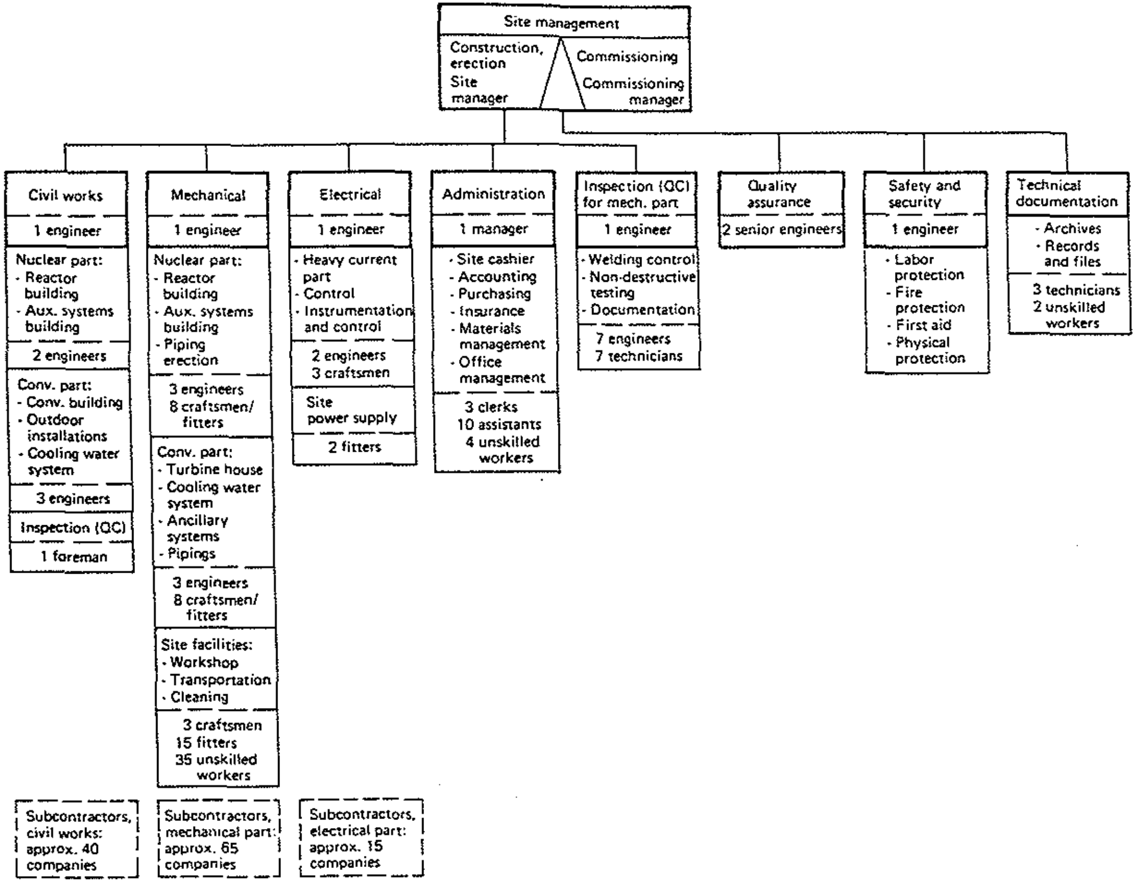


FIG. 28. Organization chart for site management of the main contractor.

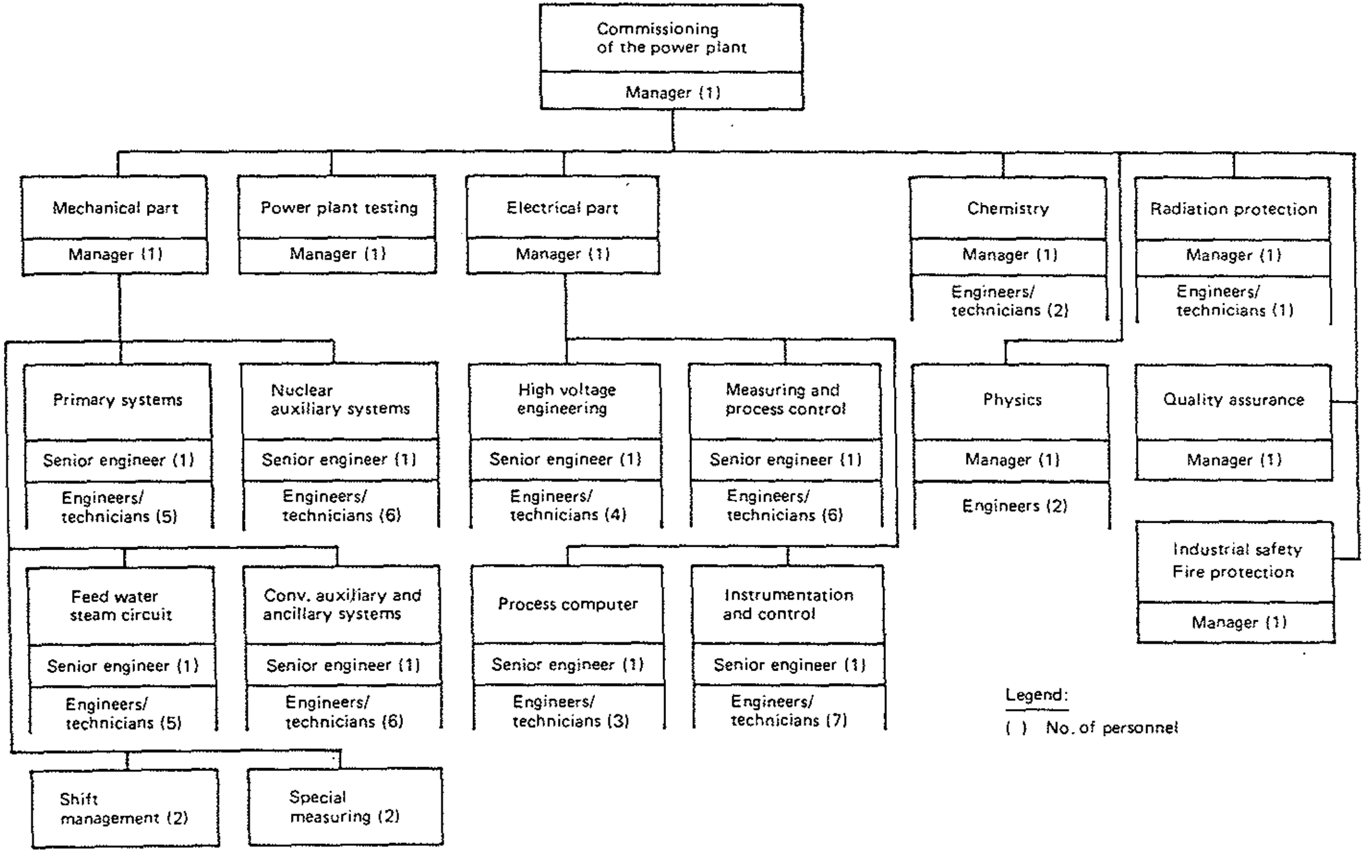


FIG. 29. Organization chart for commissioning.

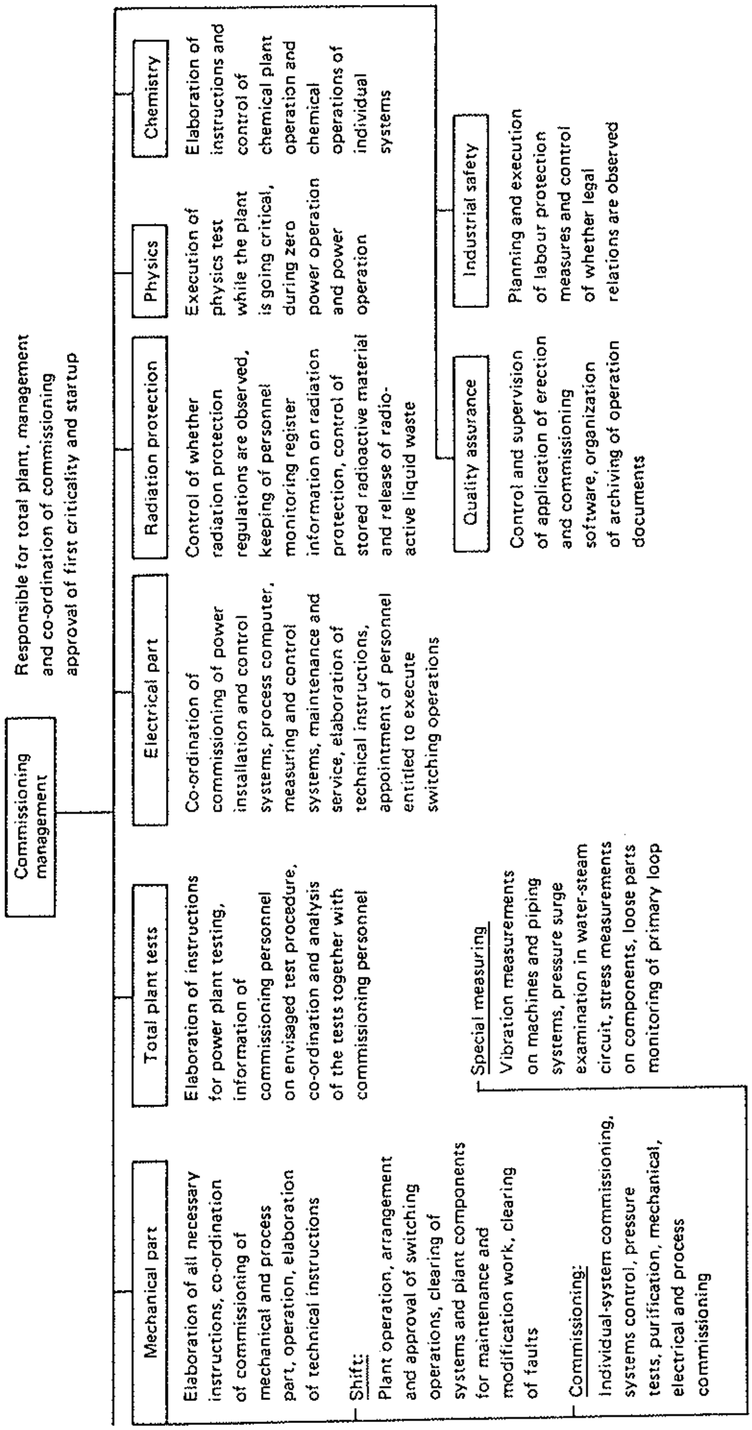


FIG. 30. Commission task description.

The site superintendents

The site superintendents are responsible for the different disciplines such as the civil work, mechanical erection and electrical erection. Each site superintendent has his detailed job description. The scope of the individual responsibilities may be defined as construction related (e.g. mechanical erection in the reactor auxiliary building) or function related (e.g. the piping erection or instrumentation and control erection, independent of the buildings in which these items are to be installed).

Within the scope of these duties, the site superintendents have to supervise also the supplies and the services to the contractors and co-ordinate all contractors working in their area of responsibility. As part of their technical duties, the site superintendents are responsible for the performance of all work in accordance with its contracts, specifications, time schedules and costs.

The commissioning manager

With the beginning of commissioning work the site organization will be completed (as shown in the example in Figs 28 and 29) so as to take care adequately of all commissioning activities. The timely sequence, the interfaces and the overlap of all activities must be co-ordinated in such a way that they are performed according to a strict schedule. The task description in Fig. 30 shows briefly the scope of duties within the different disciplines involved.

9.3. SITE PREPARATION AND INFRASTRUCTURES

The site facilities comprise all the temporary facilities necessary during the construction, erection and commissioning phases. These site facilities are arranged adjacent to the power plant areas; some may even be located in the power plant area itself.

These facilities essentially are:

- offices for the site management personnel
- daily lodging and sanitary installations for the site labour
- areas for temporary open air as well as building storage of delivered materials and components
- workshops (open air and buildings) for machining of materials and components for completion and adaptation prior to their installation
- site fabrication of equipment such as piping
- all machines, machine tools, equipment, scaffoldings, hoists, necessary for construction

— all supply and disposal installations and other temporary measures such as energy supply, communication systems, fire protection, drainage, fencing, water supply
— operation, maintenance and repair facilities.

9.3.1. Planning, installation and operation of the site facilities

The planning of the site facilities starts with the establishment of the plant layout. It is based on the overall power plant schedule and may start as early as the initial bid request for the nuclear power plant. After the NPP construction has been committed, final decisions on temporary facilities are made and agreed to by the contractors and the utility.

The following site related specifics to be taken into consideration when the temporary facilities are being designed and planned include:

— Location, size, topography and soil condition
— Adverse climatic conditions
— The connections to the public transportation systems and to the site internal road system
— The requirements, rules and regulations of the central as well as local authorities
— The size and the weight of the materials and components to be stored at the site
— An adequate loading and unloading area
— Any special security measures
— The sequencing of the civil, erection and commissioning phases.

The provision, installation and operation of the different facilities are usually handled either by the main contractor, the utility itself or a site management company on behalf of the utility. The utilities and the waste disposal facilities will be determined in nature and capacity by the scope of the other site facilities and the site population. Essentially these facilities are:

— Site roads with parking lots: approx. 4000 m roads, most of it paved and about 20 000 - 25 000 m^2 parking lots
— Site electricity supply: max. nominal load approx. 9–10 MVA, consumption for civil work, erection and commissioning totals to approx. 300 GW·h
— Site lightings, outdoors: approx. 400 kW, indoors approx. 500 kW
— Water supply (construction and drinking water): approx. 150 m^3 per hour
— Sewage system
— Rain water draining system
— Fire prevention system: approx. 3 km piping, 20 hydrants and a maximum capacity of approx. 3.2 m^3 per minute, fire protection tanker or other mobile fire extinguishing devices, fixed fire extinguishers and fire alarm system

— Garbage disposal system
— Communication systems:
  - telephone system with approx. 70 direct lines and 400 internal connections
  - teleprinter
  - paging system for personnel
  - walkie-talkies
— Security surveillance system.

The smooth evolution of the construction depends to a large extent on the efficient and timely functioning and the thorough maintenance of all of these facilities.

The efficient processing of the large quantity of data and the extensive variety of information makes it advisable to install a site computer primarily to help the site management to control the site activities efficiently. However, the contractors' work may also be assisted by this site computer.

The main applications of the computer are:

- erection control
- warehouse administration
- inspection and documentation
- site administration.

9.3.2. Site areas

The areas required for the various site facilities vary depending on local site specific construction schedules and materials deliveries. Figure 31 shows typical rough areas during the construction and erection phases. The figures for storage and workshops are in accordance with experience in developed countries. A particularly large intermediate storage volume for materials and components is not taken into consideration since the supplies can be phased in with needs on the site. This is particularly the case with the piping, the thermal installation, the ventilation and climatization ducts.

However, sites in developing countries need larger areas for intermediate storage and for workshops because of greater transportation distances and difficulties in scheduling equipment delivery. The size and scope of the workshop depend on the extent of manufacturing at the site. For example, the ventilation ducts that are fabricated from light structures are liable to transportation damage and may better be manufactured at the site.

9.3.3. Machines, tools, equipment

The variety and number of the necessary machines, tools, and equipment depend on the weight and size of materials and equipment delivered to the site and the extent of additional finishing work required at the site.

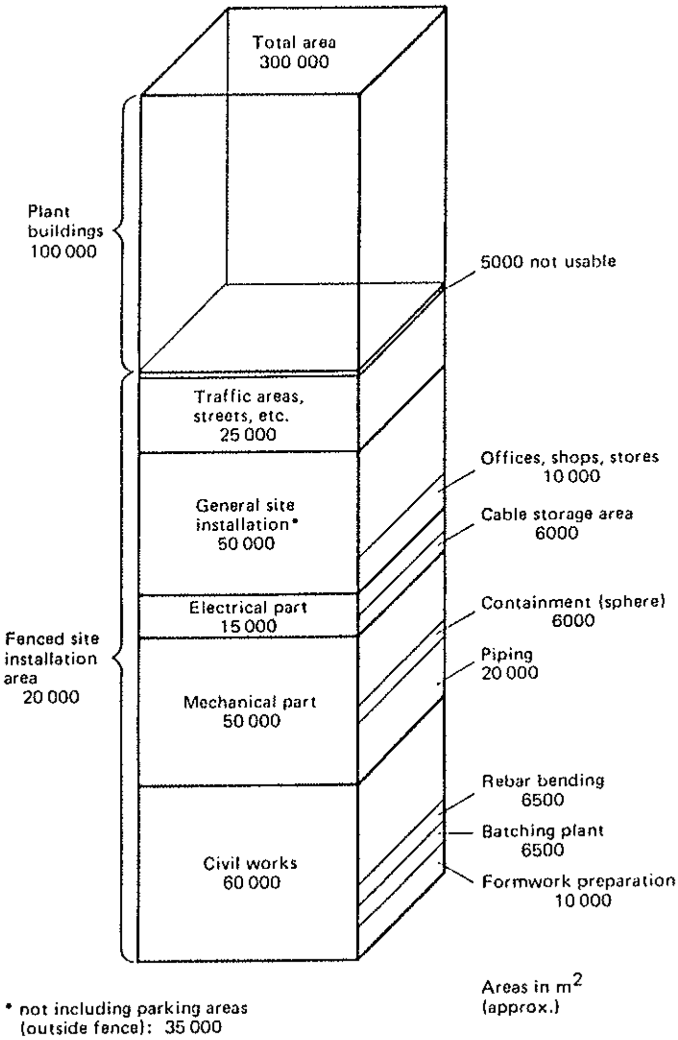


FIG. 31. Areas during civil construction and erection.

TABLE X. TYPICAL SELECTION OF MACHINES AND TOOLS NEEDED TO START CIVIL WORK

Rotary tower crane	20	2.5–12 t
Mobile crane	1	32 t
Compressor	6	5 m^3/h
Cargo truck 12 t with loading crane	1	5 t loading crane
Fork lift	1	5 t
Side lift	1	5 t
Motorized dump-car	3	
Welding devices, electrical	20	
Concrete jar–ram machine	25	
Iron bending machine	4	
Iron cutting machine	4	
Cargo truck with support	2	38 t
Concrete mixer	1	70 m^3/h
Concrete mixer	1	40 m^3/h
Concrete travelling mixer	8	6 m^3
Concrete pump, movable	1	40 m^3/h
Concrete pump, stationary	2	45 m^3/h
Concrete distributor mast	3	22 m arm
Cargo truck	25	25 t, 8 m^3
Loading caterpillar	4	2 m^3
Levelling caterpillar	4	110 HP
Mobile excavator	2	0.75 m^3
Wheel loader	2	2.5 m^3
Grader	1	
Compactor	2	60 AT
Steam roller	1	15 t
Rubber roller	1	15 t
Bitumen road finisher	1	
Woodworking machine	div.	
Pumps	div.	
Scaffolding	div.	
Instruments	div.	
Small machinery	div.	

(Source: KWU)

TABLE XI. TYPICAL TYPES AND AVERAGE NUMBERS OF MACHINES AND IMPLEMENTS FOR MECHANICAL AND ELECTRICAL ERECTION WORKS

Tools/Equipment	Quantity (approx.)	Capacity
Rotary tower crane	1	Height of lift: about 100 m Working angle: up to 75 m Lifting moment: up to 3000 t·m
Mobile crane	2	about 20 t
Heavy duty trailer with traction engine	up to 4 to be linked to one unit	
Unimog traction engine, cargo truck	15	different
Fork lift	5	2.5 up to 5 t
Electrical welding machine	200	
Welding equipment with protective gas	250	
Annealing devices	15	
Compressors	7	
Provisional building heaters	30	about 400 000 kJ/h
Tube bending machine	1	
Small machinery incl. workshop machinery, e.g. turning machine, saw, boring mill, etc.	div.	
Scaffoldings	div.	

(Source: KWU)

Table X shows a typical selection of machines and tools needed to start civil work.

While the machines and tools do not vary that much among different sites even of different sizes, the foundation methods may vary considerably. Depending on the soil, for example, very large equipment may be necessary for piling. Furthermore the site water level may require specialized extensive equipment; sheet piling may also have to be taken into consideration for the large buildings.

For the mechanical and electrical erection works Table XI shows the typical types and average numbers of machines and implements.

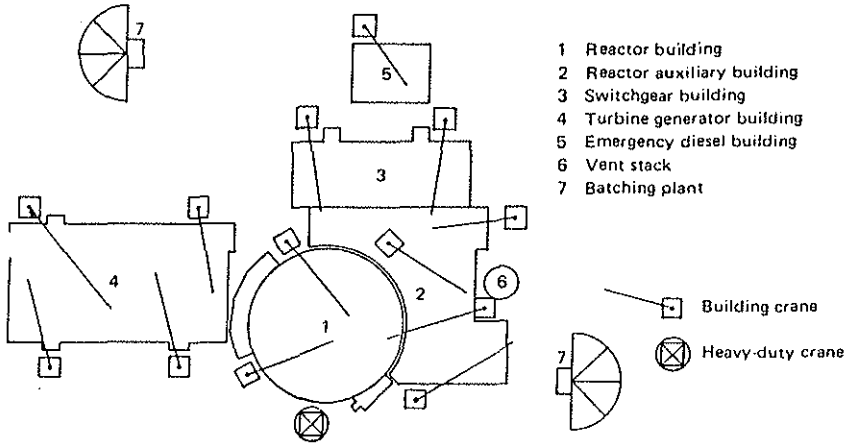


FIG. 32. Crane layout.

Special consideration must also be made for the transportation, lifting and placing in situ of the heavy components such as the reactor pressure vessel, steam generator, generator stator and main transformer. Transportation experts will need to study the methods of transporting this heavy equipment whether by sea, river, road or rail. Special care must also be taken in installing the lifting equipment. Figure 32 illustrates a typical crane layout study.

9.4. CIVIL CONSTRUCTION AND ERECTION WORKS

Compared to a conventional fossil fired power plant, the civil engineering and construction of a nuclear plant require more technical knowledge, effort and care. Some of the main reasons for such complexity include the:

- Difficult geometry of structures and tight layout of certain buildings
- Large quantities of construction materials (concrete, reinforcement, embedded parts, formwork) to be placed within a tight schedule
- High dimensional accuracy due to the requirements by the mechanical installation work
- Close interdependence with erection works which makes it imperative to keep schedule control for construction works in critical paths
- Detailed engineering required for formwork and reinforcement drawings and the complex planning necessary for the finishing works such as steel structures, coating, roofing and façades and the elaboration of related specifications with respect to constructability

- Complex construction planning, including the temporary site installations, employment of equipment, planning for formwork and scaffolding as well as construction sequences, concreting programmes and special work description
- Extensive quality assurance programmes and required manuals.

For these reasons only experienced constructors are best suited to carry out the civil works to the required standards and schedules. The contractors have to install their own technical and administrative site management, be capable of controlling construction to meet specifications and schedules and be able to take corrective actions when needed. Management personnel and labour have to be of a high level, at least as experienced as workers in conventional power plant construction. The qualification of the firms must be established prior to awarding construction contracts.

The quality control of the civil works has to be performed by a group independent of the contractor. This work includes non-destructive tests and the corresponding evaluation, survey inspection and inspection of the correct use of materials. As an example, Table XII shows the high number of tests to be performed at the site.

Some of the following structural features make the execution of work particularly difficult:

(1) The large quantities of reinforcement to be placed which require that the design work start well in advance to permit efficient job planning;
(2) In special cases, the reinforcement models which must be prepared prior to the actual work;
(3) The installation of the extremely high quantity of reinforcement which is often made additionally difficult by the necessity of providing openings for tubing and by the fixing-in of large sized embedded parts;
(4) The use of special high tensile steel for certain construction members which reduces the volume of reinforcement thus easing the placing of rebars and concrete pouring, but requires special skills and difficult engineering;
(5) The large number of embedded parts such as anchor plates of all sizes which require careful planning. Since the reinforcement steel network is extremely tight and as many auxiliary and supporting structures are required, placement is complicated;
(6) Particular attention which should be paid to formwork and scaffolding. In addition stringent requirements on accuracy and difficult shapes have to be met. Because it is vital to keep the selection of a suitable formwork system, preferably standardized and modular, to schedule, formwork planning should start well in advance.

The project time schedule outlined in Fig. 33 shows the integration of the erection works within the whole power plant construction. Before erection is started, certain requirements have to be met for each area on the particular building floor where equipment, components or a system have to be installed.

TABLE XII. MOST SIGNIFICANT TESTS OF CIVIL WORK PERFORMED AT THE SITE

Type of test	No. of tests
1. Aggregates	
— Granulometric	24 000
— Organic contents in sands	4 000
— Relative humidity	3 000
— Fine contents	4 000
— Shapes coefficient	1 000
— Soft particles	1 000
— Sand equivalent	9 500
— Specific weight	500
(1 test every 10 t)	47 000
2. Waters	
— pH	1 000
— Sulphates	1 000
— Chlorides	1 000
3. Portland cements	
— Fineness modules	5 000
— Setting speed	5 000
— Relative humidity	1 500
— Fire loss	1 500
— Compression and flexure strength	100
— Chemical test	400
(1 test every 10 t)	13 500

Type of test	No. of tests
4. Admixtures	
— Antifreezings, fluidifiers, plastifiers and accelerating agents	1 000
5. Reinforcing steel	
— Physical-chemical test and bending test	2 200
(1 test every 20 t)	
6. Bolts and embedded steels	
— Physical-chemical test	250
(1 test every 5 t)	
7. Stainless steel	
— Physical-chemical test	125
(1 test every 2 t)	
8. Rebar connections	
— Physical-chemical test	2 500
(1 test every 20 t)	

Type of test	No. of tests
9. Concretes	
— Compression strength (test specimen)	60 000
— Mix design, consistence, temperature, etc. 2 every hour	
(1 test specimen every 5 m^3)	
10. Earthwork	
— Fill compaction	25 000
(1 test every 10 m^3)	
— Natural soil (several types)	5 000
(1 test every 10 m^3)	
Total number of tests to perform	160 000

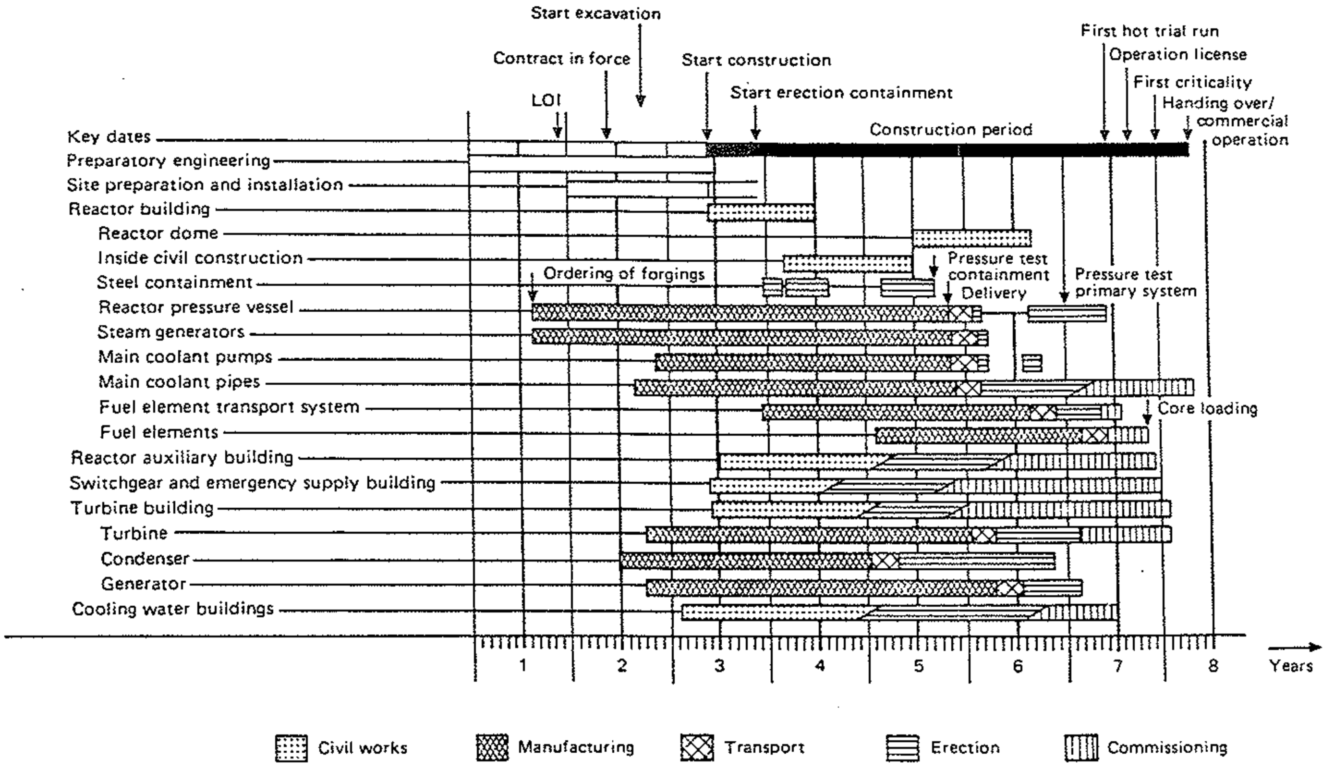


FIG. 33. Project time schedule (typical).

These requirements include:

— establishing the degree of completion of all finishing parts
— making available the documentation of all elements, components and equipment that have to be installed
— distributing all scheduling information to avoid physical interference during erection

Depending on different contractual arrangements, the erection contractor may assume total erection responsibility with or without the supervision of the equipment supplier or the latter may install his equipment with his own personnel. In this case there is no interface between supply and erection.

9.5. PLANT COMMISSIONING

The commissioning of a nuclear power plant requires close co-ordination, precise planning and strict schedule control.

There are four basic phases:

Phase A: pre-operational tests
Phase B: hot trial run No. 1 (without nuclear core)
Phase C: first core loading and hot trial run No. 2
Phase D: first criticality and power tests

The main activities within these phases are described in Table XIII.

The mechanical and the electrical/instrumentation commissioning start simultaneously with the erection of the plant and as soon as parts of the plant or part of the systems are completed. Prior to the non-nuclear total plant tests, phase A must be completed. The release to the higher power test can only be given if the results of the preceding tests and examinations permit.

Phase A: Pre-operational tests

Within phase A, the complete commissioning of the individual components and assemblies or systems is performed. Commissioning activities of phase A can also be performed in parallel to phases B and C.

Important milestones within phase A are:

— the switching in of the electrical station auxiliary supply
— the primary circuit pressure test
— the secondary circuit pressure test

TABLE XIII. PHASE ORIENTED COMMISSIONING PROCEDURE WITH MILESTONE ACTIVITIES FOR A LIGHT WATER REACTOR POWER PLANT

Phase A	Phase B	Inspection Phase	Phase C	Phase D
Pre-operational tests — Mechanical and process commissioning of individual systems — Electrical commissioning of process sytems and electrical systems *Special events:* — Switch-on auxiliary power (startup transformer) — Pressure tests: primary loop secondary loop Precondition: the required auxiliary systems have to be ready for operation	*1st hot trial run* Tests with unloaded core — Interplay of systems — 1st operation of main coolant pump — 1st heating — Bypass operation —1st steam to turboset, etc.	— Reactor pressure vessel core structure — Final erections — Acceptance reactor protection system — Borating of the system	*2nd hot trial run* 1st core loading Precondition: — Systems borated — Reactor protector system and — Core instrumentation ready for operation	*Power tests* — 1st criticality — Zero power operation tests — Power tests at 0–30% 30–80% 80–100% load — Grid behaviour ———————— Contractual trial operation Handover

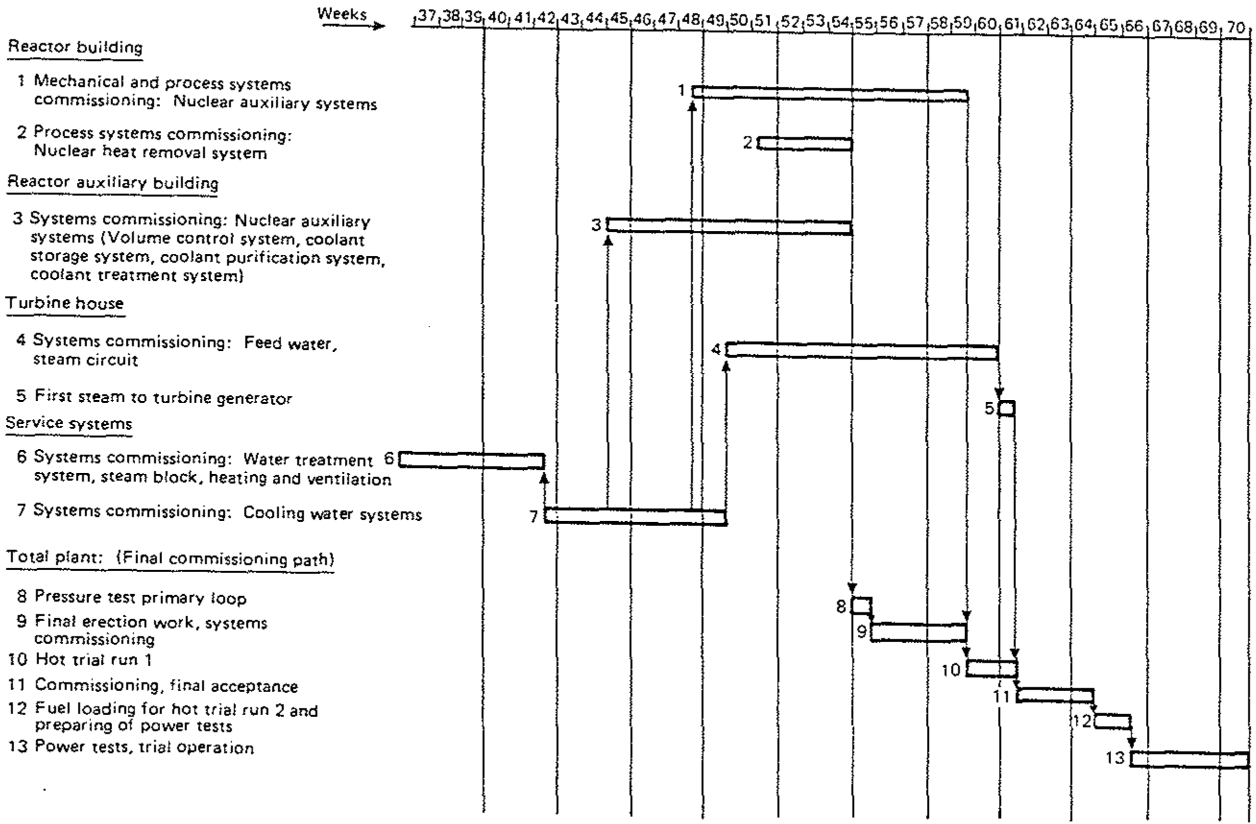


FIG. 34. Schedule of commission activities.

Phase B: First hot trial run (without core)

In the first hot trial run, the reactor coolant system together with the reactor auxiliaries and other systems operate for the first time. This procedure checks the satisfactory operation of the systems. The reactor coolant system is brought to temperature and, for PWRs, the pressurizer is filled thereby creating the nominal operational pressure. At the time of this first hot trial run, the operation with the complete shift personnel will be commenced.

During the inspection phase between the first and the second hot trial runs, the following important activities are performed:

— the inspection of components
— the adjustments for modifications due to test results
— the borating of the systems

Phase C: First core loading and hot trial run No. 2

Phase C starts with the core loading. The test which will be conducted with subcritical core serves also to prove the function and safety of the whole plant prior to the start of the nuclear operation.

Phase D: First criticality and power test

This phase can only be started if the pre-operational tests as well as the commissioning activities of phases B and C are accomplished successfully. Phase D starts with the first criticality of the reactor and follows a very precise schedule and procedure. The first criticality is followed by a zero power test during which all core physical test are performed.

After this the reactor power generation will be increased gradually within the power ranges 0–30%, 30–80% and 80–100% and the corresponding nuclear plant tests will be performed. On termination of the nuclear operational plant tests, the contractually agreed trials runs will be started and will finish with the handing over of the plant to the utility.

The schedule of the essential commissioning activities is shown in Fig. 34 within a time-frame of 70 months' total construction time.

The acceptance of a nuclear power plant or of parts of a nuclear power plant by the owner/operator/utility indicates the transfer of operating responsibility from contractor or supplier to the utility. Another type of acceptance concept consists in transferring the operation responsibility of the whole plant at a suitable moment, for example at the end of the usual four weeks' trial run.

A further option is characterized by the taking over of commissioned and functioning systems by the utility after individually executed acceptance tests. The type of acceptance of works or of a partial work is the subject of the appropriate contracts.

CHAPTER 10

FUEL CYCLE ACTIVITIES

10.1. INTRODUCTION

Nuclear fuel, the driving force behind all nuclear reactor systems, is the most important consumable reactor operation item with an ongoing requirement throughout the life of the plant. The complete nuclear fuel cycle covers all activities beginning with initial exploration, mining and refining of uranium ore and continuing through fuel fabrication, reactor operation and spent fuel storage to eventual disposal. Various fuel cycles with differing degrees of complexity are possible.

While any nation wishing to establish total self-sufficiency in the nuclear fuel cycle will eventually have to confront and master all aspects of the cycle, most nations initiating their nuclear power programmes will concentrate on those aspects which offer more immediate prospects for development. For this reason, this chapter will highlight only activities associated with fuel fabrication and spent fuel management. Information on all aspects of the fuel cycle is given in the International Nuclear Fuel Cycle Evaluation (INFCE), IAEA, Vienna (1980).

The utility is primarily concerned with two aspects of the fuel. The first one is the reliability of the supply of the fuel assemblies and the second concern is the handling of the spent fuel. To cater efficiently to these two items, fuel management has been developed as an expertise in itself, vital in both keeping the power plant in operation and holding the costs down.

10.2. FUEL FABRICATION

The fabrication of nuclear fuel involves first the basic fuel design and the definition of specification. Next the components comprising the fuel assembly have to be obtained and, finally, the fuel assembly must be manufactured. In all these stages, quality assurance and control are paramount.

10.2.1. Fuel design and specification

Fuel design and performance specifications are usually developed by the reactor vendor rather than by the fuel fabricator. Specifications sufficiently detailed to enable the utility to purchase replacement fuel are provided as part of the main reactor contract. These can also be used for domestic fuel fabrication if the associated manufacturing technology is available.

TABLE XIV. CHARACTERISTICS OF LWR AND PHWR (CANDU) FUEL ASSEMBLIES

PHYSICAL CHARACTERISTICS 1000 MW(e)		PWR 1000 MW(e)	BWR 600 MW(e)	CANDU 600 MW(e)
Length of assembly	mm	4182	4470	495
Length of element (active)	mm	3400	3760	492
Assembly side X-section	mm	230	140	—
Bundle diameter	mm	—	—	102
Weight of assembly	kg	740	268	23.7
Weight U per assembly	kg	463	178	18.8
No. of elements per assembly		300	62	37
UO_2 pellet diameter	mm	8.05	10.44	12.2
UO_2 pellet length	mm	10.00	12.50	16–18
Cladding material		Zircaloy-4	Zircaloy-2	Zircaloy-4
Cladding OD	mm	9.5	12.30	13.1
Cladding thickness	mm	0.64	0.82	0.4
NUCLEAR CHARACTERISTICS				
Average discharge burnup	MW·d/kg U	43.1	30.4	7.1
Specific power	kW/kg	38	24	25 (av.)
Initial enrichment	% U-235	1.9–3.6	1.9–3.03	natural
Initial inventory	Mg(U)	82.0	109.4	86.2

However, an understanding of the basic fuel design is necessary if the utility is to benefit from advances in fuel design and performance or from actual performance experience in its own plant. Acquiring competence in fuel design involves the development of expertise in such areas as reactor core design and performance, materials behaviour under irradiation, and materials fabrication. A key factor in developing these skills is the availability of highly trained specialists. The development of the expertise required in fuel design is a long term and costly undertaking when one is starting from the very beginning. The transfer of fuel design technology along with the training of personnel is necessary for this development. Several reactor vendors are prepared upon request to offer transfer agreements to accomplish such technical advancement.

Complete fuel design technology includes codes for design and performance under both normal and abnormal conditions. Moreover, to achieve total independence, extensive R&D activities with adequate facilities for irradiation testing and post-irradiation analysis are needed.

10.2.2. Fuel component fabrication

Nuclear fuel used in most commercial reactors in operation today is comprised of ceramic uranium dioxide (UO_2) pellets sealed in Zircaloy tubes. These fuel elements, after they have been held together by supports and end fittings, are clustered into fuel assemblies which then can be charged into the reactor. The assemblies are

TABLE XV. MATERIAL REQUIREMENTS FOR LWR AND PHWR (CANDU) FUEL CYCLES

		PWR 1000 MW(e)	BWR 1000 MW(e)	CANDU 600 MW(e)
INITIAL CHARGE REQUIREMENTS				
Natural uranium	Mg(U)	363.3	364.0	86.2
Enriched uranium	Mg(U)	82.0	109.4	—
	% U-235	2.46	1.90	—
Separative work	swu	260.1	218.1	—
Zircaloy	Mg	28.5	30.3	10.5
Total cladding tube length	km	203	149	83
AVERAGE ANNUAL MATERIAL CONSUMPTION[a]				
Natural uranium	Mg(U)	135.5	138.2	98
Enriched uranium	Mg(U)	20.4	24.9	—
	% U-235	3.6	3.03	—
Separative work	swu	114.9	109.2	—
Zircaloy	Mg	7.7	7.2	12.0
Total cladding tube length	km	51	35	95
No. of fuel assemblies		44	140	5200

[a] Quantities do not take into account manufacturing losses.

precision engineered structures and vary considerably in size and concept from one type of reactor to another, but the basic steps and standards of manufacture are similar.

Characteristics of the fuel for different reactors are shown in Table XIV and quantities required for reactor operation in Table XV. The essential components required include ceramic grade UO_2 and Zircaloy tubing, bar stock and sheets. Production of these components domestically is not a prerequisite to fuel fabrication since they can be purchased from several sources. Nevertheless a basic description of the processes involved is given here.

UO_2 production

The product of the uranium mining industry is a uranium concentrate, known as yellow cake, which must be refined to remove the impurities present. Purification is not a complex process and involves nitric acid dissolution and solvent extraction to produce a purified uranyl nitrate which can then be processed further.

For LWR fuel which requires enrichment, the uranyl nitrate is converted into uranium hexafluoride in a fluidized bed process. The uranyl nitrate after concentration is thermally nitrated to give a UO_3 powder which in turn is reduced to UO_2 with hydrogen and then treated with gaseous hydrofluoric acid to give UF_4 and eventually UF_6. All processes are carried out in fluidized beds and involve the handling of hazardous chemicals.

The natural grade UF_6 is then enriched in ^{235}U in an enrichment facility employing physical processes. The most common and well established process involves separation by gaseous diffusion in large, capital intensive facilities. More recently centrifuge separation has been used with some economies but again the scale of plant is large.

After enrichment the UF_6 is hydrolysed and precipitated with ammonia to give ammonium diuranate. This compound is thermally decomposed and then hydrogen reduced to produce ceramic grade UO_2 powder. An alternative process based on ammonium uranyl carbonate is also used in the conversion of UF_6 to ceramic grade UO_2 powder. For PHWRs where no enrichment is required, the ammonium diuranate can be produced directly from the uranyl nitrate resulting from the refining process.

Whether the fuel is enriched or natural uranium, the processes used are normally undertaken in relatively large plants which benefit from economies of scale. It is generally accepted that such plants are only economically viable at capacities of the order of 1000 tonnes of uranium per year. A nuclear power programme of several gigawatts would be required to justify construction of such facilities.

The characteristics of ceramic grade UO_2 required for the fabrication of nuclear fuel are critical to the production of acceptable UO_2 fuel pellets. Chemical impurities must be carefully controlled and the U/O ratio in the finished product is

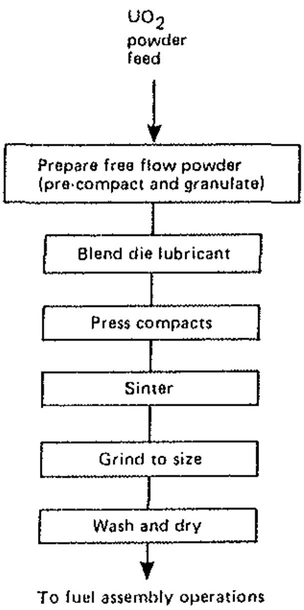


FIG. 35. Basic UO_2 pellet fabrication process.

important. In addition, physical characteristics such as surface area and particle size distribution are key to achieving the desired sintered density in the fuel pellet. These characteristics are usually achieved by careful process controls during production of the ceramic grade UO_2.

Ceramic grade UO_2 powder can be specified and verified with sufficient accuracy to ensure the desired pressing and performance characteristics. The fuel pellets are produced by a simple pressing and sintering process and are then ground to the required dimensions (see Fig. 35). Final dimensions of the fuel pellets are an inherent part of the fuel design and are critical to the performance of the fuel in service.

Zircaloy components

In addition to UO_2 pellets, only Zircaloy components are used in the PHWR fuel assembly. In LWR fuel assemblies, some stainless steel spacer grid components are used, but again the bulk of non-UO_2 materials used are made of Zircaloy.

The principal Zircaloy components are the fuel tube, whose end caps are made from bar stock, and the end plates or grids which are fabricated from strip. All these components or at least the basic form from which they can be machined are readily available from several suppliers.

Zircaloy-4 ingot

↓

Hollow extrusion (63.5 mm dia)

↓

First tube reduction (31.8 mm dia)

↓

Second tube reduction (22.2 mm dia)

↓

Final tube reduction (13.1 mm dia)

↓

Clean

↓

Stress relief anneal (525°C, 4 h)

↓

Cut to length

↓

Belt grind OD surface

↓

Ultrasonic testing
(wall thickness, wall defects)

↓

Inspection
(dimensional, mechanical properties, corrosion test)

↓

To fuel assembly operation

FIG. 36. Production of Zircaloy fuel cladding (typical).

Zircaloy is a zirconium alloy which requires considerable care in both fabrication and handling. The fabrication of Zircaloy components usually begins with the ingot which can then be formed into plate, bar stock and tubing by using standard metallurgical processes and by taking into account the reactive nature of the material.

Fuel cladding, which consists of a Zircaloy tube, is the most critical element used in fuel assembly. Cladding is a precision formed, thin walled tubing produced to an extremely tight specification. Zircaloy fuel cladding is available from a number of suppliers, but many fuel fabricators have begun to produce their own tubing when the volume of materials required justifies this. Figure 36 illustrates the basic steps in producing reactor quality tubing from the starting ingot. Quality control at all of these production stages is essential to the successful manufacture of acceptable Zircaloy tubing.

10.2.3. Fuel assembly fabrication

The first step in fuel assembly fabrication is the production of the fuel element or fuel rod. The UO_2 fuel pellets, produced to very carefully controlled density and stoichiometry (U/O ratio) and ground to precise dimensions, are loaded into a Zircaloy tube to which one end cap has already been attached. When the requisite number of fuel pellets have been loaded, the tube is filled with helium and the other end cap welded on. The fuel elements are then collected into the fuel assemblies.

The procedures used in producing the finished fuel assembly differ from one design to another and also among fuel fabricators. For example, different fabricators use various welding techniques and different methods of holding the fuel elements in position. Nevertheless, the factors common in the fabrication of all fuel assemblies include high precision, extreme cleanliness, high standards of quality assurance and intensive quality control.

10.2.4. Fuel fabrication plants

The degree of automation used in fuel fabrication plants has progressively increased over the years so that today many of the procedures are partly or fully automated. The overall capacity of the plants is generally a function of the number of lines in use rather than the capacity of individual machines. This modular approach allows a new fabricator to begin with a single line operating in a pilot mode until the processes have been fully qualified.

Qualification of a new fuel supplier is a long process, perhaps as long as 3–5 years. Once the supplier has been given access to the necessary design and manufacturing technology together with the necessary number of trained operators, he must qualify at each of the process steps. When quality fuel assemblies have been made, these components must undergo performance testing under both out-of-reactor and in-reactor conditions.

In-reactor testing of first production fuel in a power reactor is not advisable since the consequences of fuel failures can be costly or even dangerous. A means of testing fuel assemblies in small test reactors or in in-reactor loops is required together with post-irradiation examination facilities. The provision of such facilities can be a significant burden for a nuclear developing country. It is advisable, therefore, that the domestic fuel fabricator, at least initially, develop arrangements offshore for performance testing of the fuel assemblies.

The annual fuel assembly requirements for a single LWR hardly warrant construction of a fuel fabrication plant. However, in view of the long learning curve involved and if a series of reactors is planned, it may prove judicious to begin construction of a fuel fabrication plant early in the series rather than waiting until the demand fully justifies the plant.

Fabrication plants for PHWR fuel assemblies are based on a modular arrangement with each module having a production capacity of 200 tonnes of U per year; production at this level has proven to be a viable operation. Since the annual requirement of a single PHWR 600 plant is approximately half this capacity, construction of a plant to fabricate replacement fuel even for the first plant could be justified.

10.3. FUEL MANAGEMENT

Fuel management, a key activity for the utility in achieving economical operation, includes the following processes:

(1) Planning for and procurement of an adequate supply of nuclear fuel while taking into account the necessary lead times which amount to many months;
(2) Planning refuelling campaigns to achieve maximum fuel use as well as optimum power from the reactor core. This involves a detailed knowledge of the physics of the core design and requires the availability of fuel management codes for the particular reactor design;
(3) Management of spent fuel from the reactor.

10.4. SPENT FUEL MANAGEMENT

All nuclear plants are provided with on-site storage facilities for used or spent fuel. The water filled storage pools provided are usually capable of coping with several (usually ten) years' accumulation of spent fuel. Additional storage capacity may eventually be required at the site or in some other facility.

The technology associated with storage in water filled pools is well established. The water provides both shielding for the used fuel and also the means of removing heat generated by fission product decay. In the case of LWR fuel, sufficient fissile material (both unburned ^{235}U and plutonium) is present in the spent fuel so that precautions are necessary during storage to prevent criticality. This safety requirement reduces the storage capacity of a water pool for used LWR fuel compared to that for used natural uranium (PHWR) fuel or alternatively requires the provision of suitably arranged neutron absorbers within the pool.

Away from reactor storage may be feasible in a nuclear power programme of several units. Again the basic technologies are well established and readily available; however, in this case, a safe method of transporting spent fuel will be required. Transport of radioactive materials has been practised on an industrial scale for several decades without causing any serious public danger from radiation. The International Atomic Energy Agency has published internationally accepted guidelines which form the basis of national regulations on transport of radioactive materials.

The underlying principle is that the packaging of the radioactive material should be designed to contain the material and ensure the safety of personnel under all conditions, including transport accidents.

The container used to transport spent fuel is a simple, heavily shielded container whose manufacture would present few problems to a country wishing to make such equipment. Several proven designs for all fuel assemblies of all commercial reactor systems are available for both road and rail transport.

Countries with fast breeder reactor development programmes have fuel reprocessing plants to recover the plutonium contained in spent LWR and gas cooled reactor fuel. They may offer a commercial reprocessing service to others. The uranium in spent fuel which still contains approximately 1% ^{235}U may also be recovered for recycle. The technologies involved in reprocessing spent fuel are chemical in nature and are well established, but the major difficulties with the handling of highly radioactive solutions give rise to a high cost of reprocessing, even on a commercial scale. The investment cost of a reprocessing plant is relatively high due to the virtually 100% stainless steel content in the equipment.

At present, although plutonium recycle in existing LWR or PHWR designs is feasible, there is little commercial incentive to exploit this particular fuel cycle. The additional energy gained from the recovered fuel from either system does not at this stage offset the additional high costs of reprocessing and active fuel fabrication.

The technologies required for the permanent disposal of fuel wastes are being developed by several countries and are well advanced. The results of this development work are widely disseminated and there is little doubt that demonstrated commercial methods of fuel waste disposal will be available, when required, to any country entering a nuclear power programme.

10.5. TECHNOLOGY TRANSFER IN FUEL CYCLE ACTIVITIES

The technologies associated with the various fuel cycle activities have been developed by many different companies. Recognizing the interest shown in the nuclear fuel cycle, many reactor vendors have offered arrangements covering the transfer of technology for several parts of the fuel cycle.

It is neither realistic nor appropriate to expect the transfer of all the technology available with the construction of the first unit. The relatively large ratio of highly skilled personnel, both professional and technical, who would be required and the large capital investment needed to establish the necessary facilities would present an intolerable burden on the country. Also those facilities would be greatly underused until a significant nuclear programme were in place.

It follows, therefore, that the country must determine its priorities in order to decide which aspects of the fuel cycle to pursue initially. It is also important to identify those government agencies or companies in the country which will be charged with developing those chosen aspects. In the following paragraphs, each of the various aspects of the fuel cycle discussed in this chapter will be considered in relation to the kind of technology transfer which might be involved and the relative merits of that technology to the early development of the nuclear power programme.

10.5.1. Uranium exploration and mining

Exploration for and mining of uranium are simply extensions of techniques used for other minerals. With the current oversupply of low cost uranium, it is unlikely to be profitable for a country to develop the necessary infrastructure required to mine uranium unless large deposits of very high grade ore exist. A political decision may be made, however, to tap an indigenous source of uranium even if only low grade ores exist. Nevertheless, it is prudent for the country to establish the extent of its uranium resources for future development. Assistance in this area is readily available for several countries.

10.5.2. Uranium refining and conversion

The technologies involved in uranium refining and conversion to either UF_6 for future enrichment or ceramic grade UO_2 powder should be readily assimilated by a country with a developed inorganic chemical industry. The dry and wet chemical processes used require careful control to achieve the desired products, so a suitable physical chemistry analytical capability would be required if the decision were made to establish this component of the fuel cycle. A suitable number of chemical engineers and chemical technicians would be essential to the successful operation of the plant.

As indicated earlier, refining and conversion facilities only become economically viable at relatively large sizes, of the order of 1000 tonnes of uranium per year. Such a plant would provide enough feedstock for several gigawatts of installed capacity and would employ a staff of approximately 100 of which 30 would have professional training.

Unless a country has a large, easily developed, low cost uranium resource, it would be more economical to obtain the required refined and converted uranium as a finished ceramic grade powder from one of the several commercial suppliers. Technology transfer in this area is not a recommended priority despite reliance on foreign sources of fuel supply.

10.5.3. Enrichment

The technologies involved in uranium enrichment are difficult whether the process is diffusion or centrifuge in nature. From a more practical point of view, it is unlikely that the necessary technology would be available for transfer.

10.5.4. Fuel design

Acquiring a fuel design technology is regarded as one of the more important steps towards developing a total fuel cycle. At the least, a good basic understanding of the design is essential to the development of a fuel fabrication capability.

Much of the technology related to fuel design is embedded in design or performance codes. However, assimilation of fuel design technology requires a group of professionals knowledgeable in reactor core behaviour, thermal hydraulics, irradiation performance and materials behaviour. Their basic professional training will be in physics or in chemical, mechanical, or metallurgical engineering. This will be followed by training in the facilities of the fuel designer or in the well established nuclear research and development laboratories specializing in fuel development.

10.5.5. Fuel fabrication

Establishing fuel fabrication facilities is an attractive goal since the product is the most important consumable in the nuclear power plant. Many reactor vendors and fuel fabricators have indicated a willingness to transfer fuel manufacturing technology provided suitable agreements can be reached.

It is not essential to start with producing all components in the fuel fabrication step. The recommendation would be to start with ceramic grade powder and produce UO_2 pellets or even to purchase UO_2 pellets which would then be fed into Zircaloy tubes purchased elsewhere. Since Zircaloy tubing of the required quality is readily available at a reasonable price, there is no incentive to develop this technology until there is sufficient domestic demand for a tube production plant.

Fuel fabrication plants with a capacity of 200–300 tonnes per year would employ a total staff of the order of 80–100, up to one-half of whom would have professional training. The professional staff would be specialists in process control or chemical engineering and a large fraction would be involved in the essential quality assurance and quality control activities associated with the fabrication of high nuclear fuel assemblies.

The optimum timing for the introduction of a fuel fabrication plant is an open question. It has been argued that with the long learning time required before high quality reactor grade fuel is qualified, an early introduction of a fabrication facility along with the first nuclear plant may prove a good investment.

10.5.6. Fuel and spent fuel management

An expertise in fresh fuel and spent fuel management is appropriate for the utility going nuclear to obtain by transfer of technology arrangements with one or even more than one utility.

Technologies associated with the on-site storage of spent fuel should be transferred along with the construction of the nuclear plant. The facilities required should be included as part of the basic plant.

Further treatment of the spent fuel will be a distant requirement and need not be considered as requiring technology transfer in the early stages of a nuclear power development programme. Transfer of spent fuel technology will depend on the country's policy decision with respect to the back end of the fuel cycle.

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