Guidebook on the Introduction of Nuclear Power

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1982
GUIDEBOOK
ON THE INTRODUCTION
OF NUCLEAR POWER
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VENEZUELA
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YUGOSLAVIA
ZAIR
ZAMBIA

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

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FOREWORD

Over the past three decades the number of both highly industrialized and developing countries initiating nuclear power programmes has steadily increased. At the end of 1981 there were 30 countries with nuclear power plants in operation or under construction, and nuclear power has reached a stage where it is a viable, reliable, safe and competitive source for electricity production. Its use will doubtless increase worldwide and the number of countries with nuclear power programmes will also grow.

In response to the special needs of those countries that are planning or intend to introduce nuclear power, the International Atomic Energy Agency has prepared and published a guidebook named “Steps to Nuclear Power” (1975). This guidebook has found wide acceptance and has been extensively used. Since its publication new developments affecting many aspects of nuclear power have taken place, and additional knowledge and experience in the planning and implementation of nuclear power programmes and projects have been accumulated. In view of these considerations, the Agency has decided to develop the present “Guidebook on the Introduction of Nuclear Power”, which is intended to replace the earlier “Steps to Nuclear Power”, and to provide up-to-date information and guidance to decision makers, planners, managers and professional staff on the work that has to be undertaken in the preparation for and introduction of nuclear power in a country.

This “Guidebook on the Introduction of Nuclear Power” has been structured into three parts. The first part contains a survey of nuclear power, with the objective of providing general background information to the reader on the present status and future prospects of nuclear power and on the technical and economic aspects of available power reactor types and nuclear fuel cycles.

In the second part of the Guidebook, the special aspects and considerations relevant to the introduction of nuclear power in a country are discussed. The subject is subdivided into three main headings: the technical aspects and national requirements; the safety and environmental considerations; and the international aspects of nuclear power. Emphasis is placed on the tasks to be performed within the country introducing nuclear power, on responsibilities that cannot be delegated and on the need for adequate national infrastructures and long-term commitments.

Finally, the third part of the Guidebook contains more detailed information and guidance on the planning and preparatory stages of launching a first nuclear power project, including in particular: nuclear power programme
planning, siting, feasibility studies, bidding and contracting. Design, construc-
tion and operation are covered in a brief overview for the sake of completeness.

The Guidebook contains information, advice and recommendations applicable to any country, whether developed or developing, but it is intended to be especially relevant for developing countries. It has been prepared within the framework of a series of technical guidebooks of the Division of Nuclear Power, some of which have already been published, such as “Manpower Development for Nuclear Power” (IAEA Technical Reports Series No. 200), “Economic Evaluation of Bids for Nuclear Power Plants” (IAEA Technical Reports Series No. 175), and “Technical Evaluation of Bids for Nuclear Power Plants: A Guidebook” (IAEA Technical Reports Series No. 204). Supplementary guidebooks on subjects such as “Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants”, “Control and Instrumentation of Nuclear Power Plants”, “Nuclear Power Project Management”, “Bid Specifications” are under preparation.

Appreciation is expressed for their valuable contributions to all those who participated in the preparation of this Guidebook and also to the Member States for their generous support in providing experts to assist the IAEA in this work.
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PART I

SURVEY OF NUCLEAR POWER
Chapter 1

PRESENT STATUS AND FUTURE PROSPECTS
OF NUCLEAR POWER

1.1. INTRODUCTION

This chapter is intended to provide summarized background information on the history, present status and future prospects of the development of nuclear power in both industrially advanced and developing countries.

Nuclear power technology has been developed over the past three decades, reaching a stage where it is now an acceptable, reliable, safe and fully competitive source for electricity production. As of 1 January 1982, there were 271 operating nuclear power plants with an installed capacity totalling about 152 800 MW(e) and 239 units with a total capacity of 223 000 MW(e) under construction in 30 countries.

The first successful demonstration of the use of nuclear power as a source of electricity production took place in the early 1950s. Since then the technology of nuclear power reactors and the construction and operation of nuclear power plants have passed through different stages leading to the maturity of several nuclear power reactor systems now in use for large-scale electricity generation.

These achievements, which established the technical feasibility and economic competitiveness of the utilization of nuclear power, were initially motivated primarily by technological and industrial development incentives rather than by the need for energy or by economic considerations. In its first phase and up to the late 1960s the evolution and development of nuclear power technology and its use for energy production were practically confined to industrially advanced countries. Its production rose from 5 MW(e) in 1954 to a total electrical output of 16 500 MW(e) in 1970.

The introduction of nuclear power in developing countries started at a later date and it was not until 1969 that the first nuclear power plant was installed in a developing country (India, two units with a total capacity of 396 MW(e)). The difficulties encountered in introducing nuclear power in developing countries could mainly be attributed to the fact that they have relatively weaker infrastructures than industrialized countries. Nuclear power requires a complex and sophisticated technology, with strict and stringent safety as well as quality standards. Moreover, investment costs are higher than for fossil-fired plants. Another factor that limited the introduction of nuclear power in developing countries was the fact that larger and larger unit sizes were designed and built,
and these could only be introduced into the relatively large electrical interconnected systems that prevail mostly in highly industrialized countries.

Following the demonstration of the technical feasibility and the economic competitiveness of nuclear power, which occurred during the mid 1960s, a substantial worldwide expansion of nuclear power began. This took place mostly in industrialized countries, but also in a number of developing countries. At this stage economic considerations and the need for energy supplies were the prime incentives. As a result, during the last decade the installed capacity of the nuclear power plants increased by a factor of eight from 16 500 MW(e) in 1970 to 138 000 MW(e) in 1980. The number of countries with nuclear power plants in operation also increased during this same period from 14 to 22, including 7 developing countries.\(^1\)

The 1970s not only brought a worldwide increase in nuclear power, but also some major changes which affected and continue to affect nuclear power development.

The oil crisis of 1973/74, and later the continuing oil price increases culminating in 1978/79 with the second oil-price shock, effectively removed oil-fired electric power plants from their competitive position in the large-scale electricity generating market. As a first reaction to the oil crisis, substantially increased development plans for nuclear power were formulated in many countries and a spectacular future of nuclear power seemed to be assured. This, however, did not materialize, owing to the combined effect of several negative factors.

The cost of nuclear power plants and nuclear fuel increased; nuclear safety requirements became more stringent; concern about the proliferation of nuclear weapons increased and was associated with tight controls and safeguards conditions for the export of nuclear power plants and the development of fuel cycle activities; financial constraints became more and more important; the difficulties encountered in introducing complex technologies into countries with inadequate infrastructure were larger than expected; the development and availability of qualified manpower were recognized as major constraints; overall growth rates of energy and of electricity demands decreased; and finally, public opposition to nuclear power, sometimes reasoned and more often purely emotional, grew to wholly unexpected proportions in a number of countries. Under the combined effect of these factors, most of the ambitious plans for nuclear expansion were reduced or delayed.

However, in spite of the negative factors, nuclear power does retain its place as a viable energy source. No doubt, its use will increase worldwide and the number

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\(^1\) There is no clear definition of what constitutes a 'developing country'. It is, however, necessary to define which countries are classified as 'developing countries' so that the statistical data presented in this Guidebook become clear. For this purpose, those countries are considered as 'developing countries' that receive technical assistance under the IAEA or the UNDP programme.
of countries with nuclear power programmes will also grow. There are many countries, most of them developing countries, which are planning or intend to implement nuclear power programmes. This Guidebook is addressed to these countries.

1.2. THE NEED FOR NUCLEAR POWER

An assessment of the need for nuclear power can only be made in the light of the world energy situation as it has evolved to the present and as it is likely to develop in the future. Analysis of the evolution trends of the world energy consumption and future requirements leads to the following general conclusions:

(a) There has been a continuous growth of both energy consumption and of electrical energy production. On a world average, energy consumption increased at a rate of 5% and electricity production by 7.5% per annum between 1950 and 1980.

(b) Growth rates are related to the status of development of countries and regions. Highly industrialized countries have lower growth rates than developing countries.

It seems inevitable that the world energy demand will continue to grow over the next decades, though a somewhat slower rate of growth is expected than in the past. Available estimates show that the demand for energy will approximately double its present level by the year 2000.

Tables I and II show estimates of the total world energy consumption up to the year 2000 and its breakdown by type of fuel for 1980.

Electrical energy represents one of the principal forms of energy that is used to supply the large-scale requirements of industry. At present the share of electrical energy of the total energy consumption is about 25% and is expected to increase to about 40% by the year 2000. Tables III and IV show estimates of the development of installed electrical capacities and of the total world electric energy consumption up to the year 2000.

The above-mentioned estimates include the expected effects of energy conservation efforts and of the development of more efficient methods for energy conversion and final use.

Nuclear power could replace substantial amounts of fossil fuels for the large-scale production of electric energy. During 1980 the electricity produced by nuclear power plants (660 TW·h) was about 8% of the total electricity generated in the world (8330 TW·h). By the year 2000 the nuclear share is estimated to increase to about 20 to 25%.

Unlike electricity production, some other forms of energy use have no viable substitutes for fossil fuels that have been developed on a commercial scale.
**TABLE I. ESTIMATES OF TOTAL WORLD ENERGY CONSUMPTION**

Unit: 1 EJ = $10^{18}$ Joules = $23.9 \times 10^6$ TOE (Tons of Oil Equivalent).

<table>
<thead>
<tr>
<th>Country groups</th>
<th>Year</th>
<th>1980</th>
<th>1985</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. North America</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Western Europe</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>OECD</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. Pacific</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Centrally Planned Economies (Europe)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Asia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Latin America</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World total</td>
<td></td>
<td>320.2</td>
<td>373–389</td>
<td>559–654</td>
</tr>
</tbody>
</table>

**Notes:**
1. Electricity supplied by nuclear stations was converted into primary energy equivalent by using an average efficiency factor of 0.33.
2. Total energy consumption means: primary energy consumption plus net secondary energy import. It is the total energy requirement.
3. Country groups are defined in the IAEA periodic publication Reference Data Series No.1 "Energy, Electricity and Nuclear Power Estimates for the period of up to 2000".
4. The same notes apply to the other tables of this chapter.

Greater use of nuclear power for the production of electrical energy would save greater amounts of fossil fuels for such uses as are of vital importance to our modern civilization and style of life and where no viable substitutes are available.

Resources of fossil fuels are known to be limited. Estimates of the available resources of such fuels have always caused concern about their adequacy to meet the increasing energy requirements in the future. Furthermore, fossil fuels are needed as vital raw materials in chemical industries for the production of many industrial products such as ammonia for fertilizers, synthetics, plastics, pharmaceutical products and many other commodities for everyday needs. There is no doubt that fossil fuels could be more effectively and economically used for such applications, rather than by being burned as fuel for energy production.

So-called 'new alternative' sources of energy such as solar, wind, tidal, geothermal and biomass are at the very early stages of industrial development and their technologies have not yet reached the level for their efficient utilization for energy production on a commercial scale, or have a limited potential for
large-scale electricity production. It is therefore unlikely that by the turn of
the century their contribution to the total energy supply would be more than
5 to 10%. For electricity production, their contribution is not expected to reach
any significant value.

For developing countries the expected rate of growth of demand for electrical
energy will undoubtedly be higher than the corresponding rates in industrial
countries. The reasons for this higher rate of growth are related to:

(a) The larger rate of increase of population in most developing countries
(b) The existence of substantial unsatisfied demand for energy and for
electricity, and the very low per capita energy consumption in the majority of
developing countries
(c) The pressing needs for electrical energy for economic development and
industrial progress, to raise the social standard of living which is far behind that
in industrialized countries.

The present distribution of the world population and the expected trends
of its growth are summarized in Table V. It can be seen that the world population
is expected to increase by nearly 40% by the turn of the century reaching a level
of over 6000 million. For developing countries the yearly average rates of growth
are about 2.5% at present, which is three times as large as that in industrialized
countries. Though the average rates of increase are expected to become smaller
in the future, the relation between the growth rates of developing and industrialized
countries are expected to remain practically constant. The population in developing
countries will accordingly represent about 77% of the total world population by
the year 2000.

The distribution of commercial energy consumption reflected in Table VI
shows the striking disparities of total and per capita energy consumption between
industrial and developing countries. The industrialized nations, which represent
some 27% of the world population, at present consume more than 75% of the
world energy. The average per capita consumption in industrial countries is more
than eight times higher than that of developing countries. There is of course a
similar wide gap in the social standard of living, which can only be reduced by
economic and industrial development.

This process of development will necessarily involve rapid growth of
commercial energy demand and will require large amounts of electrical energy
with corresponding investments. Electrical energy is probably the key element
for achieving progress in developing countries.

The major challenge facing developing countries in the realization of
industrial and economic development is the provision of an adequate and least
expensive supply of electrical energy. To achieve this, extensive planning work
must be undertaken to assess and evaluate the possibilities of exploitation of
all available energy resources to the largest possible extent.
## TABLE II. BREAKDOWN OF THE WORLD TOTAL ENERGY CONSUMPTION BY COUNTRY GROUPS AND TYPE OF FUEL (for 1980)

Unit: 1 EJ = $10^{18}$ Joules = $23.9 \times 10^6$ TOE (Tons of Oil Equivalent).

<table>
<thead>
<tr>
<th>Country group</th>
<th>Solids</th>
<th>Liquids</th>
<th>Gases</th>
<th>Hydro</th>
<th>Nuclear</th>
<th>Geotherm</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. North America</td>
<td>21.25</td>
<td>40.07</td>
<td>24.81</td>
<td>4.93</td>
<td>3.13</td>
<td>0.04</td>
<td>94.23</td>
</tr>
<tr>
<td>2. Western Europe (OECD)</td>
<td>12.05</td>
<td>27.82</td>
<td>8.67</td>
<td>4.27</td>
<td>2.36</td>
<td>0.02</td>
<td>55.19</td>
</tr>
<tr>
<td>3. Pacific</td>
<td>3.60</td>
<td>13.12</td>
<td>1.41</td>
<td>1.06</td>
<td>0.67</td>
<td>0.02</td>
<td>19.89</td>
</tr>
<tr>
<td>4. Centrally Planned Economies (Europe)</td>
<td>28.24</td>
<td>23.95</td>
<td>17.00</td>
<td>2.32</td>
<td>0.87</td>
<td>–</td>
<td>72.36</td>
</tr>
<tr>
<td>5. Asia</td>
<td>32.77</td>
<td>11.25</td>
<td>1.35</td>
<td>1.66</td>
<td>0.15</td>
<td>–</td>
<td>47.17</td>
</tr>
<tr>
<td>6. Latin America</td>
<td>3.60</td>
<td>9.45</td>
<td>2.16</td>
<td>1.90</td>
<td>0.02</td>
<td>0.01</td>
<td>17.14</td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>6.85</td>
<td>5.73</td>
<td>1.03</td>
<td>0.61</td>
<td>–</td>
<td>–</td>
<td>14.22</td>
</tr>
<tr>
<td>World total</td>
<td>108.36</td>
<td>131.38</td>
<td>56.42</td>
<td>16.74</td>
<td>7.20</td>
<td>0.09</td>
<td>320.19</td>
</tr>
</tbody>
</table>

See notes to Table I.
### TABLE III. ESTIMATES OF THE DEVELOPMENT OF INSTALLED ELECTRICAL CAPACITY

<table>
<thead>
<tr>
<th>Country groups</th>
<th>Year</th>
<th>1980</th>
<th>1985</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. North America</td>
<td>OECD</td>
<td>713</td>
<td>859–918</td>
<td>1213–1600</td>
</tr>
<tr>
<td>2. Western Europe</td>
<td>441</td>
<td>556–601</td>
<td>985–1213</td>
<td></td>
</tr>
<tr>
<td>3. Pacific</td>
<td>178</td>
<td>247–263</td>
<td>437–578</td>
<td></td>
</tr>
<tr>
<td>4. Centrally Planned Economies (Europe)</td>
<td>368</td>
<td>532–559</td>
<td>1051–1344</td>
<td></td>
</tr>
<tr>
<td>5. Asia</td>
<td>131</td>
<td>231–237</td>
<td>945–1132</td>
<td></td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>63</td>
<td>75–84</td>
<td>232–311</td>
<td></td>
</tr>
<tr>
<td>World total</td>
<td>1996</td>
<td>2620–2798</td>
<td>5167–6564</td>
<td></td>
</tr>
</tbody>
</table>

See notes to Table I.

### TABLE IV. ESTIMATES OF TOTAL WORLD ELECTRIC ENERGY GENERATION

<table>
<thead>
<tr>
<th>Country groups</th>
<th>Year</th>
<th>1980</th>
<th>1985</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. North America</td>
<td>OECD</td>
<td>2761</td>
<td>3340–3571</td>
<td>4704–6213</td>
</tr>
<tr>
<td>2. Western Europe</td>
<td>1775</td>
<td>2184–2373</td>
<td>3856–4761</td>
<td></td>
</tr>
<tr>
<td>3. Pacific</td>
<td>725</td>
<td>1035–1103</td>
<td>1836–2429</td>
<td></td>
</tr>
<tr>
<td>4. Centrally Planned Economies (Europe)</td>
<td>1782</td>
<td>2556–2689</td>
<td>5032–6430</td>
<td></td>
</tr>
<tr>
<td>5. Asia</td>
<td>662</td>
<td>1045–1074</td>
<td>4246–5102</td>
<td></td>
</tr>
<tr>
<td>6. Latin America</td>
<td>373</td>
<td>455–515</td>
<td>1151–1468</td>
<td></td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>248</td>
<td>299–340</td>
<td>884–1214</td>
<td></td>
</tr>
<tr>
<td>World total</td>
<td>8326</td>
<td>10914–11665</td>
<td>21709–27617</td>
<td></td>
</tr>
</tbody>
</table>

TW·h = 10³ kW·h = 3.6 × 10⁻³ EJ

See notes to Table I.
TABLE V. ESTIMATES OF WORLD POPULATION GROWTH

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. OECD North America</td>
<td>249</td>
<td>1.02</td>
<td>280</td>
<td>0.52</td>
</tr>
<tr>
<td>2. OECD Europe</td>
<td>393</td>
<td>0.50</td>
<td>440</td>
<td>0.49</td>
</tr>
<tr>
<td>3. OECD Pacific</td>
<td>134</td>
<td>0.93</td>
<td>150</td>
<td>0.50</td>
</tr>
<tr>
<td>4. Centrally Planned Economies (Europe)</td>
<td>401</td>
<td>0.85</td>
<td>460</td>
<td>0.65</td>
</tr>
<tr>
<td>5. Asia</td>
<td>2304</td>
<td>2.26</td>
<td>3220</td>
<td>1.60</td>
</tr>
<tr>
<td>6. Latin America</td>
<td>367</td>
<td>2.89</td>
<td>570</td>
<td>2.11</td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>568</td>
<td>3.20</td>
<td>940</td>
<td>2.53</td>
</tr>
<tr>
<td><strong>World total</strong></td>
<td><strong>4416</strong></td>
<td><strong>2.01</strong></td>
<td><strong>6060</strong></td>
<td><strong>1.53</strong></td>
</tr>
</tbody>
</table>

See notes to Table I.

TABLE VI. COMMERCIAL TOTAL AND PER CAPITA ENERGY CONSUMPTION IN INDUSTRIAL AND DEVELOPING COUNTRIES (1980)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Total consumption ($10^{18}$ J)</th>
<th>Per capita consumption ($10^{9}$ J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>245</td>
<td>203</td>
</tr>
<tr>
<td>Developing</td>
<td>77</td>
<td>24</td>
</tr>
<tr>
<td>Ratio of consumption of industrial and developing countries</td>
<td>3.18</td>
<td>8.45</td>
</tr>
</tbody>
</table>

10
Over the past decade nuclear power achieved a prominent position among alternative energy sources. The competitive position of nuclear plants compared with fossil-fired plants attracted the attention of many countries to nuclear power as a viable alternative option for electric energy production.

The arguments supporting the need of nuclear power may be summarized in the following main points:

(a) It is an energy source that has already been developed to such an extent that it can be used immediately for the large-scale production of electrical energy, which is not the case for other ‘new alternative energy sources’.

(b) It is the only available alternative to conventional fossil-fuelled electrical plants, and hence can save and conserve fossil fuels, in particular oil, which is vitally needed for uses where no viable substitutes are available.

(c) The existing extensive experience from the operation of more than 270 power reactors throughout the world provides a well-established technological base for future development.

(d) The problems facing a country in the introduction of nuclear power are not insurmountable and, in many cases, adequate solutions could be found to resolve them.

1.3. NUCLEAR POWER PLANTS IN OPERATION AND UNDER CONSTRUCTION

Statistical information is periodically presented in several publications on the nuclear power plants in operation, under construction or planned. The most relevant IAEA publications are:

- Power Reactors in Member States
- Operating Experience with Nuclear Power Stations in Member States
- Operating Experience with Nuclear Power Stations in Member States — Performance Analysis Report
- Energy, Electricity and Nuclear Power Estimates for the Period up to 2000 (Reference Data Series No.1)
- Nuclear Power Reactors in the World (Reference Data Series No.2).

The data contained in the IAEA publications are based on the information provided by the Member States and are of a reasonably high degree of accuracy, especially regarding power plants in operation and under construction. The information is continuously updated. Table VII contains a listing of power reactors in the world. All countries with nuclear power plants in operation or under construction are Member States of the IAEA, except Taiwan.
## TABLE VII. POWER REACTORS IN THE WORLD (1 January 1982)

<table>
<thead>
<tr>
<th>Group and country</th>
<th>Operating</th>
<th>Under construction</th>
<th>Electricity supplied by nuclear power reactors during 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of units</td>
<td>Total capacity (MW(e))</td>
<td>Number of units</td>
</tr>
<tr>
<td>1. OECD NORTH AMERICA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>11</td>
<td>5494</td>
<td>14</td>
</tr>
<tr>
<td>United States of America</td>
<td>75</td>
<td>57008</td>
<td>79</td>
</tr>
<tr>
<td>2. OECD EUROPE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>3</td>
<td>1664</td>
<td>4</td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>2160</td>
<td>—</td>
</tr>
<tr>
<td>France</td>
<td>30</td>
<td>21595</td>
<td>26</td>
</tr>
<tr>
<td>Germany, Federal Republic of</td>
<td>14</td>
<td>8606</td>
<td>10</td>
</tr>
<tr>
<td>Italy</td>
<td>4</td>
<td>1417</td>
<td>3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2</td>
<td>501</td>
<td>—</td>
</tr>
<tr>
<td>Spain</td>
<td>4</td>
<td>1973</td>
<td>11</td>
</tr>
<tr>
<td>Sweden</td>
<td>9</td>
<td>6415</td>
<td>3</td>
</tr>
<tr>
<td>Switzerland</td>
<td>4</td>
<td>1940</td>
<td>1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>32</td>
<td>7627</td>
<td>9</td>
</tr>
<tr>
<td>3. OECD PACIFIC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>24</td>
<td>14994</td>
<td>12</td>
</tr>
</tbody>
</table>
### 4. CENTRALLY PLANNED

#### EUROPE

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactors</th>
<th>Total Easter Power Generated (MW)</th>
<th>Total Nuclear Power Generated (MW)</th>
<th>Net Increase (MW)</th>
<th>Growth in Nuclear Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulgaria</td>
<td>3</td>
<td>1224</td>
<td>2</td>
<td>1408</td>
<td>5.70</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>2</td>
<td>800</td>
<td>6</td>
<td>2520</td>
<td>4.09</td>
</tr>
<tr>
<td>German Democratic Republic</td>
<td>5</td>
<td>1694</td>
<td>4</td>
<td>1644</td>
<td>8.99</td>
</tr>
<tr>
<td>Hungary</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>816</td>
<td>-</td>
</tr>
<tr>
<td>Romania</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>660</td>
<td>-</td>
</tr>
<tr>
<td>USSR</td>
<td>35</td>
<td>14 036</td>
<td>25</td>
<td>24 260</td>
<td>73.00</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>1</td>
<td>632</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 5. ASIA

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactors</th>
<th>Total Easter Power Generated (MW)</th>
<th>Total Nuclear Power Generated (MW)</th>
<th>Net Increase (MW)</th>
<th>Growth in Nuclear Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>4</td>
<td>809</td>
<td>4</td>
<td>880</td>
<td>2.77</td>
</tr>
<tr>
<td>Korea, Republic of</td>
<td>1</td>
<td>564</td>
<td>8</td>
<td>6869</td>
<td>3.25</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>125</td>
<td>-</td>
<td>-</td>
<td>0.07</td>
</tr>
<tr>
<td>Philippines</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>620</td>
<td>-</td>
</tr>
<tr>
<td>Taiwan</td>
<td>2</td>
<td>1208</td>
<td>4</td>
<td>3716</td>
<td>6.30</td>
</tr>
</tbody>
</table>

#### 6. LATIN AMERICA

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactors</th>
<th>Total Easter Power Generated (MW)</th>
<th>Total Nuclear Power Generated (MW)</th>
<th>Net Increase (MW)</th>
<th>Growth in Nuclear Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>1</td>
<td>335</td>
<td>2</td>
<td>1292</td>
<td>2.18</td>
</tr>
<tr>
<td>Brazil</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3116</td>
<td>-</td>
</tr>
<tr>
<td>Cuba</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>408</td>
<td>-</td>
</tr>
<tr>
<td>Mexico</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1308</td>
<td>-</td>
</tr>
</tbody>
</table>

#### 7. AFRICA AND MIDDLE EAST

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactors</th>
<th>Total Easter Power Generated (MW)</th>
<th>Total Nuclear Power Generated (MW)</th>
<th>Net Increase (MW)</th>
<th>Growth in Nuclear Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa (Customs Union)</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1842</td>
<td>-</td>
</tr>
</tbody>
</table>

| World total                          | 271  | 152 821 | 239  | 222 969 | 673.9 | 8.1 |

*a Nuclear programmes in Austria and Iran have been interrupted; these plants are not included.*
There are several different power reactor systems which are used at present for electricity generation. The following three 'proven and commercially available for export' systems account for about 86% of the total installed electric capacity:

- **PWR** — Pressurized light-water-moderated and cooled reactors (57%)
- **BWR** — Boiling light-water-cooled and moderated reactors (25%)
- **PHWR** — Pressurized heavy-water-moderated and cooled reactors (4%)

A further 13% of nuclear electric capacity corresponds to the following other fully developed power reactor systems:

- **LWGR** — Light-water-cooled, graphite moderated reactors (6%)
- **GCR** — Gas-cooled, graphite moderated reactors (5%)
- **AGR** — Advanced gas-cooled, graphite moderated reactors (2%)

Finally, about 1% of the electricity generated by nuclear power plants corresponds to systems that might be defined as advanced or partially developed reactor systems, such as the FBR (fast breeder reactor), the HTGR (high-temperature gas-cooled, graphite moderated reactor) and the HWLWR (heavy-water-moderated, light-water-cooled reactor).

The main technical features of the various types of nuclear power reactor systems and of operation experience of nuclear power plants will be presented and discussed in more detail in Chapter 2.

Nuclear plants in operation at present include many plants with unit sizes in the range of 150 to 300 MW(e) which were built during the early stage of evolution of nuclear power. At present commercial plants are built with much larger unit sizes, of the order of 600 to 1300 MW(e). The Soviet Union is exporting plants of the PWR system known as the Novo-Voronezh type with a unit size of 420 MW(e) (net); however, all exported stations of this type consist of twin units with a total capacity of 840 MW(e). The status and prospects of small and medium power reactors (SMPRs) will be discussed in Chapter 2, section 2.6.

As listed in Table VII, as of January 1982 there were 239 nuclear power units under construction in 26 countries with a total capacity of 223 000 MW(e). Of these, 36 units with a total capacity of more than 23 000 MW(e) were being built in 12 developing countries, all of the reactors corresponding to the three types considered as proven and commercially available for export. Comparing these figures with operating reactors in the developing countries (15 units in 8 countries with 5700 MW(e)), a substantial increase is found both in absolute and relative terms.

1.4. PROGRAMMES AND FORECASTS OF NUCLEAR POWER

The future growth of nuclear power is strongly influenced by economic, social and political factors among others. Estimates and forecasts of nuclear
capacity have therefore been under constant review in the light of relevant factors prevailing at a particular time. Such factors affecting short-term plans as well as medium and long-term forecasts of nuclear power programmes are:

- **Energy conservation.** This trend has persisted to some extent since the oil crisis of 1973. It tends to preserve adequate reserve margins for many utilities and fewer utilities find it necessary to add base load units, the prime market for nuclear power plants.

- **Economic recession.** Recessions somewhat reduce energy consumption. They also reduce the growth of industry by causing reluctance to make new investments and thereby slowing the increasing demand for power.

- **Uncertainties in the availability of fuel cycle supplies and services.** Prospective nuclear power plant operators give greater consideration to the assurance of the supply of fuel and fuel cycle services, and investment decisions are conditioned to this assurance.

- **Uncertainties in the regulatory process.** The continuing evolution of regulatory criteria has an unsettling effect upon utilities. These uncertainties result in a lengthening of the lead time required to implement decisions to increase nuclear power generation capacity and in higher costs.

- **Financial constraints.** Policies resisting increases in electricity tariffs and problems in obtaining preferential long-term loans place many utilities in a difficult financial situation and tend to discourage decisions for large capital investment projects.

- **Public acceptance of nuclear power.** Some sectors of public opinion in various countries continue to question the need for and viability of nuclear power.

- **Internal politics.** In some countries, nuclear power has become an issue in party politics and election campaigns with some parties adopting an anti-nuclear position.

- **Fossil-fuel supplies and prices.** New discoveries of important resources have differing and unexpected effects on national programmes for nuclear development. Price increases of fossil fuels would tend to promote nuclear power development.

- **Social factors of a worldwide nature.** A cumulative effect upon total energy growth is produced by trends in population growth, lifestyle and environmental protection measures. In the long-term, these effects influence the growth of nuclear power.

- **Development of new energy technologies.** These will naturally influence the pattern of world energy supply, including nuclear power growth. The effects, though relatively small before the year 2000, might become important in the longer term.

- **National energy policies and international co-operation.** National policies, such as those directed towards energy independence or emphasis on international
### Table VIII. Estimates of Total and Nuclear Electrical Generating Capacity

<table>
<thead>
<tr>
<th>Country group</th>
<th>1980 Total Electric (GW(e))</th>
<th>1980 Nuclear (GW(e), %)</th>
<th>1985 Total Electric (GW(e))</th>
<th>1985 Nuclear (GW(e), %)</th>
<th>2000 Total Electric (GW(e))</th>
<th>2000 Nuclear (GW(e), %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. OECD North America</td>
<td>713</td>
<td>57.0, 8.0</td>
<td>859</td>
<td>127.4, 14.8</td>
<td>1213</td>
<td>169.7, 13.9</td>
</tr>
<tr>
<td>2. OECD Europe</td>
<td>441</td>
<td>106.4, 10.1</td>
<td>556</td>
<td>106.4, 19.1</td>
<td>985</td>
<td>292.3, 29.6</td>
</tr>
<tr>
<td>3. OECD Pacific</td>
<td>178</td>
<td>15.0, 8.4</td>
<td>247</td>
<td>24.9, 10.0</td>
<td>437</td>
<td>100.4, 22.9</td>
</tr>
<tr>
<td>4. Centrally Planned Europe</td>
<td>368</td>
<td>15.9, 4.3</td>
<td>532</td>
<td>36.9, 6.9</td>
<td>1051</td>
<td>97.2, 9.2</td>
</tr>
<tr>
<td>5. Asia</td>
<td>131</td>
<td>2.7, 2.0</td>
<td>231</td>
<td>11.0, 4.7</td>
<td>945</td>
<td>45.0, 4.7</td>
</tr>
<tr>
<td>6. Latin America</td>
<td>101</td>
<td>0.3, 0.3</td>
<td>120</td>
<td>2.9, 2.3</td>
<td>304</td>
<td>23.3, 7.6</td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>63</td>
<td>--</td>
<td>75</td>
<td>1.8, 2.4</td>
<td>232</td>
<td>18.6, 8.0</td>
</tr>
<tr>
<td>World total</td>
<td>1996</td>
<td>135.8, 6.8</td>
<td>2620</td>
<td>311.3, 11.8</td>
<td>5167</td>
<td>746.6, 14.4</td>
</tr>
</tbody>
</table>

Note: The top and bottom figures for total electric and nuclear capacity are low and high estimates, respectively. These estimates were made in April 1981.
<table>
<thead>
<tr>
<th>Country group</th>
<th>1980 Total electric (10^9 kW·h)</th>
<th>1980 Nuclear (10^9 kW·h)</th>
<th>%</th>
<th>1985 Total electric (10^9 kW·h)</th>
<th>1985 Nuclear (10^9 kW·h)</th>
<th>%</th>
<th>2000 Total electric (10^9 kW·h)</th>
<th>2000 Nuclear (10^9 kW·h)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. OECD North America</td>
<td>2761</td>
<td>287.6</td>
<td>10.4</td>
<td>3340</td>
<td>799.2</td>
<td>23.9</td>
<td>4704</td>
<td>1018.2</td>
<td>21.6</td>
</tr>
<tr>
<td>2. OECD Europe</td>
<td>1775</td>
<td>200.8</td>
<td>11.3</td>
<td>2184</td>
<td>638.4</td>
<td>29.2</td>
<td>3856</td>
<td>1753.8</td>
<td>45.5</td>
</tr>
<tr>
<td>3. OECD Pacific</td>
<td>725</td>
<td>79.1</td>
<td>10.9</td>
<td>1035</td>
<td>149.4</td>
<td>14.4</td>
<td>1836</td>
<td>602.4</td>
<td>32.8</td>
</tr>
<tr>
<td>4. Centrally Planned Europe</td>
<td>1782</td>
<td>91.8</td>
<td>5.1</td>
<td>2556</td>
<td>226.2</td>
<td>8.8</td>
<td>5032</td>
<td>583.2</td>
<td>11.6</td>
</tr>
<tr>
<td>5. Asia</td>
<td>662</td>
<td>12.4</td>
<td>1.9</td>
<td>1045</td>
<td>66.0</td>
<td>6.3</td>
<td>4246</td>
<td>270.0</td>
<td>6.4</td>
</tr>
<tr>
<td>6. Latin America</td>
<td>373</td>
<td>2.2</td>
<td>0.6</td>
<td>455</td>
<td>17.4</td>
<td>3.8</td>
<td>1151</td>
<td>139.8</td>
<td>12.1</td>
</tr>
<tr>
<td>7. Africa and Middle East</td>
<td>248</td>
<td>—</td>
<td>—</td>
<td>299</td>
<td>10.8</td>
<td>3.6</td>
<td>884</td>
<td>111.6</td>
<td>12.6</td>
</tr>
<tr>
<td>World total</td>
<td>8326</td>
<td>673.9</td>
<td>8.1</td>
<td>10914</td>
<td>1907.4</td>
<td>17.5</td>
<td>21709</td>
<td>4479.6</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11665</td>
<td>1907.4</td>
<td>16.4</td>
<td>27617</td>
<td>6771.6</td>
<td>24.5</td>
</tr>
</tbody>
</table>

Note: The top and bottom figures for total electric and nuclear generation are low and high estimates, respectively.
co-operation in energy technology development, and the pooling of resources in a world environment of diminishing energy supplies can have a considerable effect on nuclear power programmes.

It is very difficult to identify and even more so to estimate the impact of all factors that affect the future growth of nuclear power. Some factors have undoubtedly negative effects, while others tend to compensate these in providing incentives to nuclear power development. The factors themselves and their impacts also tend to change with time. However, this is a common problem to all types of forecasts, hence it must be recognized that there are limitations to the reliability of forecasting. Changes in forecasts developed at different times, under different conditions and with different assumptions should not be interpreted as invalidating the forecasting methods applied, nor the need for such forecasts or their usefulness as a basic planning tool.

Considering the above factors and in the light of changes in social, political and economic conditions, published estimates and forecasts on future nuclear capacity show considerable variation. These forecasts have been changing continually since the early years of nuclear development and particularly in recent years. Such changes should be expected to occur in the future too. It is necessary to keep forecasts and estimates under constant review, and the data presented at a particular time should be taken only as a measure of trends rather than definite or specific figures.

Tables VIII and IX contain the IAEA forecasts on nuclear power growth for the period up to 2000, as of April 1981. These forecasts are periodically updated.

On a short term, the forecasts have evidently a higher degree of reliability than on a long term. The 1985 forecasts are based on information provided by Member States and published in relevant publications, on nuclear power plants in operation and under construction (see Table I). No nuclear power plant can be put into operation by 1985 that has not been under construction in 1980 and about 80% of those under construction are expected to be finished by that date. There is also a probability of unexpected delays, but other factors affecting plans as well as medium and long-term forecasts have practically no influence on projections to 1985.

Medium-term forecasts are principally based on information regarding national nuclear power programmes as provided by the various countries, while long-term forecasts are obtained using correlations between growth rates of energy, electricity and macroeconomic indicators, taking into account also the effects of factors affecting development.

The IAEA publication "Power Reactors in Member States" contains information on 'planned' power reactors. This information, however, is incomplete. Not every Member State provides information on its nuclear power development.
plans. The time horizon as well as the definition of what is understood by 'planned reactors' also differ from country to country; the latter might refer to intentions or to fully committed projects. Periodically, information on national programmes is gathered through international enquiries by the IAEA and other organizations. Such information constitutes an important input to nuclear power forecasting, but it must be treated with caution and applied after careful evaluation and correlation.

More than 80% of the world's total nuclear capacity in operation or under construction is concentrated in a few countries. The USA accounts for nearly half of this and France, the USSR, Japan, the Federal Republic of Germany, Canada and the United Kingdom for the rest. An additional 10% correspond to Spain, Sweden, the Republic of Korea, Belgium and Taiwan, while the remaining capacity is distributed among 18 countries (Table VII).

Regarding future plans of nuclear power development, most of the countries with on-going projects have plans for expanding their nuclear capacity. Some of them, such as France, USSR, Japan, Republic of Korea and Brazil, have large programmes, others foresee more modest development, while in a few the nuclear power programmes have been substantially slowed down. The USA is among these last countries, and the impact of its slow-down has heavily affected the worldwide forecasts.

On a worldwide basis according to the IAEA forecast (Tables VIII and IX) an average annual growth rate of 9 to 11% is estimated for nuclear power over the period 1980 to 2000. This growth rate is the double of what is estimated for the average annual growth rate of total electrical consumption.

Regarding the number of countries with nuclear power, there are at present 30 countries with nuclear power plants in operation or under construction. In addition, a similar number of countries (most of them developing countries) envisage initiating their first nuclear power project before the year 2000. It seems reasonable to estimate that before the end of the century there will be a total of about 50 countries with on-going nuclear power programmes, more than half of them developing countries.
Chapter 2

NUCLEAR POWER REACTOR SYSTEMS

2.1. INTRODUCTION

Nuclear power reactors used in nuclear plants for the generation of electricity are designed, built and operated to produce heat energy through the fission chain reaction of $^{235}$U and $^{239}$Pu. A nuclear reactor is a device in which a chain reaction is maintained under control. The reactor core (mostly of a cylindrical shape) contains the fuel with fissile material ($^{235}$U or $^{239}$Pu). The fission heat energy produced in the core is transferred from the core to a cooling medium. The fuel and coolant are separated by suitable cladding material, to prevent radioactive isotopes from reaching the coolant and to protect the fuel from being corroded or eroded by the coolant.

Other main elements of the reactor core are the moderator and the neutron-absorbing materials. The moderator has the function of slowing down the neutrons emitted in the fission process to the thermal energy range at which they are more effective in producing further fissions to maintain the chain reaction. In the case of fast reactor types, no moderator is required. The function of the neutron-absorbing materials, which are either in the form of movable rods inside the core or chemical compounds dissolved in the coolant, is to regulate the fission chain reaction and control the power level of the reactor. A reflector surrounds the core to prevent neutrons from escaping from the core and hence reduce fissile material requirements and improve the power distribution within the core.

The main elements of the reactor core are assembled according to the design of the reactor system, inside a tank or a pressure vessel, with appropriate internal structures to support the fuel elements, control rods, moderator and coolant channels. Instrumentation and other operation control and measuring devices are placed in appropriate positions inside the reactor vessel, while driving motors for control rod movement and adjustments, coolant circulating pumps, piping and valves are installed outside the reactor vessel.

For safety reasons, the whole reactor circuit and reactor vessel are enclosed inside a leak-tight containment building, which provides a safety barrier against radioactive products release to the environment. The containment building may also provide protection to the nuclear reactor against outside hazards, such as an airplane crash. The design of a nuclear reactor system has therefore several important safety barriers against the release of radioactivity. These include the fuel cladding within which the radioactive fission products are retained, the reactor coolant system pressure boundary and the containment building.
In a nuclear power plant the reactor system provides the heat source that replaces the furnace in a fossil-fuelled generating station. The remaining conventional part of the plant consists of a steam-water circuit feeding steam to a turbine driving an electrical generator. Heat from the reactor is thus transferred by the coolant and used to generate steam. The steam-water circuit is adjusted to the steam conditions achievable with a nuclear heat source.

Apart from the reactor circuit, the nuclear part of the plant includes systems to handle and purify the reactor coolant, and installations for fuel management. The control of the reactor and of the conventional circuit is carried out from a control room. The plant also includes auxiliary buildings, facilities and equipment, and the cooling water supply for the condenser.

2.2. SURVEY OF NUCLEAR POWER REACTOR SYSTEMS

Power reactor systems are broadly classified according to neutron energy into thermal (low neutron energy) and fast (high neutron energy) reactors. They are further classified according to the main elements in the reactor core, namely the fuel used (including its degree of enrichment in the isotope $^{235}\text{U}$), the coolant and the moderator. Table X contains a list of the main types of power reactor systems and their classification.

Many reactor concepts and types of power reactor systems have been conceived throughout the various stages of development of nuclear power technology. However, the present survey will be confined to the review of those types that have been developed and used in large-scale nuclear power plants, the design and technology of which have been successfully demonstrated and which, have potential for further development and use in industrial commercial plants in the foreseeable future.

The types of power reactor systems have been grouped into the following three main categories.

1. Reactor types proven and commercially available for export (section 2.3)
2. Other fully developed reactor types (section 2.4)
3. Advanced and partially developed reactor types (section 2.5).

The first category includes three types of power reactor systems. All of these have reached a level of technical and industrial development that allows them to be considered as proven and mature systems for use in large-scale commercial power plants. These types are further qualified by their demonstrated licensability in the country of origin and availability for export from manufacturing countries. They are:

- PWR (Pressurized Light-Water Moderated and Cooled Reactors (section 2.3.1))
- BWR (Boiling Light-Water Cooled and Moderated Reactors (section 2.3.2))
- PHWR (Pressurized Heavy-Water Moderated and Cooled Reactors (section 2.3.3)).
### TABLE X. CLASSIFICATION OF POWER REACTOR TYPES

<table>
<thead>
<tr>
<th>Reactor type</th>
<th>Symbol</th>
<th>Neutron energy</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized light-water moderated and cooled</td>
<td>PWR</td>
<td>Thermal</td>
<td>Slightly enriched</td>
<td>Water</td>
<td>Light water</td>
</tr>
<tr>
<td>Boiling light-water cooled and moderated</td>
<td>BWR</td>
<td>Thermal</td>
<td>Slightly enriched</td>
<td>Water</td>
<td>Light water</td>
</tr>
<tr>
<td>Pressurized heavy-water moderated and cooled</td>
<td>PHWR</td>
<td>Thermal</td>
<td>Natural</td>
<td>Water</td>
<td>Heavy water</td>
</tr>
<tr>
<td>Heavy-water moderated, boiling light-water cooled</td>
<td>HWLWR</td>
<td>Thermal</td>
<td>Natural</td>
<td>Water</td>
<td>Heavy water</td>
</tr>
<tr>
<td>Steam-generating heavy water</td>
<td>SGHWR</td>
<td>Thermal</td>
<td>Slightly enriched</td>
<td>Water</td>
<td>Heavy water</td>
</tr>
<tr>
<td>Light-water cooled, graphite moderated</td>
<td>LWGR</td>
<td>Thermal</td>
<td>Slightly enriched</td>
<td>Water</td>
<td>Graphite</td>
</tr>
<tr>
<td>Gas-cooled, graphite moderated</td>
<td>GCR</td>
<td>Thermal</td>
<td>Natural</td>
<td>Gas</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Advanced gas-cooled, graphite moderated</td>
<td>AGR</td>
<td>Thermal</td>
<td>Slightly enriched</td>
<td>Gas</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Reactor type</td>
<td>Symbol</td>
<td>Neutron energy</td>
<td>Fuel</td>
<td>Coolant</td>
<td>Moderator</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
<td>-----------------</td>
</tr>
<tr>
<td>High-temperature gas-cooled, graphite moderated</td>
<td>HTGR</td>
<td>Thermal</td>
<td>Highly enriched ( \text{UO}_2 + \text{ThC}_2 )</td>
<td>Gas</td>
<td>Helium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Graphite</td>
</tr>
<tr>
<td>Heavy-water moderated, gas-cooled</td>
<td>HWGCR</td>
<td>Thermal</td>
<td>Natural ( \text{U-metal or UO}_2 )</td>
<td>Gas</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heavy water</td>
</tr>
<tr>
<td>Fast breeder</td>
<td>FBR</td>
<td>Fast</td>
<td>Highly enriched ( (\text{U} + \text{Pu})\text{O}_2 ) ( (\text{U} + \text{Pu})\text{C} )</td>
<td>Liquid metal</td>
<td>Liquid sodium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
TABLE XI. TYPES OF POWER REACTORS IN OPERATION AND UNDER CONSTRUCTION (as of 1 January 1982)

| Reactor categories and types | Operating | | | Under construction | | |
|-----------------------------|-----------|------------------|------------------|------------------|------------------|
|                             | Number    | Net electrical capacity (MW(e)) | % of total | Number | Net electrical capacity (MW(e)) | % of total |
| 1. Proven and commercially available for export | | | | | | |
| PWR | 122 | 87 267 | 57.1 | 145 | 141 035 | 63.3 |
| BWR | 63 | 38 168 | 25.0 | 50 | 52 129 | 23.4 |
| PHWR | 15 | 6 169 | 4.0 | 22 | 13 211 | 5.9 |
| Sub-total | 199 | 131 604 | 86.1 | 217 | 206 375 | 92.6 |
| 2. Fully developed but commercially not available for export | | | | | | |
| GCR | 35 | 7 284 | 4.8 | - | - | - |
| AGR | 5 | 3 089 | 2.0 | 9 | 5 533 | 2.5 |
| LWGR | 21 | 8 926 | 5.8 | 8 | 9 000 | 4.0 |
| Sub-total | 61 | 19 299 | 12.6 | 17 | 14 533 | 6.5 |
| 3. Advanced and partially developed | | | | | | |
| FBR | 5 | 1 013 | 0.7 | 3 | 1 730 | 0.8 |
| HTGR | 2 | 343 | 0.2 | 1 | 296 | 0.1 |
| HWLWR + SGHWR | 3 | 492 | 0.3 | 1 | 35 | 0.0 |
| HGOCR | 1 | 70 | 0.1 | - | - | - |
| Sub-total | 11 | 1 918 | 1.3 | 5 | 2 061 | 0.8 |
| Total | 271 | 152 821 | 100 | 239 | 222 969 | 100 |

The types of power reactor systems included in the second category are:
- GCR (Gas-Cooled, Graphite Moderated Reactors)
- AGR (Advanced Gas-Cooled, Graphite Moderated Reactors)
- LWGR (Light-Water Cooled, Graphite Moderated Reactors).

The GCR, also known as the Magnox system, has been fully developed to a level of provenness and maturity in the UK and in France. Reactors of this type have also been exported to Japan, Italy and Spain. Power plants using this system are no longer being built, nor have they been available for export for more than a decade. Recently, however, there have been indications of interest in offering this system for export in the SMPR (small and medium power reactor) range – see section 2.6.

The AGR has been fully developed in the UK as a successor to the GCR. A series of units using this system have been and are being built, but it has never been exported from the UK nor is it currently available for export. The LWGR is also a fully developed system. It has been developed in the USSR, where a series of units of this type are in operation, under construction and planned. However, it has never been exported nor is it commercially available for export.
### TABLE XII. NUCLEAR POWER PLANTS IN OPERATION OR UNDER CONSTRUCTION IN DEVELOPING COUNTRIES (as of 1 January 1982)

<table>
<thead>
<tr>
<th>Regions and countries</th>
<th>Operating</th>
<th>Under construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of reactors</td>
<td>Net electrical capacity (MW(e))</td>
</tr>
<tr>
<td>Latin America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>1</td>
<td>335</td>
</tr>
<tr>
<td>Brasil</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Cuba</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Mexico</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Total for the region</td>
<td>1</td>
<td>335</td>
</tr>
<tr>
<td>Middle East and South Asia</td>
<td>4 809</td>
<td>2 BWR, 2 PHWR</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>125</td>
</tr>
<tr>
<td>Total for the region</td>
<td>5</td>
<td>934</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>3</td>
<td>1 224</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>2</td>
<td>800</td>
</tr>
<tr>
<td>Hungary</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Romania</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>1</td>
<td>632</td>
</tr>
<tr>
<td>Total for the region</td>
<td>6</td>
<td>2 656</td>
</tr>
<tr>
<td>S.E. Asia and the Pacific</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Philippines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Korea, Republic of</td>
<td>1</td>
<td>564</td>
</tr>
<tr>
<td>Taiwan</td>
<td>2</td>
<td>1 208</td>
</tr>
<tr>
<td>Total for the region</td>
<td>3</td>
<td>1 772</td>
</tr>
<tr>
<td>Total for all regions</td>
<td>15</td>
<td>5 697</td>
</tr>
</tbody>
</table>

The main types of reactor systems which may be included in the third category are:
- FBR (Fast Breeder Reactor)
- HTGR (High-Temperature Gas-Cooled, Graphite Moderated Reactor)
- HWLWR (Heavy-Water Moderated, Boiling Light-Water Cooled Reactor)
- SGHWR (Steam-Generating Heavy-Water Reactor)
- HWGCR (Heavy-Water Moderated, Gas-Cooled Reactor).

The design and technology of all these power reactor systems have been successfully demonstrated for the generation of electricity. However, they are not considered as competitive alternative nuclear power plant systems in the current commercial market, nor are any of them being offered for export. The FBR in particular and the HTGR to a lesser extent are objects of substantial development efforts in several countries owing to their promising future potential.
FIG. 1. Schematic diagrams of power reactor types: (a) typical pressurized water reactor (PWR); (b) typical boiling water reactor (BWR); (c) typical heavy-water reactor (HWR); (d) typical gas-cooled reactor (GCR); (e) typical light-water graphite reactor (LGWR).

The HWLWR, SGHWR and HWGCR have been brought to the stage of industrial-scale prototype operation, but further development efforts have either been stopped or are maintained at a low level.

There are several additional power reactor systems that are either in very early stages of development or have only reached the prototype stage. Development efforts have been practically discontinued on most of these.
The number and electric output of the various power reactor systems in operation and under construction belonging to the above three categories are summarized in Table XI. Table XII shows nuclear power plants in operation or under construction in developing countries.

2.3. REACTOR TYPES PROVEN AND COMMERCIALLLY AVAILABLE FOR EXPORT

2.3.1. PWR — pressurized light-water moderated and cooled reactors

This reactor system was first conceived as a naval propulsion unit and has been successfully operated for submarine applications in the USA since 1954 when the first nuclear submarine NAUTILUS was launched. The system was subsequently developed for civilian power application and led to the construction of the first prototype nuclear power plant of Shippingport with a net electrical output of 60 MW(e).

The reactor core is contained in a pressure vessel in which light-water is used as coolant and moderator, circulating through a closed primary circuit. The water circulated through the primary circuit passes into a heat exchanger where steam is produced in a secondary circuit and used to drive a steam turbine-generator unit for the generation of electrical power.

A simplified schematic representation of the system is shown in Fig. 1. The operating pressure in the primary circuit is about 160 bar to prevent boiling. This requires a large and heavy reactor vessel weighing several hundred tons. Owing to the high pressure inside the primary coolant boundary, a strong containment is essential, since the potential release of energy in the event of a break in the pressure boundary would be very great. The steam inlet temperature is of the order of 280°C, and thus requires turbine designs of larger size and lower efficiency than similar size turbines in modern conventional plants.

The reactor is fuelled with a slightly enriched uranium with an average enrichment between 2 to 3% of $^{235}$U. The fuel rods are made of pellets of uranium dioxide (UO$_2$), cladded in Zircaloy-4, which has replaced stainless steel cladding used in earlier designs. The fuel element design has achieved a high degree of reliability. Average discharge burnups of up to 33 MW·d/kg U have been obtained in operating reactors. Periodically (approximately once a year) the reactor has to be shut down for refuelling.

Reactivity control is provided by neutron-absorbing control rods and by a soluble chemical neutron absorber (boric acid) dissolved to the appropriate concentration in the reactor coolant. The control rods provide rapid reactivity control for shutdown of the reactor or for reactivity changes due to variations in the operating conditions of the reactor. The boric acid concentration is varied
to control long-term reactivity changes such as fuel depletion and fission product build-up, cold to hot zero-power reactivity change, reactivity changes produced by intermediate-term fission products and burnable poison depletion. The reactor has a strong negative temperature coefficient, which is one of its built-in safety features.

The PWR has been the most widely developed system among the proven types of reactors commercially available today. As of January 1982 there were 122 PWRs in operation with a total capacity of about 87 000 MW(e) in 17 countries. There were also 145 PWR units with a total installed capacity of about 141 000 MW(e) under construction in 18 countries.

The operating experience with PWRs is extensive and it is certainly the most abundant of all available reactor systems. In operation, these plants are considered to be as reliable as fossil-fuelled thermal stations. Performance to date has been satisfactory for the large majority of plants and experience shows that plant load factors of about 70% may be assumed for system planning and economic calculations (see section 2.7).

Although refinements in design have been introduced by various companies, no major technological changes in the main components or the materials used have occurred. The major development efforts have been confined to the upgrading of unit sizes. The initial unit capacity range of 200 to 300 MW(e) in plants designed and operated in the sixties has evolved to the range of 1200 to 1300 MW(e) for plants of current design.

Regarding the export market, PWR plants have been exported and are available for export from France, the Federal Republic of Germany, the USA and USSR. The size range is 600 to 1300 MW(e), except in case of the USSR, which exports the 420 MW(e) reactor (usually twin units).

2.3.2. BWR — boiling light-water cooled and moderated reactors

The development of the BWR was originally motivated by the desire to reduce costs and to avoid the technological difficulties by eliminating the heat exchangers used in the PWR design.

Intensive theoretical and experimental work on the boiling phenomena was carried out in the USA, and confirmed the prediction that such a reactor system could be designed to be safe and stable. This led to the development and construction of the Dresden 1 BWR plant in 1960 with an electrical capacity of 200 MW(e).

The BWR direct-cycle system has many similarities to the PWR system, but differs from it in one important respect: it passes the steam directly from the reactor pressure vessel to the turbine without the use of an intermediate heat exchanger. The system is schematically represented in Fig. 1. Since boiling is allowed in the system, the operating pressure inside the pressure vessel is much lower than for a PWR system (of the order of 70 bar).
Steam temperature, pressure and moisture conditions at the inlet to the turbine are similar to those in the PWR system and also a special turbine design is required. However, the thermal efficiency is somewhat higher than in the PWR system, because steam passes directly to the turbine without energy degradation in a heat exchanger. A significant difference arises from the fact that steam is carried directly from the reactor to the turbine and hence carries with it radioactivity. This radioactivity is primarily nitrogen-16, a very short-lived isotope (half-life 7 seconds), so that the radioactivity of the steam system exists only during power generation. Experience has demonstrated that shutdown maintenance on BWR turbine, condenser and feed-water components can be performed without excessive radiation exposures. Deposits of radioactive material will, of course, be formed in the turbine, making overhaul and maintenance more difficult. These difficulties will be increased if fuel element failures occur, releasing fission products into the coolant.

The reactor is fuelled with slightly enriched uranium. The average enrichment for the initial core is in the range of 1.6 to 2.2% $^{235}\text{U}$. The reload fuel has slightly higher enrichment, with an average in the range of 2.4 to 2.8% $^{235}\text{U}$. The fuel rods are made of uranium dioxide pellets (UO$_2$) in Zircaloy-2 tubes. Average discharge burnups of over 30 MW·d/kg U have been achieved in operating plants. The reactor has to be shut down for refuelling.

The control rods using boron carbide in stainless steel tubes are moved up and down the reactor core from the bottom of the pressure vessel by either hydraulically or mechanically activated drive mechanisms which allow axial positioning for reactivity regulation and permit shutdown insertion. The control rods also perform the function of power distribution in the core by manipulation of selected patterns of rods. Supplementary control is provided by using a burnable poison, pellets of gadolinium oxide mixed with UO$_2$ powder as a matrix of material in several fuel rods in each fuel bundle. An important feature of the BWR design is that, in addition to a negative temperature-coefficient, the reactor has a negative void-coefficient, due to the internal boiling.

The BWR is the second most widely developed reactor system after the PWR. As of June 1981 there were 62 BWR power reactors in operation in 12 countries with a total capacity of 38 000 MW(e). There were also 50 units under construction in 9 countries (8 of them have BWR plants in operation) with a total capacity of about 52 000 MW(e).

The countries most heavily engaged in the BWR technology are the USA, Japan and Sweden. About 73% of all BWR units in operation or under construction are in these three countries (50% in the USA alone).

BWRs have been exported by the USA, Sweden and the Federal Republic of Germany.

In general, performance of the BWR plants has been satisfactory and similar load factors as for the PWR (about 70%) may be assumed for planning and economic studies.
Technical and economic comparisons between the PWR and BWR systems have shown that the differences between the two systems are marginal. Choice of either system has been always based on the results of detailed examination and evaluation of the relevant factors in each specific situation and according to the prevailing conditions.

2.3.3. PHWR — pressurized heavy-water moderated and cooled reactors

The use of natural uranium as a fuel requires moderators with low neutron absorption characteristics. Graphite and heavy water ($D_2O$) are such materials. The development of PHWRs started approximately at the same time as development of the PWR, BWR and GCR began, but proceeded at a slower rate. The first PHWR prototype, NPD (22 MW(e)), was put into operation by Canada in 1962. With a somewhat different design, the prototype MZFR (52 MW(e)) was completed by the Federal Republic of Germany in 1966. Both designs were further developed by these countries and constitute today the two available versions of the PHWR. The Canadian version is also known as CANDU (CANada-Deuterium-Uranium), while the German version is often called the Atucha type (the first commercial power plant of this design was installed in Atucha, Argentina).

The principal difference between the two versions of PHWR is the reactor design: pressure tubes in the CANDU and pressure vessel in the German version. Both versions are fuelled with natural uranium in the form of uranium oxide clad in zirconium alloy. Heavy water is used as moderator and, in a separate circuit, as coolant. The coolant must, as in a PWR, be maintained at high pressure to prevent boiling. The steam generators for both versions are similar to the steam generators of the PWRs.

The fuel of the CANDU is loaded into horizontal Zircaloy pressure tubes, which pass through a large tank — known as the calandria — filled with heavy water as moderator. The use of pressure tubes in the reactor core allows the coolant system to be pressurized without the need for massive steel pressure vessels.

Like the PWRs, the Atucha-type PHWR uses a steel pressure vessel. The moderator and the coolant circulate in separate systems. The moderator is separated from the coolant by the moderator tank as well as by coolant channels and is under the same pressure as the coolant, but it is kept at a lower temperature level in order to improve the neutron balance.

For both versions, refuelling and fuel shuffling is performed while the power plant is under full load, without affecting operation. The average discharge burnup achieved is up to 7.5 MW · d/kg U.

A schematic representation of the CANDU type is shown in Fig. 1; the representation of the PWR is basically valid for the Atucha type. The steam conditions for PHWR are 250°C and 42 bar, which is somewhat lower than for
light-water reactors. Owing to the cost and tritium content of the heavy water, the design criteria are for minimum leakage and recuperation of any losses that might occur.

As of January 1982 15 PHWR reactors were in operation in five countries with a total output of 6200 MW(e). In addition, there were 22 reactors under construction with a total capacity of 132 000 MW(e) in 5 countries (3 of them have PHWRs in operation). The performance of the PHWR plants has been very satisfactory. Similar load factors as for LWRs may be assumed for planning and economic studies (70%).

PHWRs have been exported and are available for export from Canada and the Federal Republic of Germany. Canada is actively pursuing domestically the CANDU line and has exported reactors of this type to India (which subsequently has developed its own design as well as the capability of constructing the CANDU) and to Pakistan, Argentina, the Republic of Korea and recently to Romania. In the Federal Republic of Germany there has been no domestic development of PHWRs after the MZFR, but two reactors have been exported to Argentina, the first one in operation since 1974, the second one currently under construction.

2.4. OTHER FULLY DEVELOPED REACTOR TYPES

Three reactor systems (GCR, AGR and LWGR) have been included in this group.

The GCR, known also as the Magnox system, has been developed in the United Kingdom and in France. The choice of graphite as moderator allows the use of natural uranium and a relatively simple fuel cycle.

In the United Kingdom, the first GCR power plant to go into operation was Calder Hall (4 X 50 MW(e)) in 1956. In France G-2 at Marcoule (39 MW(e)) went into operation in 1959. These were followed in both countries by a series of commercial GCR power plants, comprising a total of 26 units (4400 MW(e)) in the United Kingdom and 6 units (2100 MW(e)) in France. In addition, the United Kingdom exported two 150 MW(e) GCRs (Japan and Italy) and France a 480 MW(e) unit to Spain. The last units of this type were put into operation in 1972. In spite of the extensive use of this system during the early period of nuclear power development, the GCR line was discontinued. Currently, however, the United Kingdom intends to offer the GCR system in the SMPR range (see section 2.6).

Figure 1 contains a schematic representation of the GCR. The reactor is fuelled by natural uranium metal, the coolant is carbon dioxide gas (CO₂). Heat is transferred through heat exchangers producing steam to drive a turbine-generator for electricity production. The steel reactor pressure vessel of the
early models was changed into prestressed concrete pressure vessels in the later ones. Fuelling is performed on load, and the discharge burnup achieved is of the order of 3.5 to 4 MW·d/kg U. Owing to the physical properties of the material combination used in the GCR (graphite-gas), the size of the reactor is relatively large. Performance of the plants has been very satisfactory.

The AGR was developed in the United Kingdom as the successor to the GCR. The use of slightly enriched uranium (in UO₂ form) permitted a higher power density and better steam conditions and led to a smaller size reactor while retaining the graphite moderator and CO₂ gas coolant. On-load refuelling has also been retained as well as prestressed concrete pressure vessels. The prototype was put into operation at Windscale in 1963 (32 MW(e)) and shut down in 1981. The prototype was followed by 14 units (seven twin-unit stations, 2 × 600 MW(e)) in operation or under construction, all of them in the United Kingdom, which is the only country using this system. A shift towards PWRs is expected in the United Kingdom; the AGR is not being offered for export at present.

The LWGR was developed by the USSR. Figure 1 contains a schematic diagram. The first nuclear power plant (APS-1), which was put into operation at Obninsk in 1954, had a reactor of this type producing 5 MW(e). It was followed by units of 100, 200, 1000 and 1500 MW(e). There are 21 units with a total capacity of about 9000 MW(e) in operation and 8 more with 9000 MW(e) under construction – all of them in the USSR. The LWGR is on-load fuelled with slightly enriched uranium (1.8%), graphite-moderated and light-water cooled (boiling). There are plans to install further LWGR units in the USSR, but it is not being offered for export.

2.5. ADVANCED AND PARTIALLY DEVELOPED REACTOR TYPES

There has been widespread interest in the development of FBRs (Fast Breeder Reactors) since the early development of nuclear power. It is generally recognized that the introduction of fast breeders will provide a major step in the supply of world energy requirements, since the amount of energy that can be extracted from uranium resources by FBRs could be about 50 times or higher than that obtained from present technology thermal reactor systems. This is due to the particular characteristic of the FBRs whereby they are able to provide energy while, at the same time, producing (breeding) more fuel than they consume.

The design of a fast breeder reactor is based on a chain reaction sustained by the fast neutrons released in the fission process of ²³⁵U or ²³⁹Pu. The excess neutrons accompanying fission are not moderated nor are they absorbed in medium-energy capture processes, so they can be more effectively used to transform fertile material (²³⁸U or ²³²Th) to fissile material (²³⁹Pu or ²³³U). The design of a fast breeder reactor aims at maximizing the rate of production of fissile material compatible with power production and safe operation.
At present the development of FBR technology is based on reactor
designs using liquid sodium as a coolant and plutonium as fuel (LMFBRs —
Liquid Metal Fast Breeder Reactors).

Since the early fifties extensive research and development programmes have
been undertaken in many countries, much progress has been achieved and the
basic technical problems have been adequately solved. Several prototype FBRs
have been built and operated. There are at present industrial-size prototypes
in operation and/or under construction in France, the Federal Republic of
Germany, Japan, the United Kingdom and the USSR. The largest unit in operation
is the BN-600 (600 MW(e)) in Beloyarsk, USSR. The largest unit under
construction is the Superphénix in France (1200 MW(e)), expected to be put into
operation in 1983.

The HTGR is another advanced reactor system under development. The
main interest in this system lies in the possibility of achieving very high
temperatures using helium gas as a coolant and hence high thermal efficiencies.
This system provides the possibility of being used for electricity generation and
for the production of process heat with temperatures of up to 1000°C, which
could be of special interest for the gasification or liquefaction of coal. The
HTGR could be considered as a follow-up of the GCR and the AGR systems.

Prototypes have been designed and built in the Federal Republic of Germany
and in the USA. Interest in the system also led to a co-operative experimental
project of the European Community known as the Dragon reactor which was
built and operated in the United Kingdom. A 330 MW(e) prototype (Fort St.
Vrain) is in operation in the USA and a 300 MW(e) prototype is under
construction in the Federal Republic of Germany.

Several reactor concepts using heavy water as moderator but cooled by other
materials have been developed to the stage of industrial prototypes. The interest
in these types originated from the desire of reducing the heavy-water inventory and
the risk of heavy-water losses.

Prototypes using light-water cooling have been developed in the
United Kingdom (SGHWR, 92 MW(e)), Canada (Gentilly-1, 250 MW(e)), Japan
(Fugen, 150 MW(e)), and Italy, (Cirene, 35 MW(e), under construction). Proto-
types with gas cooling were built by Czechoslovakia (A-1 Bohunice, 110 MW(e),
shut down), the Federal Republic of Germany (KKN Niederaichbach, 100 MW(e),
shut down) and France (EL-4, 70 MW(e), in operation).

The original expectations regarding the potential advantages of these
concepts have only partially been fulfilled, while experience in the PHWRs has
shown that heavy-water losses can be maintained within reasonable limits. Though
technical feasibility has been demonstrated, development work on the heavy-
water moderated and light-water or gas-cooled systems has been practically
discontinued.
2.6. STATUS AND PROSPECTS OF SMALL AND MEDIUM POWER REACTORS (SMPRs)

The present generation of nuclear power plants has been developed to satisfy principally the needs of the largest market for these plants, which corresponds to the industrialized countries with electric grids that admit the introduction of large units in the size range of 600 to 1300 MW(e).

Currently SMPRs are being thought of as power reactors in the order of 100 to 400 MW(e) and as a definition ‘less than 600 MW(e)’ has been in use for some years. Applying this last definition, more than half of the operating reactors of the world would qualify as SMPRs. However, it should be noted that at the time when most of these plants were designed and built, they were certainly not considered as SMPRs, and would only qualify as such by today’s accepted definition of the term.

Many countries have electrical grids that could only admit SMPRs (using the currently accepted definition of the term), and therefore there is considerable interest in having such units available for export. There is a potential market and there are potential suppliers. No doubt the relatively small role of nuclear power in meeting the needs for electric power in developing countries could be increased considerably by the economical deployment of SMPRs. Many countries could consider the nuclear option earlier instead of relying primarily on fossil resources, which in most cases they do not possess.

Against this background, the commercial availability of SMPRs for export has been a constant issue and has motivated several meetings, market surveys as well as development efforts by potential manufacturers.

Currently SMPRs are being built in India, which developed its own standard 200 MW(e) PHWR based on the CANDU design, and in the countries that are supplied by the USSR with the 420 MW(e) ‘Novo-Voronezh’ (PWR) units — Bulgaria, Czechoslovakia, Cuba, Finland, German Democratic Republic and Hungary. Although units of this type and size are still being built in the USSR, new domestic commitments in this country are in the 1000 MW(e) range. There are some units in the 500 to 550 MW(e) range that are still under construction in Canada and Japan. Except for the above-mentioned plants, all nuclear units contracted for since the late 1960s have been in the 600 to 1300 MW(e) range. There have been plans for the acquisition of SMPRs in some countries and even formal enquiries have been held, but no projects have yet materialized.

Over the past decade several SMPR designs have been on the market. Some lasted only for short periods, others disappeared and then reappeared in a modified form. They were designs based on ship propulsion reactors, prototypes, updated versions of earlier proven reactors, and new concepts. Some were promoted as multiple-purpose plants (electricity and heat). Today designs appear to be maturing: they rely heavily on proven technology of stationary or marine
<table>
<thead>
<tr>
<th>Country</th>
<th>Manufacturer</th>
<th>Type</th>
<th>Capacity (MW(e))</th>
<th>Design basis</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>Alsthone-Atlantique</td>
<td>PWR</td>
<td>125 300</td>
<td>Submarine and stationary prototype</td>
<td>Available for export</td>
</tr>
<tr>
<td>Federal Republic of Germany</td>
<td>Kraftwerk-Union</td>
<td>BWR</td>
<td>200 400</td>
<td>VAK-Kahl prototype</td>
<td>Specially designed for export, expected to be offered</td>
</tr>
<tr>
<td>India</td>
<td>Department of Atomic Energy</td>
<td>PHWR</td>
<td>220</td>
<td>Similar currently operating plant</td>
<td>Built for domestic power programme, not available for export</td>
</tr>
<tr>
<td>UK</td>
<td>Nuclear Power Company (NPC)</td>
<td>GCR</td>
<td>300</td>
<td>Oldbury-A</td>
<td>Specially designed for export, expected to be offered</td>
</tr>
<tr>
<td>UK</td>
<td>Rolls-Royce Ltd.</td>
<td>PWR</td>
<td>200</td>
<td>Submarine</td>
<td>Offered for export</td>
</tr>
<tr>
<td>USSR</td>
<td>Atomenergo-Export</td>
<td>PWR</td>
<td>420</td>
<td>Novo-Voronezh and several similar operating plants</td>
<td>Available for export, several current export projects</td>
</tr>
</tbody>
</table>
propulsion power plants. Furthermore, the manufacturers are conducting updated reviews of their SMPR concepts with respect to the most recent national licensing criteria. Cost-reducing features are given priority consideration.

Table XIII contains a list of the currently available SMPR designs. At present exported projects only exist for one of these, namely the USSR Novo-Voronezh PWR. The Indian PHWR is a well-proven concept, but not available for export. Two submarine-based designs (France and United Kingdom PWR) have been offered for export. Both the German Federal Republic (BWR) and United Kingdom (GCR) designs are based on existing nuclear power plant technology and components. They are reviews of earlier designs, updated and modified by including new technical developments and special features to enhance their attractiveness in the SMPR range. It firm requests for bids should appear, both are expected to be available within a reasonably short period.

Practically all of these designs could be applied for dual-purpose plants (electricity and heat). Development work is being carried out, but it is unlikely that the potential manufacturers would invest significant additional resources before a serious prospect for a project realization develops. Other designs may appear on the market in answer to an effective demand.

For any project and especially for ‘first-of-a-kind’ projects the questions of provenness and demonstrated licensability have to be given serious consideration (see Chapter 10, section 10.3.2).

The principal factors favouring SMPRs are:

- Possibility of integration into relatively small or weak electrical grids
- Smaller overall investment requirements
- Ease of transport of equipment and components
- Possibility of design simplification
- Possibility of extensive shop fabrication leading to shorter construction time and easier QA and QC
- Somewhat less national industrial infrastructure requirements as a consequence of the possibility of extensive foreign shop fabrication
- Early introduction of nuclear power, which would permit the accumulation of national experience in preparation for large follow-up projects.

The principal factors against the use of SMPRs are:

- Relatively high costs per kW and per kW·h (economies of scale)
- Similar governmental, organizational, regulatory, educational, training and manpower requirements as for large nuclear plants, which imply proportionally larger efforts
- Possible lack of provenness and demonstrated licensability, especially for first-of-a-kind designs
- Relatively small potential world market for SMPRs, as compared with the market for large nuclear power plants
- Short-term national market for power plants in the SMPR range owing to grid growth and the disappearance of unit size limitations imposed by grid size.
No doubt each country with an interest in SMPRs has evaluated and will evaluate the advantages and disadvantages of implementing such a project, taking into account the above-mentioned factors together with others that may apply to its particular situation. Except for those countries that have decided or will decide on the acquisition of the Novo-Voronezh PWR system supplied by the USSR, and India which continues building its 200 MW(e) PHWRs, all other interested countries have remained in the 'potential customer' status until now. A break-through seems to be needed. This might happen if a technically and economically very attractive design appeared on the market. It could also happen if several 'potential customers' joined together. A substantial firm demand for SMPRs would constitute an incentive for major development efforts by the 'potential manufacturers' and would permit the distribution of the development costs among several projects. A third possibility for a break-through would be if a market for SMPRs developed in the industrialized countries.

2.7. EXPERIENCE WITH NUCLEAR POWER REACTORS

It is recognized that each country, utility and nuclear power plant has unique individual characteristics and that any particular experience obtained has only a very limited applicability to other situations and projects. There are, however, some common aspects and overall trends that do have a certain relevance and can be used as a basis for planning purposes.

Annually the IAEA collects relevant data from its Member States on their nuclear power plants. The data are evaluated, classified and computerized. The following documents are published each year:

- Power Reactors in Member States
- Operating Experience with Nuclear Power Stations in Member States
- Performance Analysis Report.

Nuclear power plant performance data collection and statistical analysis are also performed by several other international and national organizations. When evaluating the results of any statistical analysis, it has to be taken into account that the plants in general differ in type, size, design and age. At present any attempt to identify a homogeneous group of power plants by type of reactor and possibly range of size and duration of commercial operation results in a reduction of the number of cases to too few to justify a meaningful statistical trend. But this situation is expected to change gradually, as more experience is accumulated. At present some general trends can nevertheless be identified and these do provide meaningful guidance.

Regarding the introduction of nuclear power in a country, experience has shown that only five countries (Canada, France, United Kingdom, USA and USSR) have developed domestically their first nuclear power project. All five proceeded in this manner during the early days of nuclear power development.
The other 25 countries that have introduced nuclear power up to now acquired their first nuclear power plant from abroad. Some of them later developed their own nuclear power capability to the point where they no longer depend on foreign supply (Federal Republic of Germany, India, Japan, Sweden), while the others have increased their national participation to different degrees according to their national aims and capabilities.

About half of the 25 countries that imported their first nuclear power plant acquired that plant through an international competitive bidding process, while the others chose the direct negotiation procedure with a pre-selected supplier. Practically all of these first plants were acquired under turnkey arrangements. For follow-up plants the method of acquisition was modified in most cases, mainly depending on national participation goals and on the development of the necessary national infrastructures.

Regarding construction of nuclear power plants, experience on schedules, costs and most usual major problems is of special interest.

The construction time span for individual plants shows a wide variation between 4 and 10 years. On average, however, plants were built between 6 to 7 years. For plants that went into commercial operation during the seventies there is a clear trend of increasing construction times from initially 5 years to 7 years in the late seventies. Very few plants have ever been built on the schedule contracted or planned for. Delays of a year or two due to unforeseen occurrences seem to be the rule. For schedules of nuclear power projects see Chapter 5.

Similarly, very few plants were ever built at the cost (including contingency) originally foreseen. Cost increases due to construction delays, additional safety requirements, and design changes and modifications have occurred in the majority of cases (costs are treated in more detail in Chapter 4). However, experience also shows that nuclear power plants in operation are producing electricity not only at competitive costs but with substantial margins of benefit when compared with current fossil-fuel generation costs.

Some major problems during construction which have occurred with a significant frequency and hence would require special attention are:

- Inadequate site evaluation studies
- Interface co-ordination problems
- Increased regulatory requirements
- Delays in regulatory procedures
- Opposition by anti-nuclear groups or organizations
- Technical difficulties caused by unproven equipment, components or design features
- Lack of adequate quality assurance and quality control.

Experience in the operation and maintenance of nuclear power plants has been in general satisfactory. For nuclear power plants, base load operation is the rule. Safety and reliability are the principal parameters to be analysed.
<table>
<thead>
<tr>
<th>Reactor groups</th>
<th>Number of reactors</th>
<th>Net capacity MW(e)</th>
<th>Average LF&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Average OF</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>193</td>
<td>104 527</td>
<td>61.4</td>
<td>68.3</td>
</tr>
<tr>
<td>All excluding prototypes</td>
<td>174</td>
<td>103 764</td>
<td>61.4</td>
<td>68.3</td>
</tr>
<tr>
<td>All excluding prototypes and excluding those starting commercial operation in the second half of 1979</td>
<td>164</td>
<td>95 290</td>
<td>59.6</td>
<td>66.8</td>
</tr>
<tr>
<td>All excluding those starting commercial operation in the second half of 1979</td>
<td>183</td>
<td>96 053</td>
<td>59.6</td>
<td>66.8</td>
</tr>
<tr>
<td>Prototypes</td>
<td>19</td>
<td>763</td>
<td>63.1</td>
<td>68.4</td>
</tr>
<tr>
<td>Those starting commercial operation in the second half of 1979</td>
<td>10</td>
<td>8 474</td>
<td>81.8</td>
<td>85.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> Al-Bohunice, Arkansas One – 2, Calder, Caorso, Gentilly, Humbolt Bay, Indian Point – 1 and KWL Lingen not included.

<sup>b</sup> LF (Load Factor); OF (Operating Factor).

The safety and in particular the nuclear safety performance of the nuclear power plants have been excellent. This, however, is not perceived by the public as such, as indicated by surveys and the spread of public opposition. No doubt there have been many abnormal occurrences, incidents and accidents, some of them even involving uncontrolled release of radioactivity to the environment. All these have been heavily publicized by the information media. Nevertheless, the facts are that through more than 2500 reactor years of operating experience there has been no death or serious injury caused by a nuclear accident in a commercial nuclear power plant. Experience has shown that safety in operation
must be of primary concern, if nuclear power is to remain a viable alternative source for energy production. Experience has also shown that the effects of any nuclear accident are not limited to the nuclear plant where it might occur but affect the whole nuclear industry worldwide. Hence, nuclear safety is of common concern to all. Direct responsibility, however, lies with the operating organization of the country concerned.

Reliability performance data are compiled and classified by many organizations, including the IAEA, which has a computerized data bank. The two principal performance factors as defined in IAEA reports are:

(1) The Load Factor (LF), which is the ratio between the energy that a power plant has produced during the period considered, and the energy that it could have produced at maximum capacity under continuous operation during that period;

(2) The Operating Factor (OF), which is the ratio between the number of hours the unit was on line and the total number of hours in the reference period.

Individual power plants show rather large variations in their operating records. As to average values, Table XIV contains the operating experience summary for 1979. Figure 2 shows the average load and operating factors from 1970. Planned outages were mainly due to the performance of maintenance and repair, refuelling (except for on-load refuelling reactors), modifications due to new regulatory requirements, and testing of plant systems. Equipment failures have been a major cause of the unplanned outages. Most of these failures occurred in components, equipment or systems outside the nuclear steam supply system.

When comparing statistical performance of nuclear power plants with fossil-fuelled power plants, very similar values are found. This tends to contradict expectations for improvements with maturity.

Many important lessons have been learned from the experience in operating and maintaining nuclear power plants. Most of these may seem obvious, nevertheless, emphasizing them might be useful.

(a) Safety considerations in operation and maintenance must override other concerns
(b) Availability of highly qualified operations and maintenance management and staff is essential
(c) Qualification, training and retraining requirements must be clearly defined and complied with
(d) The power plants must be designed and constructed for good operability and maintainability, in addition to safety
(e) Operation and maintenance procedures must be clearly stated and rigorously complied with
(f) Lines of authority, distribution of responsibilities, functions, duties and tasks must be clearly defined and understood by all.
Experience with first nuclear power plants in a country and in particular with first projects in developing countries has shown that there are problems and difficulties which have to be solved. Experience, however, has also shown that these problems and difficulties can be overcome in satisfactory ways. The performance of first nuclear power plants has usually not been different from follow-up plants, and in many cases first nuclear power plants have performed extremely well indeed.
3.1. ELEMENTS OF THE NUCLEAR FUEL CYCLE

The processes undergone by materials for use as fuel in nuclear reactors and the corresponding activities to be performed comprise the elements of the nuclear fuel cycle. Fuel cycle processes and activities may be divided into the following main groups:

(a) Provision of fresh fuel for the reactors. This is usually called the front-end of the fuel cycle. It includes:
   - Exploration, mining and milling of uranium (section 3.1.1)
   - Conversion and enrichment of uranium (only for enriched U-fuelled reactors) (section 3.1.2)
   - Fuel element fabrication (section 3.1.3);
(b) Fuel management at the power plant (section 3.1.4);
(c) Spent fuel management, usually called the back-end of the fuel cycle. It includes:
   - Spent fuel transport and storage (temporary or permanent) (section 3.1.5)
   - Reprocessing of spent fuel (section 3.1.6)
   - Management and disposal of radioactive wastes (section 3.4).

The principal elements of the nuclear fuel cycle are diagrammatically shown in Fig.3. The different fuel cycle options are discussed in section 3.2.

3.1.1. Exploration, mining and milling of uranium

Since uranium is the only naturally occurring fissile material, it is the indispensable starting point for the production of the necessary fuel for nuclear reactors. Uranium contains the fissile (with thermal neutrons) isotope $^{235}\text{U}$ (0.71%) and also the more abundant isotope $^{238}\text{U}$ (99.3%) which is the 'fertile' material for the production of fissile plutonium-239 ($^{239}\text{Pu}$).

A uranium exploration programme would usually consist of geological reconnaissance, selection of favourable areas to be prospected, detection of radiometric anomalous areas, identification of uranium mineralization, exploration by
drilling or mining works, estimation of reserves, mining exploitation and studies on uranium recovery. As shown by experience, for an unknown area 8 to 10 years are necessary from the start of exploration to preparation of the mine and mill for uranium production.

Exploration is generally implemented in three stages:

1. General reconnaissance, using geological, geophysical and geochemical methods
2. Follow-up exploration, when uranium anomalies are classified according to priorities as a result of a better knowledge of their characteristics
3. Detailed surveys. Geochemistry surveys, geophysical surveys, mapping, trenching, drilling, logging, etc. are involved as needed.

Uranium exploration can involve large efforts, or relatively modest investments and a limited amount of manpower. The results, however, are usually in
proportion to the effort expended. The availability of competent geologists is essential.

The technology and equipment for exploration, mining and milling of uranium is not difficult to acquire. The mining techniques are similar to those applied in conventional mining operations, except for the special features and precautions associated with radioactivity.

Current technologies use ores having a recoverable uranium concentration in the range of 0.02 to 0.2%, but recently rich deposits have been discovered having ores with up to 3% U. Following the removal of uranium ore from the mine, it is physically prepared and chemically processed or milled to produce a commercial product, yellow cake, a concentrate of uranates containing about 80% of \( \text{U}_3\text{O}_8 \). Uranium milling is based primarily on hydrometallurgical operations such as leaching, solvent extraction or ion-exchange, and precipitation. Separation based on physical properties, such as specific gravity or magnetic susceptibility, is impractical for almost all uranium ores.

### 3.1.2. Conversion and enrichment of uranium

The conversion (to \( \text{UF}_6 \)) and enrichment processes are only required if the reactor is fuelled by enriched uranium. Prior to enrichment, the 'yellow cake' concentrate is purified and converted to uranium hexafluoride, \( \text{UF}_6 \), which is a solid uranium compound at room temperature but vaporizes at a rather low temperature of about 60°C. With this process a gaseous uranium compound is obtained, which is necessary for all subsequent processes used for the enrichment of uranium in the isotope \( ^{235}\text{U} \).

Uranium conversion to \( \text{UF}_6 \) has been a normal commercial enterprise for many years. Conversion plants are basically chemical processing plants.

Through the enrichment process the concentration of \( ^{235}\text{U} \) in natural uranium (0.7%) is increased to the required degree of enrichment, which varies from 2 to 4% \( ^{235}\text{U} \) for light-water power reactors, up to high enrichments of 20 to 90% for fast breeders and some types of research and test reactors.

For separating the lighter \( ^{235}\text{U} \) from the heavier \( ^{238}\text{U} \) molecules of the \( \text{UF}_6 \) gas, it is necessary to perform a physical work, named 'separative work'. The enrichment plant is composed of a series of 'separating elements' or 'stages', each one having its 'separation factor'. The amount of 'separative work' to be performed in a 'separating element' is a function of the 'separation factor' and the flow of material passing through the 'separating element'. Because of this property, the enrichment service price is based on the amount of separative work needed for the enrichment operation, multiplied by the price of the 'separative work unit' (commonly abbreviated SWU and expressed in mass units). It is necessary to add to this price the price of the feed material used in the operation, the feed amount being a function of the \( ^{238}\text{U} \) content of the depleted uranium left after the process (tails assay).
Because uranium enrichment provides a direct route to the production of nuclear-weapons-grade fissile material, enrichment technology still remains a highly classified area of nuclear technology. The market and political aspects of enrichment are discussed in section 3.3.2.

There are five basic methods of current interest for the enrichment process, namely gaseous diffusion, gas centrifuge, aerodynamic, chemical and laser techniques.

3.1.2.1. Gaseous diffusion

The gaseous diffusion process has been developed and used for almost all of the uranium enrichment that has been performed for reactor fuel. The enrichment process is effected by passing gaseous uranium hexafluoride (UF₆) through a porous barrier. The lighter UF₆ molecules containing ²³⁵U pass through at a faster rate than do the heavier UF₆ molecules containing ²³⁸U. The amount of separation accomplished in a single stage is rather small, and hence a large number of stages are required to achieve enrichments of practical interest. Starting with natural UF₆, enrichment to a level of 3% ²³⁵U requires some 1200 stages.

The amount of feed material of natural uranium depends on the depleted tails assay of uranium after the enrichment process; this assay usually varies between 0.2 to 0.3% of ²³⁵U. For example, with a tails assay of 0.2% ²³⁵U the production of 1 kg of 3% enriched uranium requires 5.5 kg of natural uranium feed and 4.3 SWU. With a tails assay of 0.3% the same operation would need 6.6 kg of natural uranium feed and 3.4 SWU.

Gaseous diffusion plants have been constructed and operated in the USA, the United Kingdom, the USSR, France and China. While the process is known to require large amounts of electrical energy and is subject to very large economies of scale, it is technically possible to build diffusion plants of any desired output. As an example, the plant in the United Kingdom has a capacity of only 400 tons of separative work per year.

3.1.2.2. Gas centrifuge

In this process the UF₆ gas is constrained to rotate at high speed in a centrifuge. The stabilized centrifuge forces separate the lighter UF₆ molecules containing ²³⁵U from the heavier ones containing ²³⁸U. It requires fewer stages (each of them formed by several centrifuges) and consumes less electrical energy than the gaseous diffusion process, but the investment cost per unit capacity is larger. The economics of gas centrifuge plants are not so severely affected by economies of scale as are those for gaseous diffusion plants. Hence, gas centrifuge plants could be built in smaller sizes without severe economic penalties.

The basic research and development of the centrifuge process was carried out in the Federal Republic of Germany. Pilot plants have been constructed and
successfully operated, and plants are now being constructed on a commercial scale. A consortium of the United Kingdom, the Federal Republic of Germany and the Netherlands – known as URENCO – has two plants now in operation and has started the construction of larger commercial facilities.

3.1.2.3. Aerodynamic methods

Several aerodynamic methods have been used to separate uranium isotopes. The best known among these is the 'jet nozzle process' developed in the Federal Republic of Germany, in which a gaseous mixture of UF₆ and hydrogen is forced to flow through a nozzle and expands in a space limited by a curved wall. The centrifugal forces separate the heavier molecules from the lighter ones. The stream is thus divided into two fractions, one of them being richer in ²³⁵U than the other.

The jet nozzle process has been demonstrated in the Federal Republic of Germany and a plant is to be constructed in Brazil, under its co-operation agreement with the Federal Republic of Germany. The South African enrichment process is believed to be based on the same principle.

3.1.2.4. Chemical process

In the chemical enrichment process developed by the French CEA the separation effect results from differences that occur in reaction equilibrium between the isotopic species of interacting uranium compounds. The value of the separation effect varies according to the compounds chosen, but it is usually small. Thus the basic enrichment operation has to be repeated a number of times in order to reach the degree of enrichment required. In practice, this is done by using uranium compounds in different phases, which may be gaseous, liquid or solid, but then the global kinetics, which include not only the chemical reaction kinetics but also the time lag due to interphase contact, must remain acceptable.

The nature of the chemical compounds made to react has not been divulged. It is known, however, that the interacting compounds are not usual and that these compounds enter into two liquid phases, one aqueous, the other organic. The separation factor is supposed to be greater than $2 \times 10^{-3}$ and the overall kinetics are reported to be good.

3.1.2.5. Laser techniques

The use of laser technology for uranium enrichment is still at the laboratory research stage. The process is based on using lasers to exploit the slight differences in excitation energies of $^{235}$U and $^{238}$U atoms or molecules. In principle, the laser process could achieve a large degree of separation in a single stage while consuming
relatively small amounts of energy. The most striking advantage of this process is that it could virtually eliminate the waste of $^{235}\text{U}$ remaining in the depleted uranium tails after enrichment. Hence, it would provide means of recovering the $^{235}\text{U}$ in the huge stockpiles of depleted uranium tails that are available from the enrichment plants in operation. These depleted tails contain about 35% of the $^{235}\text{U}$ originally fed to the enrichment facilities and this could provide additional substantial amounts of $^{235}\text{U}$.

It is too early to predict the future development of the laser technology for the enrichment process, but if it proves successful, it will make a significant contribution to the world's energy resources through the 'mining' of the large tails stockpiles available from the enrichment plants using other technologies.

### 3.1.3. Fuel element fabrication

The process of fabrication of fuel elements starts with either the conversion of enriched uranium hexafluoride into uranium dioxide powder ($\text{UO}_2$) or the conversion of natural uranium into $\text{UO}_2$, for all water-cooled power reactors. The basic components of the fuel elements are small cylindrical pellets which are composed of uranium dioxide powder that is compacted by cold pressing and then sintered to attain the required density and structural stability.

The uranium dioxide pellets are inserted into a thin tube made of a suitable cladding material, such as zirconium alloys, to form the fuel rods (see section 3.5.1). The fuel rods are assembled in a fuel bundle structurally bound to constitute the fuel assemblies for the reactor core. The number and arrangement of fuel rods in the fuel assemblies are determined by the specifications of the reactor core design.

Several important features are incorporated in the mechanical design and fabrication of fuel elements for power plants to ensure their integrity, stability and long-life performance. Extensive tests and inspections are carried out on fuel pellets, tubes, rods and finished assemblies to ensure high standards of reliability during operation. These tests and inspections include chemical analysis, tensile testing, dimensional inspection, X-ray and ultrasonic tests, and helium leak tests.

Unlike enrichment technology, fuel element fabrication plants are available on a commercial basis from manufacturing companies. The decision to build a fuel fabrication plant by any country would be influenced by the size and number of nuclear plants contained in its nuclear power programme.

The fabrication of fuel elements is a well-established technology of the nuclear industry. This is an essential step, more important than its contribution to the fuel cycle cost would imply, since the fuel elements are critical from the point of view of safety and performance of the reactor.
3.1.4. Fuel management at the power plant

Starting with the reception of fresh fuel at the power plant and ending with the removal of the spent fuel from the plant fuel cooling ponds, a series of activities are performed. These may be called the central technical activities of the overall fuel cycle, because it is at this stage where the whole purpose of the fuel cycle is fulfilled, i.e. where energy is produced from the nuclear fuel.

Fuel is inspected, stored, loaded into the reactor, burned, removed when spent and temporarily stored awaiting transport away from the power plant. In-core fuel management includes the long-term fuel cycle planning, development of the refuelling schedule, operational monitoring and guidance, and the economic optimization of the fuel cycle. To perform these functions, sophisticated computer models and reactor analysis techniques are applied.

3.1.5. Spent fuel transport and storage

The back-end of the fuel cycle starts with the transport of highly radioactive spent fuel away from the power plant site. This is a well-established activity. Thousands of shipments have been made in specially designed containers with few minor incidents which did not represent any danger to the public. Detailed information and guidance on the subject are provided by the IAEA publication “Regulations for the Safe Transport of Radioactive Materials” (1973 revised edition, Safety Series No.6) as well as other relevant publications such as “Advisory Material for the Application of the IAEA Transport Regulations” Safety Series No.37) or “Notes on Certain Aspects of the Transport Regulations” (Safety Series No.7).

The temporary storage of spent fuel at the power plant can cover a period of a few months to several years. Afterwards, depending on the fuel cycle strategy adopted for ultimate disposal of the spent fuel or reprocessing, the fuel will be removed from the temporary cooling ponds to away-from-reactor storage (interim or permanent) or to a reprocessing facility.

While the spent fuel is highly radioactive it is stored under water in specially constructed ponds provided with a cooling system to remove the heat generated by radioactive decay. Later, dry storage is possible. Spent fuel storage technology has been well developed; however, large central away-from-reactor storage facilities have not yet been built, except where such facilities are part of a reprocessing plant.

3.1.6. Reprocessing of spent fuel

Following a cooling-down period of about one year in the temporary storage pool, during which the most intense short-lived and intermediate half-life radioactive fission products have decayed, spent fuel can be transferred to a reprocessing
plant. The reprocessing operations involve a series of mechanical and chemical steps to be carried out in specially designed facilities, comprising hot cells, remotely operated equipment inside the hot cells and instrumentation for control and protection against radiation hazards of the highly radioactive materials to be handled. After treatment of the spent fuel, the remaining uranium and the plutonium produced are separated from the fission products by solvent extraction. Recovered uranium, which might still contain up to 1% $^{235}\text{U}$ or more, can be recycled. Recovered plutonium is converted into plutonium dioxide ($\text{PuO}_2$) providing the fissile material for the degree of enrichment required, instead of uranium-235. The fission products constituting the radioactive waste have to be treated and disposed of.

Uranium enrichment and reprocessing of spent fuel are considered the most sensitive elements of the fuel cycle from the 'non-proliferation' point of view. Fuel reprocessing is the process in which a nuclear weapons usable material, $^{239}\text{Pu}$, is recovered. Transfer of technology and international co-operation in this field have been therefore very limited and subject to tight restrictions. Several countries have laboratory, pilot-plant or full-scale reprocessing facilities in operation or planned. Commercial reprocessing services, however, are of highly restricted availability.

The last step of the back-end of the fuel cycle, management and disposal of radioactive wastes, is discussed in section 3.4.

3.2. FUEL CYCLES FOR DIFFERENT POWER REACTOR SYSTEMS

This section is primarily concerned with the technical aspects of various alternative fuel cycles used in power reactors. It is not intended to deal with the evaluation of the proliferation risks of the various cycles nor with measures designed to reduce or prevent proliferation. Such proliferation aspects are basically political and institutional, and they have been extensively discussed for over two years in the International Nuclear Fuel Cycle Evaluation (INFCE) programme, which was completed in February 1980. Some proliferation issues, however, will be briefly discussed in Chapter 7 of this Guidebook.

Nuclear fuel cycles can be either open or closed. In an open (or once-through) fuel cycle strategy (section 3.2.1) the fuel passes through the reactor only once, while in a closed cycle (section 3.2.2) unburnt fissile material is recovered in a reprocessing plant and then recycled to fuel thermal or fast reactors. Figure 4 contains a schematic representation of these alternative fuel cycle strategies.

Fuel cycles are based on natural fissile ($^{235}\text{U}$) and fertile ($^{232}\text{Th}$, $^{238}\text{U}$) materials and on man-made fissile materials ($^{233}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$). In accordance with the fissile and fertile materials used, fuel cycles may be classified into two main categories: the uranium-plutonium cycle, and the thorium-uranium cycle.
As long as a cycle does not sustain itself, i.e. as long as less fissile material is bred than is consumed, both cycles require an addition of the natural fissile material $^{235}\text{U}$. A pure Th-U cycle exists only if highly enriched $^{235}\text{U}$ and $^{233}\text{U}$ are used as fuel. The U-Pu and Th-U cycles can also be combined when employed in various reactors to form a mixed cycle. These strategies are indicated in Fig.5, which is a matrix diagram of the possible combinations of fuel cycles and types of reactors, showing also their technical status and feasibility. For reasons of brevity and clarity, the matrix has been limited to the most important types of reactors, leaving aside the more complicated combined cycles.

It can be seen from the diagram that closed cycles can be operated with almost all types of reactors and that once-through or open cycles preclude the operation of high converting or breeding systems. The open U-Pu fuel cycle with LWRs and HWRs, and closed U-Pu with recycle in LWRs are available on an industrial basis.

A more detailed discussion on fuel cycles and related reactors can be found in the INFCE Report (Working Group 8 in particular),

3.2.1. Once-through or open cycle strategy

In this fuel cycle strategy there is no reprocessing of the spent fuel and consequently no recycling of unused $^{235}\text{U}$ nor of the $^{239}\text{Pu}$ that has been produced. In other words, spent fuel is stored and ultimately disposed of as waste. In fact, it is doubtful whether this strategy can be called a ‘cycle’ at all.
The adoption of the once-through strategy involves arrangements for extended storage facilities and for the ultimate disposal of spent fuel.

For the LWR systems the fuel cycle elements involved in this strategy are mining of uranium ore, milling, conversion to uranium hexafluoride, enrichment, conversion to UO₂, fabrication of fuel elements, reactor operation, and then temporary storage of spent fuel at the reactor site. In principle, spent fuel is to be removed from the temporary storage to special facilities for its ultimate storage and disposal.

For the HWR systems, because there is no need for uranium enrichment, the fuel cycle elements involved are fewer than in the case of the LWR system. The operations involved are mining and milling of uranium ore, conversion to uranium dioxide UO₂, fabrication of fuel elements, reactor operation, temporary and ultimate storage and disposal of the spent fuel in special facilities.

3.2.2. Closed cycle strategy with fuel recycling

This strategy involves the removal of spent fuel from the temporary storage to a reprocessing plant, where the spent fuel is reprocessed to separate and recover plutonium and uranium. The separated plutonium dioxide is used for fuel enrichment in fissile isotopes by combining it with natural or depleted uranium in mixed-oxide (MOX) fuel pellets, which are then fabricated into mixed-oxide fuel elements. The recovered uranium, which is still slightly enriched (LWR cycles), may then be re-enriched to the degree of enrichment needed. New reactor core loadings would consist of a combination of mixed-oxide fuel elements and enriched-uranium elements.

The uranium and plutonium recycle fuel cycle strategy is technically feasible in both LWR systems and HWR systems and has been successfully used in some LWR nuclear power plants using mixed-oxide fuel elements. However, at present there is no unanimity concerning the economic benefits of reprocessing and recycling for thermal reactors.

3.2.3. Uranium-plutonium cycle

The annual make-up inventory of a 1000 MW(e) LWR is approximately 33 tons of UO₂ with a ²³⁵U enrichment of about 3%. After a burnup of 33 MW·d/kg the ²³⁵U content is reduced to some 0.8%. Most of the plutonium generated from ²³⁸U is fissioned immediately, contributing some 35% to the energy production. In the spent fuel elements approximately 210 kg/GW(e)·a of plutonium is unloaded.

Heavy-water reactors operated on natural uranium or low-enriched uranium require an annual make-up charge of approximately 150 t of natural uranium per 1000 MW(e). After an average burnup of 7.5 MW·d/kg the amount of plutonium unloaded is approximately 360 kg/GW(e)·a.
In the HTGRs enrichment of about 8 to 10% is required. The annual make-up charge would be about 9 tons of uranium per 1000 MW(e). Because of the high burnup of 100 MW·d/kg, most of the plutonium generated is burnt in the reactor so that the plutonium discharged is only some 70 kg/GW(e)·a.

All types of reactors mentioned so far can be operated both in the once-through or the closed cycles.

For the liquid metal fast breeder reactor, however, reprocessing and recycle are not optional but essential elements and integral parts of the closed fuel cycle. Present developments of fast breeder reactors are based on a plutonium cycle, although a Th-233U cycle may also be feasible.

Initial loading of a fast breeder reactor would contain highly enriched uranium or plutonium recovered from spent fuel of LWRs or HWRs. Subsequently, the fuel used would be mainly provided by the plutonium produced in the breeding process. In the steady state fuel cycle depleted uranium from enrichment tails or natural uranium is converted into uranium dioxide and combined with recovered plutonium dioxide and recovered uranium dioxide to fabricate mixed-oxide fuel. Spent fuel is reprocessed after exposure in the reactor to separate plutonium and uranium from the high radioactive fission products. Radioactive wastes are processed into suitable forms for permanent disposal.

Fast breeder reactors use U-Pu fuel elements. The annual make-up core charge is about 12 t of 238U with 14%, i.e. 1.7 t, of plutonium. At a breeding rate of 1.2, an excess of about 160 kg of plutonium would be produced per year.

3.2.4. Thorium-uranium cycle

In principle, all types of reactors referred to above can be run also in the Th-U cycle instead of the U-Pu cycle. This cycle involves using 232Th as a fertile material for the production of fissile 233U, and reprocessing and recycle of the separated 233U. The utilization of the 232Th-233U fuel cycle has long since been considered attractive, owing to the excellent neutron characteristics of 233U and the availability of vast thorium resources, but the technical problems to be overcome in implementing such a fuel cycle are substantial.

The use of thorium has been considered for some of the existing designs of thermal reactors. The most promising type for its application is the HTGR system. The use of thorium is also technically feasible for light-water and heavy-water reactor systems and for FBRs. In addition, some advanced reactor concepts for the development of a thorium thermal breeder have also been considered. A thorough analysis of the potential of thorium utilization in these various reactor systems can be found in the INFCE Working Group 8 Report. The results generally reveal reduced uranium ore requirements in all cases. Nevertheless, none of these concepts have been developed to practical applications.
3.3. THE MARKET FOR FUEL CYCLE MATERIALS AND SERVICES

The supply of the requirements of nuclear fuel and associated services for different fuel cycles used with various reactor systems represents one of the key elements for the present and future exploitation and development of nuclear power. To provide the fuel needed to operate the nuclear power plants, the following materials and services are essential:

(a) Uranium (section 3.3.1)
(b) Conversion and enrichment (in case of enriched U reactors) (section 3.3.2)
(c) Fuel fabrication (section 3.3.3).

For closed fuel cycle strategies and for fast breeder reactors in particular, the essential requirement in addition to the above listed elements is:
(d) Reprocessing (section 3.3.4).

The demand of alternative fuel cycles and their impact on the available resources and production capacities depends on the projections of future nuclear power in the world and on the different possible combinations of reactor types and fuel cycles.

This discussion on the market for fuel cycle materials and services is based mainly on the results of INFCE, which represent the most recent reliable overall source of information available. INFCE information and data refer to the "World Outside Centrally Planned Economies Area" (WOCA).

3.3.1. Uranium resources, production and demand

Since all reactor systems need the only naturally existing fissile isotope, $^{235}$U (contained in natural uranium), one has to look first at this fuel source.

The supply of uranium will come primarily from deposits of a type that is either being exploited or that could be exploited under current technological and economic conditions, at a cost (in 1978 US dollars) of up to US $130/kg U. Since 1965 estimates of these 'conventional' resources have been made periodically by a joint working party of OECD(NEA) and the IAEA. A report on uranium resources, production and demand, commonly known as the 'Red Book' is periodically (every two years) reviewed and published.

The NEA/IAEA divides its estimates into two separate categories, Reasonably Assured Resources (RAR) and Estimated Additional Resources (EAR) – reflecting different levels of confidence in the quantities reported, based primarily on criteria of geological assurance of existence. These two categories of resources are further separated into two levels of exploitability based on the cost of exploitation (generally not including the cost of exploration nor allowance of profit). The NEA/IAEA uranium cost categories are narrowly defined and used only as a basis for the classification of resources. It should be noted that these cost categories do not necessarily reflect the prices required to ensure the...
continuing viability of the uranium industry or those at which uranium will be
available to the user. The most recent estimates of uranium resources in these
internationally established categories are given in Table XV.

To January 1979 almost 80% of the total RAR occurred in North America,
Africa and Australia, and almost 90% of the total EAR occurred in North
America and Africa. The situation has changed recently because of the dis­
covery of large and rich deposits in Australia and in Brazil. About 75% of the
391,000 tons of RAR in Europe is attributable to the Swedish alum shales, the
future exploitability of which is uncertain for a number of reasons, environmental
among others. Resources in addition to those summarized in Table XV are known
to exist in several areas of the world, but the deposits are of low grade, so that the
cost of exploiting them would be greater than US $130/kg U. Prospects of new
discoveries, classified under ‘Speculative Resources’ category, are believed to be
favourable.

Certain low-grade sources of uranium are also providing some incremental
quantities of world uranium supply, as byproducts from phosphate ores used
for phosphoric acid production and from solutions generated in leaching of certain
copper ores. Additional uranium is also potentially available from several normally
very low-grade ‘unconventional’ types of resources, such as shales, above-average-
grade granites, coals and lignites, and seawater. In addition, ore-processing tails
and enrichment tails could also conceivably provide significant quantities of
uranium.

The demand for uranium will depend on the nuclear power growth rates and
also on the types of reactors in operation. The calculation of demand for uranium,
carried out in the course of INFCE studies, focussed primarily on reactor types
and technologies that are at present available or are likely to be available in the
near future. These include the following types:

- Once-through LWR fuel cycles
- Once-through fuel cycles based primarily on HWRs
- Large-scale introduction of FBRs
- LWRs with recycle of self-generated plutonium
- HWRs with (a) recycle of self-generated plutonium or (b) uranium/
thorium fuel recycle.

Typical lifetime requirements for uranium for the main reactor types are
given in Table XVI. It should be noted that this table presents requirements for
only natural uranium for individual reactor types based on available characteristics.
From a nuclear power programme perspective, the choice of reactor types and
fuel cycles will be affected by the total system demand for uranium and other
fuel cycle services, as well as economics, technical feasibility and other factors.
For example, substantial and increasing reprocessing capacity would be needed
if significant proportions of nuclear power growth were to employ recycle or
<table>
<thead>
<tr>
<th>Continent</th>
<th>Reasonably Assured Resources (RAR)</th>
<th>Estimated Additional Resources (EAR)</th>
<th>Speculative resources up to $130/kg U</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up to $80/kg U</td>
<td>Up to $130/kg U</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>752</td>
<td>224</td>
<td>1145</td>
</tr>
<tr>
<td>Africa</td>
<td>609</td>
<td>167</td>
<td>139</td>
</tr>
<tr>
<td>Australia</td>
<td>290</td>
<td>9</td>
<td>47</td>
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<tr>
<td>Europe</td>
<td>66</td>
<td>325</td>
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<tr>
<td>Asia</td>
<td>40</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>South Africa</td>
<td>97</td>
<td>5</td>
<td>99</td>
</tr>
<tr>
<td>WOCA total (rounded)</td>
<td>1850</td>
<td>740</td>
<td>1480</td>
</tr>
</tbody>
</table>
TABLE XVI. LIFETIME URANIUM REQUIREMENTS FOR SOME NUCLEAR REACTORS\(^a\) AND FUEL CYCLE OPTIONS CONSIDERED BY INFCCE

<table>
<thead>
<tr>
<th>Reactor type and fuel cycle option</th>
<th>Lifetime uranium requirements (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Once-through LWR</strong></td>
<td></td>
</tr>
<tr>
<td>Current technology</td>
<td>4260</td>
</tr>
<tr>
<td>15% improved</td>
<td>3720</td>
</tr>
<tr>
<td>30% improved</td>
<td>3080</td>
</tr>
<tr>
<td><strong>Self-generated Pu recycling LWR</strong></td>
<td></td>
</tr>
<tr>
<td>Current technology</td>
<td>2665</td>
</tr>
<tr>
<td>Improved technology</td>
<td>1850</td>
</tr>
<tr>
<td><strong>Once-through HWR</strong></td>
<td></td>
</tr>
<tr>
<td>Current; natural uranium</td>
<td>3655</td>
</tr>
<tr>
<td>Improved; low-enriched uranium</td>
<td>2505</td>
</tr>
<tr>
<td><strong>Self-generated Pu recycling HWR</strong></td>
<td></td>
</tr>
<tr>
<td>Natural U with Pu cycle</td>
<td>1820</td>
</tr>
<tr>
<td><strong>Thorium cycle HWR</strong></td>
<td></td>
</tr>
<tr>
<td>Denatured (^{233})U; HEU(^b) make-up(^c)</td>
<td>1685</td>
</tr>
<tr>
<td>HEU recycle; HEU make-up(^c)</td>
<td>1520</td>
</tr>
<tr>
<td>HEU recycle; Pu make-up(^d)</td>
<td>1220</td>
</tr>
<tr>
<td><strong>Thorium cycle HTR(^c)</strong></td>
<td></td>
</tr>
<tr>
<td>Denatured (^{233})U; HEU make-up</td>
<td>2375</td>
</tr>
<tr>
<td>HEU recycle; HEU make-up</td>
<td>1650</td>
</tr>
<tr>
<td><strong>U/Pu cycle FBR(^e)</strong></td>
<td></td>
</tr>
<tr>
<td>Pre-2000 technology</td>
<td>36</td>
</tr>
<tr>
<td>Post-2000 technology (reference)</td>
<td>46</td>
</tr>
<tr>
<td>Post-2000 technology (advanced)</td>
<td>49</td>
</tr>
</tbody>
</table>

\(^a\) 1000-MW(e), operated for 30 years at 70% load factor; 0.2% enrichment plant tails assay.
\(^b\) HEU — highly enriched uranium.
\(^c\) Includes the natural uranium required to establish in-core fissile inventories for the first reactor generation.
\(^d\) In-core and ex-core fissile plutonium inventories are required in addition to the uranium requirements. Uranium requirements are a mix of 1 natural U HWR per 2 Th/Pu HWRs.
\(^e\) In-core and ex-core fissile plutonium inventories are required in addition to the uranium requirements. Data for FBRs refer to depleted uranium. The uranium requirements depend on breeding gain, with increased breeding gains calling for additional uranium requirements (with associated increases in net plutonium production).
breeder reactor systems, substantial and increasing spent fuel storage and waste disposal facilities would be needed if the once-through fuel cycle were extensively deployed, etc.

For the pre-2000 period reactor mixes obtained from the national programmes, as responses to INFCE questionnaires, were used in determining the demand. In certain cases, without changing the pre-2000 mix of reactor types, recycling of plutonium or improvements to increase the efficiency of uranium usage were introduced before 2000.

An IAEA computer model, verified with other models, was used to calculate the nuclear fuel cycle requirements from the growth projections. The calculations performed showed a possible range of uranium requirements bounded by a low-demand strategy using advanced technology FBRs with one year out-of-pile time deployed throughout WOCA, and a high-demand strategy using current-technology once-through LWRs deployed throughout WOCA. This range is from 85 000 to 200 000 t/a U in the year 2000. A more plausible range of demand for uranium within the limitations of the study was judged to be defined by mixed strategies, based on the combined exploitation of LWRs, HWRs and FBRs, deployed throughout WOCA. This range is from approximately 90 000 to 160 000 t/a U in the year 2000.

The production capacity for uranium was about 39 000 t/a U in 1978. In 1980 about 41 000 tons of uranium were produced in WOCA. The cumulative uranium production in WOCA up to 1980 was more than 600 000 tons of uranium. The production capability could be increased to some 90 000 t/a U by 1985. Some further possibilities for additional capability exist beyond 1985, based on current estimates of RAR and EAR in WOCA. A peak production level of the order of 110 000 to 120 000 t/a U is potentially achievable in the 1990s under optimum conditions. Production from the currently known resources would decline thereafter, owing to depletion of some deposits and the mining of lower-grade ore from others.

The INFCE conclusion on the match between uranium supply and demand (INFCE Summary Volume, page 11), taking into account the uncertainties involved in such comparisons, is that:

"... Additional sources of production are likely to be needed before the end of the century, possibly in the early 1990s. While some of the additional production required after the mid-1990s could be made available from high-cost or unconventional resources such as shales, the bulk of the required new production will have to be supported by new discoveries. Provided that the necessary exploration and investment can be made, the uranium industry should not experience undue difficulty in meeting requirements up to the year 2000 ..."

The achievement of adequate levels of production will also depend upon numerous other factors, the most important of which are the existence of a
favourable political and market climate, sufficient manpower and equipment, and the resolution of various environmental and regulatory uncertainties, including conflicts of land use, affecting uranium exploration and development.

In addition to uranium, thorium should also be considered. The overall knowledge of the world's thorium resources is significantly less than that of the world's uranium resources because little effort by the individual countries has been put into ore prospection for their thorium resources. The WOCA Reasonably Assured Resources of thorium, probably at costs less than US $75/kg Th, are currently estimated at one million tons. Additional Resources are estimated at 2.7 million tons. Thorium is currently used only for minor industrial applications and its production in WOCA is less than 1000 tons per year. Annual production from known resources could readily be increased should demand and economics warrant. Since the introduction of the advanced converters or fast breeders using the thorium-uranium fuel cycle is not expected on a commercial basis before the year 2000, significant thorium demands would not arise until after the turn of the century. There do not appear to be any foreseeable supply problems in meeting thorium requirements for those reactor strategies employing the thorium cycle.

3.3.2. Conversion and enrichment capacity and demand

The industrial-scale conversion of yellow cake (U3O8) to uranium hexafluoride (UF6) and from hexafluoride to uranium dioxide (UO2) is a well-proven technology which is not highly capital intensive. The production capability can be easily expanded to meet the projected demands.

There is an increasing tendency in many uranium producing countries to install conversion plants of their own, in order to export uranium in a more valuable form.

Operating conversion capacity in the USA, France, United Kingdom and Canada is about 50 000 t/a U. In addition, there are plans to increase this capacity by some 20 000 t/a U in the near future. There is also large conversion capacity operating in the USSR which offers services to its customers.

Comparison of conversion demand and supply capacity indicates that the present operating and planned plant capacities are adequate to satisfy the projected demand. Today's conversion prices are in the range of US $2.5 to 3.5 per kg U. Prices have barely changed in the last 15 years, which indicates very stable market conditions.

The total commercial enrichment capacity available in 1978, according to the information developed in INFCE, was 12.7 MSWU/a in the USA, 2.4 MSWU/a in the USSR and 0.3 MSWU/a jointly in the United Kingdom, Federal Republic of Germany and Netherlands.

In the 1980s substantial additional capacity is planned in the USA. There will also be sizeable contributions from other suppliers, EURODIF and COREDIF.
TABLE XVII. ENRICHMENT CONTRACT CONDITIONS

<table>
<thead>
<tr>
<th></th>
<th>US DOE AFC CONTRACT</th>
<th>URENCO</th>
<th>EURODIF COREDIF</th>
<th>USSR (TECHSNABEXPORT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead time – Contract execution to initial delivery</strong></td>
<td>6 – 10 years</td>
<td>5 – 10 years</td>
<td>8 years</td>
<td>None specified</td>
</tr>
<tr>
<td><strong>Term, years of delivery</strong></td>
<td>10 – 30 years</td>
<td>5 – 10 years</td>
<td>10 years, with options</td>
<td>Specified by contract</td>
</tr>
<tr>
<td><strong>Commitment</strong></td>
<td>All requirements of a designated reactor facility or specified fraction thereof</td>
<td>Requirements of designated facility or bulk purchase</td>
<td>Defined number of SWU per year; no designated facility</td>
<td>Defined number of SWU per year; designated facilities</td>
</tr>
<tr>
<td><strong>Advanced payment</strong></td>
<td>$600/MW(e) at contract execution; between $3700/MW(e) and $4000/MW(e) 6 years prior to initial delivery depending on time since initial payment</td>
<td>10% of contract value, with small payment at contract execution, major payment 4 years prior to initial delivery</td>
<td>5 annual payments, each approx. 3% of contract value. Est. to be approx. $16 000/MW(e)</td>
<td>None</td>
</tr>
<tr>
<td><strong>Lead time – SWU firm-up</strong></td>
<td>6 years prior to initial delivery</td>
<td>4 years prior to initial delivery</td>
<td>Upon contracting</td>
<td>Upon contracting</td>
</tr>
<tr>
<td><strong>Period of fixed commitment</strong></td>
<td>5 years; annual follow-on rolling 5 year basis</td>
<td>Term of contract</td>
<td>Term of contract</td>
<td>Term of contract</td>
</tr>
<tr>
<td>Flexibility options</td>
<td>US DOE AFC CONTRACT</td>
<td>URENCO</td>
<td>EURODIF COREDIF</td>
<td>USSR (TECHSNABEXPORT)</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>--------</td>
<td>-----------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Delay of initial del. period and/or deferral of deliveries upon payment of carrying charges</td>
<td>(a) Schedule deferral upon penalty payment based on loss to supplier</td>
<td>(a) Schedule deferral payment of SWU carrying charges, delivery of feed</td>
<td>(a) Schedule deferral by mutual agreement customer paying unspecified penalty</td>
<td></td>
</tr>
<tr>
<td>SWU quantity flexibility of +10% in fourth year and +20% in fifth year of fixed commitment</td>
<td>(b) +20% on 4 years' notice; +10% on 2 years’ notice</td>
<td>(b) +5–15% on 2 years’ notice</td>
<td>(b) +5% on notice 9 months prior to year of delivery</td>
<td></td>
</tr>
<tr>
<td>Viable tails assay option notice prior to year of delivery</td>
<td>15 months</td>
<td>4 years</td>
<td>2 years</td>
<td>9 months</td>
</tr>
<tr>
<td>Pricing</td>
<td>130% of “full cost recovery” as published in Fed. Register</td>
<td>240 DM (1975–01-01), subject to escalation. May be re-established at “World Market” price, by agreement</td>
<td>520 FF (1977-01-01), subject to escalation. May be re-established at “World Market” price, by agreement</td>
<td>DOE price; may be re-established based at “World Market” price, by agreement</td>
</tr>
</tbody>
</table>
in France, UNRENCO (jointly United Kingdom, Federal Republic of Germany, Netherlands), PNC in Japan. It is projected that the total commercial available capacities will be 43 MSWU/a in 1985 and 81 to 84 MSWU/a in 1995. Comparing supply capacities with demand, the result is that present uranium enrichment capacities in operation or under construction would cover projected enrichment needs until around 1990, whereas adding currently planned capacities would cover needs until after 1995. Beyond the year 2000 the additional separative work capacity that would have to be installed to meet the demands of the reactor strategies with the highest enrichment requirements would require a rapid expansion. However, the effort required for such an expansion in enrichment capacity should not be prohibitive, given the effort required for the corresponding expansion of nuclear power capacity.

The enrichment requirements of those countries not possessing enrichment plants are satisfied through enrichment services offered, under safeguards arrangements, by producers. At present the most important enrichers are the USA (Department of Energy, DOE) and the USSR. The USA (DOE) had a virtual monopoly position up to 1972/73, when the USSR first started to offer enrichment services through its national trading organization, Techsnabexport. In the near future EURODIF, COREDIF and URENCO are expected to take up an increasing share of the market.

The terms of the organizations offering enrichment services are presented in Table XVII. The adjustable Fixed-Commitment (AFC) contract of DOE was introduced in the spring of 1978. It replaces the Long-Term Fixed-Commitment (LTFC) contract offered until 1974. It can be seen from Table XVII that most contract conditions of the individual enrichers are to some extent similar.

In addition to the LTFC and AFC contracts there still exists the Requirements Contract, which is the oldest contract type. The Requirements Contract was abandoned in 1973; however, contracts concluded prior to this date are still being honoured.

3.3.3. Fuel fabrication capacity and demand

For the first core and first reloads of the power plants the fabrication of fuel elements is usually carried out by the reactor manufacturers according to their design specifications and the reactor design. The fuel elements are supplied with warranties of materials, quality, reliability and performance in the reactor core.

For subsequent loadings there are many fuel element manufacturers with free capacities, competing worldwide. It is also feasible to have a local fuel element fabrication plant installed, and practically all countries with nuclear power programmes have installed such plants or are planning to do so.
Worldwide fuel fabrication capacities have been in excess of demand, and there appears to be no difficulty in meeting the projected requirements. Owing to free competition, prices have been stable compared with those of either U₃O₈ or enrichment services.

3.3.4. Spent fuel reprocessing capacity and demand

In recent years attention has been focussed on reprocessing and extensive debates have taken place on the various aspects and impacts, in countries engaged in nuclear power programmes, of reprocessing and the separation and use of plutonium for recycling in LWRs or fast breeders versus deferment of reprocessing and recycle. In these debates many studies were undertaken dealing with various aspects of the technical and economic incentives for reprocessing of spent fuel, and of the potential proliferation risks.

According to the INFCE study, in 1979 only France had an industrial-scale reprocessing plant for oxide fuel from LWRs in operation, but eight more countries had plans to introduce such plants. Current worldwide commercial reprocessing capacity (1500—2000 t/a U, mostly for metal fuel) is far below demand expressed as spent fuel being produced in the operating nuclear power plants, but by 1990 reprocessing capacity is expected to reach about 10 000 t/a U.

By the end of the century European countries and Japan expect to have reprocessed most of their spent fuel arisings. On the other hand, most of the spent fuel arisings in the USA and Canada and in the majority of non-OECD countries are not expected to be reprocessed by the year 2000. This means that over 70% of world spent fuel arisings will not have been reprocessed by the year 2000; only decisions to start reprocessing together with immediate and large-scale investments in new reprocessing capacity beyond that currently planned could significantly change the situation.

3.4. MANAGEMENT AND DISPOSAL OF RADIOACTIVE WASTES

The objectives of waste management are:
(a) To perform safely and efficiently a series of operations leading from the collection of wastes arising from nuclear operations through waste conditioning and transport to storage and disposal; and
(b) To ensure that no unacceptable detriment to humans will occur at any time as a result of these waste management and disposal operations.

It must be remembered that management and disposal of radioactive wastes are always a national responsibility.

The radiological aspects of waste disposal are discussed in Chapter 6, while the technological aspects of waste management are briefly treated in the following
sections. Two unique aspects of radioactivity are of benefit to the safe manage­ment and disposal of radioactive waste:

(1) Radioactive wastes decrease in radioactivity with time due to the natural decay process. This results in significant reductions in both their radiotoxicities and heat generation rates with time.

(2) Radioactivity can be detected and measured at very low levels with today’s sensitive instruments. This feature is used in monitoring the safety of waste management operations, so that abnormal conditions can be detected and corrected before hazardous conditions arise.

The methods used for radioactive waste management involve three fundamental approaches. Depending upon their quantities and characteristics, the radioactive materials can be:

(a) Concentrated and contained for a time long enough to ensure that any subsequent release will not result in radiation exposures to human beings in excess of acceptable levels

(b) Deposited and left to decay in storage before release to the environment

(c) Diluted and dispersed immediately into the environment.

There are very few instances where effluents from nuclear facilities can be released without some form of control or treatment. Most of the radioactive wastes arising from the operation of nuclear fuel cycle facilities require processing to remove and concentrate the radionuclides into reduced volumes that can be more conveniently handled, thereby permitting the release or disposal of the bulk of the decontaminated materials.

There are three basic elements of an integrated waste management system:

(1) Effluent control
(2) Conditioning of retained radioactive materials to facilitate their handling
(3) Storage and disposal.

3.4.1. Types of wastes and effluent control

Whenever practicable, radioactive materials are concentrated and contained so that they are isolated from the human environment until the radioactivity has decayed to acceptable levels. When release to the environment is necessary, the rates of release must be low enough so as not to exceed the local capacity of the environment to disperse and dilute materials to acceptably low concentrations. In this respect the environmental processes that may lead to reconcentration and may provide a pathway for human exposure to additional radiation must be considered.

(a) Gases

Gaseous wastes are generated in nearly all stages of the nuclear fuel cycle. Adequate control of ventilation air in underground uranium mines is required
to prevent undue exposure of miners to radon and its daughter products. Open pit mines and uranium mill tailings in open, well-ventilated areas do not present a serious radiation hazard.

In uranium enrichment and refining operations non-radioactive chemicals are often more of a problem than radioactive contaminants in off-gas streams. Small quantities of gaseous wastes are produced during reactor operation.

The waste management techniques now in use for gaseous wastes are primarily delay and decay, iodine sorption and filtration. Radioactive particulate matter and aerosols in gaseous wastes are removed by high-efficiency filtration techniques. Release of the effluent gases to the environment is ultimately through high stacks fitted with monitoring equipment which registers activity levels and flow rates, so that activity levels in discharged gases are known and recorded. At reprocessing sites, especially, a programme of environmental monitoring is carried out in the area surrounding the plant, often extending for some kilometres around to ensure that activity levels remain acceptable.

Radiation doses to the population from these emissions are kept well within the recommendations of the International Commission on Radiological Protection (ICRP).

(b) Liquids

Radioactive liquid wastes are operationally classified as high-level, intermediate-level and low-level, based on their radioactivity levels.

**High-level liquid waste** is primarily an aqueous waste solution from the first cycle of fuel reprocessing operations and the products of its treatment and conditioning. This waste contains over 99.9% of the non-gaseous fission products, the unrecovered plutonium and uranium, and the higher actinides (transuranics) generated in power reactors and contained originally in the spent nuclear fuel.

**Intermediate-level liquid wastes** are typically off-gas scrubber solutions, ion-exchange regenerates, cask and plant decontamination solutions, solvent washes, chemical decladding solutions, aqueous wastes solutions from uranium and plutonium purification cycles and some laboratory wastes.

Examples of **low-level liquid wastes** are evaporator condensates, laundry wastes, condensates from process vessel ventilation systems and possible radionuclide leakage into cooling water or process steam.

The distinction between intermediate and low-level wastes is rather arbitrary and, in addition to their radionuclide content, the classification generally depends upon the extent to which they must be processed. While intermediate and low-level liquid wastes vary considerably with respect to their transuranic and fission product content, nevertheless there is a distinct difference between their treatment processes and those for high-level waste. They are treated by a selection or combination of methods such as evaporation (with transference of the concentrate
to the high-level wastes), ion exchange, chemical precipitation and filtration. Waste ion-exchange resins, sludges and filters are retained as solid wastes. Thus, the great bulk of the intermediate-level and low-level wastes is transformed into liquid effluents that can be discharged to the environment.

One radionuclide worth special mention is tritium, formed during reactor operation. The half-life of tritium — 12 years — is rather long, and it is dispersed in the biosphere easily. Careful evaluation has shown that it presents no significant hazard to the public in the amounts in which it is released to the sea or to river systems from reprocessing plants. Nevertheless, measurements are always made both in releases and subsequently, if possible, in the environment.

(c) Solids

Solid radioactive wastes arise from all operations in the nuclear fuel cycle and may contain a wide variety of materials. Solid wastes fall into one of two categories, combustible or non-combustible.

Combustible solid radioactive waste consists of a large variety of materials such as paper, rags, absorbent cotton, plastic sheeting, protective clothing, gloves, rubber shoes, wood, cardboard, organic ion-exchange resins, filter aids, combustible high-efficiency filter media, etc. Since much of these waste materials is collected as general trash, it is generally sorted prior to incineration.

The primary constituent of non-combustible solid waste is metal, including fuel cladding, but other materials such as glass and concrete are significant. Non-combustible waste includes some items that offer difficult handling problems because of their large size, such as failed equipment, solvent extraction columns of reprocessing plants, components from the reactor core, etc.

A special category of solid wastes arises in uranium milling. In the uranium mill the ore is crushed and ground, then leached to extract the uranium. The majority of the ore is not dissolved in the leaching stage and is a waste material called tailings, which still contains most of the natural radioactive daughter products originally in the ore. The tailings are usually pumped as a slurry into a specially constructed retention system where they are confined. Control of tailings is necessary to minimize the dust nuisance, to limit natural leaching from the retention system which could lead to groundwater pollution, and to prevent access to the tailings by the public. In the past adequate care has not always been taken to control the tailings in the environment. Possible future approaches include returning the tailings to fill worked out mines or covering the tailings with soil and revegetating the whole area.

3.4.2. Waste conditioning

Waste conditioning involves those operations that transform wastes into forms suitable for transport, storage and/or disposal. Operations may include
converting the waste to another form, placing into containers and additional packaging.

For low and intermediate-level wastes the concentrates or solid residues can be immobilized by incorporation into a matrix of concrete, bitumen, plastic or metal. Residues from low or intermediate-level wastes are often packaged in drums or containers for transportation, storage and disposal.

The principal waste from reprocessing is a high-level liquid containing essentially all the fission products and the remaining transuranium elements. This is the most radioactive waste in the entire nuclear fuel cycle and is of major importance in waste management.

Several approaches have been developed for the immobilization of high-level waste, the most developed to date being the vitrification process. This immobilization process uses glass-forming constituents to incorporate the calcined waste into a glass melt, which cools to a vitrified waste form. There are numerous approaches to producing essentially the same vitrified waste form; however, the French AVM process, which started full-scale industrial operations at Marcoule in 1978, is the only process developed beyond the demonstration stage. Other forms for immobilization of high-level wastes (e.g. ceramics, metal matrices, etc.) are under development for potential future use.

3.4.3. Storage and disposal

Safe handling of nuclear waste materials has been emphasized since the beginning of the atomic stage, probably more so than for other types of toxic wastes (e.g. asbestos, arsenic, lead, etc.). Nevertheless, nuclear waste disposal is perceived by some of the public as presenting insurmountable problems, perhaps because of a misinterpretation of this emphasis on safety, or because of the unique aspects of radioactive wastes. Most people knowledgeable about nuclear waste management consider that the technology for safe disposal of radioactive wastes is already available and the situation is really one of deciding which of several possible approaches should be selected and when to implement them.

Before further discussion of the subject, it is important to define the terms 'disposal' and 'storage' (frequently called 'interim storage'):

In the case of 'disposal', there is no intention to recover the waste, although its recovery may be technically possible, or to provide for more than routine surveillance of the site for some limited time.

In the case of 'storage', the waste is accessible for inspection, recovery, repackaging, etc. and there is an intention to carry out such work.

Safe methods for the storage and disposal of low and intermediate-level wastes are operational and well founded. Solid wastes, or those that have been converted to solid forms, are often disposed of by shallow ground burial and may also be
placed in natural mines or rock cavities. When this method is used, site selection is of considerable importance because the climatological, geologic and hydrologic characteristics of the site are important in determining the likelihood that radio-nuclides will not leach from the burial site in unacceptable quantities over the time period the wastes remain toxic.

Sea disposal under controlled conditions is also used for both liquid and solidified low-level wastes.

Methods for the management and storage of high-level and alpha-bearing wastes are also operational and well proven. However, the methods for disposal of these wastes have not yet been selected or demonstrated. Extensive research and development are being performed in numerous countries to ensure that the necessary technological basis for disposal will be available when the time for decision arrives.

In the case of interim storage, a number of different designs for retrievable surface storage facilities have been examined. All proposals for engineered storage involve loading the immobilized waste into stainless steel canisters. Ten canisters, each of 0.3 m diameter and 3 m long, would be required each year for the high-level waste from a 1000 MW(e) reactor. These canisters would then be stored either individually in shielded casks in regulated open areas, in air-cooled vaults, or in water-cooled ponds. The last approach is similar to that used worldwide to store irradiated or spent fuel assemblies discharged from a reactor.

Retrievable surface storage facilities can only be used for an interim period because no man-made structure can be expected to maintain its integrity for an indefinite time. Thus, at some appropriate time the wastes must either be relocated to new storage facilities or be disposed of in an ultimate way.

Many methods for disposal of high-level and alpha-bearing wastes have been studied, but only their emplacement in deep (e.g. up to 1000 m) geological formations — such as in salt mines, hard rock or clay — is considered to be feasible to implement in the near future.

Many factors must be considered in the selection of a geologic site for disposal. The site must be located in a region with a very low frequency of earthquake and volcanic activity. Hydrogeological conditions such as rock permeability and the characteristics of groundwater in the region are important. The area should have a low potential for future oil, natural gas or mineral exploitation. However, the land requirements are not large; for example, it has been estimated that less than 800 hectares of a salt deposit would be required to dispose of all high-activity and alpha-bearing wastes generated by the nuclear industry in the United States of America until the end of this century. Salt deposits were formed millions of years ago and, since salt is soluble in water, their very existence is proof that they have never been subjected to major water erosion. Other geologic media are also available with very low groundwater content and flow rates.

A diagram of a deep geologic disposal repository for high-level and alpha-bearing wastes is shown in Fig.6. The packaged wastes are received at a facility
at the earth’s surface above the repository. The wastes are lowered into the mine and transported to one of a matrix of tunnels or rooms. From there they are lowered into pre-drilled holes. When a hole is filled with waste, it is backfilled with sealant. When all the holes in a room are filled with waste, the room is backfilled with some of the excavated rock and sealed from the rest of the repository. When the repository is full, it is backfilled and sealed.

The design and construction of mined geologic repositories are based on available mining technology resulting from extensive, worldwide experience in mining for minerals and constructing caverns. However, engineering a repository also requires consideration of other aspects unique to radioactive wastes. Thus, detailed, systematic, site-specific investigations and evaluations are required. Several features, including the natural and engineered barriers to radionuclide migration, are used to engineer a repository. Safety assessments of such a repository, engineered and operated with conservative practices, provide assurance that the radionuclides in the emplaced waste will not reach the human environment in unacceptable amounts.

There are two main reasons why a repository system for high-level waste has not yet been demonstrated. The first is that the present and projected volumes of commercial high-level wastes for tens of years are so small that the need does not yet exist. The second reason partly stems from the first. From a technical standpoint, the time is being used to perform research and development work in order to determine the best designs of a system. As a consequence, a final system design has not yet been completed. Some countries expect to initiate construction and operation of a waste repository in the next decade or two.
3.5. SPECIAL REACTOR MATERIALS

In addition to nuclear fuel, nuclear power plants require several special materials which had to be especially developed for nuclear applications. Zircaloy and heavy water are two of these special materials.

3.5.1. Zircaloy

Zircaloy is used for fuel cladding and for structural components of the fuel elements of all water-cooled reactors. In fuel elements most of the Zircaloy is for fuel-cladding tubes, but sheets, bars and wires are also needed. For the core of a 1000 MW(e) PWR about 20 tons of Zircaloy are needed. This includes about 200 km of tubes. For natural-uranium-fuelled PHWRs 6 to 8 times more Zircaloy is required annually. In addition, the PHWRs of the CANDU design also require Zircaloy for the pressure tubes.

Zircaloy contains about 98% zirconium, which has a difficult metallurgy. Zirconium is obtained from zircon sands, which are a mixture of zirconium (Zr) and hafnium (Hf) silicates. Zircon is first purified and then transformed into zirconia (a Zr and Hf oxide). It is necessary to separate Zr from Hf, because Zr is transparent to neutrons (hence it is used for nuclear fuel cladding) and Hf is highly neutron absorbing.

Once hafnium-free, zirconium oxide is reduced and metal is obtained in the form of a zirconium sponge, which is a commercial product, but cannot be used as it is. It is necessary to manufacture sheets and semi-products, in particular tube reduced extrusions (TREX). As a final step in the manufacturing process, tubes are produced from reduced extrusions by rolling or drawing.

All these successive transformations require sophisticated techniques and vacuum metallurgy. The whole process has been mastered only by a few countries and production on an industrial scale is done only by a few companies.

Zircon is rather widespread in nature. At present Australian beaches provide most of the world’s zirconium needs. Most of the world’s zirconium consumption is for siderurgy (zirconium oxides or silicates); the nuclear industry represents only a very small fraction of the demand.

Hafnium-free sponge is only produced by a few countries. The largest producers are the USA (two companies with 3000 and 1500 t/a production rates respectively) and France (one company with 1600 t/a). These are also the main producers of sheets and tube reduced extrusions. The manufacturing of tubes is more diversified; important factories exist, in addition to the USA (6700 km/a), in Europe (France, Federal Republic of Germany and Sweden — total 3800 km/a) and in Japan (900 km/a). The USSR is also an important producer.

Present and planned production rates seem adequate to supply the world-wide requirements of the nuclear industry and there have been no major
fluctuations in prices. Owing to the fact, however, that Zircaloy constitutes an essential material for keeping the nuclear power plants operating with a significant yearly rate of consumption, several countries with nuclear power programmes have decided to develop their own domestic manufacturing capabilities. Zircaloy is considered a sensitive material from the non-proliferation point of view.

3.5.2. Heavy water

Heavy water is required as a moderator and coolant of the PHWRs. By far the largest portion is needed for the initial inventory, which consists of about 0.8 t/MW(e) installed capacity. Make-up requirements are very small in comparison, about 0.5 to 1% of the inventory per year. This is due to losses. Heavy water is not consumed. In fact, it can be recovered from the reactor upon decommissioning and can be reused for new reactors. Except for some research purposes and some minor use in the pharmaceutical industry, the sole use of heavy water is in the nuclear power industry.

The world's water resources, oceans as well as fresh water, provide an essentially unlimited source of heavy water (deuterium oxide, D$_2$O). The deuterium concentration in ordinary water varies between $130 \times 10^{-6}$ and $160 \times 10^{-6}$. The quantity of deuterium thus available is so large that extraction of large quantities has no measurable effect on the concentration of that which remains. Hydrogen is another attractive source of deuterium, if available in large quantities and if there is a high degree of continuity of supply.

Though almost 100 potential processes for producing heavy water have been proposed, studied in the laboratory or tried on a pilot-plant scale, only a few can be considered economically feasible today.

The most economic processes developed up to now involve deuterium exchange between two different hydrogenous materials, one a gas and the other a liquid. The process in most widespread use is the dual-temperature exchange process using hydrogen-sulphide gas flowing in closed circuit and water flowing countercurrently to the gas. This process is called the Girdler-Sulphide (GS) process and most of the heavy-water produced in the world has come from such plants. The process is cascaded, a product which is typically 10 to 20 wt.% D$_2$O emerges from the GS unit and is then brought to reactor grade by vacuum distillation.

Water or hydrogen distillation and water electrolysis are too expensive to be used as primary extraction processes. They are used, however, to concentrate from greater than 5 to 20% D$_2$O to reactor grade (99.8 wt.%).

The GS process is fairly simple and lends itself well to large-scale use. However, potential corrosion problems require careful attention and special safety precautions must be taken due to the presence of large quantities of hydrogen sulphide, which is a toxic gas.

Another process which is being employed on an industrial scale is the ammonia-hydrogen process. This is also based on chemical isotope exchange. It
requires a large flow of hydrogen as a feed steam. Synthesis gas (3H₂ + N₂) produced for ammonia synthesis is currently the largest source of hydrogen.

Heavy-water production costs are roughly proportional to separative work, and most of this work is required to raise the deuterium concentration to about 1% D₂O from the natural abundance. Heavy-water plants are capital intensive; however, the capital investment of a heavy-water plant is about 5% of the capital investment of all the heavy-water moderated nuclear power plants for which the heavy-water inventories and make-up can be supplied by the heavy-water plant during its lifetime.

A small (20 t/a) heavy-water production plant in Norway using the electrolysis process has been in operation since 1934. In the early 1950s the USA developed the GS process and became the most important heavy-water producer. It effectively supplied the world market for about two decades. Since the early seventies Canada became the world's largest heavy-water producer with a current nominal capacity of about 2400 t/a using the GS process.

India has five heavy-water production plants with an overall nominal capacity of about 300 t/a. The first plant was started up in 1962 using electrolysis/H₂ distillation; three plants use the ammonia-hydrogen process and one the GS process. Heavy water is also produced in the USSR. Argentina has a pilot plant and a 250 t/a plant under construction.

Large quantities of heavy water (as needed for the inventory of PHWRs) are currently supplied by Canada together with the supply of the Canadian-designed PHWRs. Smaller quantities have been exported by the USA and the USSR. Heavy water is considered sensitive from the non-proliferation point of view.
Chapter 4

ECONOMICS OF NUCLEAR POWER

4.1. GENERAL CONSIDERATIONS

A rigorous analysis of the economics of nuclear power should consider this energy source within the overall energy and economic development scenario of a country. In this way, the economic effects of the nuclear power programme on the energy supply market as well as on the national industrial and manpower infrastructures could be properly assessed. Such a global assessment is very difficult to achieve, so normally a more modest approach is used, consisting of the economic analysis of the electric power-generating system expansion. This approach can provide a reasonably clear indication of the economics of nuclear power in the country. Chapters 8 and 10 discuss the electric system analysis in more detail.

A simpler approach consisting of a direct comparison between the economics of nuclear power plants and their competitors, namely fossil-fuelled power plants for base load power generation, could only provide very rough indications regarding the economic competitiveness of nuclear power. Obviously, such an analysis would disregard the effects between the nuclear (or coal or oil-fired) plants and the whole power-generating system and associated transmission facilities.

In general, it can be stated that nuclear power plants of the sizes currently on the market are and will continue to be economically competitive with oil-fired plants. In fact, the economic advantage of the nuclear power plants over oil-fired plants is overwhelming, given the present level of the international oil prices.

In comparing electricity costs from nuclear and coal-fired power plants, the results depend on a number of factors, and there is no single global answer. However, results from current IAEA studies indicate that in most situations large nuclear power plants becoming operational in the near future can produce electricity at costs as much as 10 to 40% below the costs from coal-fired power plants, depending on the cost of coal. In some special situations, however, such as in areas of the USA with low-cost coal available to plants at nearby or mine-mouth locations, coal-fired power plants can deliver electricity at costs competitive with or lower than nuclear. The key economic factor for coal-generated electricity is the cost of coal delivered to the power station. IAEA studies indicate that coal plants have an economic advantage when coal can be delivered to the power plant at costs below $30 per ton. For nuclear power the key factor is the total capital investment cost, which is significantly increased when interest rates are high and
lead times long. For coal-fired plants stringent environmental protection regulations are expected to be applied in the future. These will increase their capital and operational costs, placing nuclear power in a more competitive position.

4.2. COMPONENTS OF NUCLEAR POWER GENERATION COSTS

The main components entering into the calculation of nuclear power generation costs are listed in Table XVIII. The basic elements are capital investment, nuclear fuel cycle, and operating and maintenance (O&M) costs. Additionally, infrastructure development costs such as R&D and transfer of technology from developed countries, domestic industrial and manpower development associated with a nuclear power programme, should be factored in. But it should be considered that there are also benefits in the development of such activities. Plant performance is reflected in its load factor, power rating and economic life; the economy of the country is reflected through domestic and foreign interest, escalation and discount rates used in the analysis. All these factors will be defined and briefly discussed in the following sections. Definitions are also given in the Glossary of Terms in the Appendix at the end of this chapter.

4.2.1. Capital investment costs

The capital investment cost of a nuclear plant (or, in general, of any power plant) is the sum of all expenditures incurred in the design, licensing, manufacturing and erection, construction and commissioning of the plant.

Several accounting systems are used to distribute the capital investment cost into its principal parts; the breakdown shown in Table XIX is the one employed in the IAEA. It shows the cost structure and defines 'direct', 'indirect', 'base', 'fore' and 'total capital investment costs'. The 'fore cost' as defined here does not...
TABLE XIX. STRUCTURE OF THE POWER PLANT CAPITAL INVESTMENT COST

<table>
<thead>
<tr>
<th>Direct cost</th>
<th>Indirect cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures and site facilities</td>
<td>Construction management, equipment and services</td>
</tr>
<tr>
<td>Reactor/boiler equipment</td>
<td>Home office engineering and services</td>
</tr>
<tr>
<td>Turbine plant equipment</td>
<td>Field office engineering and services</td>
</tr>
<tr>
<td>Electric plant equipment</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous plant equipment</td>
<td></td>
</tr>
<tr>
<td>Cooling system, etc.</td>
<td></td>
</tr>
</tbody>
</table>

**BASE COST = DIRECT + INDIRECT COST**

+ Owner's costs
+ Spare parts
+ Contingency

\[ \text{FORE COST} = \text{BASE COST} + \text{Contingency} \]

+ Interest during construction (IDC)
+ Escalation
+ Interest on escalation

\[ \text{TOTAL CAPITAL INVESTMENT COST} = \text{BASE COST} + \text{Contingency} \]

**Items not considered above:**
- Initial fuel loading
- Heavy-water inventory
- Cost of land
- Taxes and fees
- Infrastructure development costs
include the effects of inflation (escalation) of prices to be paid for labour, equipment, material and services, nor does it include interest on capital borrowed during the construction period. All of these items are included in the defined total capital investment cost. Items such as initial fuel loading, heavy-water inventory, cost of land, taxes and fees have been excluded from the present definition of total capital investment costs. There are other accounting methods that do include these items or some of them, or that include all or some of the infrastructure development costs (see section 4.2.4).

The contribution of capital investment costs to the bus bar power generation costs is the result of the annual fixed charge, which includes depreciation of and interest on the total capital investment cost. The capital recovery factor is normally used as the fixed charge factor when depreciation of investment is carried out using the sinking fund method. For nuclear power plants the annual capital charge is the largest contributor to the unit power generation cost. Items excluded in the IAEA accounting system from the total capital investment cost, of course, do contribute to the power generation cost; they are accounted for in the fuel or O&M costs.

4.2.2. Nuclear fuel cycle costs

The lower nuclear fuel cycle cost as compared with fossil-fuel costs is the key factor in the competitive position of nuclear power plants.

Chapter 3 contains the main technical aspects of the various options available for the nuclear fuel cycle. The complexity of nuclear fuel cycle economics stems from the fact that it involves numerous expenditures made at different points in time before the fuel is actually loaded into the reactor and energy production begins, as well as other disbursements made a long time after the spent fuel has been unloaded from the reactor for ultimate disposal or for reprocessing, production of new fuel with recovered fissionable materials and disposal of radioactive wastes.

The front-end processes of the nuclear fuel cycle include the costs incurred in the exploration, mining and milling of uranium, conversion into UF₆ and enrichment in the ²³⁵U isotope (in case of reactors fuelled with enriched uranium) and, finally, fabrication of fuel elements. Of course, all costs for transport between processes and dispatch to the reactor site are included as well.

The back-end processes of the nuclear fuel cycle include the expenditures incurred in storage and transport of irradiated fuel, and reprocessing for extraction of plutonium and uranium, and the separation, concentration and final disposal of radioactive wastes in the case of a closed fuel cycle. The economic effect of recycling the recovered plutonium and uranium (closed cycle) is to add a credit to the nuclear fuel cycle costs. Interest on the expenditures incurred during the front-end as well as the back-end of the fuel cycle constitute the 'indirect cost' of the nuclear fuel cycle. Direct plus indirect costs determine the total nuclear.
TABLE XX. STRUCTURE OF THE NUCLEAR FUEL CYCLE COST

<table>
<thead>
<tr>
<th>Natural uranium reactor</th>
<th>Enriched uranium reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front-end costs</strong></td>
<td><strong>Front-end costs</strong></td>
</tr>
<tr>
<td>Natural uranium</td>
<td>Natural uranium</td>
</tr>
<tr>
<td></td>
<td>Conversion to UF₆</td>
</tr>
<tr>
<td></td>
<td>Enrichment</td>
</tr>
<tr>
<td>Fuel fabrication</td>
<td>Fuel fabrication</td>
</tr>
<tr>
<td>Transportation</td>
<td>Transportation</td>
</tr>
<tr>
<td><strong>Back-end costs</strong></td>
<td><strong>Back-end costs</strong></td>
</tr>
<tr>
<td>Storage and transportation of irradiated fuel</td>
<td>Storage and transportation of irradiated fuel</td>
</tr>
<tr>
<td>Reprocessing</td>
<td>Reprocessing</td>
</tr>
<tr>
<td>Credit for plutonium</td>
<td>Credit for plutonium</td>
</tr>
<tr>
<td></td>
<td>Credit for uranium</td>
</tr>
<tr>
<td>Disposal of wastes</td>
<td>Disposal of wastes</td>
</tr>
</tbody>
</table>

Direct cost = Front-end + back-end costs
Indirect cost = Interest on direct costs
Total nuclear fuel cycle cost = Direct + indirect costs

fuel cycle cost component of the energy produced by the fuel burnt in the reactor (see Table XX). Since many fuel batches of different composition may be used during the life of the reactor, it is customary to calculate the levelized cost of the energy produced by the nuclear plant throughout its lifetime.

4.2.3. Operation and maintenance costs (O&M)

Table XXI lists the components of the O&M costs as used by the IAEA in order to compare cost experiences from different sources and different types of plants. Some of the O&M costs are fixed costs (e.g. wages and salaries, insurance and other fees), while others have fixed and variable components. The variable costs depend on the number of operating hours (e.g. consumables and maintenance materials, repair costs, maintenance services performed by off-site plant staff).
TABLE XXI. STRUCTURE OF THE POWER PLANT OPERATION AND MAINTENANCE COST

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wages and salaries</td>
<td>Power plant staff and administrative staff</td>
</tr>
<tr>
<td>Operation and maintenance materials</td>
<td>Maintenance materials and equipment required to repair or replace plant equipment; repair costs; consumable materials and expenses, etc.</td>
</tr>
<tr>
<td>and equipment, repair costs, etc.</td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>Property and nuclear liability insurance fees</td>
</tr>
<tr>
<td>Inspection</td>
<td>Routine inspection fees</td>
</tr>
<tr>
<td>Purchased services</td>
<td>Maintenance services and repair performed by off-site staff</td>
</tr>
<tr>
<td>Other costs</td>
<td>All other relevant O&amp;M costs not included in the above categories</td>
</tr>
</tbody>
</table>

Items not considered: National and local taxes and fees
Cost of water

4.2.4. Infrastructure development costs

There are many tasks and activities involving certain expenses, which are needed for the implementation of a nuclear power project and a nuclear power programme but which are usually not included in the power generation costs. Such activities are:

- Planning studies
- Scientific research and development in support of a nuclear power programme
- Manpower development at all levels, except regarding the training of the operations staff, which is included in the owner's cost
- Development of national infrastructures (governmental, regulatory, industrial, education)
- National participation promotion
- Technology transfer
- Regulatory and licensing costs.

These infrastructure development costs are difficult to evaluate and express; it is also questionable whether they should be charged to a single nuclear power
plant or to a long-term nuclear power programme. It must also be considered that they can produce benefits by promoting the country's overall development. The usually accepted procedure is to assume that infrastructure development costs and the benefits resulting from them compensate each other.

4.2.5. Economic parameters and groundrules

The annual generation of a power plant is directly proportional to the plant net electric power rating and its effective use expressed by the load factor. The expected plant load factor is possibly the most uncertain parameter since, in addition to planned shutdown periods for scheduled refuelling and maintenance, forced outages always occur owing to unexpected events. The IAEA defines the annual plant load factor as the ratio between actual energy produced and energy that the plant could have produced at its rated capacity under continuous operation during the year (see also section 2.7).

The interest rate on money borrowed to meet the cash flow requirements during the construction period has a great impact upon the interest to be paid during construction (IDC) of the plant. Moreover, escalation of prices during construction will increase capital costs. Altogether, high interest and escalation rates compounded with lengthy construction periods will lead to substantial additions to the fore costs. The opportunity cost of money (i.e. discount rates) in the country (or region) where the plant is built and operated plays an important role in the economic analysis of power plants. The national discount rate to be used in the analysis is affected by the inflation rates, which are related to interest rates. Whereas the national discount rate should be used in the economic analysis of nuclear power at the country level, the commercial interest rate should be used in financial analysis at the electrical utility level.

In the economic analysis the assumption is usually made that inflation will affect power generation costs for all alternatives in the same way and, consequently, all cash flows can be expressed in constant value currency. However, for financing analysis purposes, some assumptions regarding inflation rates should be made in order to determine the expected future flow of payments.

The plant (economic) life plays a role in the determination of the annual fixed charges due to depreciation of and interest on the capital investment; the economic life and the discount rate will define the capital recovery factor to be used for calculating the annual fixed charges on capital investments.

4.2.6. Power generation costs

According to the above considerations, the total annual power generation cost of the power plant consists of a fixed charge on capital investment, an annual fuel cost and annual O&M expenses. In addition and according to the criteria
adopted, there might be an annual charge for infrastructure development costs. On a pro-rata basis a levelized energy cost (levelized cost of kW·h) can be also calculated assuming that the electric energy generated by the plant produces revenues (priced at the levelized unit cost of the kW·h) whose present-worth value equals the present-worth value of all expenditures incurred in the implementation and operation of the plant. The latter approach is the one normally followed by the IAEA.

4.3. AVAILABLE ECONOMIC DATA

4.3.1. Capital investment costs

The estimated and real (experienced) capital costs of power plants — no matter whether fossil, nuclear or hydro — show a very wide range of values. This is not surprising since the same phenomenon is experienced in constructing many other capital-intensive facilities like factories, hospitals, office buildings, etc. A scattering of capital cost values can be observed at a country level, but the range is especially wide in worldwide comparisons. An example of cost data is given in Fig. 7, which shows the evolution of capital investment costs in the USA, expressed in 'mixed years dollars', which means adding up the current expenses when they occur on a yearly basis.

Interpretation of the dispersion observed in power plant capital costs is very difficult, even if the most important parameters affecting the costs are identified. Differences can be partially explained by a combination of the following factors:

- **Economic factors** — market conditions, inflationary effects, financial costs, exchange rate of currencies;
- **Plant design** — plant type and size, number of units per site, safety and environmental protection requirements, site conditions and plant layout;
- **Project management** — type of contract, construction management, experience of suppliers and owner, plant construction time and lead time between commitment date and start of construction;
- **General policy factors** — degree of national industry participation; incentives for industrial development; regional development policy, etc.

The continued inflation observed in most countries in the last decade has contributed to hiding the actual increases in capital costs of nuclear plants, as well as for fossil-fired plants, stemming from more stringent safety and environmental protection requirements and longer lead and construction times.
For the purpose of evaluating plant capital investment cost trends, it is therefore necessary to remove from reported values the distortion introduced by escalation of prices in the power plant construction industry and focus only on the fore costs expressed in constant currency of a selected year. Such an exercise has been performed using data available for the USA for large nuclear and coal-fired power plants. The results are presented in Fig. 8 (fore costs, as defined in Table XIX). In constant 1980 dollars, the average fore cost for a LWR normalized to 2 × 1000 MW(e) unit has increased in the USA from 460 to 770 US$/kW(e) for commitments made in the years 1966 and 1971 respectively, i.e. 70% increase in real terms. A similar situation is found for coal-fired plants normalized to 2 × 500 MW(e). In constant 1980 dollars, the fore cost has increased from 360 to
The licensing and construction period of nuclear plants in the USA has steadily increased up to about 13 years. As a consequence, most nuclear units committed after 1971 are not yet in commercial operation and their total capital investment costs — containing considerable amounts for escalation and interest during construction — are still to be known.

Estimated fore costs for LWR power plants in France for commitment in 1981 are about 4000 and 3900 FF/kW(e) for 4 × 900 and 4 × 1300 MW(e) PWRs, respectively, in constant 1981 FF. A high degree of standardization has been
applied in France to about 30 PWRs of 900 MW(e) each, most of which are under construction, and to the 1300 MW(e) PWRs that are planned. The design and construction period is kept to about six years by standardization and a straightforward licensing procedure. As a consequence, interest during construction and escalation are estimated to be lower than in other countries where more time may be needed to put a large nuclear plant in commercial operation. Estimated fore costs for PHWRs in Canada are reported to be 1500 to 1900 US$/kW(e) for plants composed of four units in the range of 600 to 800 MW(e) per unit (the cost of heavy water is excluded).

4.3.2. Evolution of fuel cost components

The historical evolution of both uranium and crude oil prices is shown in Fig. 9, expressed in current US$ and also in constant 1980 US$. Most of the
increase in the natural uranium price at current dollars occurred during the period 1974–1977 reaching values in the range 88 to 97 US$/kg of U₃O₈ (40–44 US$/lb). If the U₃O₈ price is expressed in constant 1980 US$, the increase occurred in the period 1974–1976 when the U₃O₈ price reached a peak value close to 130 US$/kg (60 US$/lb), i.e. almost 5 times the U₃O₈ price existing at the beginning of 1973 (also expressed in constant 1980 US$). Starting from 1977, the U₃O₈ price in constant 1980 US$ began a steady decrease towards values in the range of 62–66 US$/kg (28–30 US$/lb) in the year 1980. The recent U₃O₈ price decrease is apparently due to (natural) uranium production exceeding demand, combined with high levels of stocks maintained by the consumers.

Comparing the uranium and oil price curves of Fig. 9, it is interesting to observe that the 1973–74 major oil price increase was immediately followed by a major uranium price increase. After these increases the price of both uranium and oil remained almost constant (in constant currency values) for several years. In 1979 a second major oil price increase occurred but this was not accompanied or followed by a uranium price increase in 1980–81.

Regarding enrichment of uranium, as shown in Fig. 10, the USA price of a separative work unit (SWU) in current dollars has steadily increased in the last ten years from 32.5 to 102 $/SWU, i.e. an increase of more than 210%. However, when the price of separative work is expressed in constant 1980 US$, the actual increase in the last ten years has been only about 27%.

Another important contributor to the nuclear fuel cycle cost is the price of fabrication of the fuel elements. Its average value (for LWRs) has increased from about 80 US$/kg U in 1970 to about 150 US$/kg U in 1980, i.e. an increase of about 90% in current dollars, but a decrease of 24% in constant dollars. The reason for this trend in the cost of this service has to be found in technological development and mass production of fuel.

### 4.4. LIMITATION AND UNCERTAINTIES OF COST ESTIMATES

Planners should avoid extrapolating existing economic analyses that were made for and are valid only for a specific case.

Cost estimates should be made for a particular country and site, accounting for all relevant factors and conditions, such as local infrastructure, current international market, trends in the national and international economy, site characteristics, etc. Moreover, a distinction should be made between cost estimates intended for economic comparisons and cost estimates needed for analysis of payment schedules (cash flow studies). Economic comparisons should be made, whenever possible, by removing from the costs the inflationary effects of the national and international economies, i.e. costs should be expressed in constant money of a selected base year. However, expected future price increases
of a particular item above expected average inflation of the economy should be accounted for by means of a differential (real) escalation rate applied to the price of that particular item. Whereas it is important to remove the distortion introduced by inflation from economic comparisons, it is relevant to include inflationary effects on payment schedules when estimating the future financial needs. This latter is particularly important when construction cost estimates are prepared for power plants with long construction and lead times.

It is emphasized that the owner's cost component of the capital investment cost requires careful evaluation, especially for the first nuclear power plant to be built in a country. Owner's cost could include large amounts of money for infrastructure development, part of which might remain for further use beyond the immediate purpose of the nuclear plant. All the upgrading of the industrial
TABLE XXII. REFERENCE FUEL COST DATA
In constant 1980 US$.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Range</th>
<th>Reference value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nuclear</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural uranium</td>
<td>$/kg U₃O₈</td>
<td>48 - 120</td>
</tr>
<tr>
<td>Conversion to UF₆, LWR</td>
<td>$/kg U</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Enrichment, LWR</td>
<td>$SWU</td>
<td>120 - 200</td>
</tr>
<tr>
<td>Fabrication, LWR</td>
<td>$/kg U</td>
<td>150 - 200</td>
</tr>
<tr>
<td>Fabrication, HWR</td>
<td>$/kg U</td>
<td>80 - 100</td>
</tr>
<tr>
<td>Shipping</td>
<td>$/kg U</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Back-end cost (net)</td>
<td>$/kg U</td>
<td>300 - 500</td>
</tr>
<tr>
<td>Discount rate, %/a</td>
<td>8 - 14</td>
<td>10</td>
</tr>
<tr>
<td>Annual load factor, %</td>
<td>60 - 80</td>
<td>70</td>
</tr>
<tr>
<td>Total fuel cycle cost, LWR</td>
<td>$10^{-3}$ US$/kW·h</td>
<td>9.5 - 10.5</td>
</tr>
<tr>
<td>Total fuel cycle cost, HWR</td>
<td>$10^{-3}$ US$/kW·h</td>
<td>5 - 7</td>
</tr>
<tr>
<td><strong>Fossil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard coal, mine mouth</td>
<td>$/t</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Hard coal, away from mine</td>
<td>$/t</td>
<td>50 - 90</td>
</tr>
<tr>
<td>Crude oil</td>
<td>$/bbl</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Total fuel cost</td>
<td>$10^{-3}$ $/kW·h</td>
<td></td>
</tr>
<tr>
<td>* Coal</td>
<td>(30 - 60 - 90 $/t)</td>
<td>12 - 24 - 36</td>
</tr>
<tr>
<td>* Oil</td>
<td>(30 - 40 - 50 $/bbl)</td>
<td>44 - 58 - 72</td>
</tr>
</tbody>
</table>

Note: It is assumed that all values remain unchanged indefinitely, in constant value currency.

infrastructure should not be charged to the nuclear programme, since the whole country will benefit of an industry operating in compliance with advanced modern standards.

4.5. COMPETITIVENESS OF NUCLEAR POWER

It is difficult to make comparisons of costs of electricity generated by nuclear, coal and oil-fired power plants since the uncertainties involved in
TABLE XXIII. OPERATION AND MAINTENANCE COST OF THE ELECTRIC POWER PLANTS

<table>
<thead>
<tr>
<th>Plant capacity (MW(e))</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>600</th>
<th>900</th>
<th>1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (constant 1980 US$/kW-a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nuclear plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LWR</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>22.0</td>
<td>15.0</td>
<td>12.0</td>
</tr>
<tr>
<td>HWR</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>29.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Coal-fired plants</strong></td>
<td>–</td>
<td>40.0</td>
<td>32.0</td>
<td>25.8</td>
<td>21.5</td>
<td>19.0</td>
</tr>
<tr>
<td><strong>Oil-fired plants</strong></td>
<td>17.2</td>
<td>16.6</td>
<td>16.0</td>
<td>15.3</td>
<td>14.7</td>
<td>–</td>
</tr>
</tbody>
</table>

estimating future capital investment and fuel costs are very large. Moreover, the technical and economic conditions prevailing in a specific country and for a specific site can lead to costs that depart substantially from reference data used in general analysis. This is particularly true for the economic parameters such as discount and escalation rates used to derive total capital investment costs and for locally applicable fuel costs.

In a general analysis of the economics of nuclear power generation, a range of values for the main economic parameters is usually adopted and a set of reference data, to provide some general guidance regarding the order of magnitude of the costs involved. It must be emphasized that general analyses have only very limited applicability and validity.

Tables XXII, XXIII and XXIV contain the reference data used by the IAEA in its current general economic analysis. The tables correspond to fuel, O&M and capital cost data and parameters respectively.

The range of values for the estimated fore costs is shown in Fig. 11 (excluding interest during construction and escalation). Economy of scale is particularly important for nuclear power plant capital investment costs. A 600 MW(e) nuclear plant has about 75% higher unit capital cost than a 1200 MW(e) one, whereas for fossil-fuelled plants the specific cost increase is only about 30%. The same peculiarity can be noticed for O&M costs. Fuel costs on the other hand are practically independent of plant size. Total capital investment costs for nuclear plants of sizes lower than 600 MW(e) [SMPRs] are very uncertain and therefore no reference range is given here. For information on the availability of SMPRs see Chapter 2, section 2.6.
TABLE XXIV. RANGE OF FORE COST OF ELECTRIC POWER PLANTS

<table>
<thead>
<tr>
<th>Plant capacity (MW(e))</th>
<th>Cost (constant 1980 US$/kW(e))</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1700 1200 1000</td>
</tr>
<tr>
<td>200</td>
<td>1400 950 850 750</td>
</tr>
<tr>
<td>300</td>
<td>1200 750 650 500</td>
</tr>
<tr>
<td>600</td>
<td>950 750 550 450</td>
</tr>
<tr>
<td>900</td>
<td>650 550 450 350</td>
</tr>
<tr>
<td>1200</td>
<td>450 350 250 150</td>
</tr>
</tbody>
</table>

**Nuclear plants**
- Low: 1700 1200 1000
- High: 2000 1500 1200

**Coal-fired plants**
- Low: 1400 1200 950 850 750
- High: 1800 1500 1200 1050 950

**Oil-fired plants**
- Low: 1400 1100 950 750 650
- High: 1700 1350 1250 900 800

**FIG.11. Range of electric power plant fore costs.**

Since total capital investment costs of nuclear plants are higher than those of fossil-fuelled plants, the key element for the economic competitiveness of nuclear power is the low nuclear fuel cycle cost.

The costs of kW·h generated by nuclear, coal and oil-fired plants are indicated in Fig. 12. The values are the results of the calculations performed using the data contained in Tables XXII, XXIII and XXIV. The costs of kW·h are expressed as a function of plant size and for indicating the ranges two variables were used:

(a) Capital investment cost of the nuclear plants
(b) Fuel cost of the fossil-fired (coal and oil) plants.
These are the two principal factors affecting the competitiveness of nuclear power with fossil-fired plants, and they are also the two factors most difficult to determine not only in a general analysis, but also for a particular study.

As shown in Fig. 12, the cost of electricity produced by a nuclear plant is, in general, substantially lower than the cost of electricity produced by oil-fired plants in the size range of 600 to 1200 MW(e), even at fuel oil prices as low as 30 $/bbl. The competition of nuclear plants with coal-fired plants in the same size range is close, depending fundamentally on the coal price and the nuclear plant investment cost assumed.

Sensitivity studies can be performed for any of the parameters affecting the cost of kW·h, introducing variations within the ranges as defined, or even beyond these ranges within reasonable limits.

In addition to the two main parameters (investment cost of nuclear plants and fossil-fuel costs), those which may strongly affect the competitive position of nuclear power are: the annual discount rate, and the plant load factor. The cost of electricity produced by a nuclear power plant is only slightly affected by even large changes in the components of the nuclear fuel cycle cost. The cost of electricity of coal-fired plants is mainly affected by the quality of coal to be burned and by the environmental protection requirements, in addition to the price (including transport) of coal.

Looking at the past evolution of nuclear power costs, it can be observed that ever since commercial nuclear power plants started to penetrate the electricity generation market they have maintained an economic competitive position with available alternative energy sources. Individual projects have shown some deviations with respect to strict competitive conditions, but such deviations were always marginal and accountable for by specific situations or unexpected factors. In effect, nuclear power could never have penetrated the energy market to the extent it has done without, in general, achieving economic competitiveness.

When in 1973–74 the price of oil was suddenly raised far above its earlier level, the economic competitive status of nuclear power could have been considerably improved. This, however, did not happen. Nuclear power costs followed the trend of oil costs with a very short delay, rising to attain a very similar competitive level to what they were holding before the oil price increase. Incidentally, coal followed a similar trend.

With its second substantial price increase in 1979 and further increases in view, oil attained a price level that has placed it substantially above the competitive range for electricity production. This left nuclear power and coal as the main competitors of the bulk commercial electricity generation market.

Economic competition between available alternative energy sources is a powerful force which acts on each of these sources. Consequently, the cost trends of nuclear power cannot be considered in isolation. It seems reasonable to assume that the future evolution of nuclear power costs will follow the overall
pattern of the evolution of the whole energy market, where each available alternative source tends to maintain its competitive position. This seems to hold especially for a regulated market, such as the energy market.

APPENDIX TO CHAPTER 4

GLOSSARY OF TERMS

Base cost (capital investment) equals direct plus indirect cost (for definition see Table XIX).

Capacity of a power plant is the electric power for which a generating unit or station is rated under the specific conditions defined by the manufacturer – MW(e).

Commercial operation date is the date when a unit/plant is declared to be available for regular production of electricity.

Constant money represents monetary units of a constant purchasing value. The particular purchasing value chosen is that of the ‘reference date’.

Current money or mixed-years money is the arithmetic sum of monetary units spent in different years. The sum is mixed because it is a sum of money of different purchasing values. The monetary units are ‘current’ because they were spent according to their then current value.

Direct cost (capital investment), for definition see Table XIX.

Discount rate \((d)\), is often called the ‘time value of money’. A perfect financial market is assumed, in which it is possible to borrow or invest money at any time at an interest rate equal to \(d\).

Escalation corresponds to a price increase due to inflation.

Fixed charge rate associated with a certain investment is the annual expense related to the investment expressed as a percentage of initial investment. Generally, the fixed charges consist of:
(a) Interest on capital
(b) Rate of recovery of capital
(c) Taxes (where appropriate)
(d) Insurance (where appropriate).

Fore cost (capital investment), for definition see Table XIX.
Gross capacity corresponds to the electric output at the terminals of the generator sets in the station; it includes therefore the power taken by the station auxiliaries and losses in transformers that are considered integral parts of the station.

Indirect cost (capital investment), for definition see Table XIX.

Inflation is the change over time of the average prices of goods and services in the general economy.

Installed capacity of electrical system is the total capacity of plants available in the electrical system to supply the system load.

Interest during construction (IDC) is the accumulated money disbursed by a utility to pay off interest on the capital invested in the plant during construction time.

Interest rate as used in engineering computations is the annual cost of the money required for the work.

Levelized energy cost is calculated by assuming that the present worth value of all revenues produced by the electricity generated (priced at the levelized cost of the kW·h) equals the present worth value of all expenditures incurred in the implementation and operation of the plant.

Lifetime (or book life) is the average service life expected from an equipment or plant before it is retired.

Mixed years money, see Current money.

Net capacity corresponds to the electric output measured at the station outlet terminals, i.e. after deducting the power taken by station auxiliaries and the losses in the transformers that are considered integral parts of the station.

Present value or present worth (PV), 'present valuing' is a mathematical process by which different monetary amounts can be moved, either forward or backward, from one or more points in time to a single point in time, taking account of the 'time value of money' during interim periods. Thus, 100 is the present value of \((1 + d) \times 100\) available one year later or of \(100/(1 + d)\) available one year earlier. In general, if it is desired to move MU monetary units by \(N\) years, the present value is given by

\[
P_V = (1 + d)^N \times MU
\]

where \(N\) is negative (discounting) when moving backward in time and positive (compounding) when moving forward in time; \(d\) is the discount rate or present valuing rate.

Real escalation, 'differential escalation' or 'cost drift' is the annual rate of price increase that is independent of and over and above inflation. This can result from resource depletion, increased demand, technology evolution, safety and environmental requirements, and the like.

Total capital investment cost, for definition see Table XIX.
PART II

SPECIAL ASPECTS AND CONSIDERATIONS RELEVANT TO THE INTRODUCTION OF NUCLEAR POWER
Chapter 5

TECHNICAL ASPECTS AND
NATIONAL REQUIREMENTS

5.1. INTRODUCTION

The introduction of nuclear power and of nuclear technology in a country entails many aspects that are specific to nuclear power. These create new requirements on the country's infrastructure and require national commitments on a long-term basis involving substantial efforts.

The varying conditions and situations, technical, economic and financial aspects, as well as various international and political issues have imposed constraints in the way of development and realization of most nuclear programmes. Owing to the special aspects and requirements, many countries, though it would have been to their benefit to do so, were rather late in the introduction and use of nuclear power for electricity generation to meet their energy requirements, while others have not started yet.

During recent years, and especially after the large increases in oil prices on the world market, interest in nuclear power as an alternative source for energy supply has been steadily growing in several countries. However, the growth of nuclear capacity is still to a large extent lagging far behind the expectations and anticipated role of nuclear power, as projected during the 1970s.

The problems and constraints leading to this situation have been the subject of extensive studies and discussions in many international forums, conferences, symposia, meetings and study groups. Much relevant published information is available for consultation (see the Bibliography at the end of the Guidebook).

In this second part of the Guidebook the special aspects relevant to the introduction of nuclear power in a country will be identified and briefly discussed, reviewing the technical aspects and national requirements (Chapter 5), the safety and environmental considerations (Chapter 6) and the international aspects (Chapter 7).

It is emphasized that for the successful introduction of nuclear power in any country the first essential requirement is a clear understanding at the decision-making level of the specific aspects of nuclear power, and a thorough knowledge of the tasks and activities to be performed as well as of the requirements, responsibilities, commitments, problems and constraints involved.

A nuclear power project requires a very large effort (money, resources, manpower, etc.) on a national level over a long period of time. The country has to commit itself to the fulfilment of the requirements and has to establish clear policies to ensure the continuity of the programme. Changes in policies or in management may cause high penalties in money and time.
TABLE XXV. SUMMARY OF ACTIVITIES IN NUCLEAR POWER PROJECTS

<table>
<thead>
<tr>
<th>1. Project planning</th>
<th>National energy supply planning</th>
</tr>
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<tbody>
<tr>
<td>(pre-project,</td>
<td>Power system planning</td>
</tr>
<tr>
<td>programme-oriented</td>
<td>Nuclear power programme planning</td>
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<tr>
<td>activities)</td>
<td>Development of legal and organizational framework</td>
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<td></td>
<td>International agreements and arrangements</td>
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<td></td>
<td>National infrastructure survey</td>
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<td></td>
<td>National participation planning</td>
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<td></td>
<td>Manpower development planning and implementation</td>
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<td></td>
<td>Site survey</td>
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<tr>
<td>2. Project implement-</td>
<td>Feasibility study</td>
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<td>tion (pre-construction</td>
<td>Site evaluation</td>
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<tr>
<td>project-oriented</td>
<td>Supply market survey</td>
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<tr>
<td>activities)</td>
<td>Definition of contractual approach</td>
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<td></td>
<td>Preparation of specifications and invitation of bids</td>
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<td></td>
<td>Definition of codes and standards</td>
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<td></td>
<td>Preparation of bids</td>
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<td></td>
<td>Bid evaluation</td>
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<td></td>
<td>Technology transfer arrangements</td>
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<td></td>
<td>Procurement and assurance of fuel and fuel cycle services supply</td>
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<td></td>
<td>Financing arrangements</td>
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<tr>
<td></td>
<td>Negotiation and finalization of contracts</td>
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<tr>
<td></td>
<td>Plant conceptual design</td>
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<td></td>
<td>Preparation of site infrastructure</td>
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<td></td>
<td>Site and construction authorization (licensing)</td>
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<td></td>
<td>Public information and public relations</td>
</tr>
<tr>
<td>3. Project implement-</td>
<td>Overall project management</td>
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<tr>
<td>tion (management and</td>
<td>Basic design engineering</td>
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<tr>
<td>engineering)</td>
<td>Detailed design engineering</td>
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<td></td>
<td>Design reviews</td>
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<td></td>
<td>Preparation and review of equipment and plant specifications</td>
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</tbody>
</table>
TABLE XXV (cont.)

<table>
<thead>
<tr>
<th>Procurement of equipment and materials</th>
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</thead>
<tbody>
<tr>
<td>Establishment of quality assurance policy</td>
</tr>
<tr>
<td>Quality assurance and quality control programme implementation</td>
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<tr>
<td>Supervision of manufacturing, construction and commissioning</td>
</tr>
<tr>
<td>Safety analysis</td>
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<tr>
<td>Emergency planning</td>
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<tr>
<td>Safeguards physical protection</td>
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<tr>
<td>Schedule planning and control</td>
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<tr>
<td>Cost control</td>
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<tr>
<td>Planning and co-ordination of the training of operations personnel</td>
</tr>
<tr>
<td>Development, review and implementation of safety and engineering procedures</td>
</tr>
<tr>
<td>Development of plant operation and maintenance manuals</td>
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<tr>
<td>Progress reporting</td>
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<tr>
<td>Public information and public relations</td>
</tr>
</tbody>
</table>

4. Project implementation (manufacturing, construction and commissioning)

<table>
<thead>
<tr>
<th>Equipment and component manufacture</th>
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<tbody>
<tr>
<td>Construction and commissioning management</td>
</tr>
<tr>
<td>Site preparation</td>
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<tr>
<td>Erection of buildings and structures</td>
</tr>
<tr>
<td>Expediting and transport of materials and equipment</td>
</tr>
<tr>
<td>Plant equipment and systems installation</td>
</tr>
<tr>
<td>Plant component and systems testing</td>
</tr>
<tr>
<td>Commissioning and plant acceptance testing</td>
</tr>
<tr>
<td>Recruitment and training of plant operations personnel</td>
</tr>
<tr>
<td>Authorization (licensing) of plant operation and of plant operations staff</td>
</tr>
<tr>
<td>Inspection and auditing</td>
</tr>
</tbody>
</table>
5.2. ACTIVITIES IN NUCLEAR POWER PROJECTS

Any nuclear power project - be it the first one for a country or a subsequent unit within the nuclear power programme - requires a series of activities to be performed by an adequate staff, following a certain schedule. There are no firm rules to establish how, by whom and where these activities should be performed, and which apply to any country, organization or situation. The ultimate goal, namely the satisfactory completion of the project in an optimum manner, will determine the possible choices and the right procedures, which will depend upon the country's prevailing conditions and capabilities.

Past experience in those countries where nuclear power has been successfully introduced show different approaches and different degrees of success. However, they all indicate that the steps to a viable nuclear project consist of project-oriented and programme-supporting activities, which are basically those listed in Table XXV. The activities in the list are performed by different groups and organizations in the owner country as well as in supplier countries, but regardless of the assigned responsibility, they are all essential. Proper judgement in assigning responsibilities and selecting the partners in the nuclear programme is the key to the viable introduction of nuclear power in a country. It must be stressed that the very same activities, carried out at the same level of quality, are applicable to both developed and developing countries. Naturally the degree of outside dependency will vary vastly depending on the country's ability to achieve self-sufficiency for as large a number of these activities as possible.
It is apparent that for a country at the outset of its nuclear power programme some of the listed activities may pose unprecedented requirements. The capability of meeting those requirements is one of the conditions that may limit the viability of a nuclear power programme in a country. A prerequisite condition is certainly the ability to provide adequate planning and competent management throughout all the stages of project development, since the formulation of policies and all the consequences that may derive from a deficient supervision remain the ultimate responsibility of those national organizations the Government has vested with the relevant competence and authority.

In this respect, a closer look at Table XXV will reveal that some activities cannot be delegated and, in performing them, the country has to take a lead responsibility even in the cases where extensive reliance is placed on suppliers (see also section 5.8.2). Naturally, and especially for the first nuclear project in the country, extensive assistance and advisory services can be sought from outside sources which, however, cannot be expected to make decisions on behalf of or substituting for the national authorities, nor can they be made liable for the consequences that may derive from or depend on those decisions.

Other nuclear power project activities may be and generally are contracted outside the country for the first project in the programme, when the associated necessary capabilities are not readily available within the country. Some of these activities, however, represent areas where the owner's self-sufficiency should be gradually expanded if national participation in the nuclear programme is to be enhanced. Some others should be profitably developed for long-term assurance of supply. Finally, there are some activities that require highly developed technological capabilities which for some countries may not be within the scope of national participation for a long time to come.

Regarding responsibilities for the performance of the different activities, the owner may choose to delegate many of them to suppliers, consultants, or architect-engineers. However, he will always have to retain the overall full responsibility for the project in every phase of its planning, implementation and ultimate operation.

Part III of this Guidebook contains more detailed information on the implementation of the activities to be performed, in particular during the planning and acquisition stages of the project.

5.3. SCHEDULE OF NUCLEAR POWER PROJECTS

One of the main aspects associated with nuclear power development programmes and the implementation of nuclear power projects is the fact that long lead times are involved. This characteristic feature of nuclear power creates difficulties for a country contemplating the introduction of nuclear power, since
FIG. 13. Schedule for a nuclear power plant.
planning and performance of a series of activities involving substantial efforts has to be started long in advance of the time when the energy needs are to be met. In addition, if the nuclear power programme calls for a series of nuclear power plants over a certain period of time, as would be the normal case, it will be necessary to proceed with the implementation of more than one plant simultaneously.

Long lead times as well as several simultaneous projects impose a heavy burden on the available resources of capital, manpower and infrastructure capabilities, especially in the conditions prevailing in most developing countries. To minimize the impact of this problem, efforts should be directed towards identifying the areas where shortening of the overall schedule associated with nuclear power programme development could be effected, or at least, where delays could be avoided.

The schedule for performing each of the activities listed in Table XXV depends on many factors, and is affected largely by the degree of planning and the adequacy and sufficiency of the staffing of the project management organization. It also depends on the approach adopted for dealing with the various tasks. There is no precise of definite rule that would define the time period required for each phase and it may vary over a wide range from case to case depending on the prevailing situation and conditions. Approximate estimates, however, may be obtained from previous experience, which would serve as guidelines and might give an indication of the ways and means that could lead to the shortening or at least not unduly prolonging the overall time schedule of a given project in a particular situation.

A typical schedule for a nuclear power project is shown in Fig. 13 as an example. It spans a period of 13 years, encompassing the major project-related activities. However, the periods shown for different activities as well as the starting points are approximate and should be considered only indicative. Supporting activities of the nuclear power programme are not included in this schedule, they begin even before the pre-project activities of the first nuclear plant are started and then continue throughout the programme.

Major factors affecting the project schedule are:

- The time needed for making decisions
- Availability of qualified manpower
- Licensing requirements and procedures
- International institutional arrangements
- Financing arrangements
- Siting studies and the procedures for site selection and authorization
- Timely completion of engineering
- Project management efficiency
- Quality assurance programme implementation
- Unforeseen manufacturing or construction problems
- Late alterations of design.
The schedule is the major control-tool of project management and is essential for the overall co-ordination of the tasks among the partners involved. There are certain milestones of the master schedule, some of which are indicated in Fig. 13. The milestones are major events in project development and connecting points of activities. Some of the typical milestones are:

- Decision to start nuclear power planning
- Establishment of national legislative framework
- Establishment of nuclear regulatory organization
- Decision to start the feasibility study
- Feasibility study completion
- Site selected
- Decision to initiate the acquisition process
- Bids requested
- Bids received
- Letter of intent issued
- Main contract(s) signed
- International institutional and financing arrangements completed
- Construction permit granted
- Site preparation started
- First structural concrete cast
- Containment erection completed
- Installation of components started
- Reactor heavy components installed
- Turbine and generator installed
- Fuel loaded
- First criticality of reactor reached
- Hot functional testing started
- Operating licence granted
- Commercial operation started.

The pre-project and project implementation activities, including the periods required for their performance and their schedule are discussed in more detail in Part III (Chapters 8 to 12) of this Guidebook. The overall time required to complete the process of planning and acquisition of the power plant up to the start of construction is estimated as about seven years, according to the schedule presented in Fig. 13 as an example. This schedule includes reasonable time for decision making.

A period of seven years from the start of nuclear power planning to the initiation of construction of the power plant may seem excessively long; however, there are ways to shorten this period. Experience shows that in some cases, even for a first nuclear power project, an overall shorter period of 3 to 4 years has been
TABLE XXVI. PERIODS REQUIRED FOR NUCLEAR POWER PROJECT ACTIVITIES

<table>
<thead>
<tr>
<th>Activity</th>
<th>Period (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear power planning study</td>
<td>6–12</td>
</tr>
<tr>
<td>Site survey</td>
<td>6–12</td>
</tr>
<tr>
<td>Site evaluation</td>
<td>18–24</td>
</tr>
<tr>
<td>Feasibility study</td>
<td>12–18</td>
</tr>
<tr>
<td>Preparation of bid specifications</td>
<td>6–12</td>
</tr>
<tr>
<td>Bid preparation</td>
<td>6–8</td>
</tr>
<tr>
<td>Bid evaluation</td>
<td>6–12</td>
</tr>
<tr>
<td>Contract negotiation and finalization</td>
<td>9–18</td>
</tr>
<tr>
<td>Plant construction including commissioning</td>
<td>72–96</td>
</tr>
</tbody>
</table>

Note: Some activities overlap (see Fig. 13). The periods given are orders of magnitude and will depend on particular situations and prevailing conditions.

achieved. Nevertheless, experience also shows that there are cases where ten or more years were required. There are also some countries that have started planning activities for their first nuclear power project in the 1960s and have still not reached the construction stage. It is therefore very difficult to generalize regarding the overall time required for these preparatory activities. A period of 5 to 8 years seems to be a reasonable target for planning purposes, but this should be analysed in detail for each particular case considering the prevailing conditions.

A summary of the estimated periods required for the performance of each of the major activities leading to project completion is presented in Table XXVI. It should be noted that some activities overlap. Siting studies in particular would start during the nuclear power planning stage and continue throughout the following preparatory stages.

Regarding the possibilities for shortening the time required, these should be evaluated with great care. Obviously, every effort should be made not to prolong the process unduly, but short cuts or a lowering of quality requirements could
result in the long run as very expensive indeed, both in money and in overall time. As to nuclear safety related aspects in particular, legitimate safety concerns should prevail over the interest in achieving shorter schedules.

5.4. LONG-TERM NUCLEAR POWER PROGRAMME POLICY AND COMMITMENT

Only a long-term nuclear power programme containing a series of nuclear power projects can justify the sizeable effort needed to plan and implement the national infrastructure development and the supporting organizational structures and activities. A single nuclear power plant not integrated into a nuclear programme may become an expensive venture.

In every country the assurance of energy and of electricity supply is ultimately a governmental responsibility. Energy and electricity supply is an essential requirement for every productive industrial and economic activity of a country, as well as for maintaining and improving the population's standard of living and lifestyle. If nuclear power is to contribute to the nation's energy supply, its development has to be planned on a long-term basis and the necessary commitments have to be made. The subject of Nuclear Power Planning is treated in more detail in Chapter 8.

One of the implications of the long-term aspect of programme planning and commitments is the need for as much continuity as can possibly be achieved in the personnel and in particular the management staff involved.

The special features of nuclear energy require the establishment of organizational infrastructures, highly competent personnel, national infrastructures, and substantial financial resources. The deployment of important national resources can only be attained in the assurance of a firm commitment at supreme governmental level to a clearly formulated long-term policy. Particularly the long-term aspect is important in creating the necessary confidence to attract investments and industrial support. In some countries the Government's nuclear policy and the commitment to its implementation has been promulgated as constitutional mandate.

The formulation of a nuclear power programme and the definition of its objectives must be adequately balanced against other equally important national commitments which also require a share of the limited national resources. If objectives are set too high, the nuclear programme may become self-defeating in as much as it might deflect too many funds and other resources from other essential sectors and promote an imbalance in the national economy. It is the Government's role to shape the nuclear programme in such a way as not to disrupt the other national objectives.
Electricity generation is the primary objective of a nuclear power programme. However, the implementation of a nuclear power project must include national participation. This participation cannot be limited to the operation and maintenance of the plant. There are other activities that are essential for national participation, and advantage should also be taken of the many technological and social spin-off effects which benefit the national industrial development at large, and which in the long run prevent excessive dependence on foreign sources of supply. Thus, additional national participation policy and objectives become an integral part of the scope of a nuclear power programme. These objectives may include:

- Development of human resources by increasing the capabilities of national staff in traditional skills and in developing new talents
- Independence in supply by exploiting national resources if available, and promoting engineering and industrial capabilities, which in turn produce new jobs and develop national welfare
- Enhancement of the quality of national products, which may even create opportunities for exporting.

The attainment of such objectives can only be pursued if corresponding national policies and strategies are formulated. The policies and strategies should be developed to support the efforts in those directions which appear most rewarding and beneficial for the country. Here again, it is the role of the Government to establish directives and to promote development with subsidies and other incentives. The investments that may prove necessary for the promotional efforts must be evaluated on a cost/benefit basis.

It is apparent that policies and strategies will vary from country to country, as they depend largely on the particular prevailing conditions. Their formulation is an early concern of the planners. From the outset of the programme the country’s current capabilities and their potential development must be clearly identified. This requires a thorough survey of the national infrastructure to assess those sectors of the nuclear programme where outside dependency can be reduced and self-sufficiency eventually attained.

The first objectives to attain in the early introduction of this new technology are those activities and services that are labour intensive and not too specific to nuclear power, and the production of those materials and components that are not too demanding in quality. These may still pose a strain on the country’s resources. These infrastructures, once available, will be used for other purposes within the country’s development programme. Development of capabilities with limited and unique applicability should be avoided at the beginning of the nuclear programme. Conversely, whatever can be readily converted and profitably transferred to other sectors should be encouraged.

Labour practices and efficiency have a large influence on the formulation of policies for national participation. New job opportunities meet the public’s favour and hinder the development of opposition to nuclear power.
As the programme progresses more skill intensive services will have to be staffed domestically. Development of new talents for complex new techniques should be the target of the long-term policy. Higher quality engineering capabilities, better management and organization, the creation of a new generation of skilled technicians and craftsmen together with the introduction of a new yardstick for quality are targets to attain. This will benefit to country beyond the scope of the nuclear programme, as the acquired capabilities have a general applicability to all industrial sectors.

The production of electrical and mechanical equipment and components could start with those items that are needed in large numbers and that have applications in other industries. To promote national industry participation, a general climate of confidence is necessary. The nuclear programme must be firm and established for the long term. New job opportunities should not be precarious, and an industry must be given time to produce results and to recover its investments.

Should delays occur in the nuclear power programme, these should in principle not result in downward revisions of installed capacity. Anything that could undermine the confidence of the investors and the trust of the public should be avoided. The establishment of the programme’s objectives must therefore be realistic and commensurate with the country’s capabilities.

It is the government’s role to co-ordinate national planning and policy development. The co-ordination of national efforts is an essential factor in ensuring a smooth introduction of nuclear energy in a country. Normally, different ministries and/or national authorities have separate responsibilities for different equally important national programmes. Though autonomy and independence are necessary for an effective administration, yet communications and exchange of data are essential for consistent planning and adequate implementation. No activities can be developed in isolation without the support of the necessary infrastructures, which include the achievements of other programmes that must progress in parallel.

5.5. ORGANIZATIONAL REQUIREMENTS

The initiation and formulation of a nuclear power programme as well as the subsequent implementation of nuclear power projects, needs efficient organizational structures for the management of required activities at the governmental level as well as in the utilities, industry, research and development, and educational institutes involved.

The management of a nuclear power programme, and of a nuclear power plant or any other project in a nuclear programme, is a major undertaking which does differ from other large industrial projects or from a conventional power
plant. Extensive planning and intensive studies for the initiation, establishment and development of a long-range programme are required. Nuclear projects need to comply both with strict regulatory and safety standards and with special quality assurance and control requirements. There are both promotional and regulatory activities, and special organizational structures are needed to carry these out.

5.5.1. Organizations for nuclear power programme management

The first task to be performed when the introduction of nuclear power in a country is considered is the setting up of a national organization to be in charge of the planning and co-ordination of the nuclear power programme, including all related activities.

In most countries that have started a nuclear programme such an organization has been initially formed by Atomic Energy Commissions, or by Governmental Ministries or Authorities concerned with the energy resources and development, such as the Ministries of Energy or Industry. In some cases, the organization was set up through the establishment of a separate body in which the appropriate divisions or departments of the ministries and organizations concerned were represented.

Whichever type of organization is formed, it is essential that this organization should be totally devoted and solely directed to the nuclear programme objectives and the related activities, during the various stages of its planning and implementation. This planning and co-ordinating organization would be the leading organization and assume the overall responsibility for the planning and initiation of the various tasks to be performed, and for the direction and co-ordination of the work to be carried out by the different parties involved in the nuclear programme development.

The nuclear power programme activities are usually performed by several national organizations together with national and foreign consulting and architect engineering firms, suppliers and contracting companies. The distribution of tasks, functions and responsibilities between the organizations involved follows similar patterns to those for any other conventional power or industrial plant, but, in addition, there will be a regulatory organization. The functions of this organization will be the regulation and control of all nuclear facilities, and ensuring that the manufacture, construction and operation of the nuclear plants comply with the safety requirements and quality standards stipulated in the regulations (see section 5.5.3).

There is no universally applicable organizational framework that is equally applicable to every country and in each situation. It should also be recognized that the formation of the organizational structures is a continuous and gradual process. As the nuclear programme develops appropriate changes are gradually introduced according to the needs and available resources.
Initially, during the planning and feasibility stages, only a small organization with relatively few but highly qualified professionals working as a project group will be required. This organization or project group will have the main tasks of defining the nuclear power programme in policy, scope, size, schedule, budget, manpower requirements, and the assessment of available domestic resources and capabilities for participation in its implementation. It could be initially a part or a department of a Government Ministry or organization, with a special board composed of selected high-level members, which will have the authority for making decisions on matters referred to it by the project group.

The tasks to be performed by this national organization cover a wide range of subjects and require extensive data and information as input to the studies to be carried out. It is therefore important that adequate lines of communication and authority be provided to that organization, to enable it to have access to the necessary data and information from other authorities or departments in the country, in many areas such as economic and industrial planning, energy research and development, electricity generation and distribution, and general statistical data and information systems.

For this stage no specialized knowledge in subjects like nuclear physics or reactor theory is required; however, the organization will need general background experience and knowledge in nuclear power and nuclear engineering. Assistance of advisors or consultants may be obtained to cover areas of technical specialities or experience, as needed.

The organization for carrying out the initial phase of a nuclear power project (pre-project activities) should be task oriented with no rigid formal structure, so as to provide flexibility and effective utilization of the available experience and resources, and to perform the work in the most efficient manner.

5.5.2. Organization for project implementation

The first essential element in the consideration of the possible introduction of nuclear power in the electricity system of any country is the assessment of the national organizational capabilities to undertake the development and implementation of the envisaged nuclear project. The projected expansion of a power system involving nuclear plants will involve organizational changes and/or extensions to the existing structures.

The project implementation phase starts when the decision is reached to proceed with planning of a specific nuclear power project. The main purposes of the tasks to be performed during this phase are to study and evaluate the project, to select the suppliers, to negotiate the contracts, to construct, and finally to operate and maintain the plant.

The organizational structure requirements for the management of the activities during this phase depends to a large extent on the contractual approach
adopted for project implementation. This will be discussed in greater detail in Chapter 11. Depending on the approach adopted, the lead responsibilities and task to be performed will be distributed between the owner, national and foreign suppliers of goods and services, and the regulatory authority. Each of the partners will have to set up its own organizational structure.

The difficult adaptation of the owner's organization from the rather simple structure used during the initial stage of programme development and pre-project activities to the more sophisticated structure of the implementation phase requires restructuring and expansion to cover the important areas closely related to the specific project under consideration. The owner's organization retains overall responsibility for the project and the functions of supervision and control of all activities as well as the review and approval of the work to be performed, even if the lead responsibility for design, engineering, project and construction management, construction, erection and testing is delegated to a supplier or suppliers. It will have also to define the extent of national participation in the supply of materials and labour and the provision of various services and supplies required during the site preparation and construction phases. Finally, full responsibility for operation and maintenance of the power plant will always remain with the owner.

The owner will have to ensure close co-operation and co-ordination between the partners involved. In particular, channels of communications, areas of responsibility and lines of authority should be well defined and clearly specified in order to ensure the completion of the various tasks on schedule, and to achieve optimum performance at reasonable costs.

There are several different types of organizational structures that can be adopted for the project implementation management. A matrix-type organization seems to be the most advisable because of the great complexity of a nuclear power project, where both specialized functions and skills and overall coordination have to be combined. Basically, this type of organization is a functional management which is overlaid by a vertical management so that staff involved that are skilled in the various disciplines and tasks work directly for a project manager, but remain connected through the basic discipline manager with the sources of technical skills that have to be provided for the project.

An important element in this type of organization is that the project manager has full responsibility of the project. He has the authority to tell the project team what to do and when to do it, while the duty of directing how the work is to be performed is left to the discipline managers. The project manager has an operational and day-to-day control over each of the members of the task force, every one of them being administratively and logistically supported by the discipline manager and technically directed by him.

Under a turnkey-type arrangement, both the owner and the main contractor will have their own organizations for project management. Both are structured along similar lines. Examples are presented in Figs 14 and 15.
FIG. 14. Organizational structure of owner's project management (example). Note: Turnkey contract -- responsibility delegated to main contractor.
FIG. 15. Organizational structure of main contractor project management (example). Dashed lines = reporting lines, dotted lines = communication lines.
The functions and principal tasks of the owner's project management organization throughout the project implementation phase include the following main areas:

- Preparation of the feasibility and siting study
- Preparation of the bidding specifications
- Detailed investigations of the site and preparation of all necessary input data for safety evaluation and licensing, and for the design of the plant by the supplier(s)
- Definition of the codes and standards that will be adopted for the plant design and construction
- Technical and economic evaluation of bids
- Contract negotiations with the selected supplier(s)
- Finalization of the contract(s) including precise definition of the scope of supply, prices, terms of payment, guarantees and warranties and all other legal and contractual conditions
- Arrangements for financing and for the supply of fuel cycle materials and services, and the conclusion of necessary agreements or contracts to provide assurance of continued long-term supplies
- Planning of the manpower requirements of the construction supervision, commissioning, operation and maintenance of the plant, and arranging for adequate training programmes.
- Provision of all items not included in the supplier's scopes such as site facilities, roads, temporary buildings, electricity and water supplies, housing, medical facilities, etc.
- Supervision, control and inspection of the supplier's work and ensuring adherence to quality assurance and quality control procedures in the design and construction.

All the above functions and tasks will equally apply for turnkey or non-turnkey contractual approaches. The essential difference would only be in the extent of the scope that is under the direct responsibility of the owner. In the case of the non-turnkey approach, the size of the owner's organization, as well as the manpower requirements and in particular the requirements for engineering capability, will be much larger and the co-ordination of the work and control of the schedule will be more difficult. Previous experience in management and engineering of similar large projects is essential. The organizational structure, however, will be fundamentally the same.

5.5.3. Organization of the regulatory authority

The establishment of a specialized regulatory authority is of primary importance for the effective discharge of the national responsibilities in ensuring
public health and safety with respect to nuclear power plants and other nuclear facilities.

The IAEA has published and has under preparation a series of publications within the framework of the NUSS (Nuclear Safety Standards) programme. Particularly relevant is the Code of Practice on “Governmental Organization for the Regulation of Nuclear Power Plants” (Safety Series 50-C-G), published in 1978.

The fundamental objectives of the regulatory authority are:

(a) Establishment of regulatory standards, codes and criteria, which will govern the design, construction, and operation of nuclear power plants
(b) Review and evaluation of the safety analysis and environmental reports submitted by the owner; issue of licences
(c) Conduct of a programme of inspections to ensure compliance with established rules and regulations.

The regulatory body may be organized into units which perform the activities corresponding to each of the above-listed objectives. An example is presented in Fig. 16.

The organization of the regulatory body will necessarily depend upon the governmental structure, the legal system and the administrative practices of the country. In setting up the organizational structure for the regulatory authority, due account should be taken of these particular aspects. Whatever structure is adopted, the regulatory authority should be:

(a) Vested by enabling legislation with a broad statutory authority and functional autonomy, to carry out its functions independently of applicants, manufacturers, suppliers and other interested parties in both the public and private sectors
(b) Staffed by highly qualified personnel.

The subject of nuclear safety including regulatory and licensing aspects is treated in more detail in Chapter 6 and also in the following section 5.6.

5.6. LEGAL FRAMEWORK

Amongst the preparatory steps required for the implementation of a nuclear power programme, it is essential that consideration be given at the earliest stage to the legal and administrative aspects thereof in order to achieve the timely establishment of an adequate legal framework and infrastructure within which the execution of nuclear power projects may be carried out, subject to appropriate authorization, co-ordination, control and supervision. The legislation governing industrial establishments of a hazardous nature and, in particular, public
FIG. 16. Possible structure of a nuclear regulatory authority.
utilities will, of course, have to apply to the erection of nuclear power plants as well. However, the most stringent safety measures required for nuclear installations because of the special nature of nuclear energy, and the effective financial protection to be ensured for victims of a nuclear incident add new dimensions to traditional patterns of regulatory schemes devised for industrial activities of a conventional type. Consequently, special legislation dealing with nuclear facilities and related matters is of primary importance and should basically be aimed at:

(a) Providing legislative authority for regulating and ensuring the safe development and use of nuclear energy in the national interests;
(b) Vesting a specialized body with such a functional status and powers that would enable it to discharge its regulatory responsibilities independently of public and private corporations, manufacturers and suppliers;
(c) Setting forth the principles and conditions under which the regulatory authority may authorize the carrying out of nuclear activities without undue risk to the workers and the health and safety of the public, with adequate physical protection of nuclear materials and facilities, with proper regard to protecting the environment, and in accordance with relevant treaty obligations entered into by the State; and
(d) Establishing the principles and rules consistent with international conventions on third party liability for nuclear damage in order to ensure adequate indemnification in the event of a nuclear incident.

Enabling legislation should, to the extent feasible, look forward into the future and accordingly provide a comprehensive framework encompassing foreseeable developments of nuclear energy applications within the national context. It should also, where appropriate, take into account approaches by other countries to the issues involved and relevant recommendations established by qualified international organizations.

The major components of nuclear legislation can be identified as dealing with the following topical areas respectively:

- Radiological protection, nuclear safety and connected matters such as environmental protection, transport of radioactive materials, radioactive waste management (section 5.6.1)
- Licensing authority and licensing requirements for activities involving nuclear facilities (section 5.6.2)
- Liability to third parties for nuclear damage and financial security covering such liability (section 5.6.3)
- Physical protection of nuclear materials and facilities (section 5.11)
- State system of accounting for and control of nuclear materials (section 5.12).

On account of the rather long time normally required under any legal system for the elaboration and enactment of legislation, especially when the
law-making process is confronted with the need of securing the fullest co-
operation of all those concerned across the governmental structure and, also,
with the search for an optimum balance of proposed undertakings in the national
interest and of adequate assurances to the public as regards its concerns of a
legitimate nature, the framing of legislation to govern nuclear installations is to
be given timely attention during the early planning stages of a nuclear power
programme. In the preparation of legislation and implementing regulations,
emphasis should be placed on ensuring continued and effective co-ordination
and co-operation between various governmental departments and institutions
concerned and qualified public and private organizations. A great deal of
concerted effort would thus be necessary from the outset with a view to securing
as much as possible the assistance of all the relevant expertise available in the
country. This would help to achieve a broad consensus on the goals to strive for
and on the principles, conditions and requirements to govern the licensing and
regulatory control of nuclear activities in the national interest.

Such a co-ordinated and co-operative approach would facilitate proper under-
standing by all those concerned, of the issues at stake and of the philosophy for and
the need of regulating them. This could subsequently turn out to be of great
help at the stage of enforcing the applicable laws, regulations and licensing
decisions.

5.6.1. The regulatory basis and authority

The enabling legislation on nuclear activities would usually provide for the
promulgation of regulations setting out basic safety standards from which safety
criteria, detailed technical requirements and implementation procedures could
be worked out, upon which regulatory actions are to be based and to which
applicants for and holders of permits should conform. Regulations, rules,
guides and procedures for implementing the basic principles and conditions
laid down in the enabling law should be prepared by the regulatory authority
in correlation with the planning of the first nuclear power project. Regulations,
which should be formulated so as to express at least the irreducible minimum
considered necessary by the regulatory body for achieving and maintaining
safety, should cover all main aspects to be dealt with at the major licensing
stages, i.e. siting, construction, commissioning, operation and decommissioning.
Guides should provide acceptable technical and administrative approaches to
meeting safety requirements specified in the regulations. These approaches are
advisory insofar as alternative approaches are acceptable if it is demonstrated
that the same or higher levels of safety are achieved. Guides, which may be
revised more easily than regulations, should encompass the latest technological
advances that development and experience have shown to be effective and
reliable solutions to safety requirements.
Moreover, on account of its specialized functions, the regulatory authority would be expected to play an incentive role or to be assigned a lead responsibility in the framing of other regulations bearing on the peaceful uses of nuclear energy such as those concerning radiation and environmental protection, the transport of radioactive materials, the physical protection of nuclear materials and facilities, the State’s system of accounting for and control of nuclear materials, since it is evident that the requirements stemming either from national legislation or from relevant treaty obligations contracted by the State in these areas are not expected to be applied in isolation from each other.

The regulatory authority should thus be regarded as instrumental in planning a regulatory programme, in initiating proposals for the elaboration of regulations, in co-ordinating the participation and collaboration of various governmental bodies in the regulation-making process, in seeking the expertise and contributions of qualified institutions and organizations, and in striving for timely adoption of regulations as they are needed. The magnitude of the system of regulations and guides to be established would, however, depend upon the size of the nuclear power programme and, of course, the resources of the regulatory body.

Some countries have adopted the practice of using the standards applicable in another country, generally the country from where they acquire their first nuclear power plant, as a regulatory basis for safety reviews and assessments for licensing purposes. However, such an interim solution consisting in regulatory determinations based on varying foreign standards and criteria is not, in the long run, a consistent and effective way of coping with the safety and safety-related issues involved in nuclear power. Countries embarking on a nuclear power programme thus particularly face the need for a homogeneous and comprehensive body of basic principles and minimum requirements in nuclear power plant safety and safety-related matters that could provide an internationally acceptable basis for regulatory developments and determinations within the context of national nuclear control requirements.

As discussed in Chapter 6, the IAEA, in response to such need, has carried out since 1975 a programme for establishing codes of practice and guides on the safety of nuclear power plants (the NUSS Programme), which is aimed at making available to Member States recommendations deemed essential to provide a basis for regulatory developments and to serve as a standard frame of reference for safety analysis, review and assessment. International standards and criteria supplemented by procedures recommended to implement them as set out in the IAEA Codes of Practice and Safety Guides can be of considerable assistance, in particular to developing countries, in providing a formalized and harmonized approach to the regulation of nuclear power plants.

In order to avoid conflicts of interest and to foster public confidence in its assessments and determinations, the regulatory authority should not be responsible for or functionally involved in the promotion and development of nuclear energy.
Therefore, it is necessary to provide for a delineation of responsibilities that should differentiate between regulatory and control functions, and promotional and development functions. Promotional activities in the field of nuclear energy may thus fall in the province of a ministry or be the responsibility of an autonomous governmental body. Whatever the system may be in this regard, the nuclear regulatory authority should statutorily be separated from them in order to preserve the credibility of its decisions throughout the licensing process (see also section 5.8).

Depending upon the governmental structure, legal traditions and administrative practices of the State, the regulatory authority may be established as a separate collective executive or within a greater governmental unit but it should be vested with a broad statutory or functional autonomy for the exercise of its duties and powers. In any case, it should be in a position to act as a focal point of responsibility for governmental authorization, control and supervision of nuclear activities within the purview of enabling legislation. It should accordingly be entrusted with sufficient discretion to carry out its functions independently of any pressures coming from within or outside the government. It should be empowered to establish or propose the adoption of regulations, rules and procedures for the licensing and control of nuclear materials and facilities, and to seek the advice, expertise and co-operation of any qualified public and private organization in the discharge of its responsibilities. To this end, it should be authorized to set up such advisory bodies as it deems necessary or expedient in regard to any regulatory matters or specific aspects of the licensing process.

5.6.2. Licensing and authorization

Depending upon the national legal system or administrative practices, the granting of a specific licence or authorization at each major stage as work progresses may be required. Various stages of licensing may also be combined into a single authorization, or a licence may be granted provisionally or only in part, subject to further safety review and regulatory determinations on the basis of additional information to be submitted by the applicant or licensee as necessary. The requirements to be placed on the applicant or licensee, his duties and responsibilities as well as matters to be subject to regulatory assessment, review and determinations are generally set forth in broad terms in the enabling law, pursuant to which, essentially:

- A proposed activity should be consistent with the general principles and safety goals set forth in the law
- The applicant should be technically and financially qualified to engage in the proposed activity
- The proposed activity should not pose undue risk to the health and safety of the public, should be provided with adequate physical protection measures and should not result in adverse impact on the environment.
The issue of a licence should not preclude subsequent changes in the licence that may be imposed by the regulatory authority or approved by it at the licensee's request, either in view of health, safety, security, safeguards or environmental considerations or as a result of experience or technological developments. A licence may be suspended or revoked when the conditions of the licence are not met to the satisfaction of the regulatory authority, or when the applicable regulations or licensing decisions have been repeatedly violated, i.e. in the event of failure by the applicant or licensee to take within a reasonable time the corrective measures prescribed by the regulatory authority.

Licensing decisions should be open to review, at the applicant's request, by higher governmental or other qualified institutions, as appropriate. However, the implementation of any regulatory decision motivated by the need for protecting workers, the public or the environment from radiological risks should not be delayed pending the outcome of a related appeal or request for review.

Among the licensing requirements, the qualifications of the operating personnel of a nuclear installation are of particular importance. The methods of evaluating their competence and reliability vary from country to country. It is to be emphasized that not only the operating personnel should be competent and reliable, but also those persons who evaluate their qualifications for licensing purposes.

The safety analysis report is the most important document for the licensing of nuclear installations. Its purpose is to demonstrate to the regulatory authority how the design of a nuclear power plant and related operational procedures will contribute to the prevention of accidents and to their mitigation, and to show that every necessary precaution to such effect has been taken in the light of existing scientific knowledge and technology. This report has to be reviewed and assessed by the regulatory authority with the assistance of its advisory bodies. This assessment usually leads to numerous licence conditions which define the regulatory authority's view of what 'necessary precaution' means. Within this category fall the problems of radiation protection and the environmental impact of a nuclear installation. With respect to the latter, in many countries additional licences are required in such areas as waste management, pollution control, environmental protection, etc. A mechanism or procedures should therefore be provided for consultations between the nuclear regulatory authority and the other competent authorities so that the latter do not issue divergent or even contradictory requirements.

The regulatory authority not only has to consider safety and safety-related matters but also the question of physical security (see section 5.11).

Experience has shown that in order to facilitate public understanding and acceptance of nuclear activities, there is a need for supplying the public with timely and sufficient, easy to understand information on the safety philosophy, regulatory requirements and licensing procedures. Some documentation, however,
may not be made available to the public in view of its confidential nature (e.g. for commercial or security reasons). It may be useful to provide by law that evaluations of plans, safety and environmental impact assessments and reviews in regard to a proposed activity should be discussed with the municipal and local authorities concerned, and made known to the public in an appropriate manner as work is progressing. Anyway, in keeping the public adequately informed of the outcome of technical studies and safety assessments at major stages, the licensing proceedings and implementation process may be expected to be carried out smoothly, with proper understanding by all those legitimately concerned.

Some countries give the public, in addition to appropriate information, the possibility to express itself on the application for a proposed activity. To this end, public hearings (or public enquiries) are organized. These hearings, which may be compulsory or have been adopted under some legal systems, have proved to be difficult to handle and often procrastinating in the licensing process. Therefore formalized procedures, including time limits for interventions and the rights and obligations of intervenors, should be established to prevent public hearings from becoming an open-ended forum for opponents without any useful feedback for the regulators or meaningful information for the public. The personality and reputation of the official in charge of conducting such hearings may be decisive factors in this connection.

It is of paramount importance to secure compliance by the applicant or licensee with all applicable regulations and rules and with the requirements and conditions set out in the licence. The enabling law should accordingly provide for the right of inspection by the regulatory authority and its enforcement powers throughout all stages of the licensing process as well as during the lifetime of an authorized activity. Continuing enforcement through inspection is a sine qua non for the effective discharge of governmental responsibilities in the public interest.

Sanctions are normally also set forth in the enabling law in order to prevent serious or repeated violations of its provisions, of regulations established thereunder and of the conditions specified in a licence. In addition to the suspension or revocation of a licence, the penalties incurred may consist of fines and other measures in accordance with the applicable penal law. It should, however, be stressed that the most important elements of a nuclear regulatory scheme are licensing and inspection; they are effective means of ensuring continued compliance with the applicable regulations and prescribed conditions and measures.

5.6.3. Nuclear liability

In as much as the establishment of licensing conditions and regulatory control is essential for ensuring the safety of nuclear installations, the adoption of legislative provisions to govern liability to third parties for nuclear damage is to be regarded as a pre-requisite to the introduction of nuclear power. In the event of
a nuclear incident and in view of the potential magnitude of damage and injuries that might arise therefrom, appropriate indemnification of victims has to be secured by law, which should not, however, expose the nuclear industry to unbearable financial burdens. A balance of these considerations has therefore led to a solution of compromise between acceptable risks associated with and the benefit expected from the peaceful uses of nuclear energy. This approach is reflected in the formulation of a special regime of liability for nuclear damage.

The basic principles were developed at the international level over two decades ago, and are based on the concept of risk instead of that of fault. These principles have been embodied in the existing international conventions (the Paris Convention of 1960, the Brussels Supplementary Convention of 1963, the Vienna Convention of 1963) which have provided a basis for the adoption of corresponding legislation by many countries in different parts of the world.

The formulation of a nuclear liability regime was motivated by two major considerations:

(1) The need for ensuring financial protection against the risks of personal injury and damage to property in taking into account the potential magnitude of a nuclear incident, the length of time involved in some cases for detecting radiation damage and, especially, the difficulty of furnishing proof of its origin;

(2) The desirability of relieving the nuclear industry (manufacturers, suppliers and sub-contractors) from unlimited risks that would hinder the development of the peaceful uses of atomic energy.

Liability for nuclear damage, both at the international and national levels, is governed by the following basic principles:

(a) **Absolute (or strict or objective) liability**

Because of the special nature of nuclear energy, liability is linked to the risk involved, irrespective of fault. Thus the victim does not have to prove that injury or damage was caused by fault or negligence of anyone. The sole burden of proof upon him is to provide evidence of a link of causation between the injury or damage suffered and a nuclear incident that has occurred.

(b) **Channelling of liability**

Liability is channelled to the operator of a nuclear installation. He is exclusively liable for all damage caused by a nuclear incident in his installation or involving nuclear material in the course of transport from or to his installation. The channelling of all third party liabilities to the operator and to him exclusively is aimed at simplifying the judicial proceedings for the victim who would not
have to sue different persons as he may have to do under the law of torts in general. This system of absolute and exclusive liability would also help to simplify the contractual arrangements between the operator and his suppliers since the latter would not need to be concerned with insurance or other financial security to cover liability for nuclear damage in connection with their services and supplies. Thus, another advantage of this principle of 'legal channelling' is to avoid a so-called ‘pyramid’ of insurance premiums.

(c) **Limitation of liability in amount**

The operator’s exclusive liability places a heavy burden on him. Therefore, as a balance to this concept of absolute liability, such liability should be limited in amount. Moreover, liability without limitation in amount cannot be effectively insured or otherwise guaranteed. The operator must obtain and maintain insurance or other financial security up to the established liability limit per nuclear incident. In the last resort, should the operator’s insurance cover or other financial security prove insufficient to satisfy all claims for compensation for nuclear damage, the State that licensed the operator liable must provide additional indemnification (State intervention).

(d) **Limitation of liability in time**

Radiation injuries may produce delayed effects but, on the other hand, the liability fund or reserve under any insurance or other financial security scheme cannot be maintained for unduly long periods. As a compromise, therefore, the conventions on nuclear liability provide for the limitation of the operator’s liability to a period of 10 years from the date of a nuclear incident, subject to possible derogation by national legislation but provided that the operator’s insurance or other financial security is also maintained during any period extending beyond the ten-year period.

(e) **Single court competent**

The existing conventions uniformly provide for one court competent for dealing with all claims arising out of a nuclear incident. The determination of the competent court also entails determination of the national law applicable to all claims for compensation.

Experience has shown that the implementation of a first nuclear power project in some countries was confronted with considerable delays in the negotiation of contractual arrangements with manufacturers and suppliers of nuclear materials, equipment and facilities. Among other things, the lack of national
legislation on nuclear liability consistent with relevant international conventions has resulted in protracted discussions on the liability clauses to be detailed in supply contracts. These difficulties indeed point to the need for early consideration of the elaboration and enactment of nuclear liability provisions in conjunction with other technical and regulatory steps required during the planning for the introduction of nuclear power.

5.7. MANPOWER DEVELOPMENT REQUIREMENTS

Qualified manpower is essential for the safety and reliability of nuclear power. Any country embarking on a nuclear power programme has the primary responsibility for planning and implementing its manpower development programme, which must begin at the earliest stages of a nuclear power programme because of the long lead-times involved in developing highly qualified manpower. Governmental support is required for consistent, long-range policies on manpower development, and decisions and commitments must be taken at the governmental level. In a nuclear power programme, whatever the contracting arrangements, there are certain essential activities, for which full responsibility has to be borne by national organizations and which have to be performed primarily by qualified local manpower (see also section 5.8.2). Therefore, before undertaking a nuclear power programme, a country must be prepared and committed to develop its manpower in order to attain the capability to perform at least these essential activities.

The availability of qualified manpower may constitute one of the principal constraints of the initiation, scope and schedule of a nuclear power programme, especially in countries with relatively weak education and training infrastructures and scarce highly skilled manpower resources. The IAEA has long since recognized the importance of manpower development and has consequently dedicated major efforts to promote it. Included in the IAEA's activities in this field are training fellowships, expert services, specialized courses, experts' meetings, panels, seminars, symposia and in particular, the preparation of a comprehensive guidebook on “Manpower Development for Nuclear Power” (Technical Reports Series No. 200, STI/DOC/10/200), which was published in 1980. Owing to the availability of this IAEA publication, which should be consulted for detailed information, the subject of manpower development will only be discussed briefly in the present Guidebook.

Since nuclear technology has many special features which are not encountered in other areas of industrial development, special requirements are imposed on manpower.

Most of these special features are related to or are a consequence of nuclear safety requirements (see Chapter 6). It must be recognized that man is the most
important link in the safety chain, from the design through the manufacture, installation, inspection and testing, to the operation and maintenance of equipment, components and systems. Skilled and proficient manpower plays an essential role in preventing nuclear accidents and in handling them correctly if they do occur. Skill and proficiency can only be achieved through appropriate education, training and experience. In nuclear power there can be no compromise on safety; high safety and quality standards must be established and strictly maintained. This can only be achieved with competent staff.

In practically every phase and activity of a nuclear power programme advanced technology is involved, which requires qualified manpower capable of understanding, adopting and adapting or developing, and finally applying it. In a country without a nuclear industry, technology is usually acquired from a more advanced country able and willing to transfer it. However, for technology transfer to be successful, the recipient country must be capable of absorbing the technology; the key to this is the availability of qualified manpower.

The nuclear fuel cycle constitutes one of the most distinguishing special features of nuclear power. Nuclear power plants and nuclear fuel must be considered together. An assured fuel supply is essential for the operation of the plant, and spent fuel must be adequately disposed of. The fuel cycle includes a series of ‘front-end’ and ‘back-end’ activities, of which some are essential for national participation, requiring specially trained national manpower for their performance. Radioactive waste disposal is an activity resulting from the use of nuclear fuel and this again requires special techniques as well as people capable of their application.

Nuclear power requires relatively large capital investments, long lead times, and a solid supporting infrastructure. Consequently, there is a need for planning and for long-term commitments on a national level, involving the government, the utilities, national industry and scientific, technological, educational and training institutions. Owing to the large overall effort involved in a country’s nuclear power programme, policy changes, interruptions, delays or mistakes have proportionately large effects on the programme and may even affect the country’s overall economic and industrial development. The role of manpower in planning, directing, co-ordinating and effectively implementing the national effort for the nuclear power programme cannot be overemphasized.

Finally, nuclear power has the special feature of involving an extremely wide range of technical disciplines and skills in practically all conventional areas as well as in specialized nuclear fields. In addition, previous professional experience is usually required to qualify people for most managerial and technical tasks and functions involving major responsibilities. This places a considerable demand on the national manpower resources and on the national manpower development infrastructure. In fact, a nuclear power programme could hardly exist as the sole case of advanced technology in a country with inadequate infrastructures.
To provide the highly qualified and experienced people at the proper time, the essential conditions to be met are:

(a) An early and full awareness of the need of manpower
(b) The careful and detailed planning of a manpower development programme
(c) The effective implementation of this programme
(d) The application of an appropriate personnel management policy.

A comprehensive manpower development programme must be an integral part of the nuclear power programme and consistent with national participation policies. It should, if possible, be organized, co-ordinated and controlled by one specially created group. It is emphasized that:

— The implementation of a nuclear power programme is not feasible without sufficient national manpower
— Only properly qualified manpower can be considered for meeting the manpower requirements for a nuclear power programme
— Manpower development is a long-term activity and must be programme oriented rather than project oriented. As many as 10 to 15 years may be required to establish the independent, national manpower development capability necessary to produce highly qualified manpower for a nuclear power programme
— Although manpower development will require what seems to be a large investment, its cost is very small when compared with the investment associated with the overall nuclear power programme.

The overall manpower requirements of a nuclear power project (national and foreign in the case of imported plants) are illustrated in Fig.17. During the pre-project and early implementation phases, relatively few (50 to 100) but highly qualified professionals are needed. The requirements start to increase strongly when the commitments are made (letter of intent, contract) to install the plant. Manufacturing and construction are the activities that have by far the largest manpower requirements, of the order of 5000 people. Most of these (about 85%) will be technicians and craftsmen. In nuclear power the requirements for unskilled labour are very low (of the order of 10%), although in some countries their proportion might be considerably higher, mainly owing to local labour practices and employment policies. Professionals during the design and construction phase are needed primarily for project management and engineering (250 to 350). Finally, for operation and maintenance, a staff of about 170 to 270 highly trained people are required. In general, it can be estimated that the manpower requirements of a nuclear power project are of the order of 6000 professionals, technicians and craftsmen during its peak period and are relatively small but not less important during the initial phases and during commercial operation of the plant. In addition, manpower is required to perform the
FIG. 17. Overall manpower requirements of a nuclear power project.
supporting activities: nuclear power programme planning and co-ordination, regulatory and licensing, fuel cycle activities, research and development, education and training.

The national nuclear manpower requirements will be defined by the activities to be performed within the country by local manpower and will fundamentally depend on:

- The scope and schedule of the nuclear power programme
- The scope and schedule of national participation in this programme
- The constraints and limitations on the scope and schedule imposed by national industrial, educational and technological infrastructures and manpower resources
- National conditions and characteristics affecting the labour market such as productivity, efficiency, competition from other large industrial undertakings, employment policies, labour costs, customs, rules and legislation.

The above factors are interrelated and thus should be considered together. It is recognized that the nuclear power programme as well as the formulation of the policies and goals for national participation should already have included the effects of all requirements and relevant constraints including those of manpower. For the determination of national manpower requirements, however, which is the first stage of manpower development planning, in-depth analysis and review of the manpower and the education and training resources are necessary. While the number of people required to perform certain functions or tasks depends on national labour practices and conditions, the necessary qualifications depend only on the nature of the function or task and not on any conditions prevailing in the country.

The power rating of the plant has practically no effect on the manpower requirements of supporting activities and most project-related activities such as pre-project activities, project management and engineering, quality assurance and control, commissioning, operation and maintenance. It has only a relatively small effect on the manpower requirements for manufacturing and construction.

In developing countries there is usually a shortage of qualified manpower and consequently a high demand for qualified professionals, technicians and craftsmen. Such a situation would normally lead to higher attrition rates and major difficulties in providing replacements. Therefore, in assessing manpower requirements, care should be taken to include, in addition to those people who actually will be needed to perform the tasks and functions, an adequate number of reserve and replacement personnel. A policy of a reasonable degree of over-staffing, especially in critical areas, is thus advisable.

It should also be emphasized that many high technology projects, and especially nuclear power projects, have been delayed and have encountered other serious problems for lack of qualified technicians. In some countries the status
and compensation of technicians do not provide sufficient incentives for recruiting and retaining those most able to fill these positions. In some cases capable technicians have attempted to become engineers in order to overcome the economic and social problems associated with the technician’s status. In this way many capable and necessary technicians can become not so capable engineers. Thus, measures must be taken to ensure the availability of sufficient numbers of the qualified technicians necessary for a safe and efficient nuclear power programme.

To start the development of a nuclear power programme it is necessary to establish a relatively small project group which will have the overall responsibility for carrying out the various studies involved in the pre-project activities. An important aspect in the formation and organization of this project group is that it should not exclusively consist of nuclear specialists but rather of senior and experienced planners and engineers who have been engaged in large projects such as conventional power plants or industrial installations, and with the general planning of power and distribution systems in the country concerned, supplemented by a few nuclear experts who are familiar with nuclear reactor engineering and nuclear power systems.

The size of this group need not be very large (25 to 40 professionals), but the important point is that they should be carefully selected with the highest available quality, competence and experience. It must be recognized that this group represents the main core of the organization of the whole nuclear programme and will have great responsibility in taking major decisions and presenting recommendations involving important and far-reaching commitments and large investments. It will be necessary to provide the staff of this project group with additional training in nuclear power, both through special courses and on-the-job training assignments, probably abroad.

A country embarking on a nuclear power programme must make a critical and realistic assessment of its organizational, educational and industrial capabilities and determine the requirements for developing the quality and quantity of manpower needed for a successful nuclear power programme. The difference - or gap - between requirements and capabilities determined by such an analysis will indicate what the resultant manpower development programme should be as well as the role of government, education, and industry to achieve the manpower development goals. It is also necessary to determine, in the course of such an evaluation, which training requirements can be met nationally and which can best be met abroad and what their schedule should be.

No amount of outside guidance can substitute for an organized, disciplined and comprehensive effort by a national team responsible for evaluating manpower requirements and defining, planning and implementing a manpower development programme. The programme for each country has its own unique characteristics that must be understood and taken into account. This is only possible when the
programme is primarily developed by national planners. General guidance, or outside expertise can and should be used wherever needed, but it must never supplant the country's own effort to define its manpower requirements from a thorough understanding of the nature of each activity and task in its own nuclear power programme and the qualitative and quantitative manpower requirements to perform these tasks. The planning process itself is an indispensable factor for an effective national manpower development programme.

5.8. INFRASTRUCTURE REQUIREMENTS AND NATIONAL PARTICIPATION

5.8.1. National infrastructure requirements

The introduction of nuclear power in a country cannot be conceived as an isolated project. The decision to launch a nuclear power programme has to be made taking fully into account the country's industrial development status and technological capabilities. Adequate minimum infrastructures must be available for any type of contractual approach in the following areas:

- Government
- Electrical system and utility organization
- Industry (engineering, manufacturing, construction and erection)
- Manpower, education and training
- Science and technology.

5.8.1.1. Government

A nuclear power programme requires major efforts on a national level, where the main responsibilities and functions of the government are:

- Development of the nuclear power programme
- Nuclear licensing and regulation
- Establishment of bilateral or multilateral agreements, for the implementation of technology transfer, training, technical assistance, exchange of information and safeguards
- Definition of national participation policy and strategy
- Legislation for nuclear power and for promoting national participation
- Survey of the available national infrastructure and its capability
- Study of the feasibility of national participation in general and in detail
- Planning and co-ordination of the national effort
- Elaboration of procedures and methods to implement and to increase national participation
Provision of financial assistance
Establishment of national policy for quality assurance.

In order to carry out its responsibilities and functions, which are promotional and regulatory, an adequate governmental infrastructure is required consisting of three essential components, which have been discussed in the preceding sections:

Organizational structures
Legal framework
Qualified manpower.

In most countries nuclear energy commissions or authorities have constituted the basic governmental infrastructures. In the early stage these organizations have had both promotional and regulatory functions, but as the power programme develops, they tend to assume the regulatory functions and to leave the task of implementing nuclear power programmes to other organizations (utilities, industry).

The staff of the governmental infrastructure should consist of high-level experienced professionals with general as well as specific knowledge of nuclear power. Such people are hard to find, especially during the initial stages of the nuclear power programme. Once the country has started its nuclear programme, the staffing requirements of its governmental infrastructure will increase, in particular in the regulatory function, but the availability of qualified staff should also improve.

It is essential that the governmental staff concerned with nuclear power is not considered as an additional administrative group of civil servants. These people have specialized technical qualifications and functions. Unless they are provided with a status and incentives commensurate with their functions and responsibilities, it will be difficult to retain them in their positions.

5.8.1.2. Electrical system and utility organization

The purpose of a nuclear power programme is the production of electricity to meet the demand. To fulfil this purpose, the introduction of a nuclear power plant requires the existence of an electrical interconnected system (generation, transmission, distribution) of adequate size and technical characteristics, which will permit its integration and efficient use. The conditions defining the adequacy of the electric system are discussed in Chapters 8 and 10. There is also an IAEA Guidebook on “Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants” expected to be published in 1982.

An adequate electrical interconnected system implies the availability of a national electrical organizational infrastructure consisting of a utility or utilities, organized and staffed with skilled people experienced in the construction and operation of conventional electric power plants.
The first nuclear power plant in a country will probably constitute the largest generating unit added to the system. In addition, due to its special features, it will impose unprecedented requirements on the electric utility, which will have to adjust its organization, capabilities and characteristics to respond to this challenge. This might be a difficult task.

It must be clearly understood that a nuclear power plant is not just another power plant. The organization in charge of the project must be able and willing to undertake the necessary adjustments, changes and developments. Electric utilities with only conventional experience may find it very difficult to undertake a first nuclear project, and it might even happen that they are not interested or qualified to do so. There are examples of countries where the implementation of the first nuclear power plant has not been handled by an electric utility but by a nuclear energy commission or by a new organization especially established for this purpose. Such solutions, however, also imply similar or possibly even larger efforts to be undertaken.

5.8.1.3. Industry

There are no firm rules regarding the industrial infrastructure requirements of a country starting on a nuclear power programme, but as a minimum, the plant has to be built, the equipment and components have to be installed and tested, and the plant has to be operated and maintained within the country. This means a basic requirement of competent construction and erection firms and of operations and maintenance capabilities. The available industrial infrastructure will probably not have all the technology, know-how, level of quality, or the expertise necessary for nuclear power but, as is shown by experience, these can be acquired. Regarding engineering industrial capability, this becomes a basic requirement if a non-turnkey approach is adopted, or if there is a policy for increased national participation.

The national engineering, manufacturing, construction and erection capabilities play an essential role in the promotion and development of the nuclear power programme. These industrial infrastructures should be closely associated with the nuclear power programme to which they provide a pool for the necessary skills and human resources. The high quality requirements of the nuclear technology call for the enforcement of an adequate programme for quality assurance and quality control (section 5.9).

Nuclear power places special demands on the industrial infrastructure:

Advanced technology is involved, which usually has to be acquired through technology transfer from foreign suppliers
Very strict quality standards have to be met, owing to nuclear safety and reliability requirements
Schedules must be complied with
Many supply items are of unique design
Cost should be at reasonably competitive levels
Unfamiliar industrial standards might have to be applied
Many special materials new to the industry are used
Equipment and components of unusually large sizes and weights have to be handled and transported.

The overall result is that the existing conventional industry is usually unable to supply the materials, equipment, components and services without first improving its capability. This means upgrading of quality assurance and quality control, acquisition of new technology, installation of additional equipment and changes in methods and procedures.

5.8.1.4. Manpower, education and training

The infrastructure requirements regarding qualified manpower and national manpower development resources have been discussed earlier in section 5.7. The IAEA Guidebook on “Manpower Development for Nuclear Power” contains detailed additional information.

The development of an adequate national educational and training infrastructure is the only real way to develop qualified local manpower. Any country for which nuclear power is a viable option must have an electric system of reasonable size and a basic industrial infrastructure, and would thus also have certain technical manpower and education and training infrastructures. This will have to be expanded and adjusted in every case to the requirements of the nuclear power programme. It is possible and may be necessary to obtain some highly specialized experts and training from abroad, in particular in the early phases of a nuclear power programme. But this can only be utilized in a very limited way and a national manpower development programme is still essential.

To develop the manpower and education/training infrastructures to meet the national requirements of the nuclear power programme, a well-planned and co-ordinated effort will be needed from the following partners:

Government
National education system, including schools and technical training institutions as well as universities and higher educational institutions
Special training centres and institutes
Research and development institutes
Utilities and industry.

It should be pointed out that for nuclear power the need for scientists and research-oriented personnel, particularly in the nuclear field, is often overestimated,
while the need for highly qualified and experienced practically oriented engineers, technicians and craftsmen is very much underestimated.

The role of education with reference to a nuclear power programme is to provide a thorough grounding in the principles onto which nuclear power technology may be grafted. Academic quality in the professional disciplines is normally assumed to be defined by an academic degree from an educational institution whose curricula have been accredited by an appropriate body. Providing qualified manpower for nuclear power will place new demands on the educational system. The curriculum must be carefully examined and formulated so that there is a coupling of scientific and technical knowledge with the needs of technology, including a functional balance between theoretical knowledge and practical training and experience. Otherwise, it cannot be assumed that an academic degree is a reliable measure of quality with respect to the ability of an individual to accomplish a specific task. This is a fundamental problem which should be carefully examined in each country’s educational system, if realistic progress is to be made in effective long-term manpower development for nuclear power.

Adequate national capabilities will have to be developed, particularly at the technicians’ and craftsmen’s levels, who constitute an essential component in the viability of a nuclear power programme. To develop the skills needed domestically, the establishment of a national training centre may become necessary.

5.8.1.5. Science and technology

It is widely recognized that national development in general and nuclear power in particular require a scientific and technological infrastructure. Such infrastructure is mainly contained in:

- National and private research and development institutes
- Institutes and laboratories for standardization and calibration
- Higher educational institutions
- Special training centres
- Scientific academies and professional associations
- National industry.

Past experience of all countries that embarked on a nuclear power programme has indicated that the establishment of a nuclear research institute, though not prerequisite to a nuclear power plant, has always proved to produce a catalytic effect upon the country’s nuclear programme development.

An important role for the establishment of a nuclear research and development infrastructure is to stimulate the activities in the various fields of nuclear science and technology, which will keep the experts active in their respective specializations. It also provides a good source of manpower in some important
areas needed for nuclear power plants, such as reactor engineering, reactor
operation, radiation protection, nuclear safety and waste disposal.

It is in general the government’s role to take the lead in establishing a scientific
and technological infrastructure for nuclear power. Depending on the objectives of
the national policies and the particular conditions prevailing in the country, this
could be done by:

- Promoting technology-oriented applied research and development activities
  in general;
- Establishing national nuclear research and development institutes and
  nuclear technology development centres with adequate staffing, funding,
  facilities, programmes and autonomy;
- Introducing nuclear science and technology-oriented curricula in national
  universities or institutes of advanced science;
- Promoting the establishment of nuclear training centres according to the
  expected manpower development requirements;
- Concluding international agreements and arrangements for the exchange
  of scientific and technical information and the transfer of technology;
- Promoting and financing the specialized training of professionals within
  the country and abroad;
- Establishing a system of socio-economic incentives to provide motivation
  for professionals to choose scientific and technological careers in the
  country.

The development of a viable science and technology infrastructure is a long-
term process which can take several years or even decades, depending on the level
of the country’s overall scientific and technological infrastructure at the beginning
of this process.

5.8.2. Areas of national participation in the nuclear power programme

Every country has the overall responsibility for the planning and imple­
mentation of its national nuclear power programme. Without national participation,
it cannot carry out this responsibility.

The introduction of nuclear power in most countries will be initially and may
remain for some time based largely on the importation from advanced supplier
countries. However, national participation is an essential element in the develop­
ment of a nuclear power programme. The extent of such participation will
significantly depend on the existing infrastructure capabilities and on the availa­
bility of local resources for the supply of necessary materials, services, equipment
and qualified manpower. While interest in the maximum use of domestic resources
in any industrial activity is a common characteristic of all countries, the degree of
national involvement in nuclear power development will be a process in which the local participation is gradually increased as the nuclear programme develops, if there is a national policy favouring the evolution of the national capabilities for such participation in the various areas of nuclear technology.

There are certain activities within the scope of a nuclear power programme, for which full responsibility has to be borne by national organizations and which should be primarily executed by national manpower whatever the contracting arrangements. These are considered 'essential' activities for national participation. Expert help from abroad could be obtained and used up to a point, but only for technical assistance and not as a complete replacement of the national effort. Which activities would fall into this 'essential' category is a question to be answered by each particular country; there are, however, some general indications based on experience which should be considered when planning the national effort.

In general, most of the activities to be performed during the pre-project and pre-construction phases (see Table XXV) would be essential activities for national participation. A country expecting to have a successful nuclear power programme must be able and willing to study, plan and prepare its first project and make all the necessary decisions itself. Should it lack resources to perform at least most of these activities, serious consideration should be given as to whether or not the country is prepared and ought to embark on a nuclear power programme at all.

The management, engineering, manufacturing, construction and commissioning of the project includes the performance of a series of activities and the supply of certain goods and services, which are essential for national participation, because importing them would not be feasible. These would usually include:

- Project management by the owner
- Establishment of QA policy
- Emergency planning
- Public information and public relations
- Safeguards and physical protection
- Site preparation
- Design reviews
- Erection of plant buildings and structures
- Plant equipment and systems installation
- Supervision of suppliers
- Planning and co-ordination of the training of operations personnel
- Radiological protection and environmental surveillance
- Nuclear regulation and licensing.

Once the plant is finished, its operation and maintenance and the supporting activities (see Table XXIV) are fully a national responsibility and hence classified as 'essential' for national participation.
No doubt a country should assign first priority to the performance and supply of the 'essential' (for national participation) activities, goods and services. However, its national effort does not have to be limited to these. National participation could be expanded into many other areas of activities and supplies such as:

- Overall project management
- Detailed design engineering
- Preparation and review of equipment and plant specifications
- Procurement
- Construction management
- Safety analysis reporting
- Plant systems and components testing
- Plant acceptance testing
- Performing and auditing the quality control activities
- Manufacturing of components that would be feasible to attain by industrial capabilities and technologies available in the country, or requiring only reasonable improvements.

To increase national participation in areas beyond essential activities and supplies, it seems advisable to assign priority to:

- Items that can be produced by an existing national infrastructure with no or only reasonable additional effort
- Items where national participation is feasible and for which long-term assurance of supply is considered important
- Engineering services that constitute the connecting link to national construction and manufacturing capabilities
- Items where the technology involved can have important spin-off benefits
- Items for which there is an assured adequate domestic market.

5.8.3. Assessment and definition of national participation

The first target for national involvement would be to adequately perform those activities that have been defined as 'essential' for national participation. Further, short-term development of those capabilities required to perform the activities set out in the priorities above would be objectives to be progressively attained in the programme. This would call for increasing responsibility of the owner for project management and development of national engineering services, as well as the enhancement of manufacturing capabilities and improvement of QA/QC in their production lines. Such a course of action would allow the initial turnkey approach (if adopted) to evolve into a split-package approach and
eventually become multiple-package management of the project. This evolution is a challenging task for the country, and requires a firm long-term policy for the nuclear programme, careful planning and realistic and critical assessment.

From the very start of the nuclear power programme the importance of national participation must be fully appreciated. One of the essential factors defining the programme’s viability will be the extent to which industrial capabilities are available and/or can be made available in the country. This is the factor to account for and the ground on which the decision of whether embarking on a nuclear programme should be formulated. Right at the start of the decision-making process the responsible authorities must take stock of the situation with a thorough survey of national industries and realistic assessment of their present and potential capabilities.

The survey should first of all identify those national industries whose production meets or might meet the quality standards of nuclear technology. Then the investments associated with the necessary development must be evaluated on a cost/benefit basis.

The problem of setting the goals for national participation is a difficult task for the country’s policy makers. Careful planning must be established with due consideration to what is realistically achievable, allowing for flexibility, for reconversion of objectives if schedules are not met, and for reassessment of the targets of the programme.

Particularly at the start of promotional efforts domestic production is heavily affected by competition from the international market. A newly developed production capability naturally cannot provide the same assurances for meeting standards and schedules as a reputable and well-experienced supplier would do. The risk of the disruption of the project schedule and consequent economic loss will have to be assessed on a cost/benefit basis. Too ambitious a target for self-reliance and/or underestimation of the necessary lead times to achieve reliability of domestic production may jeopardize the economy of the project. On the other hand, inadequate promotional effort and preference for inclusive package supply from experienced vendors may delay the future competitiveness of national participation.

A difficult task in the promotion of local capabilities is to assess the share of domestic participation in the project that is feasible at the outset and to set up realistic future objectives for increasing involvement. It must be borne in mind that 100% national participation in a nuclear programme may not be the ultimate target, even in the scope of a long-term development programme; a target of 60 to 80% might be more realistic in most countries.

Industrial promotion should essentially be oriented towards up-grading the already existing national industries. Promotion of those industrial capabilities that require acquisition of unprecedented technological processes and/or construction of unique manufacturing installations may prove to be impractical and
even beyond the scope of national participation objectives. The accelerated development of carefully selected manufacturing capabilities should be sustained without undue strain on other industrial sectors, if nuclear energy is to be integrated without unbalancing the country's national economy.

A national participation study is never really finished. It has to be reviewed and updated constantly, taking into account the development of local industry as well as the evolution of nuclear technology. It should not be limited in scope to one nuclear plant, but should consider instead the whole nuclear power programme. In fact, a national participation programme must be fundamentally long-term oriented. A prerequisite for its establishment is the existence of a long-term nuclear power programme.

International suppliers of nuclear plants and equipment can and usually do provide technical information if requested to do so. There is also a great amount of published information available which can be collected and analysed. The assistance of an experienced nuclear consultant can be very useful, but it is essential to establish a local group of well-qualified staff in charge of planning and implementing national participation. This should not be an ad hoc team formed with the sole purpose of writing a report but a well-organized group with a long-range view.

The survey of national industrial capacity will be a local effort and should be conducted by the local group. The collaboration of local official or private industrial and commercial organizations should be obtained, and consultants who are well experienced in the country can be used if needed, to assist in special fields. The survey must be based on a realistic assessment of the effective existing capacity.

To assess the present and potential capabilities of the national industries, which constitute the main objective of the survey, the methodology should be well defined. This could consist of:

(a) Listing all components of the nuclear power project
(b) Definition for each component of the relevant standards and key design parameters, such as quality class, special testing requirements, significant manufacturing/construction materials requirements, delivery time, cost order of magnitude, etc.
(c) Inspection by a qualified team of a selected and representative number of national manufacturing firms and the production of documentation describing the facilities, organization, production equipment, quality control practices, etc. of each firm
(d) Visits by qualified representatives of the national manufacturing industry to similar foreign industrial establishments
(e) Identification for each component of present and prospective manufacturers. This would indicate those manufacturing areas more in need of development, where promotion may then be concentrated
(f) Definition of the present and potential manufacturing capability of each firm inspected.

Manufacturing firms can be classified according to their capabilities currently available, attainable with little effort, attainable with major promotional effort, or unlikely to be attained.

Components can be classified according to their relevance to nuclear safety, plant reliability, plant maintenance, cost, provenness, technical difficulty, etc.

An important result that can be derived from the survey is the identification of deficiencies in the national industry. This in turn will suggest adequate remedial action through which the programme for national participation can be improved. The type of deficiencies that are generally detected and the associated areas more in need of development include:

(a) **Manufacturing deficiencies**

- Non-destructive testing equipment
- Performance testing and product control equipment
- Welding and heat-treatment equipment
- Heavy machining equipment
- Bending and forming equipment
- Surface treating equipment
- High-capacity cranes.

(b) **Design deficiencies**

- Need for parent company's assistance
- Modification of an existing design
- Additional design from existing licensor.

(c) **Quality assurance and quality control deficiencies**

- Need to introduce a complete formal QA/QC programme
- Improvement and/or expansion of presently existing QA/QC practices
- Need for additional procedures.

In practice, there are limits to what national participation goals can be achieved. These limits, which differ from country to country, are imposed by the availability of funds, manpower and time needed for the development of technologies. In addition, there are political constraints derived mainly from non-proliferation policies, which would act as impediments to the development of certain 'sensitive' technologies and their industrial applications.
What should be done by a country and where is the practical limit of convenience of national participation are questions that can only be answered by each country itself after careful cost-benefit analysis. In such an analysis costs and benefits should be interpreted in their broadest sense (national development objectives, social, political implications, etc.) and not only as economic values. The practical limits of convenience will also change in a given country as industrial development is achieved and progress is obtained in a nuclear power programme.

The manufacture of equipment and components of nuclear power plants poses a serious problem to the industry of any country, whether highly industrialized or developing. The strict requirements regarding quality, reliability and manufacture on schedule are difficult to meet and are, as past experience shows, not always met. As the knowledge and experience gained by countries and their industries increase results tend to improve, but even after considerable experience has been accumulated problems may and often do turn up. Deficiencies in quality and reliability reduce the power plant's availability and result in a higher unit cost of electricity generation. These risks should always be balanced with the benefits expected. Should deficiencies affect the safety aspects of the plant, the problems may become even more serious. Interest in national participation should never be allowed to supersede safety requirements.

National engineering capabilities would have a powerful promotion role in implementing the national participation goals of the manufacturing industry in particular. Transfer of technology requires a counterpart able to assimilate, adopt and adapt it to the national capabilities and requirements.

5.9. QUALITY ASSURANCE AND QUALITY CONTROL REQUIREMENTS

A nuclear power project involves more stringent requirements for quality than would apply to a conventional project. The overall responsibility for ensuring the fulfilment of the quality requirements is placed on the owner. The regulatory authority in turn has to ensure that the owner complies with his duties and responsibilities.

Quality assurance (QA) is defined as the planned and systematic actions necessary to provide adequate confidence that an item or facility will perform satisfactorily in service.

Quality control (QC) is defined as the quality assurance actions that provide a means to control and measure the characteristics of an item, process or facility in accordance with established requirements.

The above definitions are used in the IAEA Code of Practice on Quality Assurance for Safety in Nuclear Power Plants (NUSS 50-C-QA) published in 1978,
as well as the Safety Guides on QA, which should be consulted for additional information on the subject.

It is essential that a country embarking on the implementation of its first nuclear power plant give serious consideration to the various activities that will be required for the effective 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 correct establishment, execution and supervision of an effective QA programme.

Nowadays QA is considered essentially as a management system. It has been developed and implemented in order to facilitate the introduction, achievement and improvement of sophisticated technologies like nuclear engineering, advanced electronics or space research, where safety and reliability are the main concerns. Using a somewhat unconventional approach, the result of QA can be expressed as the 'confidence' that a certain requested quality level will be reached, objectively verified and correctly documented.

Contemporary regulations for nuclear power plant construction and operation are based on a set of safety requirements contained in safety criteria, standards, procedures, drawings, specifications and associated engineering requirements.

It is necessary to obtain the confidence that the plant is designed, constructed, installed, tested and operated satisfactorily. This will be possible if all participants in the nuclear power projects are obliged to plan, perform, control and document their work in a systematic and consistent manner. The management system entailing the function of ensuring that all activities affecting safety and quality of the plant are performed in a planned, systematic and controlled manner is the QA system.

The functions of the QA system are:

(a) To ensure correct performance of all basic functions in the design, manufacture, construction and operation of nuclear power plants and to provide objective evidence of the achieved quality of the work;

(b) To perform verifications of items and work operations to established requirements, thus ensuring timely detection of non-conformances and their elimination.

In this way, QA for nuclear power plants consists of two kinds of activities to be performed:

(1) Planning, management and documentation which ensure that activities are correctly performed. This includes such activities as quality assurance programme formulation and co-ordination, review and approval of procedures, preparation and performance of QA audits, etc.
(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.

QA is always the responsibility of the organization that has the final technical, administrative and financial responsibility for the plant. This organization is usually the plant owner, who shall discharge his responsibilities regarding QA both directly (establishing his system of QA and developing an overall QA programme for the whole plant), and indirectly through contractual arrangements with all designers and constructors of the plant. He may delegate the tasks of establishing and implementing all or parts of the QA programme to other organizations, but he always retains the responsibility for the effectiveness of the overall programme.

The QA requirements are specified in a number of national regulations for safety of nuclear power plants. The IAEA has prepared and published an internationally agreed set of requirements contained in the Code of Practice on Quality Assurance for Safety in Nuclear Power Plants. This Code contains principles for establishment and functioning of the QA system in nuclear power plant projects. According to the Code, the required system shall be established with the following constituent elements:

(a) Quality assurance organization

Activities affecting quality shall be performed in an organizational structure with clearly defined responsibilities and authorities. Achievement of quality shall be the responsibility of all participants in activities. Verification functions shall be assigned to persons and groups who have no direct responsibility in the activities being verified.

(b) Quality assurance programme

Activities affecting quality shall be performed on the basis of a documented programme. This consists of written procedures and instructions for performing activities and of plans for implementation of these procedures in corresponding activities. The QA programme shall ensure conformance of all items and activities with regulatory requirements, codes, standards and specifications.

(c) Quality assurance records system

QA records that represent an objective evidence of quality of items and activities shall be prepared, collected and maintained. Records system provides a support to confidence in the quality of products and services and shall represent
a documentary basis for evaluation of effectiveness of QA system and adequacy of QA programme.

The required QA system functions will depend on the type of organization performing activities and on its task in nuclear power projects. The overall QA programme for nuclear power plant shall specify the following functions of the QA system:

(a) Document control

Document preparation, review, approval, issue 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

Regulatory requirements, design basis, and other quality requirements shall be included or referenced in procurement documents. Purchasers shall implement regulatory requirements regarding quality through contractual arrangements with the suppliers. 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 examination of objective evidence of quality.

(d) Control of processes

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

(e) Inspection and test control

Inspection and testing as method of verification of conformance to established specifications shall be established and executed for each item or work operation where necessary, to ensure quality. All equipment used in these verifications shall be regularly checked, calibrated and adjusted.
(f) Identification and control of materials, parts and components

Identification and control of items shall be ensured through appropriate markings on the items, or on 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.

(g) Non-conformance control

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

(h) Corrective actions

Conditions adverse to quality that are identified shall be analysed and corrected. Appropriate measures shall be taken to prevent recurrence.

(i) Quality assurance programme audits

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

It must be recognized that QA is not the sole responsibility of a single group or department assigned the task to check, inspect, test, audit or otherwise verify that an activity has been correctly performed. The execution of a QA programme involves both the performers and verifiers of the work, therefore QA is implemented by all departments that perform quality-related activities. However, in an organization the functional assignment should be such that the attainment of quality objectives is the responsibility of those who have been assigned the responsibility for performing work. This includes the designer, welder, operator, etc. who may perform examinations of their own work. Verification of conformance to established requirements is accomplished by those who do not have direct responsibility for performing the work such as the design reviewer, the checker, the inspector, the tester or the auditor.

With regard to organizational arrangements, these control and verification functions can be placed in a single organizational entity called the QA department. This department has the same position in an organization as other departments such as engineering, procurement, etc. and performs all the inspections and testing as well as QA programme management and auditing. However, QC functions can
also be placed in the departments performing basic functions such as construction, procurement, manufacturing, operations, etc. In this case, QA engineering, programme co-ordination and auditing are assigned to a separate organizational entity that is independent of other departments but does not include QC personnel. Both organizational arrangements meet QA requirements if the degree of independence of the persons and organizational units performing QA activities is such that this cannot affect their ability to carry out these activities effectively.

The structure and functions of a QA department or more generally a QA unit will depend on the role and functions of the respective organization in a nuclear power project, as well as on the form of construction management selected for the project. Normally, the required QA/QC activities are performed by all participants in the project, either through organizational units or through specific functional entities.

The overall qualified personnel requirements for carrying out the QA/QC activities during design and construction of a nuclear power plant are about 30 to 50 professionals and 50 to 70 technicians. These are distributed among the owner, the project engineering organization and the suppliers and contractors, according to the contractual approach adopted. With a turnkey approach, about half of these professionals and 20% of the technicians would correspond to the owner’s organization to develop and manage the overall QA programme and perform surveillance, review, evaluation, auditing and documentation management. With a non-turnkey approach, the manpower requirements of the owner would be larger according to the increase in the functions and tasks to be performed under his direct responsibility.

5.10. FINANCING REQUIREMENTS

5.10.1. Financing constraints

The availability of adequate and secure financial resources is probably one of the most crucial constraints affecting the implementation of nuclear power projects. Though the end product of a nuclear power plant is the same as the end product of a fossil-fuelled power plant, i.e. electricity, there are certain differences from the point of view of financing. These are mainly due to:

- Relatively larger capital investment costs
- Longer construction periods
- Relatively high risks of delays and of cost overruns, resulting in additional financial requirements.
Another factor that makes nuclear power different from fossil-fuelled power plants is the level of sophisticated management, technical and engineering skills that are needed. From the point of view of a financing institution, concern may arise regarding the competence of the owner to undertake such a complex operation, in particular for a first nuclear power plant. Because of all these differences, special financing approaches are required for nuclear power plants to overcome the difficulties and constraints that may be encountered.

The total capital investment for nuclear power plants is higher than for equivalent fossil-fuelled plants (see Chapter 4). In addition, the expansion and upgrading of the transmission and distribution systems may also prove necessary and require additional funds. Because of these higher initial financing requirements, the availability of the necessary funds might constitute difficulties in relation to the gross national capital formation, balance of payments and the priorities assigned to various development projects in the country.

According to studies carried out by the International Bank for Reconstruction and Development (IBRD), power expansion investment requirements have remained at about 7 to 8% of the gross fixed capital formation. It is estimated, however, that a shift to higher capital cost plants (nuclear, hydro, lignite) will force a country to raise this proportion to 10–12%. This in time would correspond to a range of about 2 to 4% of the gross domestic product. While these figures do not represent an insuperable burden when considered as long-term averages, they tend to conceal the critical difficulties that will be encountered by many countries over the transitional period characterizing the introduction of several capital-intensive technologies in the power-producing sector.

The acuteness of the problem of financing the introduction of nuclear power plants will, of course, be a function of the balance of payments situation of the countries concerned which, in most cases, is critically dependent on the import or export of oil.

Another difficulty associated with the size of investments required is that normally no financial institution will provide 100% of the financing by itself. As a result, financing may have to be obtained from several sources, which requires long and tedious negotiations and efforts to conclude the loan agreements. In addition, financing institutions are generally reluctant to make commitments before the main commercial contracts have been signed. Should construction start before financing arrangements are definitely concluded, there is a risk of delaying the schedule of the project or even of interrupting its implementation due to lack of funds.

It seems, therefore, that a system of international financing would offer some prospect of stability in the conditions and terms of loans designed to assist the developing countries. In particular, this would help to bridge a difficult financing gap in their energy development planning, and would prove of great assistance towards meeting their potential needs for nuclear power.
5.10.2. Sources of financing

With rare exceptions, the financing of the foreign currency component for all exported nuclear power plants, when required, has up to now been through bilateral arrangements. These arrangements have sometimes involved financing by countries other than that of the main supplier.

When requested, the terms of financing have, as a matter of fact, been an essential ingredient of the bids submitted by the various vendors. They were in most cases equivalent to substantial rebates, the extent and value of which were a decisive factor in the final selection of the supplier, even though the concessionary elements did not lend themselves easily to quantitative comparisons. As a result, financing was usually related to projects and prevailing market conditions, and there was no guarantee that similar terms would be offered again in the future. Consequently, decisions had to be made on a case by case basis, making the advanced planning of a homogeneous nuclear programme difficult.

Financing of all the nuclear power plants that have been built or are under construction has been secured and financial arrangements established through a variety of sources and according to different modalities. Nuclear power represents a vast volume of investments which could be estimated at some 500 thousand million dollars, assuming the overall unit average capital investment cost for plants in operation to be $1000/kW(e) and $1500/kW(e) for those under construction at present. The plants in the industrial supplier countries have been largely either self-financed by the utilities' own resources or through local financing agencies. There are 110 units with a total capacity of about 68 000 MW(e) which have been exported by seven supplier countries. Table XXVII shows the number of units and their capacity exported from each of the supplier countries to the various developing and industrially advanced recipient countries; 45 of these units were exported to 14 developing countries.

To finance the nuclear power investments, the sources of funds which have been used may be divided into the following main categories:

(1) **Local sources of financing**

(a) Own resources
   - Equity
   - Cash flow

(b) Debt capital
   - Domestic bonds
   - Local bank credits
   - Credits from public entities.
TABLE XXVII. NUCLEAR POWER PLANT OR NSSS EXPORTS
June 1981 — in operation or under construction.

<table>
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<th>FRANCE</th>
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(a) Developing countries

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Sub-total

19 | 13411 | 4 | 3517 | 6 | 2426 | 2 | 1800 | - | - | - | 14 | 6336 |
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Sub-total       | 41    | 27,589| 3    | 2,360| -    | -    | 6    | 4,997| 2    | 1,320| 2    | 308  | 11    | 4,178| 60    | 41,000| 7    | 5,877| 6    | 2,426| 8    | 6,797| 2    | 1,320| 2    | 308  | 25    | 10,514|

TOTAL            |       |       |      |      |      |      |      |      |      |      |      |      |        | 110   |        |      |      |      |      |      |      |      |      |      |      |        |        |

Note: Nuclear power plant exports to Austria and Iran are not included.
Foreign sources of financing

(a) International markets

- Loans
- International bonds
- Foreign bonds

(b) Export credit agencies

(c) International development organizations.

In industrially advanced countries local sources of financing have been largely used by state-owned, private or mixed-capital utilities. However, over the last few years the capability of utilities in most industrially advanced countries to finance large new investments (such as those encountered with nuclear power plants) with their own resources has been declining. The utilities' internal cash flow generation capability has been substantially jeopardized by major investment expansions, the higher unit cost of new facilities, higher operating costs (particularly fuel) and interest rates and depreciation provisions generally based on non-revalued assets. The combination of declining earnings with insufficient depreciation resulted in cash flow growing more slowly than the new investments they were supposed to finance.

Utilities have attempted to fill this financing void with equity capital provided by the State for State-owned utilities or raised in local capital markets by private utilities, by tapping local sources of debt-financing such as domestic bond-issues, local bank-credits and credits from public entities. They have also been increasingly using international sources of financing over the past 10 years due to the increasing relative scarcity in local debt capital markets.

The first source for foreign financing that has been largely used by utilities in Europe is the international market. The major instruments available for this market are loans secured in the international credit markets (euroloans), or bonds that are either issued in the international capital market (eurobonds) or in the foreign capital markets (foreign bonds).

The main characteristics of euroloans are that they are extended by banks of borrowed funds, are usually non-negotiable, and large amounts are usually available. Electric utilities, particularly those involved in nuclear power, have raised in this market $7.7 billion in 1978 (80 loans) and $5.2 billion (35 loans) during the first half of 1979, among which is a loan of $732 million obtained by a developing country, namely the Republic of Korea.

For electric utilities maturities for loans obtained on this market ranged in 1979 from 10 to 12 years (exceptionally 15 years) with 3 to 7 years grace periods. The interest rates are usually floating. For example, the base rate of the London
International Bank Offered "LIBOR" has varied between a low of 6% and a high of 14% during the 1970s.

The second and the most important foreign source of financing consists of export credit agencies such as the Export-Import Bank in the USA, the Export Credit Corporation in Canada or the Kreditanstalt für Wiederaufbau in the Federal Republic of Germany. Export credits represent one of the principal borrowing instruments in particular for developing countries, through which the large majority of plants that have been built or are under construction in these countries have been financed. The main advantages provided by export credits are:

- Funds are available in substantial quantities even during international tight money situations, and particularly under the present low economic growth. Today, nuclear equipment manufacturers in most supplier countries, faced by lagging nuclear development programmes in their own countries and fierce international competition in those countries that continue their construction programmes, are eager to export.
- Financing usually covers up to 85% (sometimes up to 100%) of the cost of services and equipment from the exporting country.
- Maturities are generally longer than in the conventional financial markets. For nuclear plants export credit maturities are usually 12 to 15 years from the date of completion of the project, thus providing about 20 years overall maturity and can be even longer in specific cases.
- There is an extended grace period on repayments, which usually covers the entire construction period.
- A subsidized interest rate is offered, which is lower than commercial rates.

In spite of some variations from one country to another, most export credits schemes share the following other characteristics:

- They generally involve two levels of intervention: specialized governmental entities which deliver the appropriate credit insurance or guarantees, and official financial institutions or commercial banks which provide the funds.
- The currency in which they are transacted is generally the national currency of the exporting country. However, some countries are increasingly lending in eurodollars by borrowing the required amounts in the international market and relending them to the borrower under the guarantee of their export credit insurance agency.

The third source for foreign financing comprises the international development organizations. Although most international development organizations are active in the energy field, the only ones currently involved in nuclear power financing are the European Investment Bank (EIB) and the European Atomic Community (EURATOM), both specialized agencies of the European Economic Community (EEC).
Other international development institutions, such as the World Bank (IBRD) have not been active in this field. The only nuclear plant ever financed through the World Bank was the Latina plant in Italy in 1958. Since then the IBRD has not become involved in nuclear power financing. However, the IBRD seems ready at present to consider limited participation in the financing of nuclear power in developing countries, should the corresponding projects be the 'least cost' alternatives for supplying the growing demands for electric power, and should said participation attract other foreign sources of finance.

Summarizing, currently the most viable foreign financial sources for nuclear power projects seem to be the export credit agencies. Financing of nuclear projects have up to now been largely from such agencies through bilateral agreements between the supplier and the receiver countries.

In the past, suppliers have sometimes been prepared to assist with financing of nuclear power projects on exceptionally favourable terms. However, this type of financing is not expected to be available any longer, owing to the existing financial world situation characterized by high inflation and rapid escalation of costs. Such exceptionally favourable terms are difficult to obtain, unless some special loans with concessions or aid are secured through bilateral governmental arrangements.

5.11. STATE SYSTEM FOR PHYSICAL PROTECTION

The purpose of physical protection is to protect nuclear facilities and to minimize the possibilities of sabotage or unauthorized removal of nuclear material. The responsibility for the establishment, implementation and maintenance of a physical protection system within a State rests entirely with that State. To meet this commitment, a State considering the introduction of nuclear power and the use of special fissionable material must set up a system for adequate physical protection of nuclear material and facilities. The State must promulgate and review regularly its comprehensive regulations for the physical protection of nuclear material and facilities, whether in State or private possession. The main elements of such a system would include the following:

(a) Determination of responsibility, authority and sanctions and overall co-ordination between the various authorities and organizations involved
(b) Regulatory requirements for compliance with physical protection conditions
(c) Categorization of nuclear material based on potential hazards depending on type of material, isotopic composition, physical and chemical form, radiation level and quantity
(d) Information system which enables the State to be informed of every change at nuclear sites or regarding transport of nuclear material that may affect implementation of physical protection measures.

It is important that the State sets up the appropriate and effective organizations for implementation of the physical protection measures prescribed by the regulations, as incorporated in the nuclear legislation. It is also necessary to ensure the strict adherence to the physical protection measures by possessors of nuclear material and operators of nuclear facilities. To implement physical protection, the requirements include:

- Procedures and organization
- Protective or guard force
- Security devices
- Adequate facility design.

Though physical protection is entirely the responsibility of each sovereign State within its boundaries, there are some issues that require internationally concerted action (see Chapter 7, section 7.6).

The IAEA has published guidelines for physical protection requirements of States in document INFCIRC/225/Rev.1, which should be consulted for a detailed description and definition of physical protection measures.

5.12. STATE SYSTEM OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS

The introduction of nuclear power normally commits a country to accept international safeguards. Relevant IAEA documents provide the basis for Safeguards Agreements between the IAEA and States pursuant to the NPT, or between the IAEA and States that did not ratify the NPT. For more information on the subject of international safeguards, see Chapter 7, section 7.4.

One of the basic requirements of Agreements conforming to INFCIRC/153 is that the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards under the Agreement. Safeguards Agreements conforming to INFCIRC/66/Rev.2 do not explicitly call for States to establish and maintain a “system” of accounting for and control of nuclear material, but the fact that the document calls for agreement between the IAEA and the state on a “system of records” and a “system of reports” implies the need for an accounting and control system. The establishment of a State System of Accounting for and Control of Nuclear Material (SSAC) is needed, whether or not such a system is explicitly required. It has:
(a) A national objective, to account for and control of nuclear material in the State, and to contribute to the detection of possible losses, or unauthorized use, or removal of nuclear material.

(b) An international objective, to provide the essential basis for the application of IAEA safeguards pursuant to the provisions of an Agreement between the State and the IAEA.

These two objectives are different in nature, and the organization and functions of a SSAC with only one of these objectives may differ in many respects from those of a system with only the other. Nevertheless, there are many elements of each system that would contribute to the attainment of both objectives.

It is for each State to decide whether or not it wishes to establish one combined system or two independent systems to pursue these different objectives. When a State decides to establish a combined system, it will be necessary to distinguish clearly those requirements that are necessary for the application of IAEA safeguards from those that are necessary only for internal purposes. Such a distinction is necessary in order to identify clearly those elements that are needed in the application of IAEA safeguards, and those that are not needed for that purpose.

States may use containment and surveillance measures (largely independent of nuclear material accounting) to provide assurance that there has been no unauthorized use or removal of nuclear material from a facility. Such measures may include, for example, secure facility perimeters, seals, surveillance cameras and portal monitors. These measures are normally not the same containment and surveillance measures as instituted for IAEA safeguards, although they may serve the dual purpose of the national and international objectives. It is recommended that States take these possibilities into consideration, particularly during the design and construction phases of new facilities.

The Agency has recently published a document, IAEA/SG/INF/2, providing guidelines for the organization and functions of a SSAC designed to meet the commitments and obligations of States arising from safeguards agreements concluded with the IAEA. These guidelines are designed to assist States in establishing, maintaining and reviewing their system. The document also contains the elements of the system performance required at the State and facility levels.

5.13. PUBLIC INFORMATION AND PUBLIC RELATIONS

A nuclear power programme is a national undertaking and hence its introduction and implementation within the country, including the acceptance by the population in general, is a matter to be handled primarily by national (and regional) governmental organizations and authorities. The electric utility, which is providing a public service, also has an important role to play. A public information programme
aimed at both the general public and the population around the site of the nuclear power project should be carefully planned and implemented and start as early as possible.

The problem of informing the public is extremely complex. In spite of the fact that the safety record of the development of nuclear power and its introduction on a commercial basis compares favourably with that of any other large-scale technology, there is a growing opposition in many countries towards its use. In many cases the nuclear controversy has led to delays in plant construction, scaling down of nuclear power programmes, or, in one extreme case, even to a law forbidding the use of nuclear power for energy production.

This controversy has been the subject of extensive study, mainly in industrialized countries. In spite of the fact that the situation is different from country to country, the following seems to apply in general:

- It is important to recognize that the controversy about nuclear power has also to be viewed in the context of general discussions about political, social or philosophical issues in a country. Controversy is not a particular attribute of nuclear power and applies to other large-scale technological developments as well.

- Rational criteria have to be established against which to judge the acceptability of a nuclear power programme. Such criteria are part of an evaluation process and thus necessarily subjective. Therefore, it is the responsibility of those involved in public information to draw a strict borderline between the objective information (i.e. the technical data), the formal procedure (i.e. the evaluation methodology applied) and the subjective conclusions drawn from the analysis. For example, it might well be possible to agree with an audience on the low probability of a core melt; however, for some it might not be acceptable.

- Information about nuclear power cannot limit itself to nuclear power only, rather the role of this energy source has to be explained within the context of objectives for the social, political and economic development of a country including its interconnections with global issues and international developments.

- Nuclear power can be considered as the preferred target for the attacks of practically all protest movements: environmentalists, pacifists, radical elements, separatists and home rule groups, advocates of zero-growth, etc. It unites in particular all those who are pessimistic about the future and whose bitterness against the modern world is expressed as a nostalgia for an idealized past or a utopian dream of a more ‘natural’, ‘alternative’ way of life.

- Nuclear power has to be viewed with regard to the role it is able to play in the total energy supply of a country (including the influence of worldwide developments) and also relating to the economic and environmental aspects of other energy systems.

- Studies analysing public attitudes as a measure of favourableness or unfavourableness towards nuclear power show that all these considerations are reflected
in the structure of attitudes and thus contribute to acceptance or rejection of nuclear power, in particular psychological aspects, socio-political implications, environmental aspects and economic and technical benefits.

Thus, it seems to be necessary that all the relevant issues be addressed in informing the public. A compromise has to be reached between informing about complex issues in generally understandable language, and giving correct and complete information at the same time. It is important to provide objective and balanced information on both the positive and the negative aspects of nuclear power (benefits as well as risks). In this context, it is worth mentioning that those who are deeply involved in the development of the technology (i.e. the nuclear experts) show a tendency to concentrate on the problems to be resolved and fail to explain those issues where good solutions have been provided. They also tend to take the benefits of nuclear power for granted, and thus do not spend much effort in reporting them. With regard to the risks, three types of information seem to be especially valuable:

- General comparison of the risks of nuclear power with other risks already accepted by society. Such comparisons put the nuclear risks into a broader perspective and permit a discussion of influencing factors for acceptance of risks by individuals and society.

- Comparisons of risks of energy systems considering the total fuel cycle from obtaining the fuel (mining of coal or uranium, etc.) through normal operation to waste disposal. Such information should be as complete as possible and where reliable data are not available, it seems more appropriate to describe risks in qualitative terms than to omit information altogether. However, emphasis should also be given to describe the uncertainties. In addition, the data on risks should be as disaggregated as possible since, for example, aggregation of various health effects like early fatalities and fatal diseases or of low frequency/high consequence and high frequency/low consequence events, imply value judgements. The purpose of such information, of course, is not to discredit other energy systems, but to put the risks of nuclear power into perspective with risks of those technologies that serve the same purpose, i.e. the production of electricity.

- Since it cannot be the objective of safety policy to reduce all risks to the same absolute level, information should be provided on the cost-effectiveness of risk reduction. Since the resources that society can spend on safety are limited, it seems to be reasonable to spend them in those areas where the largest risk reduction can be achieved per unit of safety expenditures. Such information also demonstrates that risks cannot be reduced to zero, and that a compromise has to be found on what is 'As Low As Reasonably Achievable' (ALARA principle).
Opposition towards large-scale new technologies, like nuclear power, has many parallels in history, e.g. the introduction of railways, automobiles, the use of coal or of central city sewage systems. Such discussions seem to be usually a necessary part of integrating a technological system into the society that the technology is intended to serve.

It will be beneficial to both the social and technological development if, at the very early stage of starting a nuclear programme, complete and objective information is provided to the public on the benefits and the risks of this technology. This also enhances credibility, which is very difficult to regain once it has been lost.
Chapter 6

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

6.1. INTRODUCTION

Both public acceptance and economic viability of nuclear power as a major source of energy is dependent on the achievement of a high level of safety and environmental protection. Nuclear power involves the production of large quantities of radioactive materials. Protection against radiation emitted from such materials has been and still is the subject of extensive studies over a span of more than five decades. We have an understanding of the risks from radiation and of effective techniques for radiation protection. Indeed, it is fair to say that we have more scientific evidence on the hazards of ionizing radiation than on most, if not all, other environmental agents that affect the general public.

The designers, manufacturers, owners, operators and regulators of nuclear power plants and other facilities have recognized from the beginning the requirement for safety and have imposed stringent controls on the radioactive material associated with nuclear power plants and related fuel cycle facility operation. The achievement of safety and reliability requires a level of design innovation, quality assurance and human expertise not previously required in the electric power industry.

The principal goals of nuclear safety may be expressed as follows:

(a) Public safety. There should be no release of radioactive material, through accidental or other means, that will present a significant risk to the public. In normal operation the radiation exposure to individuals should be as low as reasonably achievable and within dose limits.

(b) Personnel safety. Radiation exposure to personnel in nuclear plants shall not exceed dose limits and be kept as low as reasonably achievable.

The measures used to attain the goals of nuclear safety will also help to achieve another important objective, which is to reduce the likelihood of a serious accident resulting in severe damage to the nuclear facility and in large economic loss.

These safety goals apply to nuclear power plants and all related fuel cycle facilities and activities. Because of the particular concern with the safety of nuclear power plants, this subject is treated in some detail in sections 6.3 to 6.6. However, the safety principles and regulatory measures discussed in these sections apply generally also to related fuel cycle facilities and activities.
The environmental effects of all facilities and activities related to nuclear power are discussed in section 6.7.

6.2. POTENTIAL RADIATION HAZARDS FROM NUCLEAR FACILITIES

The dominant public health and safety concern in the operation of nuclear facilities is the potential for the accidental release of large quantities of radioactive materials to the environment and their short and long-term effects on the biosphere, especially on human health.

We live immersed in radiation; the sun, the soil, the trees, the human body, the stars are all sources of radiation. Radiation is nothing new. What is new is the knowledge and the technology developed by nuclear industry regarding the effects of radiation and the proper ways to handle it.

6.2.1. Biological effects of radiation

The principal forms of radiation of biological significance are alpha-particles, beta-particles, gamma-radiation and neutrons, which affect biological material through energy transfer. This transfer causes damage to the atoms and molecules by breaking the chemical bonds and by ionization. Alpha-particles do not have high penetration and are stopped, for example, by the outside layer of human skin, while beta-particles are more penetrating, and neutrons and gamma-radiation have a much higher penetration power.

The biological effects of ionizing radiation have been studied extensively for many decades. The effects of radiation on biological systems have been examined in animal experiments, radiation accident victims, survivals of atomic bombs at Hiroshima and Nagasaki, patients undergoing radiation therapy and persons exposed to radiation in the course of their work.

Radiation can produce harm when it arises from sources outside the body or originates from radioactive isotopes within the body. The biological damage caused by different types of radiation is estimated by the amount of radiation absorbed in tissue. The amount of radiation absorbed is expressed as a ‘rad’ unit. To account for the difference in energy dissipation and biological

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2 The units of radiation used in this chapter are those now in common use. The main ones are the rad, the unit of absorbed dose (1 rad = 100 erg/g = 0.01 J/kg), and the rem, the unit of equivalent dose for different types of radiation (1 rem = 1 rad multiplied by a correction factor to equivilize biologic effects). However, the reader should be aware that new international units may soon come into general use — in particular, the gray (1 Gy = 100 rads = 1 J/kg) and the sievert (1 Sv = 100 rems). One rad of gamma or beta-radiation has one rem biological effectiveness, while one rad of alpha-radiation has a dose equivalence of approximately 20 rem and one rad of neutrons has a dose equivalence of approximately 10 rem.
effectiveness between different types of radiation a special unit called the ‘rem’ (radiation dose equivalent man) is used for expressing radiation exposure doses. Biological effects are classified broadly as somatic effects, that is to say effects occurring within the exposed individual, and hereditary or genetic effects, that is to say those effects occurring in the descendants by altering the genes of the parents.

In the extreme case, exposure of the whole body to very high levels of radiation of a few hundred rads over a short period (e.g. 3000–4000 times the annual background dose at once) will cause radiation sickness and can be fatal. At lower doses radiation exposure results in some likelihood of developing cancer and genetic effects and this likelihood decreases as the dose decreases. Radiation at low doses, referred to as ‘low-level radiation’, may result in some damage to living tissues. However, the body does have mechanisms to repair this type of damage thus providing a certain level of protection against such radiation effects. What is not known is whether there is some lower limit to radiation exposure below which man will not suffer any injury and above which he will. All persons are exposed to radiation as part of their natural environment (see section 6.3.2).

6.2.2. Radiation protection standards

The two objectives of radiation protection as stated by the International Commission on Radiological Protection (ICRP) are:

(a) To prevent acute radiation effects
(b) To limit the risks of cancer and genetic effects to very low levels.

To reach these objectives the ICRP has laid out recommendations that are guided by three general principles:

(a) No practice shall be adopted unless its introduction produces a net positive benefit.
(b) All exposures to radiation shall be kept as low as reasonably achievable, economic and social factors being taken into account.
(c) Those who are exposed to radiation in the course of their occupation (e.g. power reactor operations staff) shall not receive a dose greater than 5 rems per year. For a member of the public this dose shall not exceed 0.5 rem per year nor a lifetime average of 0.1 rem per year.

The radiation exposure limits set by the ICRP are intended to be maximum values above natural background exposure which must not be exceeded. In accepting the ICRP’s recommendations it is common practice for countries to keep radiation exposure well below the limit given in the recommendations.
Practices in the nuclear industry, for example, result in doses, even to the local population, that are a small fraction of the ICRP limits.

In estimating the risk from exposure to low levels of radiation, the ICRP also makes the prudent assumption that there may be health effects, varying directly with the dose received, right down to zero dose. For purposes of radiation protection considerations involving individuals the total risk of inducing a carcinogenic and genetic effect is assumed to be about $1.7 \times 10^{-4}$ per rem, although this assumption is not established from medical observations. It is not yet possible to estimate precisely the risk of cancer induction or genetic effects by low-dose radiation, because the degree of risk is so low that it cannot be observed directly, since other causes for inducing cancer are by far predominant in this low-level radiation range. There is great uncertainty as to the dose-response function most appropriate for extrapolating in the low-dose region.

6.3. NUCLEAR POWER PLANT SAFETY

The record of safety and environmental protection in achieving the goals of safety in the operation of nuclear power plants is outstanding. Even with the Three Mile Island reactor accident on 28 March 1979, the worst accident in the history of commercial nuclear power generation, there have been no radiation-induced fatalities or serious injuries that can be specifically identified as caused by a commercial nuclear power plant.

The record in avoiding accidents resulting in economic loss has been far less impressive. Nuclear power plants are complex and high capital cost installations. A large generating plant that is not functioning is a heavy financial burden to any utility. It should be recognized by reactor designers, constructors, operators, owners and regulators that accidents resulting in severe economic loss are far more likely to occur than a reactor accident of significance to the health and safety of the general public or to the utility employees. This is because the engineered safety features are designed to prevent radioactivity from reaching the environment and people in the course of an accident. The serious accidents to date in commercial nuclear power plants have been primarily accidents with only economic consequences because engineered safety features performed their function and protected the public. In the case of the Three Mile Island accident the costs amounted to several hundreds of millions of dollars, while the radiation health consequences were very small. Based on experience, the economic incentives alone for safety and reliability are indeed great.

6.3.1. Location and magnitude of radioactivity in reactor

The operation of nuclear power plants involves the formation of radioactive materials within the reactor system from the fission process in the fuel. The
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Inventory (MCl)</th>
<th>Half-life (d)</th>
<th>Symbol</th>
<th>Inventory (MCl)</th>
<th>Half-life (d)</th>
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<td>Half-life (d)</td>
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<td>Half-life (d)</td>
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<td>5350</td>
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<td>3.25</td>
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<td>Te-127m</td>
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</table>
fission products consist of short-lived and long-lived radionuclides which, under normal operating conditions, remain largely confined within the fuel elements. Generally, under normal operating conditions only a very small fraction of the fission products are allowed to be released and their environmental impact is not significant.

Another source of radioactivity is the corrosion and erosion products and impurities in the coolant which become activated by neutron absorption. The quantities of radioactive materials so formed are small compared with fission products and consist of radioisotopes of elements such as iron, chromium, cobalt and manganese. In addition, neutron absorption by boron, commonly used for the control of the fission process, and by deuterium in water-cooled reactors leads to the formation of tritium, a long-lived radioisotope of hydrogen. Radioisotopes of nitrogen, carbon and argon are also formed. Other coolant activation products are of less significance.

Table XXVIII lists the amounts of the more important radionuclides in a 1000 MW(e) nuclear power reactor. This table includes only fission products with half-lives greater than one hour. Short-lived beta and/or gamma-emitter fission products (half-life of the order of seconds or minutes) are dominant in a reactor core immediately after shutdown, but they decay rapidly and do not contribute significantly to the activity being released during normal operations. However, they do have to be taken into account when considering the radiation exposure of operating personnel or in accident conditions.

6.3.2. Normal operation

During the normal operation of nuclear power plants the possible sources of human exposure to radiation are:

(a) Exposure of the public to radioactivity released in gaseous and liquid effluents
(b) Exposure of plant personnel during operation and maintenance.

Most of the fission products remain in the fuel elements, but a small fraction can escape into the coolant through defective fuel cladding. Most of the corrosion products and radioisotopes released from fuel into the coolant or moderator are removed by gaseous and liquid waste processing systems. Nonetheless, a small part of the radioactive materials may eventually be released into the environment. Experience has shown that the additional doses to the public living in the vicinity of nuclear power plants are not more than about 1% of the doses from natural background exposure. The contribution to the overall population dose is very small, much less than one per cent of the dose from natural background. On the average an individual in the population will receive a dose of about 0.1 rem per year from natural background sources.
Any detriment to human health that may arise from nuclear power generation is mainly due to occupational exposure of power plant personnel to gamma rays from fission and activation products. Occupational radiation exposures are controlled by proper plant design, operating procedures, monitoring programmes, trained personnel and strong management control. Experience has shown that with a programme for maintaining exposures as low as reasonably achievable, average radiation doses to the operations staff who are occupationally exposed can be maintained in the range of 0.5–1 rem per year, which is 10 to 20% of the annual dose limit of 5 rem per year recommended by ICRP for occupational exposure. Particular attention must be given to controlling the doses to maintenance, waste-handling and health physics personnel.

6.3.3. Nuclear power plant accidents

Nuclear power plant accidents can differ from those in conventional power plants because release of significant amounts of radioactivity to the environment is a possibility. While very large amounts of radioactivity are generated by the fission process in a nuclear plant, the bulk of this radioactivity (more than 99%) remains in the fuel as long as it is adequately cooled. For large amounts of radioactivity to be released from the fuel elements, they must be severely damaged and essentially melt. Based on this knowledge, the major types of nuclear power plant accidents that may lead to large releases of radioactivity to the environment have long been recognized. All the places in which fuel is located in a nuclear power plant and the amount of radioactivity in each location are easily identified. This is done in Table XXIX for the most important places, which shows that by far the largest amount of radioactivity resides in the reactor core.

The fuel is a heat source even after reactor shutdown, due to release of energy from the decay of radioactive materials. Immediately following the shutdown of a reactor that has operated about a month or longer, the decay heat amounts to about 7% of the rated thermal plant output at the moment of shutdown but decays to 2% after 10 minutes and to approximately 1% after 2 hours. After one day the decay heat rate still amounts to 0.5%. For a large reactor of 1000 MW(e) this means a heat production of approximately 15 MW, which must be removed if fuel melting is to be avoided. Thus, while the heat has an initial rapid decrease after reactor shutdown, it constitutes a substantial heat source for some time and continued cooling of the fuel is required.

Overheating of fuel occurs only if the heat being generated in the fuel exceeds the rate at which it is being removed. This type of heat imbalance in the fuel in the reactor core can occur in different ways:

(a) *Loss of coolant.* The occurrence of a loss of coolant event will allow the fuel to overheat unless emergency cooling water is supplied to the core.
### TABLE XXIX. TYPICAL RADIOACTIVITY INVENTORY FOR A 1000 MW(e) LWR [Ref. WASH-1400]

<table>
<thead>
<tr>
<th>Location</th>
<th>Total inventory (Ci)</th>
<th>Fraction of core inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel</td>
<td>Gap</td>
</tr>
<tr>
<td>Core&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.0 X 10&lt;sup&gt;9&lt;/sup&gt;</td>
<td>1.4 X 10&lt;sup&gt;8&lt;/sup&gt;</td>
</tr>
<tr>
<td>Spent fuel storage pool (max.)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.3 X 10&lt;sup&gt;9&lt;/sup&gt;</td>
<td>1.3 X 10&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>Spent fuel storage pool (avg.)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.6 X 10&lt;sup&gt;8&lt;/sup&gt;</td>
<td>3.8 X 10&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td>Shipping cask&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.2 X 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>3.1 X 10&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td>Refuelling&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.2 X 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>2 X 10&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste gas storage tank</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Liquid waste storage tank</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup> Core inventory based on activity 1/2 hour after shutdown.

<sup>b</sup> Inventory of 2/3 core loading; 1/3 core with three day decay and 1/3 core with 150 day decay.

<sup>c</sup> Inventory of 1/2 core loading; 1/6 core with 150 day decay and 1/3 core with 60 day decay.

<sup>d</sup> Inventory based on 7 PWR or 17 BWR fuel assemblies with 150 day decay.

<sup>e</sup> Inventory for one fuel assembly with three day decay.
This identifies a class of accidents called loss of coolant accidents (LOCAs), in which a rupture in the reactor coolant system (RCS) leads to a loss of the normal coolant. This rupture allows the high-pressure, high-temperature reactor coolant to flash to steam and blow down into the containment building.

(b) Transients. Overheating of fuel can result from transient events that cause the reactor power to increase beyond the heat removal capacity of the reactor cooling system or that cause the heat removal capacity of the reactor cooling system to drop below the core heat generation rate. Transient events can be assumed to include all those situations (except LOCA, which is treated separately) that could lead to fuel heat imbalances. In safety analysis the principal areas of interest are increases in reactor core power (heat generation), decrease in coolant flow (and heat removal) and reactor coolant system pressure increases.

6.3.4. Design safety features of nuclear power plants

The prevention of accidents and the mitigation of their potential consequences have been the primary objectives of nuclear power plant safety design. It is not intended to go into any technical detail of safety design, since this could be here only a very short and inadequate survey in particular because of the many reactor concepts and design realizations that are available. The main detailed safety design requirements are to be found within the codes and guides of the Nuclear Safety Standards (NUSS) programme of the IAEA (Safety Series 50), especially those on design. Furthermore, the interested reader is referred to relevant textbooks on safety design and other international or national safety standards. A reference list supplementing the NUSS design guides is available from the IAEA on request.

In the following sections, however, the basic 'defence-in-depth' safety principles which underlay all designs of nuclear power plants are outlined. There are two aspects of defence in depth in design. One is to provide barriers that would have to be successively breached for radioactive material to escape outside the plant. In the nuclear power plant these barriers include:

- The fuel matrix and hermetic fuel cladding (first barrier)
- The reactor coolant circuit (second barrier)
- A containment or other housing structure (third barrier).

The integrity of the barriers is ensured by conservative design margins and by high quality in manufacture. Should any of these passive barriers fail, active engineered safety systems are provided to mitigate the consequences of the barrier failure. These systems include, among others, emergency core cooling, emergency feed coolant supply, containment sprays, and filters.

The other aspect of defence in depth in design is to prevent the barriers from being breached. This aspect can be viewed as consisting of three echelons.
of defence related to the way the plant is operated and to its time response under accident conditions. The borderlines between these echelons are not very precise and may be slightly different in the various designs, but basically the following objectives hold for the three echelons:

1. To ensure that the plant operates within a defined set of conditions
2. To provide a set of safety systems designed to intercept malfunctions that may result in accident conditions
3. To provide systems to mitigate accidents that result in significant release of radiation from its design location.

The first echelon of defence is to ensure that the plant systems are maintained within operational limits. This bounds all normal and anticipated operating modes of the reactor and can be characterized as the stable, expected operation of the plant.

With regard to the design this means a high quality standard of system and component design and has to include material selection and fabrication of components, the plant construction, the plant maintenance and testing procedure, the plant operation, the utilization of operating experience and the establishment of adequate safety margins to permit reliable operation. In functional terms this echelon has to ensure high reliability of all plant systems and components including instrumentation and control so that deviation from normal operation is unlikely.

The second echelon of defence is to intercept abnormal conditions that could lead to accidents in the event normal operating conditions are violated through human error or equipment failure. This level shall be established to meet the following three safety requirements:

1. To establish and maintain subcriticality
2. To remove residual heat from the reactor coolant system after shutdown
3. To maintain reactor coolant system integrity and an adequate inventory of reactor coolant.

This echelon of defence constitutes the design basis for the reactor protection system and related other safety systems.

Typical systems that establish this line of defence are automatic shutdown systems, high pressure and low pressure injection systems which supply reactor coolant to the main circuit, emergency feedwater systems within indirect cycle reactors, residual heat removal systems including their secondary heat transport circuits, emergency power supplies and others.

The third echelon of defence is to mitigate accidents that result in significant release of radioactivity from its design location. This includes provisions to mitigate accidents involving radioactive material outside the reactor coolant
system but inside the reactor building such as a fuel-handling accident. The objective is to contain and control the release of radioactive materials when significant amounts have escaped from the primary system.

Typical water-cooled and moderated reactors include a containment system, which includes systems to provide for automatic isolation of specified building penetrations, control of pressure and temperature, control of combustible gases and removal of airborne radioactivity.

The primary functions of some of the engineered safety features discussed above are illustrated in Fig. 18. The primary functions they perform are as follows:

(a) Reactor trip (RT): to stop the fission process and terminate core power generation

(b) Emergency core cooling (ECC): to cool the core, thereby keeping the release of radioactivity from the fuel into the containment at low levels

(c) Post accident radioactivity removal (PARR): to remove radioactivity released from the core to the containment atmosphere

(d) Post accident heat removal (PAHR): to remove decay heat from within the containment, thereby preventing overpressurization of the containment

(e) Containment integrity (CI): to prevent radioactivity within the containment from being dispersed into the environment.
6.3.5. Safety analysis

The previous sections described the defence-in-depth concept for the safety design of nuclear power plants. They did not indicate which features and technical requirements in detail a design must fulfil in order to meet the general safety goal. While it would go far beyond the scope of this Guidebook to explain how this safety philosophy is implemented by the various designs and different reactor types, the safety analysis should be mentioned as a very important step in assessing the safety of a plant design.

The basic purpose of safety analysis is to determine whether the design has met the defined safety goals. It is used by the designer during design development and in the preparation of the final safety justification for the plant, which has to be independently assessed before the granting of a licence to operate. The safety analysis takes into account the postulated initiating events and systematically examines the chain of further events in the plant that may result, including operator actions. To demonstrate that the safety goals (primarily defined in terms of radiological consequences) have been met, an important part of the safety analysis will be a detailed quantitative analysis of reactor and fuel behaviour during the chain of events following each postulated initiating event.

It is not possible to predict every accident sequence that might occur, even with the most comprehensive list of initiating events. Consequently, an important function of the analysis is to act as a theoretical test of the safety defences so that confidence can be obtained in the plant’s ability to cope with a wide range of fault situations.

6.3.5.1. Evaluation of the course of the event

Whilst the safety analysis is an iterative process, the starting point of the analysis is the identification of those systems that are involved on the various safety levels to limit and mitigate the consequences of a given postulated initiating event. Having at least roughly identified this, the analysis has to indicate the sequence of plant configurations that will follow the postulated initiating event. This can be done in a deterministic manner or by probabilistic analysis. In both cases some systematic written procedures should be followed.

In the deterministic method, a useful tool is the ‘event tree’ method which logically and systematically identifies possible sequences arising from an initiating event irrespective of their likelihood, taking into account the existing design features and it leads to the various possible final configurations of the plant as a consequence of the initiating event. The next step of the analysis is to evaluate the sequences of events that are considered the most likely from analysis of the reliability of equipment or engineering judgement based
on experience and agreed assumptions. Thus a limited number of final plant configurations will emerge for each initiating event.

In the probabilistic approach, values have to be attributed to each branch of the event tree. There are practical difficulties arising in this approach, primarily because of the large number of branches that may emerge. There may then be a need to eliminate those sequences with a probability lower than a certain very low value. To do this, it is necessary to know the probabilities associated with the branch points, possibly by the use of 'fault tree analysis', or again, as in the deterministic treatment, to use conservative engineering judgement. At the conclusion of the event tree analysis several more likely or more serious sequences of events leading to several possible final plant configurations will have been identified for each postulated initiating event.

6.3.5.2. Evaluation of the reactor behaviour during the event

During the course of the accident evaluation it is necessary to analyse the reactor behaviour in some detail for each postulated sequence of events, in order to show that the design meets the safety goals. The detailed analysis should yield a wide range of information but particular attention must be paid to the determination of:

(a) The sensitivity of the results to uncertainties in analytical methods, data and initial conditions
(b) The margins between expected conditions during a fault situation and those conditions which could give rise to consequential components and systems failures
(c) The performance required of the protective systems (e.g. trips, emergency cooling provisions) to maintain the plant within a state not grossly releasing radioactivity.

6.3.5.3. Operator action

In the design of some nuclear plants the operators have certain actions to perform to ensure correct plant response to fault situations. It is necessary therefore in the safety analysis to allow for operator action. Simplistically, it may be considered that the operator is one further link in the control chain. On this basis, operator action in response to a particular signal could be assumed to be simply correct, or not taken at all. However, the possibility must be considered that the operator may also attempt an action at the wrong time, or take a completely wrong course of action. Incorrect actions are most likely at times of high stress such as during a complex chain of events following an initiating event. To allow in the safety analysis for either correct action
at the right time or no action at all is relatively straightforward, in the event
tree approach both possibilities would lead to particular and well-defined plant
configurations. The problem arises in trying to allow for all the possible
maloperations that could conceivably take place in a complex fault sequence.

In designs where operator action is relied upon, certain assumptions must
be made in the analysis. The most effective protection against maloperation in
such designs is to ensure that appropriate considerations have been given at
the design stage to ensuring that the operator is presented with clear and
unambiguous information, that necessary administrative controls are simple
and that operator selection and training is effective. Provided that assurance
on these points is available, certain assumptions may be made in the analysis.
In cases where the plant configuration is very complex and the operator has
to act under pressure of time, the conservative assumption is to assume wrong
operator action. In cases where there is sufficient time to consider the intended
action, the alternative fault sequences resulting from both correct and incorrect
operator actions must be analysed.

6.4. SAFETY IMPLEMENTATION

It is important to consider safety implementation at each stage of a reactor
project. Safety is a prime management function and must be considered as an
integral part of all the activities of the project. Nuclear power requires management
qualifications and attitudes of a very special character, which places special
emphasis on safety as well as an extensive support system of scientists and
engineers. Applicable to all activities is quality assurance, which is an essential
aspect of good management. Good management contributes to the achievement
of quality through analysis of the tasks to be performed, identification of the
skills required, the selection and training of appropriate personnel, the use of
appropriate equipment, the creation of a satisfactory environment in which
an activity can be performed and a recognition of the responsibility of the
individual who is to perform the task.

Briefly stated then, a quality assurance programme shall provide for a
disciplined approach to all activities affecting quality including verification
that each task has been satisfactorily performed or that necessary corrective
actions have been implemented. It shall also ensure the production of
documentary evidence to demonstrate that the required quality has in fact
been achieved.

Detailed guidance on quality assurance is provided in the IAEA Code of
Practice 50-C-QA and related safety guides. The subject is also treated in
section 5.9.
6.4.1. Early project stage

The key safety-related activities at this stage of the project are:

Siting
Bid evaluation, including preliminary safety analysis.

The process of siting studies for a nuclear power plant (see Chapter 9) involves:

(a) *The site survey phase.* During this phase suitable land areas are systematically investigated for identifying the most suitable location. Each location is investigated to demonstrate that no phenomenon exists that could lead to the rejection of the site (i.e. faulting, liquefaction, flooding, etc.). A preliminary study of the design basis is also performed;

(b) *Site evaluation.* During this phase, measurements and investigations are performed on the site (i.e. drilling and other soil mechanics measurements, meteorological measurement, etc.) and a final evaluation of the design basis is made in relation to the specific plant design requirements.

The main considerations for nuclear safety are in the areas of:

Geology and tectonics
Vulcanology
Seismology
Engineering seismology
Heat removal
Hydrology
Meteorology (including dispersion in air and extreme phenomena)
Risks from man-made events
Population distribution.

The preferred site will be chosen and the design basis, taking into account the above-listed considerations, will be factored into bid specifications and plant preliminary design.

During bid evaluation, a preliminary safety review must be made. Among the important aspects which must be reviewed are:

(a) The engineering and safety codes and criteria to be used for the plant and how changes of these during design and construction will be handled

(b) How design input data from site conditions, e.g. seismic data, flood data, meteorology, etc., have been applied and the influence on costs of variations of these input data
6.4.2. Design stage

The reactor design stage includes the conceptual, basic and the final detailed design. It is during the design stage that the power levels and capacity of the plant are set and limits are established for its performance. Limits are set for the parameters that are amenable to measurement. The findings on the site characteristics discussed in Chapter 9 form an important part of the design basis. All decisions relating to the safety of the design are carried out during this period. The ultimate safety of the reactor itself, the adequacy of its containment, engineered safety systems and other structures must be decided during the design stage. There may be no retreat from poorly made initial decisions. It is therefore essential that considerations of safety are given a vital role at this stage of a reactor project.

It is also reasonable to expect that the most rewarding safety reviews and evaluations can be carried out during this period. Normally, subsequent reviews of the design, perhaps after some operating period, are only for correcting or updating the information originally available or for considering the acceptability of changes.

Thus, the important basic design decisions and the important safety reviews should be made as early as possible in a reactor project. However, it should be recognized that unless standardized designs are available, much of the detailed design information will not be available until well into the construction period.

Detailed guidance on design for safety of nuclear power plants is provided in the IAEA Code of Practice No. 50-C-D and related safety guides.

6.4.3. Construction stage

During the construction stage it is necessary to ensure that the plant is constructed in accordance with the design. The best possible construction practices must be adopted. These include welding practice, inspection methods, testing of materials and components, etc.

This requires a highly skilled project management and their complete support for a strong QA programme. The execution of a good reactor design, if not properly carried out, can nullify the safety features. The most rigorous inspection programme and work surveillance should be instituted and maintained at all times. It is at this stage that agencies with responsibility for inspection
should assure themselves that an adequate inspection programme is being carried out and that the quality of workmanship in the installation is high.

6.4.4. Operation stage

The operating organization has the full responsibility for the safe operation of the nuclear power plant.

Before fuel loading is commenced for the first load all safety requirements must be met and all preparations for emergencies demonstrated. The pre-operational testing programme shall be completed and satisfactory results obtained to show that the plant systems meet design intent and assumptions.

Testing continues after fuel loading in steps of increasing power until full power output is obtained on the basis of a programme that ensures that no safety related system is operated that has not been tested thoroughly.

Operation of the plant is to be in accordance with constraints to limit operation only to plant conditions shown to be safe. These constraints are embodied in the operational limits and conditions (OLCS) set down in writing. The operation must be in accordance with detailed operating instructions that are consistent with the OLCS.

Maintenance must be in accordance with a written programme prepared before loading the reactor with fuel for the first time. Outages of plant components and equipment for maintenance and restoration must be authorized by the shift supervisors in charge of the plant. Modifications are undertaken only in accordance with a procedure that ensures that appropriate reviews are carried out.

A radiological programme must be developed for the protection of site personnel and for the monitoring of the radiological effects of station operation on the environment and its effects on man. This includes the management and control of radioactive waste.

An overall emergency plan should be prepared to provide for effective co-ordination of the arrangements made by the operating organization for on-site activities together with all the other emergency capabilities that may be required in the event of an accident leading to, or likely to lead to a significant release of radioactivity beyond the site boundary. The emergency plan to be drawn up by the operating organization should form the basis for the overall emergency plan. In the development of the plan there should be close liaison with all bodies with duties to perform such as governmental and local authorities.

All of the above activities require properly trained and competent personnel and good management on site and in the operating organization concerned with nuclear power plant operation. Safety depends very strongly upon the quality of the personnel involved.
As a useful tool of good management and to obtain assurance that safety requirements are being met, a comprehensive quality assurance programme covering all safety-related activities must be developed and implemented. Detailed guidance on safety in nuclear power plant operation including commissioning and decommissioning is provided in the IAEA Code of Practice No. 50-C-O and associated safety guides.

6.5. LICENSING AND SAFETY ANALYSIS REPORTS

The primary responsibility for the safe siting, design, construction, commissioning and operation of the nuclear plant is with the owner/licensee. The safety of the nuclear power plant must be demonstrated by the applicant in a safety analysis report usually through arrangements with the vendors, architect-engineers, consultants and contractors. The regulatory body is responsible for making an independent assessment of the adequacy of safety by a technical review of the information presented by the owner and other organizations supporting his presentation. The adequacy, independence and effectiveness of the review and evaluation depend on the competence of the regulatory staff and upon the adequacy of the information supplied in safety analysis reports and supporting documentation. The size and composition of the regulatory body, including consultants and advisory committees, should reflect the extent of the nuclear power programme to be adopted and its schedule for development.

Detailed guidance on governmental organization for the regulation of nuclear power plants is provided in the IAEA Code of Practice No. 50-C-G and related safety guides (see also sections 5.5.3 and 5.6).

6.5.1. Objectives and scope of safety analysis reports

The principal purpose for the preparation and submission by the applicant of a safety analysis report is to inform the appropriate authorities of the detailed nature of the nuclear power plant and plans for its use. Its submission is usually required by law and it represents the principal communication between the applicant and the regulatory authority. The information provided must be concise, but sufficient to permit an independent review of whether the facility can be built and operated with due consideration given to the health and safety of the general public and operating personnel. To accomplish this it must contain a systematic presentation and analysis of the nuclear safety aspects of the site and plant design, construction and operation. The prime objectives of the documents are to present:

(a) A detailed analysis of the safety aspects of site characteristics and of the safety-related structures, components and systems of the plant;
(b) A clear identification of the safety-related design bases (objectives) and standards, and a demonstration of compliance with them;

(c) A safety analysis which includes the response of the plant to anticipated disturbances, malfunctions or failures and analysis of the potential radiation exposure of the plant personnel and the public during normal operation and accident conditions;

(d) The qualifications of the applicant’s staff, a plan for the applicant’s organizational structure, including a description of the measures within which the plant will be operated.

The documents must contain sufficient information to enable a competent regulatory authority to perform its own independent safety assessment and to decide upon any modifications or specific conditions for operation of the plant. The safety report must reflect all of the information on the design available at the time of submission. If certain information is not available, the criteria and design basis to be used in developing the required information, the concepts or alternatives under consideration and the schedule for completeness and submission of the information in the form of supplements or amendments to the safety report should be included.

To ensure that the safety reports submitted are as complete as possible, various documents have been proposed which specify in detail the organization and information requirements. The IAEA in recognition of the need for specific guidance has issued Safety Guide No. 50-SG-G2 “Information to be Submitted in Support of Licensing Applications for Nuclear Power Plants”, and various Member States have issued detailed standard formats.

6.5.2. Regulatory review and assessment

Review and assessment is one of the regulatory body’s principal activities. The regulatory body may use a number of methods and techniques for reviewing and assessing the information supplied. The information should be checked for compliance with such rules, regulations and requirements as may be in effect and applicable to the particular case. In addition, the degree of consistency with appropriate non-mandatory guidelines and criteria, as recommended by international governmental and private sources, should be ascertained. In performing the assessment, to the extent appropriate use should be made of information obtained from previous evaluation of and experience with other reactors approved for construction or operation.

During the early years it may not be necessary to emphasize all areas usually associated with safety analysis. For example, the routine accident analysis and reactor transient behaviour will be similar for the plant being reviewed and for other plants designed by the reactor vendor for its own domestic market and for the international market. The regulatory body could
concentrate only on features that differ between the plant being constructed and the reference plant usually specified in the contract or other similar plants and the reasons for the differences. This approach has several advantages. First, becoming familiar with the complex systems can serve as an essential means of training for both utility and regulatory staff. Secondly, when the comparison is done not only to the reference plant, but also to a more recent plant, it can serve as a means of following new developments.

When use is made of information obtained from a reference plant, several cautions should be observed:

(a) The use of a reference plant cannot be a substitute for the regulatory body acquiring the basic understanding of the design basis and features of the proposed plant;
(b) Specific site conditions and their impact on the design must still be assessed;
(c) Care must be exercised to account for changes in requirements, structures and auxiliary equipment that may have occurred.

In assessing the safety of plants closely similar to plants already approved abroad, it will be desirable, and possibly necessary, to place some reliance on related licensing documents and findings of foreign regulatory bodies. This will be especially true for countries with limited nuclear experience which are purchasing established nuclear hardware and technology abroad.

The regulatory body should be prepared to undertake or commission such independent calculations and analyses as are judged necessary to verify the applicant’s information and to provide a firm basis for making the required findings in respect to safety. These independent efforts may include checks of replication of actual calculations and design procedures and analysis done by the applicant.

Finally, it should be noted that determinations by a regulatory body regarding the licensing of a nuclear power plant involve a careful weighing of factors, some of which are highly qualitative or conflicting. Thus, reference to regulations, documents and independent calculations cannot and should not supplant the need for employing professional judgement in making decisions. This fact points up the importance of the regulatory body having an experienced and well-trained technical staff.

The regulatory body should prepare safety assessment reports that describe and explain the results of the body’s review and assessment process, the basis for its findings and its conclusions or recommendations. These safety assessment reports may be issued at any stage of the licensing process, but most importantly at the construction approval stage and the continuous-operation approval stage.

Detailed guidance on the conduct of regulatory review and assessment during the licensing process for nuclear power plants is provided in the IAEA Safety Guide No. S0-SG-G2.
6.5.3. Safety codes, regulations, guides and standards

Safety codes, regulations, guides and standards play key roles in ensuring the safety of nuclear power plants. They:

- Serve as the foundation of safety and environmental protection
- Define performance requirements that establish acceptable levels of risk
- Codify good practice proven by experience
- Provide the foundation for equipment standardization
- Provide the basis for inspection and enforcement
- Encourage public acceptability.

The regulatory authorities in various major supplier countries have established safety codes and issued regulations and regulatory guides which include the design, construction and operational safety requirements of nuclear power plants. Manufacturers and owners of nuclear plants must comply with the regulations and are to submit all documentary evidence for their compliance in order to obtain the licence or construction permit from the regulatory authority. Unfortunately, there are no universal safety requirements accepted by all supplier countries, so that a reactor that is licensable in a given supplier country would not necessarily be so according to another supplier country's regulations.

This situation poses a difficult problem for a country starting its nuclear programme and which most probably has no safety codes and regulations of its own. However, in most cases of countries importing nuclear plants this problem is overcome to a certain extent by adopting a policy that any nuclear project licensable in its country of origin would in principle be satisfactory to the buyer's regulatory authority, subject to specific requirements that are stated or that might be developed.

This solution, however, presents a number of problems which, in addition to the non-uniformity of safety requirements, are due to the non-standard features of nuclear power plants for export and the unique aspects of supply, construction and operation in a particular country.

The differences in the currently available reactor types that occur among the various exporters are only one aspect of the non-standard nuclear power plant export. More important are the differences between the domestic plant in the supplier country (sometimes termed the reference plant) and the supposedly similar plant as finally constructed in the importing country. These differences result from the usually lower power rating of the exported reactor, dissimilar site characteristics that significantly affect the design, balance of plant considerations which can include system designs from different architect-engineering firms or from several supplier countries, and the continuous evolution in design and safety requirements during design and construction.
This non-standard nuclear power plant export must be examined in relation to the non-uniform safety requirements that currently exist. Since many of the smaller and certainly the less industrialized countries do not have a base of engineering standards, they must essentially adopt the standards and requirements of the exporting country. This is complicated, however, by four important issues: the significant differences in exporting countries; the differences in content and application of specific standards; the non-applicability of some domestic standards to the export situation; and, finally, the continuous development and evolution of safety standards and requirements. For the importing country the above factors lead to difficulty in determining if design and construction are indeed similar to that of the reference plant, in ascertaining what the safety requirements are and whether they are being met and may contribute to a lack of understanding of the reasons for many safety requirements, in turn leading to obvious difficulties in making important ‘updating’ or ‘back-fitting’ decisions.

Because of this diversity between the safety requirements in various countries, the IAEA programme of Nuclear Safety Standards (NUSS) is especially important. The main objective of this programme is the development of a set of international safety codes and guides acceptable by all supplier and recipient countries.

The programme is divided into the following five areas:

- Governmental organization
- Siting
- Design
- Operation
- Quality assurance.

All the IAEA safety codes and guides are listed in the references and bibliography at the end of this Guidebook. The IAEA codes of practice and safety guides for nuclear power plants are undoubtedly an important step towards unification and harmonization of nuclear safety requirements and should facilitate the task of the selection of requirements by any country introducing nuclear power.

6.5.4. Inspection and enforcement

Through regulatory inspection the regulatory body satisfies itself that the licensee is fulfilling the conditions set out in the licence and regulations. The regulatory body should plan its regulatory inspection programme to assure itself that all nuclear power plants are constructed in conformity with the designs approved by the regulatory body, that all safety related structures, components and systems of the nuclear power plants are of the required
quality, that the nuclear power plant personnel are competent to operate the
reactor safely and that the nuclear power plants operate within limits and
conditions specified in the licence.

Regulatory inspection, both announced and unannounced, by the regulatory
body is an activity which continues throughout all stages of the project. It may
be convenient for the regulatory body to use the services of consultants, but
this should not limit the responsibility of the regulatory body.

Continuing co-operation of the applicant/licensee with the regulatory
body is essential to ensure that regulatory inspection functions are carried out
effectively and efficiently.

The principal objectives of the regulatory inspection are to ensure that:

(a) Persons responsible for the siting, construction, commissioning,
operation and decommissioning of a nuclear power plant possess the
necessary competence for the efficient discharge of their functions;

(b) The quality and performance required by the regulatory body are
achieved and maintained in components, structures and systems
throughout all stages of the licensing process;

(c) All specifications, codes and practices accepted by the regulatory
body for siting, construction, commissioning, operation and
decommissioning of the plant are complied with;

(d) Deficiencies are corrected by the licensee without undue delay;

(e) Experience is fed back to the regulatory body.

It is essential that the regulatory body be given adequate powers to enforce
compliance with its regulations and licences.

Detailed guidance on matters of inspection and enforcement will be found
in IAEA Safety Series No. 50-SG-G4 “Inspection and Enforcement by the
Regulatory Body for Nuclear Power Plants: A Safety Guide”.

6.6. EXAMPLES OF SOME POWER REACTOR RISK STUDIES

The intent of the design safety features, safety assessment, safety implementa-
tion and regulatory measures previously discussed are to accomplish the
objectives of the ‘defence-in-depth’ safety philosophy. Under the regime, the
plant conditions that are required to be considered and accounted for in the
safety design and analysis include anticipated operating occurrences, events
with the potential for small to moderate releases of radioactivity, and the
design basis accidents and events that are postulated to establish performance
requirements for the ultimate safety systems for the plant.

The anticipated operating occurrences are transients that would lead to
little or no release of radioactivity and include such things as turbine trip, loss
of electrical power from off-site sources, partial loss of feedwater or reactor coolant flow, or improper control rod withdrawal.

The events that might release small to moderate amounts of radioactivity include such things as partial failures of the radwaste system, malfunctions leading to leakage of gaseous fission products and steam generator tube failures.

The enveloping design basis accidents and events include refuelling accidents, loss of coolant accidents, steam line break accidents, rod drop or ejection accidents and all the natural phenomena such as large earthquakes, storms and floods.

The calculated consequences of all of these events, even from the unlikely and extreme areas, are required to be within the safety guidelines. All of these events and accidents are within the design basis envelope of the plant and thus are provided for in the design of the plant and its engineered safety features.

However, the envelope of design basis accidents has not included all events that are conceivable and physically possible for a nuclear plant. At the very low probability end of the spectrum of all possible events there is a residuum of conceivable accident sequences that could, if they occurred, lead to serious radiological consequences outside the plant boundary in considerable excess of the radiation protection guidelines. Such accidents may involve sequences of failures, each one of which is in itself relatively unlikely. One obvious source of accidents beyond the design basis is to assume that a given accident occurs and that all of the safety systems provided to mitigate the consequences of an accident fail to function.

In such a situation, it has to be considered that the heat sink would be partially or completely lost which could then lead to a partial or complete core melt. To estimate the risk of such hypothetical accidents, it is important to obtain information about both the consequences of such accidents and the probability of their occurrence. For this purpose two important reactor safety studies have been completed. The first was completed in the United States in 1975 and published by the US Nuclear Regulatory Commission. It is known as the Rasmussen Report or WASH-1400. The second was published in August 1979 by the Federal Republic of Germany and is known as the “German Risk Study for Nuclear Power Plants”.

Whereas earlier studies concentrated on an upper estimate of potential consequences (US WASH-740, 1957), the Rasmussen Report (WASH-1400, 1975) presented for the first time a comprehensive probabilistic risk assessment of core melt-down accidents.

Since such accidents are predicted to be very rare, it is not possible to base probabilistic estimates on the usual statistical analysis applied to other natural or man-made hazards. Rather, in order to derive a probability estimate of a reactor core melt, the WASH-1400 Study (and subsequent studies like the German Risk Study) applied fault tree and event tree analysis where probabilities of
total failure sequences are synthesized from information on the reliability of system components (e.g. pumps, automatic control systems, pipes, valves, vessels). Such information is either available from experience with identical equipment in other areas or can be extrapolated from similar equipment.

Some basic insights from the reactor safety studies are:

- The use of risk assessment techniques provides valuable insights into potential 'weak links' in the defence-in-depth concept;
- Large loss-of-coolant accidents are not the largest contributions to the overall risk, small LOCAS and transients being much more significant;
- Human error is a major contributor to the overall risk;
- While the societal risk associated with nuclear power reactors appears to be lower or equivalent to other risks to which mankind is exposed, the occurrence of accidents involving fuel damage has a higher likelihood of occurrence than was previously estimated; however, such an accident need not necessarily have catastrophic health and safety consequences.

Based on the analysis in the study, WASH-1400 estimated the total probability of a core melt for LWRs to be $5 \times 10^{-5}$ per reactor-year. This estimate was confirmed by the "German Risk Study", which derived a value of $9 \times 10^{-5}$ per reactor-year.

It is clear that because of these low probabilities there are no historical statistical data with which to verify the analytical results.

The analysis of core-melt accidents shows that in the large majority of cases the consequences will be very limited. The German reactor study shows that altogether the probability is more than 99% that a core-melt accident would not cause acute fatalities. A great number of fatalities could occur only if adverse weather conditions coincide with unfavourable site characteristics and the most severe accidents. This results in a very low probability of large-consequence events.

However, there remains a low probability of large potential consequences to the public. Figure 19, from the WASH-1400 study, shows the estimated early fatalities and the related probabilities for 100 nuclear plants in the USA and for other man-caused events in the form of a cumulative probability distribution. The approximate uncertainties of the estimates for nuclear power are represented by factors of 1/4 and 4 for consequence magnitudes and by factors of 1/5 and 5 for probabilities. It can be derived from this diagram that the probability of accidents from nuclear power plants is estimated to be 3 to 4 orders of magnitude less than comparable accidents caused by other man-made sources.

The reader is referred to the reports WASH-1400 and the "German Risk Study for Nuclear Power Plants" for further details of the findings of the studies.
FIG. 19. Frequency of man-caused events involving fatalities (WASH-1400). Note: Fatalities due to auto accidents are not shown because data are not available for large-consequence accidents. Auto accidents cause about 50,000 fatalities per annum.

6.7. ENVIRONMENTAL EFFECTS OF NUCLEAR POWER

The generation of electricity by nuclear power, or by fossil fuels, has some environmental effects even when all performance standards are met. One of the objectives in the design of nuclear power plants and other nuclear facilities is to minimize the impact of various possible effects of releases from the plant to the surrounding environment. Potential sources of releases to the environment from the operation of nuclear power plants include mainly radioactive gaseous or liquid effluents, heat discharges from waste steam, and chemical discharges from different systems of the plant. Various releases from the plant are subject
to strict controls both by batch processing of effluents or by continuous monitoring before discharge to the environment to ensure that the established permissible levels are not exceeded.

The possible environmental effects are non-radiological and radiological effects.

6.7.1. Non-radiological effects

6.7.1.1. Thermal discharges

Nuclear power plants, like fossil-fuelled power plants, require large amounts of cooling water for the condensers. All steam-powered electrical generating plants have a common characteristic in their need to release unused heat to the environment. Heat from the combustion of fossil fuel or from the fission of nuclear fuel is used to produce steam, which drives a turbine connected to a generator. The 'spent' steam from the turbine is condensed by passing through condensers cooled by large amounts of water. The heat transferred to the cooling water normally raises its temperature by 5°C to a maximum of 15°C under full load conditions.

The reactors on the market at present operate at a lower thermal efficiency than most modern fossil-fuelled plants of the same generating capacity. For this reason and also because about 10% of the heat from fossil-fuelled plants is discharged directly into the atmosphere through the stack, nuclear plants reject about 50% more heat to the cooling water than do fossil-fuelled plants. This difference may be reduced in the future with the advanced reactors now being developed.

Various constraints including economic and biological costs, aesthetics and requirement on water quality and cooling water sources govern the choice of the method of disposal of condenser cooling water. One of the most important factors is the source of cooling water available for a particular steam-electric plant. The body of water to be used may range from fresh water lakes and rivers to estuaries and coastal marine waters. In many countries or in parts of them there may be little choice but to use estuaries and coastal waters, because there are no adequate lakes or rivers for cooling purposes.

Basically, there are three methods of disposal of heated discharges:

- By a closed-cycle cooling system
- By a variable-cycle cooling system
- By once-through operation.

In a closed-cycle system the condenser cooling water will flow from a condenser to an atmospheric heat exchanger (either a cooling tower or an artificial lake or pond) where it will lose heat before being returned to the condenser for re-use.
A variable-cycling cooling system rejects some of the heat from the condenser cooling water in a cooling tower or flow-through cooling pond before discharge into a natural water body. Some of these systems are capable of operating at any point between the two extremes of closed-cycle and once-through operation.

When the supply of water is not a problem, plants may use the once-through system, in which the cooling water is taken from nearby rivers, lakes, estuaries or coastal waters and returned usually to the same source.

Engineers and biologists are making considerable efforts to take into account the needs of both the aquatic biological community and the power plant in developing suitable designs for power plant cooling systems. Physical studies concerning water temperatures enable predictions of temperature patterns resulting from heated discharges to be made. Information on temperature and behaviour of heated discharges from the site is needed:

(a) To avoid recirculation of heated discharge waters which would decrease plant efficiency
(b) To comply with regulations on water temperature standards
(c) To provide sufficient basic data to enable biologists and ecologists to assess thermal effects.

Perhaps no other single environmental factor affects aquatic life as profoundly as temperature. Unfavourable temperatures may affect reproduction, growth, survival or larval forms, juveniles and adults and all the life processes necessary to maintain a healthy state. Regulatory agencies at various levels of government are developing or have established water temperature standards which are used to govern heated discharges from steam/electric plants. If discharges of heated water are controlled, then the primary concern is in ‘monitoring’ effects to make sure that no serious trends requiring corrective action are taking place on account of subtle temperature effects on populations, communities and ecosystems.

If cooling towers are used, the environmental effects of humidity increases, fog formation and blowdown from the towers must be evaluated and controlled.

6.7.1.2. Chemical discharges

Normal operation of a nuclear power plant requires the discharge of certain chemicals from the turbine condenser cooling system, the radioactive waste system and the sanitary waste system. The chemical content of the discharges from these systems will vary from plant to plant. For example, chlorine or some other biocide may be added intermittently to cooling water to remove accumulations of organic matter inside the condensers, phosphate and zinc compounds may be used as corrosion inhibitors, sulphuric acid may be used to
adjust the alkalinity of recirculating cooling water and demineralizers may be
regenerated periodically with sulphuric acid and sodium hydroxide, the
regenerants then being neutralized before discharge. The maximum concentrations
of some of these chemicals in the discharge canal could conceivably exceed
levels that are toxic to aquatic life. Temperature as the ‘master factor’ affecting
rates of all metabolic functions can influence the speed with which toxic
substances exert their effects and, in some instances, it can influence the
threshold concentrations for toxicity.

The technical assessment of the potential impacts of chemical and sanitary
wastes from nuclear plants is included in the environmental evaluation made
in the early stages of planning.

6.7.1.3. Land requirements

For nuclear power plants land requirements may vary from plant to plant.
Typical values for site requirements are estimated to range from 40 to 60 hectares
per unit. A long-range land-use problem may arise from the need to control
population patterns near large nuclear power plants. In environmental impact
assessments allowance should be made for long-range population trends taking
into account that the availability of large amounts of power and of waste heat
may attract additional industries and their employees to the neighbourhood
of the nuclear plant site.

For fuel cycle facilities the largest environmental impact in terms of
land-use is uranium mining and milling. For opencast uranium mines about
one third of the total land is disturbed temporarily by the actual mining
operation while the remaining two thirds remain idle. In the milling stage,
most of the land area is used for a pond for disposal of mill tailings. For a
1000 MW(e) LWR once-through fuel cycle about 16 ha of land would be
temporarily disturbed and 1.5 ha permanently committed per year. For processing
facilities (conversion, enrichment, fuel fabrication or reprocessing) waste is
handled at or adjacent to the facilities. The land-use for waste conditioning would
be rather insignificant compared with the land-use of the related process activity.

6.7.1.4. Social effects

The aesthetic impact of power plants, whether nuclear or fossil-fired, and of
the associated switch yards and high-voltage transmission lines varies widely in
the visual impression they make. Depending on one’s point of view, their
appearance may be judged as blending harmoniously with their surroundings
or as an insult to an otherwise attractive countryside. Objectively, suitable
architectural treatment utilizing colours and textures, reflections in cooling
ponds and a distribution of masses can do much to enhance the plant’s appearance.
There has been some objection to the appearance of tall hyperbolic cooling towers. To the observer who does not cherish their stark graceful lines they may appear objectionably obtrusive. Attempts to camouflage by painting or surrounding with a shroud rarely have been successful. Where their appearance is considered unacceptable, alternative means of providing comparable cooling capacity may have to be explored. The aesthetic impact of high-voltage transmission lines has also been criticized. The plant location and power line routing should not therefore impinge on areas valued for their historic or touristic significance.

Other major social impacts associated with waste management and in mining and milling operations are that they provide employment opportunities often in remote areas. Large opencast mines may have some social benefit after decommissioning, as large areas of water for recreation, or the support of fauna and flora in an arid climate.

6.7.2. Radiological effects

The environmental impacts of the nuclear power industry discussed in section 6.7.1 are generally similar in nature to those of the fossil-fuel power industry. However, a dominant concern in the nuclear power industry is with radioactive releases and their effects on the biosphere, especially on human health. Owing to this concern, dose rate limits are established, protective measures devised and their application enforced.

6.7.2.1. Mining of uranium ores

Radiological effects of uranium mining are due to exposure to radon and radon daughter products which are given off from uranium ores. Following inhalation of radon and its daughter products, the tissues of the lung and respiratory tract are irradiated with alpha-particles. In some uranium mines whole-body exposure to gamma-radiation can also be significant.

6.7.2.2. Milling of uranium ores

Radiological effects in milling operations result from the release of dusts containing uranium and uranium daughter products, radon and radon daughters, etc. Radon is released from the leach tank vents, ore piles, tailings retention system and the ore crushing and grinding ventilation system. Most of the radium in the ore is insoluble and remains in the tailings solids; a small portion, about 1 per cent or less, is dissolved. The waste solutions contain radium-226, thorium-230, uranium and small concentrations of radon decay products.
6.7.2.3. Uranium conversion, enrichment and fuel element fabrication

Radiological effects from these fuel cycle operations may arise from the release of uranium isotopes and other radionuclides to the environment.

6.7.2.4. Nuclear power plant operation

During the operation of nuclear power plants radionuclides are formed by fission of the nuclear fuel and by neutron activation of structural materials, corrosion products, and impurities in reactor coolant. Most of the fission products remain in the fuel elements, but a fraction may escape into the coolant. Most of the radioactive isotopes released into the coolant are removed by processing systems. Nonetheless, part of the radioactive material may eventually be released into the environment.

Of the many radioactive fission and activation products generated during reactor operation, emphasis has been given to the environmental impacts of tritium, carbon-14 and radionuclides in particulate forms released to the atmosphere and water bodies. Special consideration is given to tritium and krypton-85, as both radionuclides are long-lived. In particular, krypton-85 deserves attention because of the inherent difficulty in controlling it and its essentially unreactive and mobile nature in the environment. Because of the long half-life of carbon-14, the radiation exposure commitments resulting from its build-up in the environment are considerably larger than those from noble gases and tritium. Several radionuclides, particularly iodine-129 and iodine-131, are radiologically significant in the local environs. Iodine-129 is also significant globally. Noble gases, tritium in the form of tritiated water vapour, carbon-14 and iodine enter into the environment as airborne effluents. Aerosols containing fission and activation products as well as the decay products of noble gases may also be released as airborne effluents.

The risk to human health arising from nuclear power generation is mainly due to occupational exposure to gamma rays from fission and activation products. The population exposure arises from the release of radionuclides into the environment. Radionuclides released into the environment as airborne or liquid effluents during reactor operation undergo a series of complex physical, chemical and biological processes before reaching man. Such processes depend on the location of the reactor, meteorological conditions and the different exposure pathways.

Radionuclides discharged in liquid effluents may result in doses to man through the pathways of drinking water and fish consumption. A portion of the population may also be exposed on shorelines to external irradiation from radioactive sediments.
6.7.2.5. Reprocessing

In the spent fuel elements essentially all the radioactive fission gases are trapped physically or chemically in the zirconium cladding, in the fuel matrix itself and in the fission gas plenum at the end of each fuel pin. These gases are released in the early stages of reprocessing, usually during chopping of the fuel elements or dissolution of the fuel. The gaseous wastes contain krypton-85, iodine-129, some tritium and carbon-14. Techniques for removing each of these elements from the off-gas stream have been developed. Only radioiodine is currently removed; the other gaseous wastes are diluted and dispersed in the environment, in accordance with accepted practice.

6.7.2.6. Radioactive waste management

Radioactive wastes accumulate as either liquids, solids or gases with varying radiation levels. The bulk of the wastes occur at the front-end of the nuclear fuel cycle (mining and milling), while the more radioactive wastes occur at the back-end of the cycle (spent fuel reprocessing in the case of the recycling option).

Radioactive wastes are categorized as low, intermediate and high-level wastes; some are contaminated with transuranic elements. The technological aspects of the management and disposal of radioactive wastes are discussed in Chapter 3, section 3.4.

From the radiological viewpoint, the ultimate objective of the various waste management systems is to prevent the release of unacceptable amounts of radionuclides in wastes from the nuclear fuel cycle to the human environment. Waste disposal practices generally follow fundamental principles recommended by the International Commission on Radiological Protection in its publication ICRP-26, i.e. all radiation exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account, and shall not exceed the appropriate dose limits now or in the future. In addition, it is generally accepted that radiation exposure to future generations should be not higher than that acceptable to present generations.

In accordance with the above principles, the practices followed in radioactive waste management and disposal allow some waste constituents to enter the human environment. Thus, gaseous and liquid effluents released routinely from nuclear power facilities contain very small, controlled quantities of radionuclides; underground disposal of conditioned wastes containing the balance of the waste radionuclides is regarded as allowing some of the radionuclides eventually to enter the human environment, but with a time delay and dilution sufficient that their concentrations will be insignificant at any point of potential uptake by humans. On these bases, waste disposal carried out
TABLE XXX. GLOBAL DOSE COMMITMENTS FROM VARIOUS RADIATION SOURCES
(Source: IAEA Bulletin, Vol.22, No.2)

<table>
<thead>
<tr>
<th>Source of exposure</th>
<th>Global dose commitment (d)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-year exposure to natural sources</td>
<td>365</td>
</tr>
<tr>
<td>One-year of commercial air travel</td>
<td>0.4</td>
</tr>
<tr>
<td>Use of one year's production of phosphate fertilizers at the present production rate</td>
<td>0.04</td>
</tr>
<tr>
<td>On-year global production of electric energy by coal-fired power plants at the present global installed capacity (1000 GW(e))</td>
<td>0.02</td>
</tr>
<tr>
<td>One-year exposure to radiation-emitting consumer products</td>
<td>3</td>
</tr>
<tr>
<td>One-year production of nuclear power at the present global installed capacity (111 GW(e))</td>
<td>0.83</td>
</tr>
<tr>
<td>One-year of nuclear explosions averaged over the period 1951–1976</td>
<td>30</td>
</tr>
<tr>
<td>One year's use of radiation in medical diagnosis</td>
<td>70</td>
</tr>
</tbody>
</table>

\(^a\) The global dose commitment for each radiation source is expressed as the duration of exposure of the world population to natural radiation that would cause the same dose commitment. The occupational contribution is included.

under appropriate control at suitable sites is expected to give rise to no significant public exposure.

6.7.2.7. Decommissioning of nuclear facilities

Decommissioning of a nuclear facility can be defined as the measures taken at the end of the facility’s lifetime to ensure the continued protection of the public from the residual radioactivity and other potential hazards in the retired facility. Two basic approaches are generally considered in this regard, one being immediate dismantling and the other, safe storage with or without deferred dismantling. Methods for decommissioning nuclear facilities range from minimal removal and fixation of residual radioactivity with maintenance and surveillance, to extensive clean-up, decontamination and entombment. Each of these methods of safe storage requires surveillance and care during the holding period, which may vary in length from a few years to decades.
6.7.2.8. Transport of radioactive materials

In the transport of radioactive material the actual quantities involved are very small in comparison with the transportation requirements for coal-fired stations, which in fact account for a major environmental impact of such stations. It is only the radioactivity that raises concern. Radioactive materials arising in the nuclear fuel cycle are generally transported by truck and to a lesser extent by rail or sea. Regarding protective measures, extensive experience is available.

6.7.3. Comparative risk

The detriments resulting from the nuclear power industry form a small fraction of the detriment of the world population from exposure to natural radiation and other sources of radiation, as shown in Table XXX.

A comparison of the detriments with other known energy technologies shows that nuclear energy is less detrimental to the society during normal operations. Figure 20 illustrates this point.
BIBLIOGRAPHY TO CHAPTER 6

IAEA NUCLEAR SAFETY STANDARDS (NUSS) PROGRAMME (see References and Bibliography at the end of the Guidebook).


Chapter 7

INTERNATIONAL ASPECTS OF NUCLEAR POWER

7.1. INTRODUCTION

The first part of this chapter (Section 7.2) will examine in its broadest aspects international co-operation in the development of nuclear power. The second part (sections 7.3 to 7.6) will focus more specifically on the question of safeguards to ensure that nuclear energy is used only for peaceful purposes and on other associated topics.

In the early stages of the first nuclear research and development the peaceful and military uses of nuclear energy were generally closely intertwined. This connection was gradually reduced as these two uses became separated and as new countries began nuclear power programmes through nuclear supply and technology transfer from industrially advanced countries.

The linkage between peaceful and military uses is also reflected in the Statute of the IAEA, in particular in Article II. This Article provides that the first objective of the IAEA is to “seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity through the world”, while under its second objective “... it shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose.”

With the passage of time, peaceful and military applications have increasingly diverged. Nevertheless, the questions of peaceful international trade in nuclear energy and of adequate safeguards continue to be linked. No international agreement for the supply of nuclear fuel, plant and technology would be conducted today without safeguards to ensure their peaceful use.

7.2. INTERNATIONAL CO-OPERATION

Probably all plans to introduce a major modern technology involve co-operation between nations. There are few technologies, however, in which such co-operation is required so extensively as it is for nuclear energy.

There are many reasons for this. The novelty, complexity and cost of nuclear technology meant that it could only be developed at first by a handful of nations able to make the vast investments in research and development needed to move from the laboratory and pilot plant to full commercialization. Thereafter complex arrangements were needed at both the governmental and the commercial level to transfer the technology to other industrial countries as well as to developing
countries, not least because of the potential risks involved in nuclear operations and because of possible diversion to military purposes, both of which can have worldwide implications. Given the magnitude and the difficulty of the task, it is a remarkable achievement that since the first nuclear power plant came into operation in the early 1950s twenty-two countries, seven of them ‘developing’, have already been able to build and operate nuclear power plants, producing in 1980 8% of the world’s electricity.

After the outbreak of the Second World War all nuclear technology was placed under the strictest security controls and until 1954 there was virtually no cooperation between States in the peaceful uses of nuclear energy.

From 1946 to 1951 there was discussion in the United Nations of far-reaching US proposals to set up an international atomic development authority to which should be entrusted all phases of the development and use of atomic energy, starting with raw materials and including managerial control or ownership of all potentially dangerous atomic energy activities. By 1952 these discussions had reached an impasse. In December 1953 President Eisenhower in his “Atoms for Peace” speech to the UN General Assembly launched the idea of setting up an international body with more modest aims, and after three years of negotiations this proposal bore fruit in the International Atomic Energy Agency in 1956 and 1957. (The Statute of the IAEA was approved on 23 October 1956 by a conference at United Nations Headquarters, and entered into force on 29 July 1957.)

International co-operation has taken many forms; for some purposes bilateral or regional channels remain the preferred and most effective course, for others international co-operation, chiefly through the IAEA, is essential. After twenty-four years of operation the IAEA is able to provide most of the services that its members require from it (and it is they that decide what services the organization should offer) in a reasonably effective manner, based on substantial experience in serving as a bridge for technical co-operation between nations.

7.2.1. Bilateral co-operation

Pending the establishment of the IAEA, the USA, the USSR, the United Kingdom, France and Canada, the countries that still had a near-monopoly of nuclear technology, began co-operation with each other and with third countries. During the late fifties and early sixties they concluded a large number of bilateral agreements under which they arranged to supply research reactors and nuclear fuel (and subsequently power reactors). In most cases the bilateral agreements required the purchasing or receiving country to accept the safeguards of the supplier to ensure that the items supplied were not put to military use. The bilateral agreements with the USA specified that these safeguards might later be turned over to the IAEA. It was chiefly as a result of these bilateral agreements that research reactors are in operation today in 44 countries outside the five states already mentioned.
The bilateral channel remained the preferred route for the supply of nuclear hardware (plant and fuel). Of the 110 nuclear power plants under construction or in operation today that have been imported from abroad (in the sense that at least the nuclear steam supply system has been supplied by other countries) only three have been ‘supplied’ through international channels and the international aspects of these three transactions have been limited to legal, safety and safeguards matters. All commercial arrangements had been made directly between seller and purchaser.

This preference for the bilateral channel is not surprising. Most transactions for nuclear plants involve the grant of very large credits by the financial institutions of the supplying country and all require intimate technical and managerial cooperation between the purchaser and the seller. It is generally simpler to make these complex arrangements directly rather than through a third party.

Nevertheless, the international organization concerned (so far always the IAEA) can play a crucial, if small role in helping the importing country to launch a nuclear power project or programme. The forms of co-operation given by the IAEA include advice and guidance on the legal and administrative framework for the nuclear programme, on programme and project planning activities, assisting the purchaser to prepare specifications and to evaluate competitive bids from suppliers, site selection for a power plant, evaluation of the safety of the project and help in providing trained managerial, operating, safety and auxiliary personnel. In situations where the purchaser, in deciding on a very large investment, has to choose between several potential suppliers, in other words, has to take a decision that may well dictate the future shape of the purchaser’s national energy programme, impartial advice and assistance from an international body may be of great value. The help the IAEA can provide is examined in greater detail in section 7.2.3.

In recent years bilateral arrangements between seller and purchaser have sometimes extended beyond the supply of a single nuclear plant and have embraced entire nuclear power programmes, including the provision of fuel cycle technology.

The supply of nuclear fuel has also been largely arranged on a bilateral basis. The arrangements are often extremely complex, involving purchase of uranium in one country, enrichment in a second, fabrication in a third and possibly reprocessing in a fourth. Clearly, direct commercial negotiations between the countries and organizations concerned will be preferred in such cases.

These tendencies are likely to be reinforced by the emergence in recent years of a buyer’s market, with nuclear fuel, enrichment services and plant manufacturing capacity in oversupply.

The emphasis changes when other aspects of co-operation are considered, such as information exchange, nuclear safety, technical assistance and training. Here, over the years, bilateral arrangements have played a diminishing role except in regard to the provision of detailed specifications and training when an individual plant is being supplied.
7.2.2. Regional co-operation

The late 1950s saw the establishment of three regional bodies for promoting the peaceful uses of nuclear energy as well as one international body, the IAEA. The regional bodies were:

(a) The (European) Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD)
(b) The European Atomic Energy Community (EURATOM)
(c) The Inter-American Nuclear Energy Commission (IANEC), as part of the Organization of American States (OAS).

Since the work of these organizations, with the exception of IANEC, has currently little to do with the introduction of nuclear power, and since IANEC's own activities are very limited, this survey deals only very briefly with the three bodies concerned.

7.2.2.1. NEA

The NEA today includes almost all market economy countries, in other words, the USA and Canada, Western Europe, Japan, Australia and New Zealand. Its members thus account for some 85% of the world's installed nuclear capacity and some 80% of its fuel production capacity and reserves.

Co-operation between NEA and the IAEA has been very close since their inception and, despite some overlapping aims, it has been possible to avoid significant duplication of work. Today NEA concentrates its activities almost entirely on technical questions of nuclear safety and waste management and on fuel cycle studies. Under informal arrangements between the two organizations, NEA recognizes that it is the responsibility of IAEA to develop and promulgate international safety standards, codes, guidelines, etc. NEA (as well as EURATOM and interested UN agencies like WHO and ILO) takes part in preparing these standards, etc. NEA focuses its work on detailed technical problems and projects in nuclear safety and waste management in which it seeks to pool the resources of interested members for reaching well-defined technical objectives.

NEA and IAEA co-operate closely in preparing periodic surveys of the world's resources, production and demand for uranium and in studies of nuclear fuel cycle requirements. The two bodies also co-sponsor two or three international symposia each year, usually on subjects related to nuclear safety or waste management.

Other fields of co-operation include the exchange of information on nuclear data and computer programmes.

The NEA activity of most direct interest to the developing countries is in the framework of IUREP (International Uranium Resources Evaluation Project).
Under this, NEA has helped to finance, on request and through the medium of the IAEA, exploratory studies of uranium resources of a number of developing countries.

7.2.2.2. EURATOM

EURATOM is the nuclear counterpart of the Common Market and of the Coal and Steel Community set up in the late 1950s between Belgium, France, Federal Republic of Germany, Italy, Luxembourg and the Netherlands and later expanded to include Denmark, Greece, Ireland and the United Kingdom. EURATOM directly assists major nuclear industrial research projects. It operates a number of regional Research and Development (R&D) centres, including the Joint European Tokamak (fusion project), it promotes the exchange of information, establishes regional safety standards, and applies a regional safeguards system.

Most of the co-operation between the IAEA and EURATOM has been in the joint application of safeguards in the non-nuclear weapons States of EURATOM (and recently in France and the United Kingdom), co-operation in advanced technologies such as fast breeder and fusion R&D and co-operation in international nuclear information exchange, particularly through INIS (the International Nuclear Information System of the IAEA).

7.2.2.3. IANEC

In the early 1960s IANEC, operating on a very modest budget, helped to promote information exchange and training and other forms of technical assistance in its Latin American Member States, usually in co-operation with the IAEA. IANEC’s activities subsequently declined but there has been recently a revival of support and suggestions that IANEC and the Agency should co-operate in developing a regional agreement for research co-operation in Latin America similar to that which the IAEA has helped a number of Asian countries to set up (RCA – Regional Co-operative Agreement for Research, Development and Training related to Nuclear Science and Technology).

7.2.3. IAEA technical co-operation activities

The chief fields of international co-operation of direct interest to those countries that are introducing nuclear power are IAEA technical co-operation and training, nuclear safety and information exchange.

The total value of technical assistance given by or through the IAEA is now of the order of 22 million dollars a year. It usually takes the form of:
Services of experts
Supply of limited quantities of equipment directly related to technical co-operation
Education and training (fellowships, training courses, scientific visits, visiting fellowships, on the job training, etc.).

About half of the IAEA's technical co-operation programme is now allocated, at the request of the Member States concerned, to activities in or closely related to the field of nuclear power. This proportion has tended to grow during the last two decades.

Of special interest from a nuclear power point of view have been the international training courses that the IAEA has arranged since 1975 at advanced nuclear centres. Currently, about eight such courses are being held per year in Argentina, France, the Federal Republic of Germany, Spain and the USA. Up to 1981 about 1100 persons from 56 developing countries had been trained at these courses. The courses place special emphasis on activities involved in the planning and implementation of nuclear power projects, such as energy and electric system expansion planning, nuclear power programme planning, siting, safety, quality assurance and project management.

Two activities that cannot be carried out effectively in the nuclear as well as other domains unless there is broad international co-operation are the setting of international standards for safety and the world-wide exchange of scientific and technical information.

As is well known, concern about the safety of nuclear power plants and their environmental impact and about problems of nuclear waste disposal has severely hampered the development of nuclear power in several leading industrial countries and has had repercussions in some developing countries. As one result, the IAEA's programmes in nuclear safety and related questions have been expanded in recent years, as discussed in Chapter 6 in some detail.

The main barriers to the exchange of nuclear information have been military secrecy, proliferation concerns and the withholding of information that could be industrially damaging or of commercial value.

The first barrier largely disappeared in 1955. In that year the United Nations held at Geneva the first international conference on the Peaceful Uses of Atomic Energy. The conference was a great success and marked a turning point in information policy. The participating governments, and chiefly the nuclear weapons states of that time, submitted full reports on every branch of nuclear technology including the reprocessing of spent fuel and extraction of plutonium. Only the technology of enrichment and the processes used in the final fabrication of nuclear explosives remained secret.

The 1955 conference was followed by the three further Geneva Conferences in which the IAEA played an increasing and finally a dominant role. The tradition
of Geneva was taken further by the IAEA’s Salzburg Conference of May 1977, which was exclusively devoted to “Nuclear Power and its Fuel Cycle”. Another conference of the same type, to be held in Vienna in September 1982, will review nearly thirty years of experience in the generation of electricity by nuclear steam supply systems. From the start the IAEA has also convened specialized international symposia, advisory group meetings, technical committee meetings, etc. on many topics related to nuclear power.

In recent years the IAEA’s main means of exchanging information has been the International Nuclear Information System (INIS), established in 1969. Briefly, INIS works as follows:

- Each participant (country or international body) sets up a centre to survey and collect all nuclear science literature published in that country (or by the body).
- The centre then prepares a detailed bibliographic description and compiles abstracts for each item of this literature. The centre sends this material, usually on computer magnetic type, to Vienna where it is merged with the existing file or ‘data base’ as it is called. This file now exceeds well over one-half million items.
- Approximately each fortnight the Agency publishes a journal, “INIS Atom-index”, giving bibliographic descriptions and full abstracts covering all new additions to the data base. Atomindex is also available on computer magnetic tape.
- Since it is not enough merely to announce new literature, INIS also provides (on microfiche) the full text of that literature which might be most difficult to obtain through ordinary channels.

By the end of 1970 more than 45 countries and international bodies were taking part in INIS. About 4000 items of new literature were announced during its first operating year; in 1980 this had risen to 76 000.

INIS’ scope is very broad. It covers all main and peripheral topics of nuclear science and technology. This wide coverage has, to some extent, protected INIS from the restrictive tendencies that have begun to affect the flow of information to the IAEA’s international meetings. INIS also has no competitors; no other world-wide nuclear information system exists.

Over the years the intellectual content and direction of the information exchanged at IAEA meetings and through INIS has tended to change. In the early days the chief purpose was to disclose and discuss the latest scientific and technical advances. The information exchanged today in regard to nuclear power reactors is chiefly a review of operating experience, costs and reliability of plants or components, and, of course, nuclear safety.

As a result of non-proliferation concerns, there has been a tendency to close again, at least partly, the gates that were opened in 1955 and to impose restrictions
on the exchange of technological information about so-called sensitive technologies. Commercial sensitivities also sometimes tend to inhibit free and full communication of experience, but these two restrictions are only minimally involved in the IAEA's work of exchanging information.

7.3. THE DEVELOPMENT OF A NON-PROLIFERATION REGIME

Nuclear power technology and its use as a source for energy production, unlike other fields of industrial and technological development, is strongly linked to major considerations of national and international policies. Nuclear energy has a unique characteristic, which is that its peaceful uses are unavoidably accompanied by the production or use of large quantities of material, plutonium or in some cases highly enriched uranium, which could be used for the manufacture of nuclear explosive devices and nuclear weapons. In addition, there is also great concern that such fissionable material would be diverted and put to illegal use by terrorists or subnational groups.

These dangers caused growing concerns about the spread of nuclear technology that could lead to the proliferation of nuclear weapons production capabilities to non-nuclear weapon states through the acquisition of nuclear power plants and associated fuel facilities. These concerns have existed since the very beginning of nuclear energy and have led to the development of international mechanisms designed to control and supervise the supply of nuclear facilities and materials. An intricate network of international treaties, agreements, instruments and practices were developed to provide the framework for the supply of nuclear material, equipment and technology, at the same time ensuring the non-proliferation of weapons.

The concerns about possible weapons proliferation have always had to be balanced carefully against the expanding need for nuclear reactors, first for research but later as an essential component of energy supply in a steadily increasing number of countries. As a result, the system of agreements and treaties set up to ensure non-proliferation has in itself shown a steady evolution towards a more generally acceptable and applicable non-proliferation regime.

In 1953 the USA took the initiative in President Eisenhower's "Atoms for Peace" plan to promote the peaceful uses of nuclear energy all over the world, at the same time linking this promotion to bilateral co-operation agreements which provided for bilateral safeguards against any military use of material or equipment supplied. This policy was also applied by the USSR and other supplier countries in their bilateral co-operation agreements.

During the 1960s most bilateral safeguards on supplied material and equipment were gradually shifted to the international safeguards of the IAEA through a series of trilateral agreements. This, however, generally did not affect any of the additional
non-proliferation requirements that some supplier states had incorporated into the bilateral agreements, such as a right of prior consent before any fuel material can be moved to, e.g., reprocessing.

The possibility of a further spread of nuclear explosive capability was still seen as a major threat against world peace, and in the latter half of the 1960s negotiations were carried out under UN auspices to formulate a general treaty for non-proliferation of nuclear weapons. This Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was opened for signature on 1 July 1968 and entered into force on 5 March 1970. It has been one of the basic institutional arrangements for dealing with proliferation risks from diversion of peaceful nuclear activities to military purposes.

The successful negotiation of this important treaty gave the IAEA a new and more important role in applying safeguards than ever before. Article III of the Treaty provides for the application by the IAEA of safeguards on all source or special fissionable material in all peaceful nuclear activities within the territory of States Party to the Treaty, or under its jurisdiction or carried out under its control anywhere. A comprehensive review of the IAEA safeguards system was carried out in 1970 for the purpose of adapting it for the application to States Party to the NPT in accordance with the principles set forth in the Treaty. A new safeguards document was elaborated by the Safeguards Committee and subsequently adopted in 1971 by the Board of Governors of the IAEA. This document contains a model agreement which the States concerned are required to negotiate with the IAEA (INFCIRC/153).

One of the important elements embodied in the NPT are the provisions of Articles IV and V of the Treaty. According to these two articles, the Parties to the Treaty shall co-operate in contributing alone or together with other States or International Organizations to the further development of applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear weapon States Party to the Treaty with due consideration for the needs of developing areas of the world. Furthermore, Article V provides that States Party to the Treaty undertake to take appropriate measures to ensure that, under appropriate international observation and procedures, potential benefits from any peaceful applications of nuclear explosions will be made available to non-nuclear States Party to the Treaty on a non-discriminatory basis, and that the charge to such parties for the explosive devices used will be as low as possible and exclude any charge for research and development. These articles thus seemed to provide for comprehensive assistance by supplier States in all peaceful applications of nuclear energy, but in reality they have done but little to ease the additional non-proliferation constraints laid down in bilateral supplies.

However, it is important to bear in mind that the primary purpose and motivation for the NPT were to control the spread of nuclear weapons and nuclear weapons capabilities. States Party to the NPT, therefore, agree inter alia in Article I
that nuclear weapons States undertake not to transfer nuclear weapons or explosive
devices, nor in any way to assist, encourage or induce any non-nuclear weapon
States to manufacture or otherwise acquire a nuclear weapons capability. In
Article II it is agreed that each non-nuclear weapon State Party to the Treaty
undertakes not to acquire such capability directly or indirectly, nor to manufacture
nuclear weapons or other nuclear explosive devices.

By the end of 1980 the NPT had been ratified by 113 States including three
nuclear weapons States (United Kingdom, USSR and the USA) and the IAEA had
concluded NPT-type safeguards agreements with 78 non-nuclear weapon States,
while other such agreements were being negotiated. In addition, there was an
extensive coverage of safeguards by the IAEA through the application of the IAEA
safeguards system in 10 other non-nuclear weapon States not party to the NPT,
pursuant to their co-operation agreements with other countries. In these cases
IAEA safeguards would, however, normally be limited to materials and equipment
supplied under the bilateral agreement.

The interpretations by States Party to the NPT of Articles I and II on the
one hand and Articles IV and V on the other have been the basis of many non-
proliferation and nuclear supply policies and actions. Differences of interpretation
also led to disagreements between States. INFCE (see section 7.4) succeeded in
reducing significantly the differences of interpretation and in improving international
co-operation, while reducing possible areas of confrontation.

Another important instrument which contributes to non-proliferation
objectives is the Tlatelolco Treaty for the Prohibition of Nuclear Weapons in
Latin America. Opened for signature in February 1967, 22 States were in 1980
full Parties to the Treaty, 25 had signed and 24 had ratified it. This Treaty also
establishes a control system and requires the conclusion by each State of a safeguards
agreement with the IAEA. While proposals for other nuclear weapons free zones
of a similar nature have been made, none have so far materialized.

7.4. INTERNATIONAL SAFEGUARDS

As mentioned in section 7.3, the first safeguards were bilateral, based on
co-operation and supply agreements between countries, including provisions in
which the exporting country requested an undertaking for peaceful uses only and
also reserved the right to verify and inspect the materials and facilities supplied.

Subsequently, the administration of this safeguards function was transferred
by the supplier countries to the IAEA in accordance with the IAEA safeguards
system developed and approved by the Board of Governors and published in its
present form in document INFCIRC/66/Rev.2(1968). Safeguards application was
confined only to specified nuclear facilities and materials, and to materials and
technical assistance provided by the IAEA.
Initially, the IAEA safeguards system was confined to small and relatively non-sensitive facilities. In 1961 the first safeguards system adopted by the IAEA called for reports, records and inspections on reactors of increasing size up to a limit of only 100 MW thermal. Subsequently, however, IAEA safeguards were further developed to include all reactors without limitation on size, and extended not only to material and equipment originally supplied under safeguards but to all fissionable material produced from this material or through the use of the supplied facilities. Safeguards may now also be triggered by the transfer of certain sensitive technologies and apply to “facilities for reprocessing, enrichment or heavy-water production, utilizing technology directly transferred by the supplier or derived from transferred facilities, or major critical components thereof”.

IAEA safeguards would also apply to any such facilities constructed in the recipient country during an agreed period after the initial transfer.

Acceptance of IAEA safeguards became a condition required by most supplier countries for their bilateral assistance to supply nuclear material, equipment and facilities. For any non-nuclear weapon State the supply of a nuclear power plant and other facilities from any supplier country requires the conclusion of a co-operation agreement that includes the acceptance of the application of IAEA safeguards.

The review of the IAEA safeguards system carried out in 1970 resulted in a comprehensive system, which can be used for full-scope safeguards application in all types of facilities in a country. It was approved by the Board of Governors in 1971 and is published in the form of a model agreement under the reference number INFCIRC/153. This safeguards document contains several new concepts. It focusses the safeguards activities on material rather than facilities. It introduces the concept of material balance areas for the determination of material flow and inventory, and it defines in detail purposes and scope and limits access, frequency and intensity of inspections. It states that “the objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection”. Safeguards agreements concluded between the IAEA and non-nuclear weapon States Party to the NPT use the safeguards system as described in INFCIRC/153. Non-NPT Parties conclude safeguards agreements in accordance with INFCIRC/66/Rev.2. As the safeguards system of INFCIRC/153 will be likely to be used in most new agreements, the following description will mainly refer to this system only.

The basic concepts of the IAEA safeguards approach can be described in one word: ‘verification’. To verify means ‘to establish the truth of’. In the case of safeguards, verification is to establish the truth of statements regarding the amounts and location of nuclear material contained in records to be kept by facility operators and reports to be submitted to the IAEA by the States concerned.
The verification process can be described as consisting of three distinct functional stages:

(1) The examination of the information provided by the State in:

(a) Design information describing the safeguards relevant features of the nuclear facility
    Accounting reports stating nuclear material inventory, receipts and shipments
    Documents of amplification and clarification of reports
    Advance notification of international transfers of nuclear material.

(2) The collection of information by the IAEA through:

    Inspections for verification of design information
    Inspections to verify nuclear material inventories and to check records and reports
    Special inspections in case of unusual findings.

(3) The evaluation of the information provided by the State and collected in inspections for the purpose of determining the completeness, accuracy and validity of the information provided by the State.

The results of verifications are sent by the IAEA to the State concerned in the form of statements; if unresolvable anomalies are found, a report is made to the IAEA Board of Governors.

The most important safeguards measures on which the verification process rests are material accountancy complemented by containment and surveillance.

7.4.1. Material accountancy

In analogy to financial accounting in business, it is the purpose of nuclear material accounting to establish the quantities of nuclear material within defined environments and the change in those quantities that takes place within defined period of time, in order to detect unexplained losses which may be the result of diversion. Material accountancy refers to a collection of measurements and other determinations that enable the State and the IAEA, in verifying the State’s findings, to maintain a current picture of the location and movement of nuclear material into and out of Material Balance Areas (MBAs).

An MBA is an accounting area where all material entering or leaving is measurable and where an inventory of the material can be determined when necessary. The establishment of MBAs is done in consultation between the State
and the Agency and their designation is included in Subsidiary Arrangements, which regulate in detail the implementation of the agreement. Measurements are made at strategic points, called Key Measurement Points (KMP), which are locations where essential information of flow or inventory can be gathered and verified and at which nuclear material appears in such a form as to lend itself to such measurement.

Accountancy, in the IAEA system, consists of the initial determination of physical inventory for a facility or MBA, the perpetuation of a book inventory based on the original determination and subsequent measured inventory changes, verification and updating of the book inventory and periodic physical inventory measurements and verification, and the submission of reports to the IAEA by the States. Based on these reports, the IAEA maintains a set of accounts parallel to that of the State, and these are subject to verification and comparison with the records kept at the facility. For facilities with nuclear material in unsealed bulk form, because of the measurement uncertainties, there is usually some difference between the book inventory and the physical inventory. There may also be discrepancies for other reasons, e.g. failure to measure parts of the inventory or an unmeasured loss of material or diversion. The difference between book inventory and physical inventory is the Material Unaccounted For, abbreviated to MUF. If the size of the MUF is found to be beyond a value attributable to known uncertainties, the possibility of diversion must be investigated.

7.4.2. Containment and surveillance

A containment measure is one that takes advantage of existing structural characteristics, such as walls, containers, tanks or pipes, to establish the physical integrity of an area or item by preventing the undetected movement of nuclear material or equipment. Such measures may involve the application of tamper-indicating seals or surveillance devices to ensure that any change in the inventory within that containment will be detected. If any containment measures have been, or have to be, breached, the IAEA must normally be notified by the fastest means available. For example, if certain specific seals have been broken or compromised in any way, immediate notification is usually required, and a physical inventory of the sealed inventory may have to be verified.

Surveillance refers to both human and instrumental observation aimed at indicating the movement of nuclear material. Surveillance may involve, for example, mounting cameras or other devices at strategic points to monitor containment measures or observe inventory changes. Personnel may fulfill similar assignments from key observation points. If human surveillance by the IAEA is applied directly, the inspection access constraints as reflected in the Subsidiary Arrangements negotiated with the State would, of course, have to be observed.
IAEA containment and surveillance techniques are carefully designed and implemented to avoid imposing any additional physical restriction on the movement of or access to material, but they have to provide to the IAEA information as to whether such movement or access occurred while inspectors were not present, in order to preserve the integrity of prior measurements of nuclear material by the IAEA and to provide the IAEA with knowledge of material flows at important points in a facility.

The safeguards system given by INFCIRC/153 contains another important new concept, namely that a State would establish its own national system of accounting for and control of all nuclear material and that the IAEA shall make full use of this system in its verification activities (see also section 5.12). Training courses are provided routinely by the IAEA to assist its Member States' personnel in designing and implementing a system of accounting for and control of nuclear material.

7.5. POSSIBLE NEW APPROACHES TO RESOLVE NON-PROLIFERATION AND ASSURANCE OF SUPPLY ISSUES

The entry into force of the NPT was followed by a period of relative consensus, based on an understanding that peaceful nuclear development could take place with the risk of proliferation kept at an acceptable level under a system of international safeguards. During this period in the early and mid 1970s an increasing number of countries (including several developing countries) started nuclear power programmes, in some cases including extensive fuel cycle operations.

The NPT as well as the safeguards system of the IAEA were, nevertheless, seen by some critics as not being sufficiently comprehensive and effective. There is no doubt that the Indian nuclear explosion in 1974 contributed to this opinion, although it was carried out by the use of nuclear facilities and material that had never been placed under IAEA safeguards. The growing concerns over further proliferation led to more restrictive approaches in the non-proliferation regime. The transfer of sensitive information and the supply of nuclear material and equipment became subject to additional requirements which were manifested, e.g., in the guidelines published by the Nuclear Suppliers (London) Group in 1977, and in the US non-proliferation policy in 1977 and nuclear non-proliferation act of 1978. A major concern was that the presence of weapons-usable material in substantial quantities in a country, although applied to peaceful uses and under safeguards, could in itself increase the risk of proliferation owing to the short time that would be needed for its conversion.

These concerns and the actions taken led to the International Nuclear Fuel Cycle Evaluation (INFCE), which was proposed by the USA in October 1977, and in which more than 60 industrially advanced and developing supplier and
recipient States participated. INFCE provided a unique opportunity to discuss the issues involved in the reconciliation of the two complementary objectives of maintaining and enhancing the supply of nuclear energy and nuclear technology, and of minimizing the risks of proliferation.

The studies carried out by eight working groups, and the active discussions that took place throughout the two year period of the study within its Technical Co-ordination Committee (TCC) and Plenary Conferences, have improved understanding between supplier and recipient countries, and have provided the basis for further discussions based on mutual confidence, understanding and international consensus.

INFCE was a very complex study, which cannot be summarized in brief terms. For a full understanding reference must be made to the INFCE Summary Volume and the eight Working Group Reports, published by the IAEA in 1980.

In connection with the bilateral supply agreements between industrialized and developing countries, it was found in INFCE that experience would indicate that developing countries need arrangements of broad scope, which will not only cover the supply of equipment and materials but also give long-term assurances for the development of the necessary trained manpower and of the domestic participating industry, and for research co-operation and financing.

At the start of INFCE it was hoped that some technical measures could be identified that could reduce the risk of proliferation. It was found, however, that institutional safeguards measures are more important than technical measures.

One of the most important results of INFCE was the recognizing of the general principle that assurance of supply and assurance of non-proliferation are complementary. The institutional measures that have been proposed to improve such assurances have thus acquired special importance. No doubt, continuing consultations on both bilateral and multilateral bases would be of value. In this connection, the IAEA Board of Governors has set up a Committee on Assurances of Supply (CAS) which had its first meeting in the autumn of 1980 and follow-up meetings in 1981.

The concept of multinational nuclear fuel cycle centres has been proposed and widely discussed as a possible institutional arrangement. Based on a preliminary study carried out by the IAEA in 1975 to assess the economic benefits that might result from the establishment of regional nuclear fuel cycle centres, an expanded and detailed study project was undertaken during the period 1975—1977, and the results of this study were published by the IAEA in 1977 (STI/PUB/445). The study covered a wide range of activities involved in the back-end of the fuel cycle, including transport, storage, reprocessing, fabrication of fuel for recycling, and radioactive waste management.

In principle, any group of Member States could co-operate in the establishment of such a centre as an international undertaking, without necessarily belonging to the same geographical region. The concept would also allow the centre not to be limited to the back-end of the fuel cycle, but include some front-end activities.
The results of the studies carried out so far and the discussions of the subject indicate that there are significant technical and economic incentives for the establishment of multinational fuel cycle centres. Such centres would entail economies of cost for the participating States, improved assurances of the supply of services, and at the same time provide a promising way to reduce the possibilities of diversion and proliferation. It has, however, also to be recognized that such an international undertaking would require solutions to many legal, technology transfer, and operational problems.

There are also efforts directed towards seeking an international agreement on a regime for the storage of plutonium. Development of such arrangements, where plutonium could be only used or returned back to customer States under predetermined, uniform conditions and under international safeguards, would, no doubt, be a significant step towards reducing proliferation risks and still make plutonium available for meeting research and energy production needs.

Some specific arrangements to improve assurances of fuel supply against interruptions have also been discussed during INFCE. They include back-up arrangements, based essentially on stockpiling of fuel, a uranium emergency safety network or sharing system, and an international nuclear fuel bank.

It is clear that there are still a number of complex issues to be resolved, which include the extent to which non-proliferation aspects should be taken into account in such fuel assurance schemes, the access conditions that a recipient member should comply with, the prices to be charged for services and materials, etc. The arrangements are still at a very early stage, and only future discussions will show if any of these institutional measures can be effectively implemented.

7.6. INTERNATIONAL ASPECTS OF PHYSICAL PROTECTION

In the face of growing concern about the threat by terrorism and criminals, the physical protection of nuclear material and facilities has been attracting much international attention over the past several years. Since 1971 Member States have encouraged the IAEA to take an increasing role in the development of protection measures and guidelines. Accordingly, the IAEA issued in 1972 a set of recommendations concerning organizational and technical measures to be applied for the physical protection of nuclear material in use or storage within a State, or during national or international transport. These recommendations were updated in 1975 and 1977 and are contained in the publication "Physical Protection of Nuclear Material" (INFCIRC/225/Rev.1).

The recommendations include categorization of nuclear material in order to ensure an appropriate relationship between the material concerned and the protection measures to be taken. The categorization is based on the potential hazard of the material for misuse or for diversion to nuclear weapons. The extent
of such hazards depends on the quantity, type, physical and chemical form, and the radiation level of the material. The recommendations in INFCIRC/225/Rev.1 have been favourably received and widely recognized by Member States as helpful in the design or improvement of their national systems of physical protection. Many States have used the recommendations for guidance in the preparation of their national regulations in the field.

Although physical protection of nuclear material and facilities is primarily a matter within the domestic jurisdiction of States, there are certain issues that require agreement among States to ensure application of adequate physical protection measures to nuclear material, particularly during international transport. This has found particular expression in the adoption in October 1979 of the final text of the Convention on the Physical Protection of Nuclear Material, which sets out levels of physical protection to be applied for various categories of nuclear material in international transport, and to establish the forms of internationally agreed measures and commitments of States in the field of physical protection.

The Convention on the Physical Protection of Nuclear Material (INFCIRC/275/Rev.1) was opened for signature on 3 March 1980 at the Headquarters of the IAEA in Vienna and at the Headquarters of the United Nations in New York. The convention will enter into force when 21 States have ratified it. As of 1 November 1981 32 States and the European Atomic Energy Community (EURATOM) had signed the convention and three States had ratified it.

The Convention focuses primarily on the protection of nuclear material during international transport, although several of its articles deal with the protection of nuclear material in domestic use, storage and transport. (For the purpose of the Convention, “international nuclear transport” means “the carriage of a consignment of nuclear material by any means of transportation intended to go beyond the territory of the State where the shipment originates beginning with the departure from a facility of the shipper in that State and ending with the arrival at a facility of the receiver within the State of ultimate destination.”)

Under the Convention each party must take steps to ensure that, during international transport, nuclear material is protected at the agreed level as long as the material is within its territory or on board a ship or aircraft under its jurisdiction. Each party also agrees not to export or import nuclear material or allow its transit through its territory unless it has received assurances that the nuclear material will be protected at the agreed levels during international transport. A party also must apply the agreed level of protection to material which, during transit from one part of its territory to another, will pass through international waters or airspace. The party responsible for receiving the assurances described above must provide advance notice of the transfer to the States through whose territory the nuclear material will pass.

The parties to the Convention agree, in the event of theft, robbery or any threat thereof, to co-operate and provide assistance to any requesting State in
the protection and recovery of such material. To this extent States not party to the Convention can invoke the benefit of its co-operating provisions. For this purpose, the parties agree to inform each other, directly or through the IAEA, of their respective authorities responsible for the physical protection of nuclear material and for any response or recovery operations related to its unauthorized removal, use, or alteration.

The convention also requires parties to consult and co-operate directly, or through international organizations, in order to improve the design or maintenance of physical protection systems for international transport.

Another important component of the convention is found in Article 7, where each party is obliged to make certain acts offences under its national law and to make such offences punishable by penalties that take into account their grave nature. These include robbery, embezzlement and extortion in relation to nuclear material, and acts without lawful authority involving nuclear material that cause or are likely to cause death or serious injury to any person or substantial damage to property.

International training courses on physical protection have been organized by the IAEA since 1978 in co-operation with the Government of the United States of America. These courses are designed to establish an awareness of the need for the physical protection of nuclear facilities against the threat of radiological sabotage and theft of nuclear material, to familiarize participants who are involved in the establishment of a State system of procedures and practices in the field of physical protection, and to assist Member States in developing and implementing their systems with specific reference to organizational aspects, technical instrumentation and methodology.
PART III

STAGES OF INTRODUCTION OF NUCLEAR POWER
Chapter 8

NUCLEAR POWER PROGRAMME PLANNING

8.1. PURPOSE AND SCOPE OF A NUCLEAR POWER PLANNING STUDY

A nuclear power programme consists fundamentally of a long-term development strategy that includes a series of nuclear power projects which are planned and implemented one after the other. In addition to the study, acquisition, design, construction, commissioning and operation of each individual power plant, a nuclear power programme also includes the fuel cycle activities required for the provision of fresh fuel to the plants and the disposal of spent fuel and waste, together with the development of the necessary regulatory and supporting infrastructures and services.

Thus, a nuclear power programme becomes a major undertaking involving a great variety of activities, several organizations, large human and material resources and a substantial effort on the national level. Programme planning is a continuous activity due to the requirements of constant up-dating and adjustments to the progress in programme development and the ever-changing conditions in the country concerned.

Each country is responsible for the organization and management of its energy planning in general and electricity production in particular. Energy planning would be the responsibility of governmental authorities; electricity expansion planning might fall under the direct responsibility of a governmental authority, or it might be performed by electric utilities supervised and controlled by the government.

Whether nuclear power is considered or not, planning has to be performed in a continuous way to ensure the efficient and economic supply of energy and of electricity to the country.

When consideration is given to the possible introduction of nuclear power in the electricity generating system, the first task to be performed is a nuclear power planning study (NPPS). The primary objectives of such a planning study are:

(a) The establishment of the need for and viability of nuclear power as an alternative to other electricity generation sources
(b) The determination of the extent and schedule of the nuclear power development that might be required.

The results of the NPPS will fundamentally define the demand for nuclear power, which in turn will constitute the basis for planning the nuclear power programme activities aimed at satisfying this demand.
In a NPPS, the long-term (20 to 30 years) energy needs and the extent of meeting those needs by the available resources would be examined. A comparison of the available energy options and the merits of various expansion plans for the development of the electricity supply system would be carried out. This comparison will provide the basic elements upon which the role that nuclear power could play in the long-term energy programme would be assessed. This evaluation would include, in addition to the economic competitiveness of nuclear power with alternative energy options, a number of other factors and considerations, such as:

- Financial requirements and viability
- Assurance of the energy supply
- Influence on the country's overall economic, technical, social, and industrial development
- Effects on the society and the environment
- Disposal of radioactive waste
- National infrastructure requirements and capability
- Manpower requirements and development
- Sources and assurance of supply for nuclear power plants, nuclear fuel and fuel cycle services.

Important factors to be taken into account when defining the size and timing of the nuclear plants to be installed are:

- Compatibility with the electric system (size and stability)
- Lead times necessary for project implementation and for infrastructure development
- Commercial availability of nuclear power plants
- Cost estimates, foreign currency and financial requirements.

A nuclear power planning study is programme-oriented and therefore its scope will be long-term. A wide coverage of all relevant factors is more important than a detailed in-depth study of some particular aspects. Of course, this does not mean that detailed in-depth studies should be avoided. On the contrary, these would tend to increase the level of confidence and credibility of the results and thus facilitate the decision-making process.

The NPPS will lead to the determination of policies and strategies. Within the framework of the nuclear power programme, detailed siting and feasibility studies will be required for each nuclear power project (see Chapters 9 and 10).

The main elements to be covered in a NPPS and that will be treated in the following sections of this Chapter are:

(a) National energy market analysis (section 8.2), which includes surveys of past trends, current energy balance, energy demand by sectors, energy resources, demand forecast, supply alternatives, share of electric energy in the overall energy market;
(b) *Electricity market analysis* (section 8.3), which includes reviews of past trends and present situations of the electricity demand and supply, the study of the electricity generating system and the determination of the demand forecast;

(c) *Assessment of factors affecting the potential nuclear power programme* (section 8.4), which includes the survey of the international supply market of nuclear power plants, technology and fuel, survey of national infrastructure requirements and capabilities, siting possibilities, evaluation of benefits, disadvantages, requirements and constraints of the introduction of nuclear power;

(d) *Electricity generating system expansion planning* (section 8.5), which includes the definition of the technical, economic and financial characteristics of available options and the comparative evaluation of alternative expansion plans.

The tasks to be performed require a small but highly qualified professional team with ample experience covering a wide range of subjects, of which specific nuclear knowledge is only one. It is difficult to find professionals who satisfy completely the technical qualifications, especially in a country that is starting to plan a nuclear power programme, so the national team should be complemented by foreign advisors or consultants as needed. However, it is not advisable to delegate completely the responsibility for the performance of these studies to foreign advisors or consultants.

Nuclear power planning studies have been carried out in several countries and have provided the basis for the initiation of nuclear power programmes in a number of these countries. Well-established methodologies have been developed and are available from many sources.

The IAEA has been particularly active in assisting its Member States in this field. Since 1975 it has organized a series of international training courses on nuclear power. Especially relevant to nuclear power planning were the courses on:

- Nuclear power project planning and implementation
- Role of nuclear energy within a national energy plan
- Electric system expansion planning
- Siting for nuclear power plants
- Environmental impact assessment for nuclear power plants
- Regulation of nuclear power plants
- Nuclear fuel cycle.

Altogether some 20 courses on the above-listed subjects have been held through 1981, and approximately 600 participants from more than 40 developing Member States have been trained. In addition, a large number of IAEA fellowships, expert missions, meetings and seminars have contributed to the education and training of professionals in nuclear power, which is the objective of these efforts.

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On request, the IAEA can also perform a NPPS for a country as part of the advisory services it provides for its Member States. This would normally involve a joint national and IAEA team.

8.2. NATIONAL ENERGY MARKET ANALYSIS

The production and intensive use of energy is one of the fundamental aspects of modern civilization. The supply of energy is essential for any economic and industrial activity as well as for maintaining and improving the level and style of life of humanity. Energy is also a factor of progress and is closely related to the stage of development achieved in a country.

Whether nuclear power is considered or not, an energy market analysis should be performed and kept under constant review in any country. Relatively simple to very sophisticated methodologies have been developed and are available worldwide for such an analysis. They all involve an analysis of past trends and present situations of the energy market, a survey of energy resources and forecasts of energy demand and supply.

The results of an energy market analysis lead to the elaboration and definition of energy supply and to the development of policies and strategies for the energy sector in the country concerned.

8.2.1. Structure of the national energy market

A nuclear power programme using current technology will be directed towards electricity production (heat production could also be an objective in some instances). Its insertion into the national energy supply plan is made through the electricity share in the overall energy balance of the country. The determination of this share depends on the analysis of all the energy forms in the energy mix and the substitution possibilities between them.

If a national energy balance is not available, it should be performed as an integral part of the nuclear power planning study.

The analysis of the structure of the prevailing energy market includes the following main aspects:

(a) Final energy consumption by energy forms and sectors
(b) Primary energy production by energy sources and forms
(c) Domestic energy production, imports and exports
(d) Cost structure of energy produced and consumed.

The past evolution of the energy market should be analysed as thoroughly as is possible with the available statistical data. The objective is the determination of trends in the composition of the different energy sources, forms and costs.
8.2.2. Survey of energy resources

The national energy requirements can be fulfilled from domestic or foreign sources or a combination of both.

In principle, the use of domestic energy resources should have priority for any country, but there might be situations in which, due to economic reasons, importing is the preferred approach even if there are available domestic resources.

To be able to develop a national energy policy, a survey is needed that should provide a reasonable knowledge of the country's available and potential energy resources.

While information on the country's energy resources may be readily available, its periodic review constitutes an important part of the activities to be carried out in the nuclear power planning phase in order that alternative power generation possibilities can be fully and correctly considered. This is especially relevant for those countries that are poorly endowed with indigenous energy resources and for which nuclear power could be a key factor for sustaining or increasing economic development.

The most relevant energy resources to be surveyed are:

- Uranium
- Hydro-power
- Coal, lignite
- Oil
- Natural gas.

A general survey of other energy sources, in particular the renewable ones, such as geothermal, wind, biomass, tidal, solar, etc., should also be performed, because one or more of these might also become relevant within the period of planning.

In general, the survey of energy resources should be as complete as possible, taking into account the following main aspects:

(a) Quantity in terms of the degree of knowledge of the resources (proven, probable, possible, speculative, etc)
(b) Quality in terms of energy content and composition and characteristics affecting the environment
(c) Costs in terms of development up to its effective use, including environmental protection measures
(d) Technical feasibility of development and use.

It is difficult to evaluate the availability of energy resources for planning purposes, especially when medium and long-term planning is the objective. Proven reserves, for which the costs and the technical feasibility of development and use are known with a high degree of certainty, normally only represent a
fraction of the overall energy resources of a country. The evaluator will have
to exercise technical judgement to extrapolate from known data and make
estimates on the basis of past experience and incomplete information. The
results should be interpreted as indications of orders of magnitude, and should
be classified according to the degree of confidence.

If a country has uranium resources, the costs and technical feasibility of
their development would form a significant part of the survey.

The energy resources survey should not be carried out in isolation from the
other activities associated with the nuclear power planning phase. Indeed,
 systematic feed-in and feedback of information in relation to the evaluation of
power market/system review, potential alternatives for power generation plant,
economic review, etc. are major factors in the planning work.

8.2.3. Energy demand forecast

The forecast of energy demand constitutes the frame of reference for any
analysis regarding the composition of the energy supply development. The
method used for forecasting, the period to be covered and the purpose of the
study are related. The results obtained are obviously dependent on the data
used and criteria applied, in addition to the method adopted. Such forecasts
are usually classified according to the period they cover. Thus, they could be
grouped into the following types:

(a) Short term (1 to 5 years)
(b) Medium term (10 to 15 years)
(c) Long term (20 to 30 years)

Short-term forecasts are intended to predict the evolution of the energy
demand in the immediate future. They are of the nature of a market analysis
and are based on an evaluation of prevailing conditions and of programmes
under development.

Medium-term forecasts are intended for planning the actions that have to
be taken in the near future in order to ensure an adequate energy supply. Such
forecasts and studies are usually project-oriented and provide the background
information needed for investment decisions. The methods used for forecasting
are based on the extrapolation of the evolution during a period similar to the
period covered by the forecast, taking into account also prevailing conditions
and programmes under development.

Long-term forecasts provide the basis for supply policy and strategy decisions;
they are of a statistical nature. Past and prevailing trends and data are extrapo-
lated, usually applying correlations between growth rates of significant macro-
economic indicators, economic development programmes and energy consumption.

For the purpose of providing a basis for nuclear power planning studies,
long-term energy demand forecasts are required. These forecasts are usually
done for 'secondary energy'. The demand for primary energy is then derived from the results, taking into account losses that occur during conversion and transmission of energy.

In the case of developing countries, it is generally advised to pay great attention to the growth rates of the urban and the industrial sectors.

The validity of the forecasts lies in general not so much in whatever methodology is adopted, but in the profound knowledge of energy systems and uses, and of the macro-economic development of the country concerned.

In order to provide assistance to its Member States, the IAEA has developed a special method known as the Model for Analysis of Energy Demand (MAED). This model is used for the estimation of future final and useful energy demands. A computerized Energy and Economic Data Bank (EEDB) containing the main energy data and economic indicators of IAEA Member States has also been developed for use in this work.

The analysis of future energy demand is carried out with the MAED simulation model, with the main purpose to provide a flexible framework for exploring the influence of social, economic, technological and policy changes on the long-term evolution of energy demand. The objectives of MAED are as follows:

- To identify the major factors determining energy demand
- To provide a tool for evaluating the influence on energy demand of changes in the evolution of these factors
- To determine, by means of scenario analysis, the energy demand growth resulting from the development of various sectors of society
- To make use, in the scenario writing process, of the work of sociologists, economists and policy analysts on the future evolution of society.

The MAED approach involves the following steps:

1. A systematic analysis of the social, economic and technological system in order to identify the major factors determining the long-term energy demand evolution
2. Disaggregation of the total energy demand into a multiplicity of end-use categories. The selection of the categories to be considered depends upon the objectives pursued by the modeller and on data availability
3. Organization of all determinants into a multi-level structure, from the macro to the micro level, showing the 'macro-determinants' affect each end-use category.

8.2.4. Energy supply planning

Energy supply planning should be based on the final and primary energy demand forecasts of the country and should take into account the major constraints that could limit the development of energy supply. These include:
- Availability of national energy resources
- Availability and assurance of supply of energy resources from the international market
- Availability of conversion techniques (when needed) from primary to final forms
- Current and estimated future costs of energy (primary and final)
- Investment and financial requirements (national and foreign currency) for energy supply
- Conservation of resources.

There are many sophisticated methodologies in use for the optimization of the energy supply. Possibly more important than the choice of the methodology is the definition and evaluation of the applicable constraints and their effects.

During the past three decades the relative use of different energy sources has followed trends contrary to what seems to be a rational policy for the use and conservation of natural resources. The exception to these trends has been the use of nuclear power. Past trends are mainly results of a predominant influence of short-term economic interests. Recent events, however, assign a new and different meaning to the consideration of immediate economic benefits as a factor in the development of future energy policies. The far-reaching consequences of possible restrictions of energy supply have created an ‘energy conscience’ which will pressure governments and planners towards establishing conditions assigning priority to the assurance of an adequate energy supply. The use of available domestic resources, especially when renewable, self-sufficiency in energy supply and diversification of energy sources, all tend to increase the assurance of energy supply of a country.

In the establishment of national energy supply policies and strategies, factors and conditions that will in general promote the use of nuclear power are:

- Large and fast growing demand for electricity
- Well-developed interconnected electrical systems
- Predominant use of oil for energy supply
- Strong dependence on imported oil
- Few or distantly located (from load centres) hydro-power resources
- Poor or distantly located coal resources
- Adequate national industrial, technological and manpower infrastructures.

8.3. ELECTRICITY MARKET ANALYSIS

The objective of the electricity market analysis (demand and supply) is to provide the basis for the planning of the electric power system expansion (section 8.5).
8.3.1. Demand structure and forecast

A detailed and comprehensive survey of the structure of the consumer market and an analysis of its past development is required to establish the starting point for electricity demand forecasts.

The electric utility(ies) (or electricity authority) constitute the main source of information for the provision of the necessary database. As the objective of an electric utility is the production and commercialization of electric energy, it always has reliable and complete statistical information on its customers. This information is limited, however, to the demand that is effectively supplied by the utility.

A part of the electricity demand of the market may be supplied by communal or private generation capacity which might or might not be interconnected with the public service grid system operated by the utility(ies). This might represent a small to a substantial fraction of the overall demand according to the conditions prevailing in the country, and statistical information is generally more difficult to compile.

In addition to the demand that is effectively supplied either by the utility or by independent producers, there might be a component of the overall demand called suppressed or unsatisfied demand, which is not supplied due to a lack of sufficient generation, transmission or distribution capacity. Such situations are rare in highly industrialized countries but they frequently occur in the developing world. This component of the overall demand is difficult to estimate; the number of potential customers not connected to the distribution system and possible deficiencies of the reliability of supply (voltage or frequency variations beyond permissible limits, frequent planned or unplanned load shedding) can provide quantitative indications.

The demand structure should be analysed in detail for each sector of users (domestic, commercial, industrial, etc.) and in its geographical distribution. The most relevant aspects to be considered are:

- Electric energy consumption
- Peak power demand
- Load duration and variations (daily, monthly, seasonal)
- Transmission and distribution losses.

The data to be compiled regarding past development should cover a period of 10 to 20 years, if possible. Data for each independent electric system must be analysed separately.

Demand forecasting is the most important input for system expansion planning, because this constitutes the target for the supply. Demand forecasting is generally performed by the generating authorities or electric utilities within their own organizations on a continuing basis or periodically. A nuclear
power planning study is not expected to provide a new, independent demand forecast, but rather to make a critical review of the current forecasts.

Methods used for demand forecasting vary considerably. Depending on the particular characteristics of a given country or area served by a utility and conditions prevailing at a given time, any one or more of the following might well prove suitable:

(a) Extrapolation of past trends  
(b) Correlation between macro-economic indicators such as GNP and energy demand  
(c) Correlation to known industrial expansion programmes  
(d) Aggregation methods, i.e. analysing individual sectors of the economy  
(e) Comparison analysis which examines trends in countries or areas having similar characteristics  
(f) Establishment of targets for demand to be supplied at a future date.

8.3.2. Power system survey

The power system consists of electrical generating capacity and the transmission system. A survey of the existing system is a pre-requisite to the planning of any expansion. The purpose of this survey is to establish the basic characteristics and parameters of the existing supply system (power plants and transmission) together with any committed expansions (under construction, ordered or decided). The identification of weaknesses, problem areas or constraints is especially relevant, because these will affect the planning of future expansion, which will have to be optimized both for supplying future demand growth and for correcting deficiencies that may exist.

The survey should also include an analysis of past experience of the system expansion in particular regarding implementation schedules, costs, availability and load factors, identifying any deviations between what was originally planned and what was achieved in reality and for what reasons. This will provide a useful input for determining realistic assumptions for the future expansion alternatives.

The possibility of interconnecting independent electric systems should receive particular attention.

8.4. ASSESSMENT OF FACTORS AFFECTING THE POTENTIAL NUCLEAR POWER PROGRAMME

In the planning phase of a nuclear power programme, it is essential to consider various factors associated with nuclear power, which can strongly influence the decisions on whether or not nuclear power can be considered a viable energy option in the system expansion planning.
8.4.1. International supply market

During the first decade of worldwide nuclear power development various industrialized countries initiated their nuclear power programmes by developing the technology on their own, designing and constructing prototypes and then demonstration, industrial and commercial power plants. This approach, which involves a very large effort and requires a highly developed industrial infrastructure, was justified at that time when there was no other alternative approach available.

Since nuclear power plants became available for export, every country that initiated a nuclear power programme, whether highly industrialized or developing, has adopted the approach of importing its first nuclear unit. It is assumed that this last approach would be adopted by any country initiating its nuclear power programme in the future.

Under this assumption, the viability of initiating a nuclear power programme would be conditioned by the commercial availability of nuclear power plants in the supply market, as well as of fuel and essential materials and services beyond the capability of national production (see Chapters 2 and 3). At a later stage of its nuclear power programme a country may gradually increase its national participation, acquiring the technologies and developing its industrial infrastructure according to its needs, goals and capabilities.

8.4.2. National infrastructure

Even if the approach of importing the first nuclear power plant on a turnkey basis is adopted, there are certain minimum national infrastructure requirements to be fulfilled. In fact, a nuclear power programme could hardly exist as a lone case of advanced technology in a country with inadequate infrastructures.

The organizational, manpower, regulatory, governmental, industrial, educational and training infrastructure requirements of nuclear power programmes have been discussed in Chapter 5 of this Guidebook. These infrastructures will have to be gradually built up as the nuclear power programme evolves, but at the start of the programme some basic infrastructures are already required so that the studies and activities of the first project can proceed smoothly.

There should be a survey to establish a clear understanding of the scope, schedule and costs involved in the development efforts, as well as of the feasibility of achieving the required results taking into account the country’s prevailing possibilities and constraints.

It might happen that a lack of adequate national infrastructure and the effort and time that would be required for its development will constitute the principal constraints to the implementation of a nuclear power programme. Such constraints could effectively determine the schedule for the introduction of the first nuclear power plant.
8.4.3. Siting considerations

The identification, selection, evaluation and authorization of suitable sites for nuclear power plants require extensive studies and the consideration of a large number of factors.

In addition to those factors considered for the siting of conventional fossil-fuelled power plants, special attention has to be given to the safety aspects and environmental effects of the nuclear power plants (see Chapter 9). Sites that are adequate for the location of conventional plants may not satisfy the requirements for siting of a nuclear power plant.

Preliminary site surveys are required not only from the point of view of providing the necessary basis for site selection, but also to provide the required input to the electric power system expansion planning studies. Therefore, a reasonable number of alternatives should be identified and investigated in sufficient depth to enable preliminary decisions to be reached as to their suitability and to assess their implications.

The studies might well be carried out largely on the basis of existing data and information. Sites identified require to be categorized in order of merit (preferred sites).

In principle, it can be assumed that suitable sites can be located in any country. Site related factors might affect substantially the cost of a nuclear power plant.

8.4.4. Expected benefits and constraints

The desirability of launching a nuclear power programme should not be evaluated exclusively on the grounds of economic competitiveness with available alternative energy options. The production of electricity at a minimum cost per kW-h is certainly an important factor, but not the only one to be considered.

It is the responsibility of each country to choose and weigh the factors and aspects it will consider as relevant to its decision, and to apply them to the assessment of nuclear power within the framework of the national policies, conditions and characteristics.

Some of the main benefits and constraints that have been applied as a guidance to decision making are the following.

From the economic and financial points of view, while nuclear power could offer a lower electricity production cost than alternative sources, it will require larger investments than fossil-fired power plants. Nuclear power might require more foreign currency during construction of the plants, but once the plants start operating, less foreign currency will be required than if imported fossil fuels are necessary. The economic and financial factors are the ones relatively easy to quantify, but to weigh their relative importance, as for example
production cost benefit versus investment constraints, is much more difficult and cannot be generalized.

For the long-term assurance of energy supply and the conservation of natural resources for uses where no substitution is currently possible the benefits of nuclear power are obvious. However, assurance of supply (from foreign sources) of nuclear power plants, technology, fuel or essential materials and services have raised some concern for importing countries.

The introduction of nuclear power, subject to the scope of national participation, can have large spin-off benefits affecting the technological and industrial development of the entire country by raising the level of industrial qualifications, standards and capabilities and through the development of highly qualified manpower. A disadvantage with the introduction of a new technology is the risk of unexpected difficulties and costs, which would require substantial national efforts.

The electricity market analysis might show that available national energy resources (e.g. hydropower, coal) could well cover the needs of the country for the next two or more decades. However, if after that massive introduction of nuclear power plants would be required, it might be wise to start introducing nuclear power plants at an earlier date in order to acquire the necessary experience and to develop the necessary infrastructure.

Nuclear power has been recognized as the safest and cleanest among energy sources, but there are also risks and dissenting opinions. Opposition to nuclear power might develop and reach unexpected proportions.

8.5. ELECTRIC POWER SYSTEM EXPANSION PLANNING

The prime objective of electric utilities is the reliable supply of electric energy at the lowest possible cost, with attention to ensuring public safety and environmental protection. Electric system expansion planning is a continuous activity performed in order to achieve this prime objective.

8.5.1. Planning methodology

The traditional method of evaluating the competitiveness of nuclear power plants with fossil-fuelled plants has been to calculate generating costs for each type of plant using suitable capital, operating and fuel cost estimates along with an assumed plant load factor and cost of money. One had only to compare nuclear and fossil-fuelled units of a given size, the size being selected intuitively depending on the size of the system. Hand calculations were usually adequate for such an approach.

Such a method of power system planning now appears to be inadequate for a number of reasons:

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There is a wide choice of alternative generating units, which include hydro plants, pumped storage plants, various types of fossil-fired units, gas turbines and various types of nuclear plants; Because of the very large investments involved, the choice of optimum size of units becomes important; The position of a plant in the loading order influences its load factor, and comparisons of alternatives using the same load factor may not be valid; It is necessary from an economic standpoint to minimize total system costs taking into consideration plants that might be added over a long term; The level of system reliability and the estimated costs of energy not supplied have to be included in the analysis since these factors influence the magnitude of the most suitable capacity reserve margin.

Currently, the basic tools being used in performing system expansion planning are packages of computer programmes for the comparative economic analysis of the various alternative system expansion options. It would be impractical and time-consuming to try to perform the planning study without computers. The computer programmes and mathematical models designed to simulate the operation of the power plants in the electric system evaluate the operating costs of each plant, calculate the present-worth value of these operating costs and the capital costs associated with all plant additions during a specified study period, and determine the total present-worth value of these costs, discounted to a given year. Several plausible patterns of power expansion for the specified study period could be selected based on past trends and future constraints and the corresponding values of total present-worth costs computed to find the minimum cost configuration. The cost of the unsupplied energy due to insufficient generating capacity and/or energy is included in the economic optimization.

The methodology provides an overall electric system expansion optimization, determining optimum sizes and timing for generating plant additions, taking into account load characteristics and system reliability and economic parameters.

An example of computer programmes, which has been used in several nuclear power planning studies, is the Wien Automatic System Planning Package (WASP). Originally it was developed by the Tennessee Valley Authority and the Oak Ridge National Laboratory of the USA to meet the needs of the IAEA's “Market Survey for Nuclear Power in Developing Countries”, which was carried out in 1972 to 1973. Subsequently, the WASP programme was further developed by the Agency in 1976 (WASP-II version) and in 1980 (WASP-III) to include many improvements and extend its capabilities for carrying out nuclear power planning studies in Member States. It may be made available to Member States under special arrangements. In fact, it has already been released to some 40 countries and to five international organizations. The IAEA has also trained in its use some 120 people from 25 countries and recently (1980) published a “WASP
8.5.2. Definition of the expansion alternatives, parameters and constraints

The use of sophisticated computerized methodologies is certainly advisable for electric system expansion planning, because this saves time and effort and permits the consideration of the large number of relevant factors that are involved. It also reduces errors that might be introduced through simplifications needed in less complex methods.

The results of the study, however, depend principally on the accuracy of the input data. This cannot be emphasized enough, though it is a well-known fact. The computer time requirements to carry out a study are measured in seconds or minutes; the establishment of the input data might require several months of effort by highly qualified and experienced professionals, familiar with the national electricity system.

The required input data, which is listed in Table XXXI (see Appendix to Chapter 8), can be grouped according to different categories:

(a) Technical and economic data of the existing electric system (generation and transmission)
(b) Technical and economic data of the committed expansion of the systems
(c) Technical and economic characteristics of the alternative expansion options
(d) Demand forecast
(e) System operations practices and reliability criteria
(f) Economic ground rules and constraints.

8.5.3. System reliability and admissible unit size

The findings of the power system survey and the identification of potential sites for new power generating facilities provide the basis for the establishment and analysis of the power system network configurations. These studies evaluate load flows, transmission line requirements, voltage levels, system stability, etc.

The analysis of load flows based on system data will identify expansion required in the transmission system. Load flows will also have to be determined at times of power plant outage. The results of the load flow studies may also have a feedback effect on the selection of the preferred area for siting.

In addition to carrying out the steady state studies, the transient stability of the system should also be analysed. The system must be examined for all possible sources of electrical disturbance to ensure that synchronization can be
maintained with large plants connected to it. The system must be stable in the event of the largest plant tripping when operating at full power. In this regard, the technical characteristics of other plants in the system become critical. The plants must be able to accept sudden increased load without allowing an unacceptable fall in frequency.

In order to perform a meaningful comparison of alternative expansion programmes for an electricity system, each one must conform to the following interrelated conditions:

(a) The capacity additions in each year of the programme must satisfy a reasonable 'loss-of-load probability' (LOLP) and expected amount of unserved energy for the adopted demand forecast with due regard to maintenance schedules, forced outage rates, seasonal load variations and hydrological conditions;

(b) The transmission network must be capable of meeting the power flow requirements at any time with due regard to load distribution, power station siting, circuit and switchgear ratings and transient stability limits;

(c) The system must be capable of withstanding the sudden loss of the largest generating unit (and also its prolonged scheduled maintenance) without undue disturbance.

These conditions will determine the system reserve margins, transmission grid characteristics and requirements, and the acceptable limits of unit sizes.

Values of LOLP and the expected amount of unserved energy are important parameters in the planning study and specific values or a range of acceptable values need to be established since any specific system expansion plan is optimum only for a specific value of the LOLP and energy not served. The larger the system reliability requirements (smaller values for LOLP) the larger the reserve margins needed and the system investment costs.

Values that are regarded as acceptable for planning studies carried out in developing countries range from 0.002 to 0.01 for LOLP and US $ 1-5/kW-h for unit cost of energy not served. Although these values may be substantially higher than the acceptable values for the industrialized countries, they are considered to represent the prevailing reliability requirements for electricity systems in most developing countries. It should be emphasized that the selection of these values is difficult and therefore sensitivity studies should be done.

In the comparison and assessment of alternative system expansion plans, it is only necessary to take account of major differences in transmission requirements between one plan and another. To identify special transmission requirements, it is generally necessary to analyse the long-term development of the transmission system in each case. The normal transmission limitations encountered are thermal ratings, excessive short-circuit levels and transient stability limits and these may require special measures such as the introduction of a higher grid voltage.
The permissible disturbance to the system that can be tolerated due to the sudden loss of the largest generating unit has to be assessed within the framework of a given load shedding policy. The permissible disturbance is measured in terms of frequency and voltage deviations and grid integrity.

The complete analysis of the frequency transient and grid integrity following a sudden power change is a complex study which requires detailed information on speed governor characteristics, machine inertias, variation of load with frequency, protection relay schemes, etc. Analysis of the maintenance schedules of power plants requires also detailed information about maintenance needs and time, manpower availability, detailed load forecasts, etc. However, for the purpose of a planning study, simplified approximate methods provide sufficient accuracy. Such methods have been developed and are available.

The economy of scale plays a major role in reducing the specific cost of installed generation and this is particularly so for nuclear power generation (see Chapter 4). On the other hand, increased unit size has associated penalties in system requirements such as generation reserve capacity and upgrading of the transmission network. Thus, there exists an economic optimum size for each system for overall minimum power cost delivered to the consumer. To achieve a reasonable standard of supply reliability, the system should be capable of meeting the normal and first contingency power flow requirements without exceeding circuit thermal ratings, loss of system stability and without having recourse to load shedding. In addition, the short-circuit levels should be chosen with sufficient margins to cover system development in the foreseeable future taking into account average transmission distances, load density and the relative expected proportion of local and remote power generation.

The effects of increased generating unit size on non-availability and forced outages rates can be allowed for in the corresponding generation planning models. In this manner, the economic optimum unit size can be determined within the technical constraint of the permissible disturbance effects. In general, for relatively small or weak grids the technical constraints have a dominant influence.

The system frequency drop following the sudden loss of a large generation unit has been found of prime interest in the assessment of the technical limit. Figure 21 illustrates the relationship between the largest admissible unit size and the interconnected system peak load, with or without load shedding after the sudden loss of the largest unit. These are approximate values which should be confirmed for each system.

There are some rule-of-thumb criteria indicating the maximum unit size as a fraction (10 to 15%) of grid size or peak load. Such criteria are usually based on a degree of reliability of meeting demand which, as experience has shown, often is not met even in very large grids and which may not be required in some situations, especially in developing countries. In some cases distribution grids have also been structured so that non-essential loads, e.g. irrigation pumping
loads, can be shed if and when a generating unit drops out. It seems worthwhile to keep this possibility in mind when grids are planned.

The application of rule-of-thumb criteria is in general not recommendable for system expansion studies used for nuclear power planning. It must be recognized, however, that maximum admissible unit size is related to grid size. Hence an increase of the grid through interconnection with neighbouring networks is worthy of consideration. Besides providing potential economic advantage, exchange of power can offer improvements in system reliability and for relatively small networks such factors could become of importance. For systems with important hydroelectric components advantages can be taken from different hydrological characteristics.

For nuclear power plants commercial availability is an additional factor to be considered and this may prove to be a major constraint (see Chapter 2).

Experience has indicated another problem of some importance, i.e. the detrimental effect that the disturbances on a weak grid may have on the nuclear power plants through frequent power cyclings and stoppages forced on the plant by the grid. This emphasizes the need for careful advanced planning of the grid before any nuclear plant is introduced, whatever its size.
8.5.4. Economic optimization

An electric power system expansion planning study will include as one of its principal elements an economic optimization within the applicable constraints and reflecting the input data.

Various models can be used for the economic optimization process, including linear or dynamic programming and models classified according to the scope of optimization, i.e. simulation models, which optimize the system operation on the basis of a pre-determined investment strategy, and global models, which simultaneously optimize both the long-term strategy and the operating mode. The optimization criteria may also vary from one model to another. Some models such as WASP are based on minimum discounted costs of the expansion programme, whereas others may search maximization of the rate of return or minimization of foreign exchange expenditures, or some other economic indicator.

The aim of the electric power system expansion (economic) optimization study is to determine the least cost pattern of system expansion to meet the electricity demand over a given period. Ideally, the performance of this task would require analysing and comparing all benefits and costs, both direct and indirect, arising from alternative system development patterns, in order to determine the power expansion plan yielding maximum total net benefits. In practice, however, it is necessary to reach a compromise between practical constraints and theoretical consistency.

In the methods of minimum discounted costs it is assumed that costs rather than net benefits are the only yardstick. This is tantamount to assuming that all programmes of electric system expansion meeting projected demand with the imposed constraints on reliability offer the same total benefits, and that the least-cost programme is consequently the most advantageous for the ultimate consumers. In comparing alternative ways of producing the same commodity, as is the case of electric power, this seems to be a reasonable approach. The method, however, ignores such indirect effects as, for instance, assurance of supply different work opportunities arising from different power programmes, the effects on savings and investment, the value of acquiring a pool of skilled manpower, up-grading of local industry or the impact on the balance of payments.

Only costs directly connected with electricity production are taken into account. In particular, such external costs as those arising from environmental pollution are disregarded in the basic analysis. The imposition of strict environmental controls by industrial countries leading to higher capital and fuel costs for thermal power plants shows that ‘external’ costs may easily become ‘internal’ over time.

Costs are defined as costs to the national economy rather than costs to the electricity producers. A major consequence of this criterion is to eliminate direct taxes and duties or subsidies on all types of fuel and equipment from all cost
inputs. This, in particular, is a critical assumption in the case of countries imposing a heavy fiscal burden on some types of fuel and in particular on fuel-oil as a matter of national energy policy. Since the countries concerned are the best judges of their tax policies, which may involve items of social benefit disregarded by the study, and since the electric utilities certainly view taxes on fuel and equipment as elements of costs, alternative computations treating taxes as elements of costs can be carried out for cases that are expected to show critical differences in results.

The aggregation of domestic and foreign currency costs may be carried out using the official rates of exchange prevailing at the time the study is undertaken. It is recognized that for many countries the official exchange rates are somewhat arbitrary and do not take full account of the supply of and the demand for foreign capital. Evidence for this is the existence of foreign exchange rationing and control, and parallel markets. As this approach may substantially underestimate or overestimate the true value of the ratio of foreign to domestic costs, alternative assumptions regarding foreign currency expenditures might have to be developed and applied.

The aggregation and comparison of time flows of costs is done at their present-worth values calculated at a discount rate that is assumed to remain constant in time. In theory at least, the discount rate represents a rate of return at which money can be obtained in unlimited amounts in the national economy or, alternatively, a rate equal to the marginal rate of return of investment in the national economy.

In the present state of economic theory there is no completely satisfactory way of computing this rate on the basis of general economic data and objectives, so its estimation always contains an element of arbitrariness. To compensate for this arbitrariness, ranges can be defined and sensibility analysis applied.

Those countries that have capital constraints should use a relatively higher range of rates to reflect not only their capital scarcity but also the larger profitability of their new investment projects which compete for limited financial resources. Finally, the use of monetary units of constant value throughout the study is highly recommended, to avoid the disturbing influence of different and varying rates of inflation, which otherwise would have to be estimated and then compensated for.

APPENDIX TO CHAPTER 8

THE WIEN AUTOMATIC SYSTEM PLANNING PACKAGE (WASP)

The steps involved in an electric system expansion study using the WASP methodology are shown schematically in Figs 22 and 23. Briefly, these steps are:

1. Correlate historical data that might be used to forecast the future demand for electricity (population, gross national product, energy consumption, electricity consumption etc.)
FIG. 22. WASP input data model.
(2) Select a forecast of peak demand to be used as the basis for the study and define the shape of the load duration curves
(3) Define the characteristics of the plants in existence or committed for the electric power system being considered
(4) Define the characteristics of generating plants that might be considered as expansion alternatives
(5) Evaluate the role of indigenous energy sources such as coal, gas and hydroelectricity
(6) Define the economic data and parameters to be used
(7) Determine the approximate size of the largest generating unit that the system can accept from the standpoint of frequency stability, power system integrity and maintenance requirements
(8) Determine the optimum (minimum cost) expansion programme
(9) Determine the sensitivity of the results to variations in the economic data
(10) Estimate the financing requirements for a selected power expansion programme
(11) Check for transmission system and operational constraints
(12) Check for financial constraints
(13) Check for other constraints, e.g. lead times, infrastructure capabilities, manpower availability, etc.

The input data required for WASP are listed in Table XXXI. They are grouped according to the following categories:

(a) Technical and economic data of the existing electric system (generation and transmission). These data are obtained as a result of the power system survey (see section 8.3.2) and should be highly reliable, because there are no estimates involved.

(b) Technical and economic data of the committed expansion of the systems, i.e. generation and transmission, under construction, ordered or decided. These data are also obtained in the Power System Survey, but there are some estimates involved, in particular regarding schedules and investment costs. Estimates should be as realistic as possible; they might differ from supply commitments or conditions.

(c) Technical and economic characteristics of the alternative expansion options. The input data requirements are similar to those of the existing system and committed expansions, but all of them are necessarily estimates. Reliable technical information on fossil-fuelled thermal plants and transmission systems is normally available on the market. Estimates of construction schedules and investment costs should also be reasonably reliable, if adjusted to local conditions. The most difficult problem is the assessment of probable fossil-fuel prices over the lifetime of the plants. This requires long-term forecasting based on a set of assumptions, criteria and guesswork involving national resources (if available) and world market trends.

The consideration of national hydro-electric resources as expansion options requires extensive studies to be performed. Reliable investment cost estimates are especially difficult to obtain. Experience shows that these costs as well as project schedules tend to be underestimated.

The characteristic of the nuclear power options would in principle be defined by the prevailing and expected future availability of plants and fuel on the commercial supply market. For a country planning to introduce nuclear power it is a difficult task to assess confidently this option. Access to foreign experience and reliable advice would be needed. The IAEA is a possible source of information and provides assistance on request.

(d) Demand forecast. This has been treated in section 8.3.1. The system expansion will be planned to supply the demand forecast. Should the forecast underestimate the real development of the demand, the limited supply capacity will reduce the reliability of supply and might
### TABLE XXXI. INFORMATION REQUIREMENTS FOR AN ELECTRIC POWER SYSTEM EXPANSION STUDY USING THE WASP PROGRAMME

1. **Thermal power plants (fossil-fuelled or nuclear)**

   *For each plant in operation, under construction, ordered, decided, or to be considered as an expansion option:*

   - Identification
   - Status (in operation, construction, etc.)
   - Location
   - Date of commissioning (past or earliest possible)
   - Type of fuel
   - Fuel heat content (kcal/kg)
   - Number of units in the plant
   - Gross and net capacity (MW(e))
   - Minimum operating level (MW(e))
   - Admissible overload (% of full load)
   - Forced Outage Rate (FOR)
   - Maintenance requirements (d/a)
   - Heat rate at full load and minimum load (kcal/kW-h)
   - Total capital investment cost including financing charges
   - Construction time
   - Procedure of fuel (national or imported)
   - Fuel cost (at plant site), current and forecast
   - Fixed operation and maintenance cost ($/kW-a)
   - Variable operation and maintenance cost ($/kW-h)
   - Economic lifetime (decommissioning)

2. **Hydro-electric power plants**

   *For each plant:*

   - Identification
   - Status (in operation, under construction, ordered, decided, to be considered as an expansion option, specifying stage of study)
   - Site
   - Date of commissioning (past or earliest possible)
   - Construction time
   - Plant lifetime (years)
   - Plant type (run-of-river, seasonal storage, daily or weekly regulation, multipurpose, pump-storage)
   - Volume of the upper reservoir (GW.h)

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*a Hydrology data should be obtained for as many years as possible, or preferably, for predetermined precipitation conditions (average, dry, wet years) including the corresponding probability of occurrence.*
TABLE XXXI (cont.)

Number of generating units in each station and capacity (MW(e)) of each. Net average head (m) of the power station and maximum flow for each turbine (m³/s)
Historical or estimated gross energy generation (GW-h) - monthly, quarterly or annual
Historical water inflow conditions (m³/s) - monthly or quarterly
Historical or estimated variation of net average head (m) and capacity (MW(e)) of the station - monthly or quarterly
Operation and maintenance costs, fixed component ($/kW-a) and variable component ($/kW-h)
Total capital investment cost including financing charges

For each pumped storage plant, in addition:

Pumping power requirements (MW(e)) and pumping efficiency (%)
Generating power capacity (MW(e)) and efficiency (%)
Operation cycle including maximum feasible energy per cycle or maximum number of hours per day

3. Transmission system (interconnected)

For each existing, under construction, ordered, decided or planned transmission line:

Identification
Status (existing, under construction, etc.)
Routing
Number of lines
Voltage (kV)
Length (km)
Transmission capacity (MVA)
Date of commissioning
Total capital investment cost including financing charges

4. Electricity demand

Background information:

Past and projected population
Past and projected Gross National Product (GNP) by economic sectors (industry, mining, etc.), gross formation of the fixed capital, and other economic information of interest (main products, imports/exports, etc.)
National energy resources (hydro potential, fossil fuels, uranium, geothermal, etc.)
Past and projected total energy consumption by sectors (industrial, residential, services, etc.)
Existing plans for oil substitution, rural electrification, electric transportation, etc.

Electricity demand information:

Historical development of electricity consumption by sectors and generation by type of plant (GW-h)

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TABLE XXXI (cont.)

Historical development of annual peak load demand and of installed capacity (MW(e))
Monthly, quarterly or seasonal variation of the peak load
Load duration data (daily, monthly, quarterly, seasonal, annual)
Estimate of suppressed or unsatisfied demand (GW·h and MW(e))
Number of days of energy not served and total time of energy not served (hours)
   (i) Number of isolated systems in the country and plans for interconnection
   (ii) Interaction of systems with neighbour countries. Size of neighbour electric systems

Demand forecast:

   Period of forecast
   Basis and methodology of forecasting
   Annual electricity demand (consumption and generation) forecast (GW·h)
   Annual peak demand forecast (MW(e))
   Forecast of peak load and of load duration variation
   Participation of the industrial, residential, rural, commercial, governmental and other sectors in the electricity demand

System operating practices and reliability criteria:

   Reserve margins over system peak load or reserve in function of largest machine in operation
   Acceptable limit for the loss-of-load probability (LOLP)
   Operating practices and future considerations for loading the generating units (merit order)
   Frequency stability considerations, specifying maximum allowable frequency deviations (Hz) and load shedding practices including frequency deviation values (Hz) at which the load should be shed and the block of load shed (MW(e))

5. Economic ground rules and constraints

   Interest rate in the absence of escalation (%/a)
   Discount rate in the absence of escalation (%/a)
   Escalation rate forecast
   Present and forecasted national participation rate in construction and operation (proportion of national and foreign expenditures)
   Foreign exchange rate and penalization (if any) applicable to expenditures in foreign currency
   Purchasing price exchange rate
   Cost to be charged to unsupplied electrical energy ($/kW·h) and if possible the variation of this cost with the relative amount of unsupplied energy
   Consideration of taxes, duties or subsidies
   Policy for the use of renewable resources
   Policy for the preferential use of national resources or certain types of fuel
   Economic or financial constraints
   Infrastructure development constraints
even be the cause of suppressed demand or rationing of supply. Should the forecast overestimate the real demand growth, there will be temporary idle capacity and premature investment.

The aim of the forecaster is to be as realistic as possible, avoiding both underestimates and overestimates. However, for a country with an unsatisfactory electricity supply capacity and suppressed or hidden demand, a generous approach to demand forecasting seems to be more desirable than an overly conservative one. Constraints on the availability of capital, on the other hand, tend to promote a conservative approach for demand forecasting.

(e) **System operations practices and reliability criteria.** If prevailing practices regarding reserve margins, system stability, load shedding, maintenance outages, loading order, etc. are satisfactory, then they can be maintained as the basis for the definition of reliability criteria of the system expansion. If they are not considered satisfactory, then appropriate modifications should be planned and a system reliability target defined, which fundamentally consists of determining the acceptable limit for the loss-of-load probability (LOLP).

No doubt, reliability of the supply of electricity is of prime importance, but it should also be realized that the achievement of high reliability is expensive. Consequently, the reliability targets should be reasonable, taking into account the country's real needs and constraints. Section 8.5.3 contains more information on this subject.

(f) **Economic ground rules and constraints.** To be able to proceed with an economic optimization of the system expansion, certain economic ground rules will have to be defined. These should conform to the country's overall economic and financial situation and development prospects, and to the national energy and electricity supply market. The principal parameters are the interest and discount rates to be used, the value assigned to foreign currency expenditures and the cost to be charged to unsupplied electricity.

Practically any type of technical or economic restriction or constraint can be introduced into the system expansion study. Such constraints are usually the results of national policy and strategy decisions, or the consequences of national infrastructure capabilities and development potential. They are difficult to define and might affect the results in opposing ways. To analyze their effect on the results, they can also be treated as inputs for sensibility studies.
Chapter 9

SITING OF NUCLEAR POWER PLANTS

9.1. INTRODUCTION

An important stage in the development of a nuclear power project is the selection of a suitable site and the study of this site to establish the site-related design inputs for the plant. The selection of a suitable site is the result of a process in which the cost, the impact to the environment and the risk to the population are minimized.

The purpose of the power plant is to provide economic electric power, therefore in general:

(a) The distance from the plant to the centre of consumption of electric power should be small
(b) A feasible cooling system should permit the efficient discharge of heat from the plant.

A good site should also minimize the plant’s impact on the environment. A large power plant will certainly affect the environment through the heat rejected and may affect it through radioactive releases. However, with the careful selection of an appropriate site location and a good plant design, this impact could be reduced to an appropriate level. It is important that the large amount of rejected heat has no significant adverse effects on the species present in the aquatic environment into which the heat is discharged, or if cooling towers are used, their possible effects on the microclimate should remain within tolerable limits. It is also necessary to minimize the potential radioactive releases.

A site is considered acceptable from the safety point of view if:

(a) It cannot be affected by phenomena against which protection through the design is impracticable;
(b) The probability of occurrence and the severity of destructive phenomena against which the plant can be protected (at reasonable additional cost) are not too high;
(c) The site characteristics (population distribution, meteorology, hydrology etc.) are such that the consequences of potential accidents would be within acceptable limits.

Briefly, the activities related to siting of a nuclear power project consist of the following two main stages:
(1) **Site survey:** The purpose of the site survey is to identify one or more sites that are likely to be suitable (preferred sites). This involves general studies and investigations of a large region to eliminate unacceptable areas. This is then followed by systematic analysis and comparison of the remaining areas, defining potential sites and finally selecting the preferred sites.

(2) **Site evaluation:** The purpose of this stage, which might also be called site qualification, is to demonstrate that the preferred sites are acceptable from all aspects, and in particular from the safety point of view. The site-related design inputs are evaluated before the start of the construction.

After the start of construction and prior to start of plant operation, additional studies and site investigations are performed, to complete and refine the assessment of site characteristics, as needed for plant operation, and in particular for developing emergency plans for the case of potential accidents.

The process of siting large industrial plants has now reached a high degree of sophistication, and a multi-disciplinary methodology has been developed for performing site studies. The subject of this chapter is to introduce the main concepts of the various siting techniques, particularly for application to the siting of a nuclear power plant.

### 9.2. NUCLEAR POWER PLANT SITE CHARACTERISTICS AND REQUIREMENTS

The main site characteristics and requirements to be considered are:

- Engineering characteristics and requirements
- Safety-related characteristics defining the effects of natural site-related phenomena on the plant (e.g. earthquake, flooding)
- Safety-related characteristics influencing the impact of the plant on the site (e.g. population distribution, dispersion in air and water)
- Environmental aspects.

Other characteristics related to socio-economic or cultural aspects will be only briefly mentioned. The socio-economic aspects include effects on the availability of local services (e.g. housing, schools) due to the construction and operating personnel; and the cultural impact can include effects resulting from the construction of the plant on the archaeological or aesthetic conditions of the area around the site.

For each of the above characteristics some indication is given of the relevant procedures to be used at the site survey stage, when several proposed sites are selected, and at the site evaluation stage, when the characteristics of a particular site are assessed in detail.
9.2.1. Engineering characteristics and requirements

There are two basic engineering requirements to be considered for siting of a nuclear power plant, namely:

Integration to the electrical system
Cooling water supplies.

A nuclear power plant, as any electric power plant, needs to be as close as possible to load centres in order to economize on electricity transmission costs and to reduce power losses. The information needed to consider this factor is load forecast data, together with data on expected development of industry and population in each region of the country. Detailed knowledge of the electricity generation and transmission system is also needed to analyse the integration of the plant to the electrical grid. The distance between load centres and possible sites is the first important factor to be considered in the siting survey.

The nuclear power plant requires adequate and reliable startup power, which is another factor needing consideration. If suitable electrical power cannot be supplied to the site from the existing network, an appropriate generating plant for startup purposes may be required, at extra cost. Adequate electrical power for the construction period must also be available.

The availability of an adequate supply of water for cooling purposes is another primary consideration in siting. In addition, water quality and temperature are also to be considered. The quantity of water required will depend mainly upon the system of cooling adopted (once-through cooling or recirculation with cooling towers and/or cooling ponds), the heat output of the plant to be dissipated, and the ambiental conditions. As an example, a plant of 1000 MW(e) capacity may require roughly about 100 m$^3$/s of water for a cooling system of the once-through type and a temperature drop in the condensers of about 8$^\circ$C. If recirculation (wet cooling towers, ponds, etc.) is adopted, the amount of water make-up required is about 2–5% of the above quantity. Regarding quality, silt content and chemical impurities are relevant. Too high temperatures affect negatively the plant efficiency (see also section 6.7.1).

Data on the water sources (e.g. rivers, canals, reservoirs or the sea), such as their supply potential, committed uses if any, and reliability, are collected. The suitability of the site is evaluated taking into account that the amount of water supplied to the plant should be a small portion of the total minimum available supply.

Maps of sources of cooling water should be prepared if not available. Water sources located far from the site involve economic penalties and may influence the reliability of the supply. Physical features at the site that reduce pumping power or separate the warm water plume from the intake (e.g. steep slope in the
sited, or protruding land mass) are economically advantageous and hence should be sought.

There are a number of other engineering requirements. Adequate communication links should be available at the site. Transportation routes are necessary for conveying the large and heavy equipment of the nuclear power plant to the site. In this context, the existing and planned roads, waterways and railroads have to be studied with respect to adequacy for the sizes and weights of the plant equipment to be transported from the manufacturing plants or from the port of entry into the country.

The extent of work necessary for site preparation and, later on, for construction is a relevant factor in a site survey, where these aspects are usually evaluated through the analysis of topographic maps. Site cleaning or levelling, foundation works, and water intake and outlet structures are the main aspects to be analysed in a preliminary way. During the site evaluation phase these as well as other relevant aspects such as site infrastructure, local labour market etc. require an in-depth study. Most of these aspects and factors are similar for all thermal power plants, nuclear or fossil-fired.

Since foundations and cooling-water structures can be very expensive, sites with unfavourable characteristics related to these two aspects in particular should in principle be avoided.

9.2.2. Effects of the site on the plant

The effects of the site on the plant include all environmental phenomena and man-induced events that may affect the safety and reliability of the plant, such as earthquakes, flooding, extreme meteorological events, air crashes and explosions.

As a result of the study of these characteristics, a site may be eliminated because of a significant probability of occurrence of extreme events against which, with the present-day technology, it is not possible to protect the plant. Examples of such extreme events are displacement of the ground due to a capable fault, collapse of the ground due to major cavities, etc.

Design bases are determined (design input data and parameters) for other extreme events against which it is possible to protect the plant. These define, in engineering terms, the effects against which measures must be taken when designing the plant (see also section 9.2.4).

9.2.2.1. Geological characteristics

Under geological characteristics are included those features that determine the potential risk for the plant being affected by important destructive phenomena, such as surface faulting, volcanic eruption, ground subsidence, etc.
The main phenomenon to be considered is surface faulting. Surface faulting is a displacement of the ground that occurs during very severe earthquakes, along the faults generating the earthquakes (capable faults). Such displacements may reach values of several metres.

It is very difficult to design the plant against these phenomena, so that the practical solution is to select a site that is not affected by them. To be able to do this, it is necessary to study carefully the geology of the whole region, in particular the neotectonics (the geological change that occurred during the Quaternary period).

From this study the regional faults that may generate important displacements are identified. Usually, the areas around these faults are considered as not suitable for a nuclear power plant site. When the site is selected, studies have to be performed to ensure that capable faults of lesser dimensions do not affect the site.

Studies are to be carried out to indicate the absence of significant capable faults at or near the potential sites. If capable faults are present and if it is decided to continue the study of the site, it becomes necessary to describe the direction, extent and history of their movements, and to estimate the age of the most recent movements with the hope that it can be demonstrated that these are old enough to be acceptable.

All linear topographical features shown on aerial photographs or by remote sensing devices are investigated in sufficient detail to explain their cause or to establish lack of geological cause. In some situations this may require detailed geological and geophysical studies at points remote from the site area. Very sophisticated and expensive techniques exist for assessing the age of the last movement of a fault. Some examples are: structural superposition (a geological structure of known age lying over the fault is not disturbed); stratigraphic superposition (strata of known age laying over the fault are not disturbed); and isotopic geochronological methods (based on dating undisturbed material on the fault with radioisotope techniques). The use of one or more of these methods may be applicable to a particular site. It is desirable to use diverse techniques as a cross-check to improve reliability.

Another phenomenon to be considered is subsidence, regarding which investigations have to be performed to determine its potential at the site area. The existence in the site vicinity of a thick groundwater aquifer used over years, of extraction of hydrocarbon deposits, and of mining activities may indicate a potential for subsidence. If an important subsidence is expected during the lifetime of the plant, the site is usually considered unsuitable.

The possibility of collapse in the site area may also pose a serious risk to the stability of foundations and the integrity of structures. Such a risk of collapse may be posed if the following are present in the site vicinity:

Cavernous or karstic terrains (subsurface voids caused by dissolution and transport of soluble subsurface materials)
Man-made underground works.
If the investigations cannot exclude this risk of collapse of the site, it should be considered unsuitable.

9.2.2.2. Seismology

Another important phenomenon that has to be taken into account in siting is ground shaking due to earthquakes.

In principle, it is considered possible to design the plant to withstand the ground shaking, if the subsurface material of the site is suitable (liquefaction or differential settlement can be excluded). However, the seismic design for values above approximately 0.2 g is very expensive and the cost increases more than linearly with the severity of the ground shaking. For this reason, sites are preferred where the ground motion against which the plant has to be protected (design basis earthquake) is less severe. This is considered at the site survey stage using seismic risk maps or, for highly seismic countries, by developing a seismotectonic study of the region, so that a preliminary value of the maximum potential ground motion may be evaluated for each potential site.

The elements for determining the design basis earthquakes are:

(a) A collection of historical data on past earthquakes, and instrumental data referring to more recent times
(b) A complete study of the seismotectonics of the region, to identify the structure causing these earthquakes.

For the definition of the design basis earthquake (ground motion), two methods are being discussed currently: the ‘deterministic’ and the ‘probabilistic’ methods. Both methods use models for the seismicity of the region based on a study of the seismotectonic structures and province. For each province the seismotectonic structures are identified and for each structure the related maximum potential earthquake evaluated. This will be the extrapolation of all the past earthquakes that can be associated with the given seismotectonic structures. However, other historical earthquakes that could not be associated with known structures may exist. Therefore, a maximum potential earthquake in the province not associated with seismotectonic structures must be identified and taken into account. This is sometimes called the ‘floating earthquake’.

For evaluating the design basis event in the deterministic method, the ground motion limit for the site is identified and the hypothesis is made that the maximum potential earthquake associated with seismotectonic structures occurs along these structures at the point nearest to the site. The probable maximum vibratory ground motion on the site is then evaluated by a proper attenuation of the maximum earthquake motion propagating from the seismotectonic structure to the site. With floating earthquakes the maximum ground shaking occurs when the earthquake
epicentre is located in the immediate vicinity of the site; the related vibratory
ground motion represents another input.

In the probabilistic method the same seismotectonic model is used, but
appropriate stochastic source terms are considered for each element of the
seismotectonic structures in an area of the tectonic provinces. These source terms
represent the frequency with which earthquakes of given magnitudes may be
generated on each element of the seismotectonic structures in an area of the
provinces. For each of these earthquakes the ground motion at the site is calculated.
All these contributions may be integrated for the site to obtain a graph giving the
value of the ground motion parameter (e.g. ground acceleration or velocity) as a
function of its probability of not being exceeded. In these integrations the
uncertainty in the evaluation of the maximum magnitude, of the focal depth, and
of the attenuation law is taken into account.

9.2.2.3. Volcanism

In volcanic regions, volcanism has to be taken into account in siting, because
the nuclear power plant may be affected by phenomena such as:

- Burning clouds
- Ash falls
- Lava flows
- Ground shaking.

It is possible to protect the plant against some of the phenomena, such as ash
fall and ground shaking. The only protection against burning clouds and lava flows
is distance. Consequently, the site has to be located at a sufficient distance from
the active volcanoes, to ensure that the plant is safe from these last effects.

For protecting the site against phenomena such as ash fall and ground shaking
design bases are evaluated. The evaluation of these design bases may be performed
by studying the characteristics of the volcano near the site and extrapolating the
effects of historical eruptions from existing volcanoes similar in characteristics to
the one under examination. In these evaluations it is frequently difficult to assess
if a particular volcano has to be considered completely inactive or potentially
active. This can be done by evaluating the age of the lava beds of past eruptions.

9.2.2.4. Flooding

The nuclear power plant has to be protected from the static and dynamic
effects of flooding, therefore an appropriate design basis flood has to be evaluated
for the site. In principle, the site should not be in areas where the flood hazard
is severe.
A nuclear power plant on a river site has to be protected against floods due to precipitation and floods due to failure of water-controlling structures (dam collapse). At the start of the site survey usually maps showing historical floods in the region are used to identify the areas which were particularly affected by floods in the past. At later stages, on the basis of flood levels evaluated with simplified and empirical methods, the sites less affected by floods may be identified. A design basis flood has to be determined at the stage of site evaluation.

The probability used in some countries for defining the design basis flood is lower than \(10^{-4}/a\). Statistical methods to determine floods with such a low probability of occurrence present a great degree of uncertainty. Therefore, the method used mostly is deterministic and is based on the evaluation of the maximum probable precipitation of the basin, and on the unit hydrograph technique for evaluating the mass flow and the level of the river that are produced by the maximum probable precipitation.

The maximum probable precipitation of the basin approximates the maximum that is physically possible for the region. It is evaluated from the historical data of precipitation over the drainage basin and in the meteorological homogeneous region that includes it. The assessment starts by selecting a model for the storm, then the values for humidity. Extension and location of the storm are extrapolated in such a way as to generate the probable maximum precipitation.

The most widely used method for evaluating the runoff is the unit hydrograph. This represents the mass flow of the river resulting from a unit rainfall excess (precipitation less losses) distributed over the basin. It is normally derived from a proper extrapolation of records of the flood on the river. Having obtained the design basis mass flow from the maximum probable precipitation, the maximum level of the water is evaluated with the usual methods of hydrology, taking into account the status of the basin before the maximum probable precipitation fall and a proper combination of waves generated by the wind and other phenomena affecting this level, such as tides in estuaries. The nuclear power plant on a coastal site has to be protected against surges, tsunamis, and wind-generated waves.

At the site survey stage the area along the coast most adversely affected by surges, tsunamis or extreme wind-produced waves is identified, and the most suitable coastal sites selected on the basis of historical information. This may be relatively easy for surges and wind-generated waves, which are relatively frequent phenomena, but more difficult for tsunamis, which are a more rare phenomenon. If a coastal site is selected for qualification, an evaluation of the design basis surge, tsunami and wind wave has to be performed.

Usually a deterministic method is adopted. It consists in the evaluation of a probable maximum storm for the surge, a probable maximum earthquake for the tsunami and an extreme wind for the waves. With a complex hydrodynamic model using as input the storm, the seabed movement or the extreme wind, the effect of these phenomena on the shore may be evaluated.
9.2.2.5. Potential effects of man-induced events

Certain installations that handle dangerous materials, and certain activities such as air traffic may represent risks for a nearby site through chemical explosion, drifting of poisonous or explosive gas mixture, or air crashes. The region is investigated to identify installations and human activities to ensure that the site of the nuclear power plant is not within dangerous distance. A distance of several kilometres is usually sufficiently safe.

Among the sources of man-induced events to be identified, the main ones are:

(a) Installations that handle, process, and store hazardous materials such as explosive, flammable, corrosive, toxic or radioactive materials
(b) Pipelines for hazardous products
(c) Mines and quarries that use and store explosives
(d) Airports and their take-off and landing strips, and holding patterns; in some cases also air traffic routes
(e) Sea or inland waterways or ports
(f) Military installations that handle, store and use hazardous materials and may be associated with hazardous activities.

If the risk of man-induced events is high, the plant has to be properly protected. Today, techniques exist for protecting the plant against most of these man-induced events, but the protection of the plant through design measures may be very expensive. Usually, a more practical solution is to avoid sites affected by severe man-induced events.

For particular situations where it is not possible to select a site unaffected by man-induced events the related design basis has to be determined during the site evaluation stage. For this a probabilistic approach is usually followed. The basis of this approach is that if the probability of occurrence of an event that may cause important damage to the plant is less than a particular value (in some countries, in the range of $10^{-6}$ to $10^{-7}$ per year) no special protective measures are needed. If, on the contrary, the probability is higher, the plant must be protected.

9.2.3. Impact of the plant on the site

The study of the factors related to the potential impact of the plant on the site results in the determination of the consequences of potential accidents and normal releases. It deals mainly with the effects on the population in the site area or region.
9.2.3.1. Population distribution

The criteria for evaluating the suitability of the population distribution around a site are difficult to establish. They differ from country to country. Many factors play a role in the assessment, in addition to the characteristics of the reactor and of the site. Especially relevant are the overall population density of the region, the general level of socio-economical development, and the transportation and communication systems (important in an emergency).

The general concept is that the population distribution around a nuclear power plant should be such as to allow a workable emergency plan to be established. In the event of an accident, the population within a certain distance around the plant (in the sector of prevailing wind direction) could be affected; therefore, the main variables for the analysis of the population distribution are:

(a) The number of people within circles centred on the plant and of increasing radii
(b) The number of people within segments of sectors centred on the plant, having an angle of 20° to 30° and limited by increasing radii
(c) The population in these areas that cannot be easily evacuated, such as: hospitals, schools, etc.
(d) Transient populations such as vacationers, etc. that in particular periods can be in the plant’s vicinity.

A number of methods have been adopted and used for evaluating and comparing sites. All these methods compare the weighted values of the population per sector and radii of different sites with respect to each other or with certain standard curves. The weights allow more relevance to be given to people who are near the plant and who would receive a higher dose in a shorter time. It would be difficult to put an emergency plan into action if a large number of people have to be evacuated in a short time.

In most countries the exclusion area around the plant is 0.5 to 1 km or more. Within this exclusion area the public’s access is controlled and permanent residence is not allowed. Outside this exclusion area and within several kilometres from the plant the population could be affected by accidents occurring at the plant. The probability that accidental releases affect this area is very low, but as an additional safety measure an emergency plan is prepared. Therefore, the number of people within this area should be such as to allow the preparation of a workable emergency plan.

At the site survey stage this factor should be taken into account by establishing a preference for areas of low population density, and for sites at a considerable distance from main towns.

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9.2.3.2. Radioactive release

The radioactivity released from the plant in normal and accidental conditions should be evaluated (guidelines exist for this). On the basis of population distribution, the radiation doses may be calculated and their acceptability assessed. For this reason it is necessary to take into account the site characteristics regarding dispersion of radioactivity in the atmosphere and in surface and groundwater. It can then be established whether the engineering safety features of the plant are adequate for the population distribution around the plant.

The studies during the site survey stage are directed towards avoiding locations where the dispersion conditions are unfavourable. During the site evaluation phase the studies become more refined. They evaluate more precisely the dispersion characteristics of the site under various conditions in order to be able to assess in the preliminary safety report the impact of radioactive releases and to have information available for the preparation of the emergency plan.

The region around the site should not present adverse atmospheric dispersion characteristics. Sites located in closed populated valleys or on shores facing densely populated islands are in principle to be avoided.

To perform the assessment during site evaluation, an appropriate model for the diffusion of airborne material at the site has to be developed and the necessary basic data collected. For defining the dispersion characteristics to be included in the safety report, usually, a meteorological tower is built, which should be somewhat higher than possible release points. At various heights of this tower wind speed and direction and temperature gradients are measured. At least one year’s data are necessary for evaluating the site atmospheric diffusion characteristics.

To evaluate the possible impact of the plant regarding release in the hydrosphere, the water uses near the plant have to be analysed and the characteristics of the site for dispersion of radioactive material in water have to be assessed.

Information has to be collected on the uses of both surface and of groundwater. Particular attention has to be given to open reservoirs or water ducts, to wells, and to industrial uses of water. Sites in the immediate proximity of large reservoirs of water ducts for which no alternative sources of water exist are not suitable for nuclear power plants. Research and investigation are required to evaluate a suitable model for dispersion in surface and groundwater.

9.2.4. Impact of extreme events

The extreme events that have relevance for the design of nuclear power plants are the natural extreme events and the man-induced extreme events that could damage the plant if it is not properly protected. Natural extreme events are disastrous natural phenomena, such as tornadoes, earthquakes, surges, floods, etc.
Extreme man-induced events are disastrous events produced by activities of man, such as air crashes, chemical explosions, drifting explosive clouds etc.

A nuclear power plant has to be protected against any disastrous events that have a high enough probability of occurring. A practical solution of the problem is to evaluate for each type of event two levels of severity, the expected events and the limit events.

The expected events are those that are expected to occur at least once during the lifetime of the plant; they are also called ‘operating events’ because usually the plant is designed to withstand them and continue in operation. Such events are, for instance, the operating earthquake, or the operating wind.

The limit events, also called ‘probable maximum events’, represent either the physical limits of the phenomena, or events of very low probability. The plant must be able to withstand these events without large radioactive releases. The value of the probability is selected (according to the IAEA code on siting) on the basis of the equivalence of the risk for accidents of internal and of external origin. This means that the risk to the environment from accidents originated in the plant by external events should not be higher than the risk derived from accidents in the plant of internal origin.

The design of the plant against expected events differs from the design against limit events. For expected events the structures, systems and components must remain operational, and normally allowed stresses should not be exceeded. For the limit event the structures, systems and components should perform only the intended safety function, and limit stresses for extreme conditions should not be exceeded.

Expected events are usually evaluated by processing the data using statistical analysis techniques. These consist of collecting the data, selecting an appropriate probability distribution law, and deriving a curve giving the values of the severity of the event as a function of the related probability. Adopting an acceptable probability, the design basis expected event is then defined. This procedure is feasible for expected events because only a relatively small extrapolation of the historical data is required.

The following procedure is usually followed for defining a probable maximum event:

(a) A model for the event is selected which is a function of one or more variables (e.g. earthquake of a certain magnitude, along a given fault location, generates a given ground shaking at the site)

(b) A probable maximum event is identified:
   (i) Either on the basis of the physical limit of the variables appearing in the model, with the deterministic approach (e.g. probable maximum earthquake on the fault at the nearest place to the site generates the probable maximum ground motion at the site);
(ii) Or with the probabilistic approach, on the basis of only such values that correspond to a probability of occurrence above a defined very low limit (e.g. ground motion that has a probability of occurrence less than $10^{-4}$/a is excluded).

Methods that include a combination of deterministic and probabilistic considerations are also used, and are called combined approaches.

It is very difficult to evaluate the design basis events. In the definition of the reasonable limits it is easy to exaggerate and to determine values that are far too conservative and expensive for the design. It is also possible to underestimate and to define values that are not severe enough. The knowledge and experience of experts are the dominant considerations. The procedure is never automatic and considerable expertise and engineering judgement are necessary. It is essential to collect data and to compare the values arrived at with historical data, as well as with extrapolations based on statistical analysis.

9.2.5. Environmental considerations

The construction and operation of a power plant of any type (nuclear, fossil-fired or hydraulic), as well as any large industrial installation, will affect the environment.

The impact on the aquatic environment is due to the local increase in temperature and possible changes in salinity to which the aquatic organisms of the cooling water source are subjected. Aquatic organisms in water bodies on or near the site may also be affected due to dredging and clearing of vegetation.

The largest impact on the terrestrial environment occurs during the clearing of terrain for construction of plant facilities. Other construction and operational activities may generate noise, dust, and emissions of biocides.

If cooling towers are used, their effect on the microclimate conditions of the surroundings (humidity, visibility, fogging, icing and diffusion) as well as the effect of climatic conditions on the operation of the cooling towers have to be evaluated. In addition, the effects of deposits on agricultural land should also be considered.

The existing and planned land use in the site area such as agriculture, recreational facilities, tourism are also to be taken into account.

9.2.6. Socio-economical and cultural aspects

The construction and operation of a power plant involves several non-safety related factors that influence local population. In areas of high unemployment a power plant may generate a significant number of jobs during the construction phase. On the other hand, the work force associated with the plant may also
place demands upon local infrastructure resources (housing, schools, community). It is desirable that possible adverse social impacts of the plant are minimized and social benefits are enhanced.

The construction and operation of a power plant also generate traffic causing noise, and visual effects which may disturb some local residents. It can also disturb or limit the access to important archaeological remains if there are any, and it may modify the landscape in a way that local communities might not like. Usually, acceptable solutions may be found in all these cases.

9.3. SITE SURVEY STAGE

The objective of a site survey is the identification in a region of interest of one or more preferred sites that have a high probability of being suitable for the installation of a nuclear power plant. The region should be large enough to give sufficient options for the site selection, so that if the site survey is conducted in a rational and systematic manner, the preferred sites obtained would be among the best that could reasonably be identified in that region.

All site characteristics that could affect the suitability of a site should be considered in the site survey. These have been presented and briefly discussed in section 9.2.

9.3.1. Procedure and methodology

The site survey may be divided into the following phases:

- Phase 1: Regional analysis and identification of potential sites
- Phase 2: Screening of potential sites and selection of candidate sites
- Phase 3: Comparison of candidate sites.

In each of these phases those relevant site characteristics are considered that may lead to the rejection of unacceptable areas or sites, and to the identification of the more suitable ones. The details of the data required and the complexity and sophistication of the selection processes increase as the site survey advances towards its goal of selecting preferred sites. It must be recognized that the quantity and quality of information to be collected during the various phases vary in relation to the site characteristic under consideration.

It is necessary to establish for each region:

- The characteristics to be considered at each phase
- The criteria for rejecting areas and sites
- The criteria for assigning a weighting factor to each characteristic of the sites
- The comparison methodologies.
The main safety requirements that have to be satisfied during a site survey are that all safety characteristics should have been considered at least once, and that the suitability of the site from the point of view of each safety-related factor is confirmed in the last phase.

Two approaches may be followed in performing a site survey: a ‘parallel approach’ or a ‘series approach’. In the parallel approach, all the necessary information is collected for all areas and sites. In the series approach, all the necessary information is only collected for areas and sites not rejected previously. The advantage of the parallel approach is that it is not necessary to await the result of the rejection process before proceeding with the collection of additional information; the advantage of the series approach is that the amount of work involved is smaller. In general, the parallel approach is adopted in site surveys, and this will be described in the following paragraphs.

Phase 1 — Regional analysis and selection of potential sites

In the regional analysis available information on certain site characteristics is used to reject major areas of the region from further consideration. The region of interest is usually very large and a detailed survey of every part cannot be performed, nor is it necessary. The site characteristics elected for the regional analysis are preferably ones for which information is readily available and for which simple rejection criteria may be adopted (such as cooling-water availability, electric load and transmission considerations, access, population density, surface faulting, topography, vulcanism and seismicity). Much of the information needed for the characteristics selected for the regional analysis are already available or easily obtained from maps, census data, existing geological and seismic data or cursory surveys of the region.

The results of the regional analysis is the delineation of the areas that have not been rejected within the region of interest. Within these areas, sites of a few square kilometres are identified as ‘potential sites’. These potential sites are somewhat larger than required for a power plant site so that during a later stage of the siting process the exact plant location can easily be accommodated therein. The identification of these potential sites in the areas that are not rejected by the regional analysis may be accomplished by the application of good technical judgement. The overall objective is to obtain a set of potential sites that include a complete representation of the different areas of the region, so that the selection process may proceed in a comprehensive manner. A considerable number of potential sites (10 to 15) will usually result from the process, although smaller or greater numbers are also possible.
Phase 2 — Screening of potential sites and selection of candidate sites

The potential sites are screened using site characteristics not considered in the regional analysis, and more refined criteria than those that were adopted for the previous phase. It will not be economically or technically feasible nor is it necessary to make an in-depth study of all site characteristics of all potential sites. Some potential sites may be readily rejected on the basis of site characteristics for which sufficient information can be readily determined. It should be understood that at this phase one deals with sites, while in the preceding phase areas were dealt with. Therefore, certain characteristics such as foundation conditions or cooling-water structures can be taken into account at this stage for excluding less suitable sites. Visits to potential sites and elementary site examination may provide useful information for this purpose.

Further screening of potential sites may be accomplished using simplified techniques of suitability scaling and comparison methodologies. This screening phase results in a more manageable number (less than 10) of ‘candidate sites’.

Phase 3 — Comparison of candidate sites

The comparison of candidate sites is performed on the basis of more detailed information and a limited amount of field work. All the characteristics of candidate sites that were taken into account in the previous phases have to be confirmed. It should be feasible, owing to the limited number of sites in this phase, to gather detailed information on the characteristics of the candidate sites, and to use sophisticated scaling and comparison techniques.

Since this is the last phase of the site survey, a check should be made to ensure that no relevant safety-related site characteristics have been overlooked.

The analysis should be well documented since it will be required for the subsequent stage of site evaluation.

At the conclusion of this phase the remaining candidate sites are ranked according to preference and a complete report on the entire site survey is prepared. The final site selection invariably involves judgements based on safety, economics, environmental and other considerations.

9.3.2. Organization and management

The direct responsibility for the site survey usually lies with the organization responsible for the nuclear power project (electrical utility). A review by the regulatory body of the results of the site survey is normally required.

The responsible organization may choose to perform the site survey with its own staff (assisted or not by outside experts or consultants), or it may assign the whole effort to a contractor. Frequently, in the case of a first nuclear power plant,
the site survey contract is assigned to foreign companies. A substantial amount of work, however, is usually performed by local organizations or companies as subcontractors to the main contractor, mainly because they might find it easier to perform this work.

For performing a site survey, the experts have to cover the principal disciplines involved in the work. They have to be selected taking into account the need to collect and process information which is often only available in the local language, while other information might be available in the international literature.

For disciplines related to the more important site characteristics full-time experts are usually selected. For other disciplines part-time experts may be sufficient. It is important to appoint a person with knowledge and experience in site surveys to be in charge.

An example of a site survey group could include the following experts:

Manager
Nuclear safety engineer, experienced in siting
Engineer, experienced in electric generation system expansion planning
Geologist, competent in late Quaternary tectonics and in seismotectonics
Soil mechanics engineer
Civil engineer, experienced in power plant construction
Hydrogeologist
Oceanologist
Meteorologist
Seismologist (for high seismicity areas).

Staff members of the regulatory body should closely follow the development of the site survey work. Another important responsibility of the regulatory staff is the development or the selection of a set of standards for siting. It is difficult to develop a site survey if these standards have not been established. This may represent a difficult task for the regulatory body of countries embarking on a first nuclear power project. The adoption of the code of practice and guides of the IAEA’s NUSS programme may help to resolve this problem.

The site survey has to be performed and organized in such a way that all the relevant information is collected and properly analysed to determine in particular its quality and completeness. The organization has to be capable of efficient collection of all local information, which may be available only in the local language and from sources that are best known by local experts. Data have to be compiled in a format that allows their retrieval, comparison and use to the fullest possible extent. The organization of the data analysis has to allow for the prompt identification of information gaps and for the assessment of the need and methods for filling in such significant gaps.

In order to manage the data properly, standard format and maps of standard scale have to be used. All decisions on map scales and nomenclature, references,
co-ordinates, and cartographic formats have to be carefully documented and established. The scale of the maps has to be such that all the needed details can be seen.

A site survey programme is usually developed at the beginning of the survey, including:

- Identification and description or specification of the tasks to be performed during the site survey
- Sequence diagrams showing the relationship between the various tasks (for example, site characteristics to be considered at each phase)
- Criteria adopted for the regional analysis, screening of potential sites and comparison of candidate sites. The criteria should be listed for each site characteristic
- Outline of the procedures for applying these criteria and a list of sources of information needed for their application
- Comprehensive schedule.

As a result of the site survey, the preferred sites are identified and ranked. All the data and information collected or developed have to be included in the final report, because they represent the starting point for the following stage of site evaluation.

Based on the ranking of the candidate sites, the most preferred site could be selected (at least tentatively) at this stage. This procedure would require a relatively high degree of confidence in that the site evaluation studies will not result in a rejection of the chosen site, nor in a change in the order of preference. Should there be reasonable doubts, the definitive site selection could be kept open at this stage, and the site evaluation studies initiated for more than one (possibly two or three) sites. This approach would obviously require more effort, but it would substantially reduce the risk of delaying the project, if the selected site should prove to be unsuitable or much less suitable than originally believed. Favouring this approach is also the fact that sites will be required for follow-up nuclear power plants within the scope of the nuclear programme. Consequently, the effort involved in evaluating a second or third site would only be premature, but certainly not useless.

9.4. SITE EVALUATION STAGE

Evaluation of a site from the nuclear safety point of view consists fundamentally of:

(a) Proving that the site presents no characteristics that would constitute an impediment to a safe design
(b) Evaluating the design basis for protecting the plant against extreme limit external events and the expected events that the plant should withstand while continuing in operation
(c) Assessing the characteristics of the site related to the potential impact of the plant on the environment in normal and in accident conditions.

All the characteristics of the site are assessed during the site evaluation, whether safety-related or not. The objective of the site evaluation is different from the objective of a site survey, because now the site is identified and the studies and investigation are deeper and more extensive.

9.4.1. Procedure and methodology

The methodology of site evaluation consists of systematically collecting or developing all the relevant information on each particular characteristic of the site. It is necessary first to study each aspect in general for the whole region, then in particular once more in detail for the site vicinity and the site itself.

9.4.1.1. Procedures for site evaluation

The following steps are usually followed in performing a site evaluation:

(a) The regulatory authority establishes or selects the standards according to which the site will be evaluated and reviewed;
(b) The organization responsible for the site evaluation (usually the electric utility) defines the approach for performing the work. Depending on the approach adopted, the site evaluation group is organized, and consultants or a specialized company selected, if required;
(c) The site evaluation group (or specialized company) collects all relevant information, performs a critical analysis, prepares a programme of investigations, develops the design basis for the critical events and the models for dispersion in air and water, performs all special studies and investigations, and obtains all the results and data needed for evaluating the site;
(d) All results are reviewed by the responsible organization (utility) and included in a site report to be presented to the regulatory authority;
(e) The regulatory authority reviews the applicant’s site report and may issue a formal or an informal site approval. Before approving the site, the regulatory authority might require additional studies or information from the applicant.
9.4.1.2. Selection of standards for siting

The applicable standards have to be available before site evaluation can start. The applicant needs to know which standards for siting the regulatory authority of the country will apply, because the design basis depends on the standards to be used. There exist different national and international standards concerning siting. Among the national standards, the most complete are those used by the USA. These USA standards are divided into:

(a) Code of Federal Regulations and related appendices;
(b) Regulatory Guides of the US Nuclear Regulatory Commission (USNRC) and Standards of the American National Standards Institute (ANSI).

They constitute as a whole a complete but very complicated set of regulations, which have been, in certain aspects, developed only for United States conditions. To give an example, the regulatory guides for tornado divides the territory of the USA into zones which for the design basis tornado have different levels of security, but little is said of the criteria adopted for selecting the design basis tornado. The national standards developed in other countries are less complete, and even more dependent on the particular characteristics of the region for which they have been developed.

Among the international standards, a nearly complete set is the one being developed by the IAEA. It is composed of one Code of Practice on Siting (50-C-S) and a series of Siting Safety Guides.

The IAEA Safety Guides on extreme events concern:

Earthquakes (SG-S1 and SG-S2)
Floods (SG-S10A and SG-S10B)
Extreme meteorological events (SG-S11A and SG-S11B)
Extreme man-made events (SG-S5).

Three IAEA Guides concern dispersion of radioactive releases in air and water:

Atmospheric dispersion (SG-S3)
Dispersion in surface water (SG-S6)
Dispersion in ground water (SG-S7).

The set is completed by three further guides on:

Site survey (SG-S9)
Population distribution (SG-S4)
Radiological protection aspects in siting (SG-S12).
All the Safety Codes and Guides of the IAEA are prepared for possible application in any country and thus represent the most convenient set to be adopted by a regulatory body in a country that has not as yet developed its own standards.

9.4.1.3. Approaches of the responsible organization (utility) for the site evaluation

The possible approaches are:

(a) Performing the work directly, with some assistance, if needed, from specialized consultants who have experience in site evaluation;
(b) Performing part of the work directly (with the assistance of consultants) and part of the work with one or more specialized companies;
(c) Assigning all the work to a specialized company, retaining only a supervisory role.

The feasibility of the first option, i.e. the evaluation of a site performed directly by the utility, depends mainly on the availability of qualified expert staff. This approach is rarely adopted for a first nuclear power project, but it might be adopted for the second or third plant in the country if the utility has used every earlier opportunity for training its staff. Site evaluation may cost around one or two million dollars, while its impact on the plant may be twenty to fifty times this amount. It is thus prudent not to try to save expense in this very critical area.

In the case of this first approach, the site evaluation work is directed by a team composed of the utility’s staff. If and when assistance is needed, it is essential to select competent consultants who have already had adequate experience in siting nuclear power plants in similar regions. Selecting such competent consultants is not easy because most of them are employees of specialized companies. The team of the utility needs to have sufficient competence to direct the work, especially in the more sensitive areas of:

- Tectonics and seismology
- Flooding
- Soil mechanics
- Dispersion in air and water.

It will be most difficult to decide on the right amounts of money and effort to be spent on the investigations corresponding to each critical area, and on selecting the design basis while maintaining an appropriate balance between the necessary conservatism dictated by prudence and excessive conservatism dictated by lack of experience or fear.
When the evaluation of the site is performed partly by the utility and partly with specialized companies, among the parts of the work that are usually carried out directly by the utility are those that do not require very sophisticated methods, such as population distribution or man-induced events.

Among the parts of the work that are frequently assigned to specialized companies are those related to seismology and tectonics, and dispersion in groundwater. It is essential that the company has proven experience in siting nuclear power plants. This experience is particularly needed in the characteristics that are very important for the safety of the site. For example, if a country is seismic, the company should have experience in siting nuclear power plants in highly seismic areas. If the specialized company is foreign, it should have experience in working abroad, and preferably in the client's country.

The third approach, assigning all site evaluation work to a specialized company is frequently adopted for the first nuclear power plant. It does not necessarily mean that all the site evaluation work is done by a foreign specialized company. It should be established in the contract that a substantial amount of work will be performed by local subcontractors. With this approach particular attention has to be paid to selecting the specialized company. It should have extensive experience:

- On siting of nuclear power plants (evaluation of one or two sites would not be sufficient);
- In regions with similar critical characteristics as the region of the site to be evaluated;
- In working with subcontractors, particularly in setting up the necessary organization and in co-ordinating the work.

Bid specifications have to be prepared by the utility for selecting the company and assigning the work. The following points should be included:

The site survey report
Precise identification of the area of the site to be evaluated
Standards to be adopted in the siting, and the procedure to be adopted for interpretation of the standards
Scope of the work to be performed
Preparation of the site report(s)
Preparation of the site-related design inputs for the plant
Assistance in defining the interfaces with the designer of the plant, and in the discussions of the report with the regulatory body
Invitation to the bidder to collect directly information on the site for preparing the offer, and for checking any information provided
Conditions for supervising the work of the contractor.
Information requested from the bidders should in particular include:

Data on the qualifications of the company as a whole, experience on previous siting work performed, characteristics of the region(s) where this work was performed, experience with subcontractors
Information on the specialists participating in the work, their qualifications and their identification by name.

Site evaluation includes the following types of work:

Collection of information
Performance of studies and investigations
Development of mathematical models for evaluating basic design inputs and effects on the environment
Supply of certain services such as drilling, trenching, analysis of samples, and construction of a tower for meteorological measurements.

It is convenient that only those activities that require specialized skills unavailable within the country be performed by a foreign company. All other activities, particularly the collection of information and the supply of services, may usually be performed by local subcontractors.

The results of the evaluation of a site are contained in a report that demonstrates the acceptability of the site and identifies all site-related inputs for the designer. To achieve these results, information has to be collected, investigations made, and physical models developed. All the work required to achieve the results cannot be measured and precisely established in advance, so that flexibility in management of a contract of this type is necessary.

The contract management has to be done, therefore, using special arrangements:

A team of utility staff under the direction of a project manager must follow closely the work carried out by the specialized company and report regularly to Headquarters

A committee for the management of the contract should be established and convened regularly. It should follow the work and make all necessary decisions with minimum delay.

The following concept may help in taking the necessary, and sometimes difficult, decisions. The investigations to establish certain design bases (e.g. design basis ground motions) usually involve a small fraction of the extra cost of designing the plant to withstand it. Moreover, designing the plant for these design bases costs substantially less than backfitting the plant for increased design basis levels after
the start of construction. Therefore, it pays to do a more complete job in siting and to expand all needed investigations, rather than to run the risk of uprating the design of the plant later and incur the higher costs of backfitting.

It is also essential that an effective QA programme be organized for the site evaluation process, starting from the collection of information and including all activities to be performed. A manual for Quality Assurance should be prepared and strictly implemented under surveillance of the electrical utility.

9.4.2. Organization, staffing and schedule

Independent of the approach adopted to carry out the site evaluation, expertise in the following fields will be required:

- Geology (expertise in tectonics of the Quaternary)
- Seismology
- Vulcanology (for vulcanic areas)
- Soil mechanics
- Meteorology (expertise in evaluation of extreme events and in dispersion in air)
- Hydrology (expertise in evaluation of extreme events and in dispersion in water)
- Oceanography (for coastal sites)
- Emergency planning
- Radiological protection
- Industrial safety
- Nuclear safety
- Environmental effects
- Civil engineering
- Transport.

The fields of specific competence are in general similar to those that are required for the site survey stage. The knowledge and experience of the experts who have to carry out site evaluation will have to be extensive, because their work will consist of developing sophisticated physical models to evaluate design bases and dispersions among other aspects.

A team consisting of 15–20 experts is required to carry out the work, possibly half of them full-time, the others part-time. Moreover, a certain amount of field work has to be performed on the site such as drilling, seismic prospecting, meteorologic measurements and collecting of soil samples for analysis. For many of the measurement programmes, a full year's data are necessary.
TABLE XXXII. PRINCIPAL NUCLEAR SAFETY-RELATED RESULTS OF THE SITE EVALUATION

Demonstration through investigations that there is no risk from events against which the plant cannot be protected:
- No surface faulting affects the site
- No important cavities exist underneath the site
- No liquefaction risks exist
- An emergency plan is feasible at the site.

Determination of design bases against extreme events, such as:
- Design basis ground motion
- Design basis flood
- Design basis extreme meteorological phenomena
- Design basis man-induced events.

Modes for dispersion in air and water for normal and potential accidental radioactive release.

Determination of the distribution of the population around the site, including the identification of the location of population groups difficult to evacuate.

Development of the basis for the emergency plan.

The total manpower effort for the site evaluation is approximately 20 man-years, and the duration is usually of the order of one and a half to two years. For difficult sites with particular problems these values might be multiplied by a factor of two or even three.

The main nuclear safety-related results to be obtained from site evaluation studies are presented in Table XXXII. However, these are only partial results of the study. What has to be achieved is a complete understanding of the characteristics of the site to ensure that events against which engineering solutions do not exist can be excluded for the site and that reasonable inputs for other events that can occur are prepared for the designer of the plant. In addition, of course, all those aspects and characteristics of the site (safety-related or not) that may affect the design, construction and ultimate operation of the nuclear power plant will have to be investigated, and presented in the site evaluation report.

9.5. TECHNOLOGY TRANSFER IN SITING

The most convenient way to accomplish the technology transfer (apart from participation in training courses in which the theory of the different methodologies...
is studied) is the direct participation of local experts in siting work. This can be done by attaching them to a team that is performing siting work in another country or by working with foreign consultants, advisors or companies in the home country, attaching a large number of competent local experts to the foreign team. Another way is to make extensive use of local subcontractors to perform the more conventional parts of the work, on the basis of specifications prepared by foreign experts.

If foreign consultants or specialized companies are employed for the siting work, the transfer of technology should be considered at the stage when the bid specifications are prepared. Arrangements should be made in the contract so that:

- All the software (technical reports, digital computer codes, etc.) should be made available to the local organization
- Qualified local personnel should be attached to the foreign teams working locally and in their own headquarters abroad
- As much work as possible should be performed by local subcontractors according to the detailed specification to be prepared for them. However, the selection of the work to be performed by local subcontractors has to be evaluated carefully, taking into account the specific experience available in the country.

9.6. SITE REVIEW AND APPROVAL BY THE REGULATORY BODY

The site report produced by the organization responsible for siting is usually submitted to the regulatory authority for review. The regulatory authority may issue a formal or an informal site approval.

It should, however, be pointed out that the task of the regulatory body for the first nuclear power plant of a country could be very difficult unless, at a very early stage, appropriate measures are taken. It must be understood that what is required from the regulatory staff is to review critically work which might have been performed by reputed international experts with many years of experience in the field of siting.

To enable the staff of the regulatory body to perform this review, some years before the utility starts to perform the work of site evaluation the regulatory staff should participate in training courses on siting and one or two leaders of the regulatory siting group should be attached to another country's regulatory body to acquire direct experience in the siting work. However, this is not always feasible; in particular, it is very difficult to get attached for on-the-job training to another country's regulatory body. Under these conditions, the only possibility that remains is that the regulatory body employ consultants to assist in performing the review work. However, even if the consultants carry out the review of the
site reports, the decision on the selection of an accepted site will always remain ultimately the responsibility of the regulatory body. It is therefore essential that the responsible staff of the regulatory body understand clearly the various implications and technical aspects underlying site selection decision-making.

9.7. IAEA ACTIVITIES IN SITING

As pointed out in section 9.4.1, the IAEA is developing a set of codes and standards for the siting of nuclear power plants. Training courses are also organized by the IAEA regularly on general aspects of siting. On-the-job training as a follow-up of these courses can also be arranged for participants. Other courses on specialized topics on siting are now being organized, in particular for implementing the safety guides of the NUSS programme, e.g. courses on earthquakes and associated topics.

Site-related safety missions to developing countries are also carried out by the IAEA on request. Experts in the more important fields needed for the site to be studied visit the country, review the work being done or that has been completed, and provide advice on the review of the studies and on further investigations that may be required as well as on the actions to be taken by the regulatory body. If the mission is requested at the appropriate time and the material to be reviewed is available, the benefits to be obtained from missions may be substantial. The mission and its experts should not be considered a substitute for the review by the regulatory body (conducted by its own staff and consultants). Nevertheless, the mission could be helpful in clarifying some pending issues between the organization responsible for performing the siting work and the regulatory body.

The degree of success of such missions depends largely on the prior preparation of the data, information and reports. The mission should be requested for before the work is completed and at an appropriate stage, so that the advice from the mission can be easily included while the work is progressing.
FORMULATION AND FEASIBILITY OF THE FIRST NUCLEAR POWER PROJECT

10.1. OBJECTIVES AND SCOPE OF THE FEASIBILITY STUDY

Once nuclear power has been established as a viable alternative to other energy sources and a need for the development of a long-range nuclear power programme has been indicated through the planning study referred to in Chapter 8, the next step would be the detailed in-depth study of the first nuclear power project to be implemented within the established long-range nuclear programme.

For this purpose, a feasibility (or a pre-investment) study for the detailed definition and assessment of a specific nuclear power project must be undertaken, as well as a siting study, which is discussed in Chapter 9.

There is sometimes confusion between the objectives and scope of a feasibility study and the nuclear power planning study previously discussed. However, there is a precise distinction between the two studies. The planning study gives an indication of the general and long-term viability and convenience of the introduction of nuclear power, while the feasibility study deals in detail and in depth with a specific nuclear plant of given characteristics at a particular site and under well-defined conditions. The nuclear power planning study is programme-oriented, while the feasibility study is project-oriented; but it is understood that the project itself is an integral part of a long-term nuclear power programme.

There is no doubt that a well-performed nuclear power planning study will make a considerable contribution to a feasibility study. The planning study would certainly provide much useful input data and information in several important economic and technical areas, such as maximum unit plant sizes that can be introduced in the grid system, timing for the addition of new generation capacity, approximate possible locations and the economic ground rules that will be used in the feasibility study.

The feasibility study is primarily intended to provide the relevant authorities with all necessary detailed information needed to decide on the implementation of the project. It will also be of importance in the negotiations for financing of the project, as it is usually requested by all financing institutions.

Although the content and scope of a feasibility study may vary depending upon the particular associated conditions, the basic objectives will include the following:

- Evaluate in detail the integration of the nuclear power plant to the electric power system
— Determine the size and main features of the nuclear power plant
— Determine the preferred site and identify any specific problems associated with the selected site (might be a separate study or part of the feasibility study; see Chapter 9)
— Determine which type (or types) of reactor should be the basis of bids
— Carry out detailed cost and economic evaluations and compare with alternative options
— Determine the organizational and manpower requirements to implement the project and to operate the plant
— Determine the overall project schedule
— Determine financial viability of the project and the possible sources for financing
— Determine the contractual approach to be adopted for the acquisition of the plant
— Analyse the international market for nuclear power plants, fuel cycle and essential materials and services
— Define the country's infrastructure requirements and survey the national participation possibilities
— Define the nuclear safety criteria to be applied.

The feasibility study should provide detailed analysis and information on all these aspects, with specific recommendations to enable the authorities concerned to make appropriate decisions for the implementation of the project. It should also outline the further steps to be taken and identify the areas in which more detailed investigations are still needed.

The scope of the feasibility study will depend on the factors associated with a given situation and project characteristics. The depth of evaluation will also be influenced by the degree of effort that was applied in the nuclear power planning phase and in this regard, parts of the feasibility study will involve an updating and closer investigation of the work performed in the previous planning study.

Typically, the framework of the feasibility study would consist of studies pertaining to the areas listed in Table XXXIII.

It is emphasized that the reliability of the results and of the recommendations will largely depend on the input data and information used in the study and analysis, therefore utmost care should be taken to ensure a high degree of accuracy and reliability of these data and information. It should be noted in particular that information on the reference designs and cost estimates to be used for the study, which may be obtained from the suppliers or provided by consultants, should be reviewed and thoroughly checked and adjusted to the prevailing local conditions.

To perform such an interdisciplinary study, 10 to 15 professionals would be required, assisted by part-time experts (advisors, consultants) in specific
TABLE XXXIII. CONTENTS OF THE FEASIBILITY STUDY REPORT (Example)

1. INTRODUCTION
   1.1. Objectives
   1.2. Scope
   1.3. Background information
   1.4. National energy market analysis

2. ELECTRIC SYSTEM ANALYSIS
   2.1. Electric system description
   2.2. Demand forecast
   2.3. Generation expansion programme

3. CHOICE OF UNIT SIZE
   3.1. Electric supply grid analysis
   3.2. Unit size definition
   3.3. Station size

4. SITE CONSIDERATIONS
   4.1. Site survey
   4.2. Site evaluation

5. TECHNICAL ASPECTS OF NUCLEAR PLANTS
   5.1. Nuclear power supply market survey and choice of reactor types
   5.2. Design characteristics
   5.3. Construction schedule
   5.4. Fuel cycle evaluation

6. NUCLEAR COST ESTIMATES
   6.1. Basis of cost estimates
   6.2. Capital costs
   6.3. Fuel costs
   6.4. Operation and maintenance costs

7. GENERATION COSTS
   7.1. Annual charges
   7.2. Total generating costs
   7.3. Cost estimates and comparison of alternative sources

8. FINANCIAL REVIEW
   8.1. Financial review of utility/owner
   8.2. Financial requirements of nuclear project
   8.3. Financial projections for utility/owner
   8.4. Survey of financing sources
TABLE XXXIII (cont.)

9. PROJECT DEVELOPMENT
   9.1. Project organization
   9.2. Project development schedule
   9.3. Contractual approach
   9.4. Safety criteria
   9.5. Legal framework

10. STAFFING AND TRAINING REQUIREMENTS
    10.1. Project management
    10.2. Construction
    10.3. Commissioning
    10.4. Operations and maintenance
    10.5. Industrial infrastructure

11. NATIONAL PARTICIPATION
    11.1. National participation policy and strategy
    11.2. Survey of industrial infrastructure
    11.3. Participation goals and implementation measures

12. CONCLUSIONS AND RECOMMENDATIONS
    12.1. Feasibility of nuclear power project
    12.2. Implementation programme

subjects. It is essential that the best available resources and experienced people be made available for performing the studies. The local staff should be carefully selected at the highest possible technical level of the various organizations concerned with the areas related to the study.

Some of the personnel involved in the nuclear power planning study would logically expand their work into this activity and would form a team with other professionals who could have gained their experience in non-nuclear projects. The performance of a feasibility study usually requires a year to a year and a half, not including site survey and evaluation, which would be an on-going activity during the time the feasibility study is being performed.

A sample of contents of a feasibility study report is given in Table XXXIII. Feasibility studies have been prepared in various developing countries. In some countries such feasibility studies were prepared by foreign consultant firms, in others consultants were only used in an advisory capacity by local teams and there are a few cases where the feasibility study was a wholly national effort.
While the performance of a feasibility study should always be undertaken by the local authorities, it is often delegated to some well-known and experienced foreign firm of consultants. The main reason for this delegation is that the feasibility study will be of importance in the negotiations for financing of the project and it is assumed to carry more weight if performed by reputable and experienced foreign consultants. Should this approach be adopted, it is essential to define with great care the scope of the study and the terms of reference under which it is to be performed before the study is started.

If requested, IAEA assistance could be available for guidance and help in feasibility studies.

10.2. ELECTRIC SYSTEM ANALYSIS

This analysis will take into account the preliminary work undertaken in the previous nuclear power planning study and the consideration of the location of the nuclear power plant.

The analysis of the electric system should be performed following fundamentally the same methodology as has been outlined in Chapter 8, but with a change in approach and emphasis.

The feasibility study is expected to provide a critical review of the current long-term electric system expansion programme, which might be the one proposed during the nuclear planning study or a later updated version. It is assumed that such a system expansion programme is available for review, if not, than its preparation would fall within the scope of the feasibility study.

The emphasis of the electric system analysis in the feasibility study should be directed to the period when the nuclear power plant is expected to be integrated into the system, within the framework of the long-term analysis. For this specific period the system analysis should be more detailed and in depth than the level required for the planning study. Both the effect of the introduction of the nuclear power plant on the interconnected system, and the effect of the system on the technical and economic characteristics of the nuclear power plant are to be analysed. These two aspects not only complement each other but they are also interrelated. The introduction of the nuclear plant will affect the electric system and might require grid modifications and adjustments. On the other hand, the electric system will affect the size and mode of operation of the nuclear power plant to be installed.

The electric system analysis will provide necessary information for the definition of the admissible unit size, which will also depend on the commercial availability of nuclear power plants, in addition to the constraints derived from the operational characteristics of the plants and from grid characteristics and system reliability criteria.
To achieve the economic benefits of increased unit size, the following principal measures or a combination of them can be contemplated and analysed:

- Enlargement of the electric system by interconnections with neighbouring (national or foreign) systems
- Sharing of the nuclear power plant between two neighbouring systems (joint project, which might be international)
- Initial operation (a few years) of the nuclear plant at a reduced power level
- Acceptance of relatively low reliability criteria for system operation during the initial period of the nuclear power plant's operation
- Acceptance of a limited amount of load shedding as admissible operational procedure
- Introduction of improvements into the system, such as centralized load dispatching, increase of transmission voltage or capacity, special protective communication and control systems, etc.

Each of these measures involves technical difficulties and costs which should be included into the overall cost/benefit evaluation. They would tend to be compensated by the potential economic benefits expected from the larger unit size and improved operational characteristics of the electric system. Whatever measures are adopted, there is still a definite limit to the maximum unit size an electric system can accept.

In highly industrialized countries electric systems are large, with adequate reserves and able to maintain stability, integrity and quality of power supply. The designs of modern commercial nuclear power plants have been developed and standardized for these conditions, where their integration into the system does not pose special problems. However, in smaller systems where shortage of generating capacity provokes mismatch of power supply and demand and inadequacy of grid interconnection may render the system vulnerable, the commercial standardized designs may not be applicable without modifications that would enable the safe and reliable operation of the plant.

Aspects of the electric system which require special consideration are:

- Cold and spinning reserves available in the system
- Power transmission capacity of the grid during critical conditions
- Power control and load-dispatching system
- Voltage and frequency fluctuation control equipment
- Probability of supply interruptions and grid disturbances.

The main technical characteristics of the nuclear power plants, related to their integration in the electric system, are:
‐ Start-up capability
‐ Load change and load following capability
‐ Effects of power cycling on components and fuel elements
‐ Ability to withstand externally induced disturbances.

Within limits, both the electric system and the nuclear power plant can be modified and mutually adjusted, if necessary. The recommendations as to what modifications or adjustments should be undertaken are one of the results expected from the feasibility study.

The IAEA has prepared a Guidebook on the “Interaction of Grid Characteristics with Design and Performances of Nuclear Power Plants”.

10.3. EVALUATION OF THE NUCLEAR POWER SUPPLY MARKET

10.3.1. Supply of nuclear power plants

It is assumed that the implementation of a first nuclear power project will be through importation from an experienced foreign supplier or suppliers. There will be national participation too, which would vary from case to case and will depend mainly on the available infrastructure of the country (see also section 5.8).

One of the main objectives of the evaluation of the supply market is to identify the reactor or reactor types and sizes that are commercially available and that offer distinct economic or technical attractions for the case under consideration and to analyse how fuel cycle requirements can be met. It is not necessarily the purpose of the feasibility study to select a particular type of reactor system, but rather to undertake those evaluations that will support the selection of the reference concepts for detailed economic and technical analysis and comparison among each other and with alternative projects. It will also facilitate the final decisions to be taken after the project is firmly committed and will help to define the approach and procedure to be followed during the acquisition stage of the project implementation (Chapter 11).

A general survey of the various types of power reactor systems has been presented in Chapter 2. It is recommended that for the first nuclear power plant in a country, preferably the proven reactor types should be considered. Obviously, they must also be commercially available for export.

A pre-selection of one reactor type may impose limitations on the desirable competition between various suppliers. On the other hand, the preparation of bid specifications and the evaluation of bids for different power reactor types would be more difficult and complicated. In general, a recommended approach would be to limit the bidding to well-specified reactor types, keeping the competition open between several suppliers.
Each reactor type and available design presents a number of distinctive features, with advantages and disadvantages for the specific case under study. Within the scope of the feasibility study these should be analysed and evaluated in order to compare them and define the criteria upon which the final decisions are to be taken in the subsequent stage of implementation of the project.

The choice of reactor type for the first nuclear power plant should also be seen as a possible long-term commitment to that type for a series of additional units to be built within the scope of the nuclear power programme, and also to the type of fuel cycle and associated supply requirements. The decision on the first nuclear power plant could be taken on economic and financial grounds. However, because of the international supply and potential international long-term commitments for both the reactor plants and the fuel services, political considerations would probably have a strong influence on the decision. Furthermore, it is necessary to bear in mind the development potential of the reactor systems and the possibility of early obsolescence when the choice is to be made. Early obsolescence would not appear to be a real risk for the currently commercially available power reactor systems. This, however, could well be the case for special designs, particularly if their economic advantages are marginal or largely influenced by exceptionally favourable financial terms.

Among other factors that should be taken into account in the choice of reactor type are the possibilities for local participation in the project, financing prospects, and transfer of technology possibilities; a long-term perspective will help in considering these. If the project is regarded as the first of a series of essentially the same type of nuclear plants (but possibly from different suppliers), the prospects of increasing local participation with each successive project seem to be better than for a series including different types of reactors. Technology transfer can also be established on a systematic basis. In this regard, the nuclear power programme will be a potentially powerful tool for industrial development and domestic training of qualified technical staff. On the other hand, advantageous prospects for financing the first plant could be very attractive. This, however, should not carry too much influence on decisions regarding the long-term programme.

The analysis of the nuclear power plant supply market includes also the evaluation of the potential supplier countries as well as the supplier industry.

The international trade in nuclear power is conducted under the control and supervision of the governments involved and is under a strong political influence. Up to the present only the following seven countries have exported nuclear power reactors: Canada, the Federal Republic of Germany, France, Sweden, the United Kingdom, the USA and the USSR. Some other countries already well-advanced in developing their local capabilities in nuclear power might decide to enter the export market of power reactors in the future. Depending on the political and commercial relations between the importing country and the
potential exporters, the effective availability of suppliers might be limited to some of the potential suppliers or even to only one of them. This would imply also a possible limitation on the choice of the available reactor types. The following reactor types have been exported by the various supplier countries that have exported reactors in the past:

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactor Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>PHWR (pressure tube design)</td>
</tr>
<tr>
<td>Federal Republic of Germany</td>
<td>PWR, BWR, and PHWR (pressure vessel design)</td>
</tr>
<tr>
<td>France</td>
<td>GCR, PWR</td>
</tr>
<tr>
<td>Sweden</td>
<td>BWR</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>GCR</td>
</tr>
<tr>
<td>USA</td>
<td>PWR, BWR</td>
</tr>
<tr>
<td>USSR</td>
<td>PWR</td>
</tr>
</tbody>
</table>

Regarding the evaluation of the potential supplier industry, the following factors are especially relevant:

- Commercial interest
- Reliability
- Experience
- Technical capability and resources
- Financial resources.

The evaluation is elaborate and requires objective value judgements based on a thorough analysis of relevant aspects, such as:

- Willingness of potential suppliers to provide technical and economic information as well as the quality, detail and depth of such information;
- Expression of intent to bid in a formal enquiry and willingness to present a preliminary non-binding bid, if requested to do so;
- Experience of former or current clients with the supplier;
- Adherence to agreements and contractual commitments in the past, especially regarding unilateral actions;
- Current issues that might affect the future reliability of the supplier;
- Experience of the supplier in producing and providing the goods or services he would offer;
- Export experience of the supplier in general and to the interested country in particular;
- Restrictions regarding the use of technology;
- Willingness to transfer technology;
- Qualified manpower resources of the supplier;
— Technical, industrial and financial resources of the supplier, his organization and efficiency;
— Operating experience of plants, systems or equipment previously provided by the supplier.

To perform an evaluation, the potential buyer should establish direct contact with the potential suppliers; he should request information and then analyse and confirm it to his satisfaction. During the feasibility study stage, the buyer should obtain a clear understanding of his prospects regarding project acquisition, potential suppliers and any relevant constraints.

10.3.2. Provenness and demonstrated licensability

A nuclear power project is a major undertaking involving a large financial commitment. It also involves sophisticated equipment which incorporates new technology. Hence, importing a nuclear plant involves commercial and technical risks, probably greater than in other large industrial projects. These risks range from the economic burden of capital and operating costs exceeding expectations to the risk of not having the plant available when the power is needed. In addition, there is of course also the nuclear safety risk.

Protection against such risks is generally obtained through the confinement of procurement to proven equipment and manufacturers. In addition to the concept of 'provenness', another concept to be used in the context of the limitation of risk is the concept of 'demonstrated licensability'.

A too strict application of the provenness criterion could eliminate practically all types and designs of nuclear power plants from the market as no export plant has been a duplicate of an existing one. On the other hand, the supplier who intends to protect his standing in the export market shares — up to a point — the risks involved in the project and hence will, in principle, not offer his product unless he satisfies himself as to the acceptability of his own risk.

Based on the above considerations, those nuclear power plants that are available for export at present can be considered as reasonable commercial risks from the point of view of provenness. It should be emphasized, however, that the buyer's design review must be careful, detailed and well-informed, in particular in order to ascertain where new and unproven systems, components or design features are involved, and if they are acceptable.

Regarding 'demonstrated licensability', the application of this concept helps to reduce the safety risk involved in a nuclear power plant and facilitates the regulatory procedures, even if it does not relieve the buyer country of its basic responsibilities. It has often been recommended that licensability be demonstrated in the supplier's country through the use of a licensed reference plant, implying an acceptance of the supplier country's licensing requirements and procedures.
Usually, however, the selected reference plant shows significant differences, due to the evolution of technology, to site-related features or to new safety criteria, rules and guides that have been developed. Therefore, the application of the 'demonstrated licensability' criterion using the reference plant concept only provides guidance.

An exported nuclear plant cannot be licensed in the supplier’s country. However, what might be achieved is to comply with the condition that the exported plant should be 'licensable' in the supplier’s country if it were built there, by designing and building it according to the applicable current safety criteria, regulations, rules and guides. This stresses the requirements for capability to perform a regulatory review in the buyer country and extensive documentation to be provided by the supplier, often going beyond the documentation that he may have to provide to the regulatory body in his own country.

Both provenness and demonstrated licensability are thus criteria of limited applicability in the present situation of rapid technological development and even more rapidly developing safety regulations and criteria in the supplier countries. Even though they cannot be fully complied with, they should be applied as far as practicable.

10.3.3. Supply of nuclear fuel and fuel cycle services

The supply of a nuclear power plant and the supply of its fuel must be considered simultaneously. In fact the fuel supply possibly requires an even more careful consideration than the supply of the power plant, because fuel must be provided during the whole lifetime of the plant, which is a much longer period than what it takes to build the plant. A failure in supplying the plant with fuel would not only mean being left with an unproductive investment, but would also affect negatively the electricity supply of the country, which might have serious consequences on its economic and industrial activities.

One of the important factors that influence the choice of reactor type is the adoption of the fuel cycle and related services and activities. Fuel cycle policy decisions not only affect the first nuclear power plant, but also — and possibly even more — the nuclear power programme of the country. Though the decision on a first plant does not necessarily mean that all successive plants will have to be of the same type and use the same fuel cycle, there are obvious advantages regarding the build-up of national capabilities if a certain line is followed through.

Assuming that a country starting its nuclear power programme will limit its selection to proven and commercially available reactor types, it has the basic choice between adopting a natural uranium or an enriched uranium fuel cycle.

The main advantage of a natural uranium fuel cycle lies in the fact that it offers the possibility of self-sufficiency and independence for fuel supply. The existence of uranium ore deposits in a country could provide the necessary supply
of uranium for its national nuclear power programme, without being dependent on foreign uranium suppliers, nor on the market fluctuations of supply, prices and political conditions related to nuclear export policies of supplier countries. Of course, the development of national uranium resources would require facilities and technical know-how for the recovery and milling operations. Industrial facilities would also be needed for conversion to uranium dioxide and the fabrication of fuel elements for reactors. Such facilities involve relatively accessible technology and could be obtained on a commercial basis from various suppliers (Chapter 3).

Should a country have insufficient or no national uranium resources, it could obtain natural uranium on the world market from several suppliers in various countries.

It should be noted, however, that a nuclear power programme based on the use of natural uranium and PHWRs does require heavy water, for which there is a limited market. Heavy-water production plants are relatively expensive and the production technology is complex (see also section 3.5.2).

Regarding uranium enrichment services and heavy-water supply, these can only be obtained from a few suppliers and under conditions that might restrict their free availability. Long-term contracts including safeguards considerations must be negotiated. Proven enrichment technologies are not available commercially because of non-proliferation concerns. There is a possibility to participate as a shareholder in multinational enrichment companies, which may offer certain advantages in ensuring supplies. This may be of particular interest to those countries that have uranium resources and/or a sound financial status.

Considering the economic aspects, it is in general shown that natural uranium reactor systems require larger capital investment and have lower fuel cycle costs than enriched uranium reactors. However, the differences in power generation costs are very difficult to estimate and can in practice only be assessed on the basis of firm offers from the various supplies, and the economic parameters used in the calculations.

After use in the reactor, both initially enriched and natural uranium fuels contain plutonium. To recover the fissionable materials, reprocessing in chemical plants is required. Initially enriched fuel could be recycled as the uranium is still slightly enriched after being burnt in the reactor, while spent natural uranium is written off at no value and may be stored indefinitely. It may well be economical to plan to store also enriched spent fuel, at least until commercial reprocessing becomes more readily available.

It is difficult to draw definite conclusions or make generalizations about the choice between the natural and the enriched uranium fuel cycles. Ultimately, this is a national policy decision depending on a variety of conditions related to the specific situation of the individual country concerned. The decision may be based in certain cases on purely economic considerations of the competitiveness
between the two systems. It also can be influenced by special financing arrangements, or favourable conditions of supplies of fuel and fuel cycle services, or by the availability of indigenous uranium resources. The feasibility study must provide the technical basis and the outline of the items and factors that should be considered for the national policy decision.

A few countries have selected the natural uranium option for their nuclear power programmes, the majority has chosen the enriched uranium system. Some pursue both, and of course many have not made their selection yet.

Whatever fuel cycle (natural or enriched) is chosen, assurance of supply is to be considered for each essential stage of the cycle. As has been mentioned earlier, natural uranium can be acquired on the world market from several suppliers using long-term contracts. Sudden and substantial general price increases are possible, as well as restrictions on export. To avoid these, the development of domestic uranium production capabilities is indicated, wherever local resources are available or can be located, even at somewhat higher costs than the prevailing world market price. For countries without adequate uranium resources, long-term contracts, diversification of suppliers and stockpiling are measures that can be taken.

For most countries enrichment of uranium (if needed) will remain an item to be imported for many years to come. Long-term contracts based on governmental agreements with available suppliers seem to offer at present the best assurance of supply. Stockpiling and diversification of sources of supply might also be beneficial.

It must be understood that the assurance of external supply of nuclear fuel, together with fuel cycle materials and services, is closely related to the non-proliferation assurances. An intricate network of international treaties, agreements, instruments and practices provide the framework for the supply of nuclear materials, equipment and technology and for non-proliferation. A number of measures at both the commercial and governmental levels that could improve assurance of supply in the interests of national needs and consistent with non-proliferation have been examined by Working Group Three of the International Nuclear Fuel Cycle Evaluation (INFCE) (see also section 7.5).

The various proposals considered during the INFCE discussions include several arrangements through which the assurances of supply for nuclear fuel and fuel cycle services may be improved. These new international arrangements cover the following main areas:

For short to medium term, two possible mechanisms were discussed:

(a) Back-up or safety net arrangements such as uranium emergency safety network or uranium emergency sharing system

(b) Establishment of an international nuclear fuel bank.
For the long term, the contribution of multinational fuel cycle arrangements to supply assurance was discussed, such as multinational facilities or regional nuclear fuel cycle centres.

There are more sources of supply for fuel element fabrication than for power reactors, though most of them only supply fuel for certain types of reactors. First charges and options for a few years refuelling are usually included in the scope of supply of the power plants. To ensure the long-term supply of this essential service, the development of domestic capability seems to be a feasible solution, accessible to any country with a reasonably sized nuclear power programme.

Assurances regarding spent fuel management and disposal of radioactive waste are also to be considered by the buyer.

In principle, the available options for handling of spent fuel, whether natural or enriched uranium, include the following:

(a) Extended spent fuel storage at the reactor site or in suitable selected sites away from the reactor site, with no reprocessing of the spent fuel;
(b) Establishment of a national fuel cycle centre for reprocessing, fabrication of fuel and recycling of separated plutonium and uranium;
(c) The use of outside services for reprocessing with possible arrangements of storage of separated plutonium and its subsequent use for recycling or in fast breeder reactors.

An additional option might become available in the future, consisting of the establishment of multinational or regional fuel cycle centres serving several countries for reprocessing and fabrication of fuel and recycling of separated plutonium and uranium.

For the initial stages of the development of a nuclear power programme the first option of extended spent fuel storage or the third option of using outside reprocessing services might offer the most practical approaches available at present.

For management and disposal of radioactive wastes there are several available methods. Provisions should be made to locate a suitable depository (see section 3.4).

10.4. TECHNICAL ASPECTS OF THE NUCLEAR POWER PROJECT

10.4.1. Reference designs

Part of the feasibility study will be the definition of the designs of reference plants. The degree of detail will vary from case to case but as a minimum it must be carried out in such depth as to provide a realistic basis for detailed cost and economic evaluations. It should also provide the basis for preparing bid specifications
in the next phase of the project, by identifying important site-dependent design features and criteria. The main requirements are:

(a) Preparation of overall plant descriptions, design and performance data
(b) Preparation of general plant layouts for the specific site.

Within the scope of this work full consideration should be given to the project management approach and to the potential influence of local participation. Further, all factors related to detailed site investigations need to be established.

The technical descriptions of proven and commercially available nuclear power plants are widely available and are normally provided by suppliers on request in adequate detail and depth for the purpose of a feasibility study. These descriptions usually correspond to a typical plant which would be the basis of an offer in response to an enquiry, subject to adjustments and modifications according to the specific site in question and special requirements of the buyer as contained in the bid specifications.

Within the scope of the feasibility study, it is sufficient to study the available technical descriptions complemented by the analysis of the characteristics and the performance of similar plants, identifying problem areas and differences in design between operating plants and the current technical descriptions, in particular regarding any new unproven features.

Special attention should be dedicated to the study of those features, systems, components and equipment that might be supplied by national industry, in order to be able to complete a survey of the potential national participation in the construction of the plant (see sections 10.6 and 5.8).

The analysis of the operational characteristics and constraints of the reference plants, such as start-up, load following capability, excess reactivity, xenon override, refuelling schedule, fuel burnup, core stretch-out, efficiency, planned maintenance requirements, etc., will provide input information for the study of the integration of the plant into the electric system and will also lead to the adoption of the expected load factors that will be used in the economic evaluation.

10.4.2. Project schedule

One of the principal technical aspects of the project is its schedule, which should be analysed in detail (see also section 5.3). Both the shortest possible schedule and the reasonably expected schedules should be defined. The shortest possible schedule defines the ideal minimum time required before the project can be completed and indicates possible shortcuts that could be taken to accelerate project implementation, if conditions should permit it. The reasonably expected schedule is the one to be used for project planning. It depends on local conditions and the approach to project implementation.
By the time the feasibility study is finished and a corresponding report prepared, the siting study must have reached the stage where the site is selected and sufficiently evaluated so that its final approval can be considered as highly probable.

The feasibility report is presented to the relevant authorities for evaluation and for deciding whether to proceed with the project.

In principle, the feasibility study should contain all detailed information needed for this decision. In practice, however, the evaluation of the feasibility report usually produces requests for additional information or studies to be undertaken. This process of evaluation, additional studies and decision-making should normally take a few months and certainly not longer than a year. The more people and organizations that are involved in the evaluation process and the less they were involved in the feasibility study itself, the longer it will take to reach a decision. If the evaluation process is excessively protracted, the feasibility study could become obsolete and consequently would have to be revised and updated.

Once the decision to implement the project is adopted, the acquisition phase starts (see Chapter 11). This stage will require about 30 to 50 months to complete. The most important decisions regarding the project are taken at this stage and both financing arrangements and international agreements also require time and effort. The regulatory procedures including site review and approval and plant construction authorization will proceed in parallel with plant acquisition, but may constitute the critical path in the overall project schedule.

The above-mentioned periods should be treated as no more than general indications. The feasibility study should define the project schedule for the specific conditions of the country, taking into account all relevant factors and aspects.

10.5. ECONOMIC AND FINANCIAL EVALUATION

10.5.1. Cost estimates and economic evaluation

The feasibility study includes the complete economic evaluation of the project with the intention of determining the plant costs and of determining whether the nuclear unit is economically competitive with alternative generating capacity expansions.

Cost estimates should be in as much detail and as precise as possible. They should be determined on the basis of the reference plant designs that have been adopted, and for the site that has been selected.

Economic information should be obtained from all available sources, mainly suppliers of plants, component and equipment manufacturers and construction and engineering firms, both foreign and domestic. There is also much published
information available on nuclear power economics, but this is difficult to apply directly to the feasibility study of a specific project, because most of this information might be outdated, too general or relevant only to a different specific project. More details on the economics of nuclear power are presented in Chapter 4.

Prospective suppliers identified through the evaluation of the nuclear power supply market (section 10.3) can be approached with requests for non-binding indicative offers. Suppliers might provide such offers, if they feel that there is a serious intention to implement the project, if they believe that they have a reasonable chance to become selected for the supply, and if they have assurance that the information they provide will receive highly confidential treatment.

The methodology to be used in the feasibility study to demonstrate the economic competitiveness of the nuclear power project with alternative options for the electric system expansion is fundamentally the same as the one described for the nuclear power planning study (Chapter 8). The input data for the nuclear project and for its alternative options are especially important and would require a higher degree of accuracy than that needed for planning purposes.

The comparative analysis is performed within a specific set of economic ground rules, assumptions and cost estimates. The assessment of the project should include a sensitivity analysis assigning reasonable ranges of variations to the most relevant parameters and data.

10.5.2. Financial analysis and sources for financing

Another part of the feasibility study is the financial analysis of the investment requirements and a survey of potential sources of financing of the nuclear power project (see also section 5.10). This, of course, is an essential element upon which the viability of the project ultimately depends.

The feasibility study should therefore explore the possible ways and means for securing the financing of the project through national and foreign financing sources, including commercial financial institutions, and development or aid institutions. Detailed financial analysis of the nuclear project will be required and should include:

(a) Estimates of the financial requirements of the project and comparison with alternative projects
(b) Review of the experience of the owner's organization in project financing
(c) Financial viability analysis of the project.

The financial requirements of the project include the estimated total investment cost of the project and associated facilities plus an allowance for
working capital during the initial years of the plant’s operation. Financial require-
ments should be broken down between foreign exchange and local currency
requirements, and the prospects for both domestic and foreign financing possibilities
should be reviewed.

Since all costs are directly affected by the length of the construction period
and by escalation, the financing plan is worked out to include expected cost
escalation during the construction period. Additionally, a supplementary financial
plan should be developed in which the impact of a delay in the project imple-
mentation is specified. Financial requirements should also include a contingency
reserve that allows for possible errors in cost estimates, changes in technical and
safety requirements, and delays in construction. Similarly, the cost of additional
investments such as transmission lines, grid reinforcement, etc. should also be
taken into account.

A demonstration of the financial soundness of the project should be made
through various financial tests. The most significant indicators are:

The return on average net future assets in operation
The number of times the debt service is covered by internal cash generation
The debt/equity ratio
The number of times the interest is covered by net income
The payback period
The cost/benefit ratio
The internal rate of return
The impact on the tariff.

A thorough sensitivity analysis should examine potential financial bottlenecks
and risks related to the project implementation. In particular, impact of escalation,
of investment and operating costs, various financing modes of the project, tariff
policy of the utility, etc. should be investigated, and marginal values of examined
factors conditioning the project’s financial viability should be specified with
comparisons as appropriate to alternative possibilities.

10.6. ORGANIZATION, MANPOWER, AND INFRASTRUCTURE
REQUIREMENTS AND DEVELOPMENT

The nuclear power project represents an addition of a single large generating
station into the electrical system, which will in most cases be the biggest unit size
to be introduced and will involve the largest investment for a generating plant.
For the execution of a project of such magnitude, which in addition involves a
new and complex technology, a capable and competent organization is needed to
administer and implement it (see also section 5.6).
The feasibility study should include a review of the existing organizational structure for electric power generation and distribution in the country and the history of its development. This organizational structure will vary from country to country and the government’s involvement may range from some control of private utilities to the establishment of a single national generating authority within a Ministry of Electricity or a Ministry of Energy. The electric utility or authority might be in charge of the nuclear power project, but this responsibility could also be assigned to a National Atomic Energy Commission or to an entity especially created for this purpose.

Based on the current structure of whatever entity is in charge of the nuclear power project, the feasibility study must analyse and recommend workable internal organizational arrangements for the tasks to be carried out in the subsequent stages of the implementation of the project and ultimately for the operation and maintenance of the nuclear power plant.

Detailed organizational charts for the nuclear power project should be prepared. These diagrams should show the organizations for project management and all other activities during plant acquisition, construction and operation. Proposals for recruitment plans of staff and for the training that will be required should be included.

The preferred organizational structures and number of personnel involved will depend upon many factors akin to the particular country, utility and the project. The staffing requirements should be established for each activity and function/task with definitions of the numbers of personnel involved, their disciplines and professional or trade qualifications.

In fact, the feasibility study should contain the outlines of a manpower development programme. The IAEA Guidebook on “Manpower Development for Nuclear Power” contains detailed information on this subject, which is also discussed briefly in section 5.7 of this present Guidebook.

The infrastructure requirements and capabilities for national participation in nuclear power programmes have also been discussed earlier in section 5.8 of this Guidebook. In the feasibility study phase a survey should be undertaken of the local industrial manufacturing, engineering and construction capabilities to assess their possible contribution to the implementation of the nuclear power project. This survey will provide input data and information for the evaluation of what contracting approach should be adopted (section 11.4).

The potential for national participation will vary from country to country. It might prove to be better than expected even for countries with relatively modest industrial infrastructures, or it may constitute a major constraint to the feasibility of implementing the nuclear power project.

Experience shows that all too often the question of national participation is only evaluated in a superficial way, or not at all, during the feasibility study. If it is left to the acquisition stage and to be evaluated by the suppliers, the results...
will probably lead to an absolute minimum rate of national participation, in spite of any 'good-will' or 'best-effort' statements or contractual clauses that might be agreed upon for maximum national participation.

Based on the technical aspects of the nuclear power project, the evaluation of national infrastructure should include a systematic survey of the major national engineering, construction and manufacturing firms with emphasis on:

Technical capability
Experience
Reliability
Quality
Costs
Delivery schedules.

The survey must be detailed, analysing the industry for the potential supply of each item (similar items might be grouped together), classified according to the following categories and in order of priority:

(a) Goods and services that have to be supplied or performed locally, because importing them would not be feasible
(b) Goods and services that could be produced by national industry with no or only reasonable additional efforts
(c) Goods and services of special interest for national supply, due to considerations such as long-term assurance of supply or important spin-off benefits to national industrial development.

The feasibility study should also contain a strategy outline and recommendations regarding the implementation of the national participation goals. In particular, these recommendations should refer to the contractual approach to be adopted and to the development of a consistent set of governmental actions and incentives promoting national participation and transfer of technology.
Chapter 11

NUCLEAR POWER PLANT ACQUISITION

11.1. TASKS, SCOPE AND SCHEDULE

After completion of the planning study and establishment of the needs and merits of a nuclear power programme, the decision to undertake the first nuclear power plant project would be taken on the basis of the evaluation of the results of the feasibility study. The tasks to be undertaken to implement the project can be divided into two stages, the first is the acquisition stage, which includes the necessary steps leading to the finalization of the contracts with a vendor or vendors for the supply of the plant, and the second is the construction and commissioning stage of the plant (briefly considered in Chapter 12, together with operation and maintenance).

The acquisition stage includes the following tasks:

1. Establishment of the organization and staffing (section 11.2)
2. Completion of data and information requirements (section 11.3)
3. Definition of contractual approach (section 11.4)
4. Preparation of specifications and invitation of bids (section 11.5)
5. Preparation of bids (section 11.6)
6. Evaluation of bids (section 11.7)
7. Selection of supplier(s) (section 11.8)
8. Arrangements for financing (section 11.9)

For the discussion of the above sequence of tasks in this Guidebook it has been assumed that the procedure of competitive bidding is adopted for the acquisition of the plant. This is not necessarily the approach in every case. Some countries may be limited in choice to only one supplier for policy or political reasons, others may select at the feasibility study stage a supplier or a certain reactor type or concept that is only produced by one supplier.

The purpose of a competitive bidding procedure is to enable the buyer to take advantage of the competition between suppliers. If this can be achieved without going through all the time and money-consuming steps of a formal international bidding procedure, direct negotiation would be in order. It is the achievement of the purpose that is important not the procedure itself. Of course, when there is no possibility of competition, it would be a useless exercise to go through a formal bidding procedure.
An international bidding procedure in itself is no guarantee that the buyer's best interests will be served by receiving the optimal offer he can hope to get. The preparation of a serious offer involves considerable effort and expense for the supplier, which he might decide not to expend if, in his judgement, his chances are remote or if he feels unable to meet the requirements included in the specifications, which might otherwise be subject to negotiation. Some suppliers might even adopt the policy of not participating in any international competitive bidding at all. However, without such a procedure, the buyer cannot make any real comparison between what is offered by the available suppliers and he would lose any benefits he might obtain from competition.

In a direct negotiation approach the above-mentioned listing of tasks would still be valid up to a point, but with a substantially reduced scope. The selection of supplier(s) would in practice constitute the start of the acquisition procedure; the establishment of a project organization and staffing and the completion of data and information requirements would still be needed; the other tasks would be included into what might be called 'direct contract negotiation'.

Within the international competitive bidding approach, each task listed has a definite purpose and scope which will be discussed in the following sections of this Chapter. There are also important milestones:

- Invitation for bids
- Receipt of bids
- Issue of letter of intent (formal notification of the selected supplier(s))
- Signing of main contract(s)
- Effective contract validation.

Regarding the schedule of the acquisition tasks, the establishment of the organization and staffing and the completion of the data and information requirements might need a few weeks or several months, depending on what has been achieved in the feasibility and siting studies, and on what approach (owner's staff or consultants) is adopted for the preparation of specifications. The lack of essential data and information or the need for selecting and contracting consultants could mean substantial delays at this stage.

The preparation of bid specifications usually requires a period of about 6 to 8 months for a turnkey approach; for split package or multiple package contractual approaches a year or more might be needed. A formal invitation for bids marks the end of this period and this requires a decision that would probably involve national authorities and require some time.

In response to the invitation, the interested suppliers will prepare their bids in about six months. If extensive national participation is requested by the buyer, if the specifications are very demanding and strict or if they require substantial adjustments of available commercial designs, a few months
more might be needed. The formal receipt of bids marks the end of this stage and the start of the next one.

Bid evaluation would usually require some six months to a year and would end with the selection of the supplier or suppliers and their formal notification (letter of intent). This again is a major milestone in the project and will probably involve national authorities, which might need several months to reach a decision.

Contract negotiations overlap somewhat with bid evaluation. An additional six months to a year would normally be needed before the contract(s) can be signed. After this formal act and depending on the contract terms, ratifications, international as well as financing agreements and arrangements, and possibly downpayments will be needed to establish the contract(s) as effectively valid. These requirements might need several additional months to be completed.

The overall schedule for the acquisition phase of the project would thus be about 30 to 50 months, assuming no major delays in decision-making. It must be recognized that practically all major technical, economic, financial, policy and political decisions regarding the project are made during the acquisition phase. It is desirable that the execution of each task should be accomplished in the shortest possible time to ensure the start of the subsequent stage of project implementation in time to meet the schedule for plant operation. Priority, however, should always be given to the quality of the performance of each task. Even small mistakes committed at this stage or minor omissions can become very expensive indeed later on.

11.2. ORGANIZATION AND STAFFING

The organizational and manpower requirements for nuclear power projects and related activities were discussed briefly in Chapter 5. For plant acquisition specific organization and staffing requirements must be considered for the tasks to be performed during this stage as well as in preparation for the subsequent stages.

This includes first of all either the re-orientation of the project group set up for the feasibility study and the definition of the areas of experience where additional staff is required, or the setting up of a new group. The extent of outside experience needed to cover the areas that cannot be met by locally recruited staff should be specified. An extensive amount of work will be needed for the preparation of reports and documents, which can be handled expediently and efficiently by a team with previous experience in such type of work.

The establishment of the local organization composed of highly qualified engineers and experienced professionals is therefore one of the immediate and
important tasks to be undertaken by the authority charged with the responsibility for the nuclear project. For the initial tasks, the size of this local organization is usually not very large, probably of the order of 10 to 20 professionals under the direction and co-ordination of a project manager. The team will have to be expanded to about 30 professionals during contract negotiations. It is emphasized that it is not the number of people that is important, but their quality and experience.

If local talent is not available, it would be necessary to employ a competent foreign consulting engineering firm to assist the buyer in the acquisition of the plant. Nevertheless, the buyer can never delegate his prime responsibilities to a consultant, and should he be unable to put up a basic organization and staff for the acquisition, it might be questionable whether he is effectively ready to proceed with the acquisition of a nuclear power plant at all.

The role of a consultant is always advisory. It is important to note that a consultant without a strong counterpart of qualified local staff will probably not produce effective results and can be wasteful and costly.

Careful consideration should be given to the selection of the consultant and to the terms of the agreement for his services. There is a wide range of choice from a large number of firms. The procedure to adopt in making this selection in a timely and effective manner is to request bids from a limited and pre-selected list of well-known firms. The pre-selection of the firms should be based on a number of main considerations which may include the following:

- Experience in nuclear power projects and in the types of reactor systems chosen for the project under consideration;
- Experience in other projects in the country and familiarity with the prevailing conditions of the country and the site;
- Experience in the scope of work in all areas and stages of the project implementation;
- Reputation and impartiality towards prospective suppliers for the plant;
- Ability to provide adequate numbers of qualified staff with experience in nuclear projects to ensure continuity and efficiency in carrying out the work.

Other aspects can also be considered such as the advantages and disadvantages of having a consultant from the same country as the prospective supplier of the plant or from another country.

Taking into account the economic commitments involved in the acquisition of a nuclear power project, the selection of the consultant should not necessarily be based on the least-cost offer. The cost of the consultancy is a factor to be considered in evaluating the various consultants' bids, but should not be the primary consideration. Quality, reputation and guarantees of obtaining the best possible advice should constitute the main decision factors.
It is obvious that there would be advantage in retaining the same consultant for every phase of project implementation, but it is also necessary to ensure that the best possible advice is obtained at each stage.

11.3. DATA AND INFORMATION REQUIREMENTS

Data and information regarding the site and the national and local (site-related) infrastructures is especially relevant to the preparation of bid specifications (section 11.5) and must be available in sufficient detail and depth to permit the bidders to prepare their offers. Siting is discussed in Chapter 9.

Regarding information on the local infrastructure, this will be needed for project planning purposes and will affect project cost and schedule. Especially relevant are:

- Availability of construction materials
- The local labour market
- Construction industry and equipment in the area
- Local construction and labour rules, regulations, customs
- Housing
- Hospital and first-aid facilities
- Recreational facilities
- Schools
- Security
- Access
- Electricity supply
- Water supply
- Docking and transport facilities
- Lifting facilities.

Nuclear power plants are often located at remote sites, relatively distant from industrial and population centres. This would normally imply relatively weak site infrastructures. The information and data on what is effectively available should be complemented by information regarding plans, schedule and costs of the work to be performed to remedy deficiencies or to provide the necessary facilities or services that are unavailable. This might lead to an early initiation of site development work, even before plant acquisition is completed.

11.4. DEFINITION OF CONTRACTUAL APPROACH

Nuclear power plants have been built in many different ways. At one extreme, a single contractor has been given complete responsibility to design,
build and commission a complete nuclear plant, handing it over to the owner already operating. At the other extreme, the owner has bought only the basic hardware of the Nuclear Steam Supply System (NSSS) from a reactor supplier, designing the rest of the power plant and buying all the other equipment himself.

Basically, there are three main types of contract approaches that have been applied for nuclear power plants so far, namely:

(a) **Turnkey.** A single contractor or a consortium of contractors takes the overall responsibility for the whole work (section 11.4.1);

(b) **Split package.** The overall responsibility is divided between a relatively small number of contractors, each in charge of a large section of the work. The involvement of architect-engineering is needed (section 11.4.2);

(c) **Multiple package.** The owner, by himself or with the help of his architect-engineer (AE), assumes the overall responsibility for engineering the plant, issuing a large number of contracts to various contractors for carrying out part of the work (section 11.4.3).

One of the key decisions, which has to be made by the owner prior to the preparation of the specifications and bidding documents, is the choice of the contractual approach for the acquisition of the nuclear power plant. This decision also involves how the project management and particularly the construction management is to be organized and how the responsibilities, not only for the project work, but also to some extent for the final quality and reliability of the plant, are to be shared.

Because of the importance of this decision and its consequences for project implementation, it should receive the greatest attention and be based on careful analysis and evaluation of all salient factors, taking into account the prevailing conditions and available resources in the country in which the project will be implemented.

The main objective of most generating authorities or utilities entering the nuclear field is to build a nuclear power plant to the required schedule which will reliably produce electricity at as low a price as is consistent with adequate safety and acceptable environmental effects. In addition, other objectives could be to make optimal use of domestic resources and to gain experience from the project so that future stations can, if necessary, be better adapted to the needs of the country and depend less on foreign expertise and hardware. These last objectives determine the amount of technology transfer that should be obtained in building and operating nuclear power plants.

The main factors and considerations for the evaluation and selection of the type of contractual approach are the following:

- Local factors and conditions, including existing management, engineering and construction capabilities, industrial infrastructure, national planning and implementation policy of the first project and subsequent projects in the long-term nuclear power programme;
— Experience in project management of similar projects, particularly of fossil-fuelled power plants;
— Potential contractors and their capability, reliability and experience with different contractual approaches;
— Economic and competitiveness considerations;
— Foreign financing possibilities;
— Assurance of supply.

11.4.1. Turnkey contracts

The turnkey type of contract by definition refers to a complete power plant, ready for commercial operation, to be supplied by one supplier, the so-called main contractor. Such a turnkey order demands from the main contractor comprehensive responsibility for completing all parts and all phases of the project to the satisfaction of the client, including design, engineering, construction, erection, supply and installation, testing and commissioning of the plant. The main contractor will also be in charge of the overall project management.

The main contractor might be a single company or a group of contractors operating as a consortium with usually one member acting as the sponsor or speaker for the group. In the latter case it is extremely important that the consortium be the only and directly fully responsible party to the owner. This must be clearly defined and specified in the contract.

In a turnkey approach the main contractor is fully responsible to the owner for:

- Plant generating capacity and efficiency
- Plant quality and functionality
- Plant completion date
- Plant investment costs, excluding items within the owner's scope of supply (this responsibility might be shared with the owner).

The main contractor has to cover by his guarantee both his own delivery and services, and the deliveries and services of all his subcontractors, foreign and local. Additional requirements could consist of the preferential use of local material, equipment and labour.

Turnkey contracts vary to some extent. Reactor suppliers have in the past often accepted the turnkey contract responsibility and in some cases hired an architect-engineering firm for design and construction supervision of the balance of plant. In some countries the reactor vendors still prefer to undertake the complete turnkey contract responsibility but in other countries this is not the case. Financing institutions have in some cases indicated a
preference for split-package contracting with an architect-engineering or
engineering-construction firm serving in an overall project management capacity.

With the placing of an order for a nuclear power plant on a turnkey basis, all technical and commercial conditions for the determination of the scope of supply and performance will be agreed with the main contractor. All the provisions can be contained in a single, complete contract document, from the development of the site to carrying-out of power test operation and plant acceptance. The essential advantage of this system lies in the homogeneity of responsibility, because a single main contractor is held responsible by the buyer for all risks. In particular, the following advantages are to be obtained with the turnkey approach:

- Better possibilities through contractual arrangements for the highest degree of integration and homogeneity to be reached in the scope of supply;
- Guarantees affecting the entire plant, e.g. net power output, efficiency, delivery time, material and workmanship guarantees for all systems and components;
- Narrowing of risk for overall schedule delays;
- Simpler and quicker handling of the licensing procedures, as licensing matters that affect the whole plant can be better co-ordinated and solved;
- The utilization of standard techniques for the whole plant;
- Greater flexibility in making up for delays through re-arrangement of erection procedures or commissioning work;
- Easier interface management.

Turnkey contracting also presents disadvantages:

- Limited possibilities for competitive bidding for major systems;
- Since the turnkey contractor will have overall responsibility for the project management, the buyer's direct control over the project will be limited to whatever contractual arrangements are agreed;
- Under a turnkey contract the vendor accepts a considerable economic risk for delays and failures. This will most often be reflected in a higher bid price for the whole plant;
- Since all suppliers are not willing to accept turnkey contracts, this might reduce international competition;
- The owner's involvement in the design and construction of the project is limited, and transfer of technology may therefore also be limited, unless specifically provided for in the contract;
- If the vendor is not experienced or reliable, there is a very large risk of delays and overall failure of the project.
In summary, the turnkey approach seems especially advisable when there is little or no project management and heavy-construction experience in the country and when a large amount of training over a long period of time is required to attain the necessary skills. However, it is also used in some countries where qualifications and staff exist.

Finally, some remarks about the interpretation (or misinterpretation) of the concepts ‘turnkey’ and ‘responsibility’.

‘Turnkey’ might be used implying that all the owner has to do is to sign a contract, wait for the power plant to be completed, receive the ‘key’ to it, pay for it and then operate it. Nothing could be further from reality. There is always an owner’s scope of supply and there are essential tasks and activities that the owner has to perform himself and which he cannot possibly delegate to others. In addition there are the country’s responsibilities regarding nuclear safety.

The concept of ‘responsibility’ might also be interpreted in different ways and should be used with caution. The ultimate ‘responsibility’ for the success of the nuclear power project always remains with the owner and in particular he retains the direct responsibility for nuclear safety and plant reliability. The owner can and does delegate partial or lead ‘responsibilities’ to his contractors for the execution of tasks and the provision of supplies, which may consist of a complete nuclear power plant in operating condition, under the turnkey approach. But it must be clearly understood that the ‘responsibilities’ thus delegated to the contractors or to the main contractor are limited. Contractors are fundamentally ‘responsible’ for complying with their contractual obligations within the limits of their scope of supply and of the contractual terms and conditions. In particular, their ‘responsibilities’ are restricted by the penalty clauses for non-compliance with their obligations. It is the owner’s ‘responsibility’ to control and supervise that the contractors fulfil their ‘responsibilities’. He might delegate this task to a consultant, but then he will retain the ‘responsibility’ for the control and supervision of his consultant’s work.

11.4.2. Split package

In the non-turnkey contractual approach the buyer places a number of separate contracts for various portions of the plant and assumes the responsibility for overall project management himself or through an architect-engineer (AE) and of making all key decisions related to overall aspects of the project. Non-turnkey contracts may be divided into two main types, namely the split-package approach and the multiple-package approach.

In the split-package approach, the overall responsibility for design and construction of the plant is divided among a relatively small number of
contractors, who manage, engineer, construct and/or manufacture large functionally complete portions of the work, e.g. entire systems, buildings, etc. Each portion is called a package.

The usual split-package approaches according to the number of packages are:

(a) Two-package approach. By dividing the plant into two packages, the nuclear island and the conventional island, a certain competition and technical choice can be achieved. The owner (with or without an AE) retains part of the balance of plant (BOP) and the responsibility for harmonizing the interfaces among the two islands, which require overall project management capability. A problem may arise from having two civil constructors working simultaneously close to one another. This can be avoided if each contractor of an island is asked to select his civil subcontractor by a sequential bidding technique. The bidding for the civil works can then be arranged so as to choose a single civil subcontractor for both parts of the station.

(b) Three-package approach. This approach separates the civil works from both the nuclear and turbine islands and makes them as a third package a separate contract placed directly by the owner. Both competition and interfacing needs are increased, while the potential problem of having two constructors on site are avoided.

(c) Five-package approach. The initial bidding is for separate nuclear and conventional packages, Nuclear Steam Supply System (NSSS) and Turbine Generator (TG), each with reduced scopes of supply compared with the corresponding islands. When the two contractors have been chosen, the owner (or his AE) issues appropriate bid invitations for civil works and mechanical and electrical BOP lots to complete the power station. In practice, the electrical and mechanical lots may be let as a number of separate contracts over an extended period of time. Overall project management and interfacing would be handled by the owner, who is also directly responsible for much of the electrical and mechanical equipment. Should the owner decide to contract these services with an AE, this might be considered as an additional package.

Regarding the bidding procedure, the owner has several choices which affect overall project management and interfacing. These are:

Linked bids
Harmonized bids
Independent bids
Sequential bids.

Under the split-package approach the interface problems represent a risk to the owner of delays and extra costs. One way to avoid this while
keeping separate contracts is to invite linked bids for the nuclear island and the turbine island. Under this scheme pairs of reactor and turbine vendors are asked to submit bids for their respective scopes of supply together with a guarantee that the interface problems have been considered before the bids were submitted and that the pairs of bids are compatible.

Harmonized bids correspond to a procedure where the reactor and turbine vendors submit independent bids in response to an enquiry that specifies the interface. When the favoured bidders have been identified, they are asked to 'harmonize' their interfaces and then to quote any cost variation involved in this. This of course involves a delay in the bidding process.

Owner-engineered independent bids represent the most normal type of split-package approach and the one where the buyer takes direct responsibility for many aspects of the design of the station. The buyer takes it upon himself to negotiate any necessary amendments to the interface directly with each bidder.

It time permits, a sequential bidding procedure can be utilized for the split-package approaches. In this case bids will first be invited and assessed for the nuclear island (with or without civil works) or NSSS. The bid specification for the conventional island or TG lot can then be issued with much better-defined interfaces.

11.4.3. Multiple package

The owner (either within his own organization or through his architect-engineer) assumes the direct responsibility for the design and construction management of the project with a large number of contracts (of the order of a hundred).

The multiple-package approach has now been adopted as a normal way of contracting in many countries. Bids are invited for NSSS and TG packages, the suppliers are selected, contracts are placed and the owner (or his AE) then designs the balance of plant around this equipment. He will produce a very large part of the safety report and supervise construction, usually erecting the plant himself. This approach clearly offers the maximum opportunity to the buyer to select the plant that suits him best and to influence the design as he would wish. It also gives him, if he is well qualified and experienced, a good chance of having a minimum-cost plant. On the other hand, it gives him (or his AE) the maximum amount of work and responsibility for the proper technical design, the cost, the schedule and the plant performance.

In principle, the same bidding procedures can be applied as for the split-package approach. The interface problems between the two main suppliers are, however, limited to the main steam and feedwater conditions, so that there is no particular need to have linked or harmonized bids.
11.4.4. Use of architect-engineers

When adopting a non-turnkey approach, utilities with no previous nuclear experience should only embark on a nuclear project with the help of a competent architect-engineer (AE). In such a case the selection of the AE as well as the proper division of activities and responsibilities between the parties involved are key issues for the success of the project.

The division of activities and responsibilities between the owner and the AE depends to a great extent on the availability of qualified personnel on the staff of the owner. The AE usually gets lead responsibility in:

Overall project management
Procurement
Project engineering
Erection and equipment installation
Commissioning
Quality control
Schedule and cost control.

The tasks of the AE differ in nature and scope for split-package and for multiple-package approaches. For example, in designing the plant the AE in case of a multiple-package approach is concerned with layout and detailed system design, whereas in the case of a split-package approach he is only concerned with the review of the design proposed by the contractors and the interfaces between the large packages.

The selection of an AE for a nuclear power project must mainly be taken on the basis of his competence in the field and on the key personnel that he can make available for the project.

As an alternative to the use of an AE, the owner might consider one of the contractors (usually the NSSS supplier) to take the additional tasks of architect-engineering, i.e. overall project management, design, engineering, etc. Such arrangements have been applied in a few cases.

11.4.5. Comparison of non-turnkey approaches

Non-turnkey contracts have been mostly used in those countries where the utilities have experience in nuclear construction and in handling this type of contractual approach either directly or with the assistance of a competent AE or a main contractor as discussed in the previous section.

The multiple-package and the split-package approaches are the two non-turnkey contracting possibilities that reflect the basic differences in industrial practice between the USA and Europe.
In the USA the large industrial concerns mainly manufacture components and do basic engineering, whereas project engineering (layout and detailed system design) is carried out by specialized architect-engineering companies. The multiple-package approach is mainly based on US practice in constructing large industrial facilities, including nuclear power plants. The approach is also applied in countries that are strongly influenced by US industry, or in countries such as France or the UK where there is a large electric utility with its own engineering capability and staff for the implementation of its electric power plants.

The responsibilities of the owner are greater by far in the case of a multiple-package approach than in the case of a split-package approach. This, in particular, is the case as regards organization, management and costs. Moreover, the division of tasks, functions and responsibilities for a collaboration (if any) with an AE is more difficult.

The involvement of the owner depends on the work to be carried out by the AE, but is in general greater for a multiple-package approach than for a split-package approach. This allows, on the other hand, more influence on the design, more flexibility in the event of changes, a larger learning effect and better chances for local participation.

The main problem areas for the multiple-package approach are the overall project management and the division of responsibilities between the owner, his AE and any other engineering companies involved and possible construction problems due to the lack of appropriate co-ordination. In the split-package approach the problem is mainly the management of the few large contracts and the interfaces between them. This split-package approach has been applied to a large extent in the construction of conventional power plants and offers in general a fair amount of freedom in selecting suppliers and equipment for the different parts of the plant.

In some developing countries non-turnkey contracting could be considered with the adequate assistance and services of a competent AE. The main contractor alternative to the AE approach should be carefully evaluated and is in general only possible if the chosen contractor has full in-house capability and capacity for managing and engineering a nuclear power project.

In principle, the multiple-package approach offers the possibility of more competitive bidding than the split-package approach, and this should lead to a minimum overall cost. However, in practice, due to a higher probability of cost overrun, the final cost of the plant may be higher.

Each supplier can only be expected to offer guarantees and warranties for his own scope of supply (including his subcontractors). The more individual suppliers are involved, the less overall guarantees on the power plant can the owner expect. Similarly, as the number of suppliers increases, so do the problems of co-ordination, communications and the risk of misunderstandings and inefficiency, which may lead to delays and cost overrun.
11.5. BID SPECIFICATIONS AND INVITATION OF BIDS

11.5.1. Purpose, scope and procedures

Bid specifications are intended to provide information to the prospective suppliers who are invited to present their bids. This information should be as complete and precise as possible, so that the suppliers obtain a clear understanding of what the buyer wishes to purchase, what are his requirements and what are the conditions and circumstances under which the suppliers' tasks are expected to be performed. Furthermore, the bid specifications are intended to present to the bidders the buyer's requests for information, in a manner that will facilitate the buyer's bid evaluation. Finally, the bid specifications are intended to serve as the basis for the contract documents to be developed together with the successful bidder.

In all further discussion of the subject it is assumed that the acquisition approach of the buyer consists of competitive bidding. In a direct negotiation approach with a pre-selected supplier the preparation of a formal bid specification document would not serve any useful purpose. The pre-selected supplier would still need fundamentally the same information from the buyer and would have to provide him with the same information as in a formal bidding procedure, but this information exchange would take place within the framework of direct contract negotiations.

The preparation of formal bid specifications is required for any type of competitive bidding. The content will depend on the contractual approach and on the scope of supply requested by the buyer.

Table XXXIV contains a summary of the contents, which might be used as a guide for the type of information to be included in the bid specifications for a nuclear power plant or package (Nuclear Island, NSSS, etc.). The general outline of this example would also correspond to the reactor core (section 11.5.5).

Bid specifications are not confidential documents. They could be available upon request from the utilities that have prepared them in the past and could be consulted as useful reference material. However, bid specifications always refer to specific situations and therefore cannot be adopted without extensive adjustment.

The preparation of specifications for a bid invitation of a nuclear power plant is a highly specialized task which requires an experienced staff. Part of the information required has already been developed during the earlier studies and any experience acquired during the bidding and acquisition of fossil-fired power plants will be very useful.

The utility/owner would have experienced staff in the acquisition, construction and operation of conventional plants. There should be also
TABLE XXXIV. SUMMARY CONTENT OF BID SPECIFICATIONS
(Example)

I. Information provided by the owner

1. Invitation letter
2. Administrative instructions
3. General information
   (a) Project description
   (b) Site information and data
   (c) Electric system
   (d) National infrastructure
4. Technical requirements and criteria
   (a) Design
   (b) Construction
   (c) Operation
   (d) Safety and licensing
   (e) Quality assurance
   (f) Training
   (g) Schedule
   (h) Documentation
   (i) Codes and Standards
5. Scope of supply
6. Technology transfer
7. Terms and conditions (draft contract)

II. Information requested from the bidder

A. General

1. Technical description
2. Safety analysis report of bidder’s standard design
3. Scope of supply
4. Commercial conditions
5. Quality Assurance programme
6. Deviations and exceptions
7. Relevant experience

B. Summary of selected information

1. Technical conditions $desc$.  
   (a) Design
   (b) Construction
   (c) Operation
   (d) Safety
   (e) Quality Assurance
TABLE XXXIV (cont.)

<table>
<thead>
<tr>
<th>2. Commercial conditions</th>
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<tbody>
<tr>
<td>(a) Prices and currency</td>
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<td>(b) Escalation formula, indices</td>
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<tr>
<td>(c) Payment schedule</td>
</tr>
<tr>
<td>(d) Financing</td>
</tr>
<tr>
<td>3. Scope of supply</td>
</tr>
<tr>
<td>(a) Foreign</td>
</tr>
<tr>
<td>(b) Local</td>
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<tr>
<td>4. Guarantees and warranties</td>
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<td>5. Deviations and exceptions</td>
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qualified professionals available within the country who are experienced in the acquisition of large industrial plants, and others who have received specialized training and education in subjects relevant to nuclear power.

It is highly recommendable that the buyer organizes a team from his available staff, augmented by others recruited for the specific purpose of preparing the bid specifications. Depending on the contractual approach, about 15 to 25 qualified professionals would be needed. It is generally advisable to have also the assistance of a well-qualified consultant to supply any missing experience and knowledge in the owner’s team.

The preparation of the bid specifications constitutes the first stage of the plant acquisition process. The bid specifications must be clear, precise, unambiguous, consistent and comprehensive. What is needed is a technical, commercial, legal contractual document. It is advisable to have the specifications reviewed by people used to preparing and handling contracts, even if they have no nuclear experience. Nuclear engineers might have a profound technical and scientific knowledge in their specialty, but they do not necessarily command the techniques involved in the preparation of bid specifications and later on of the contracts.

As a complement to the bid specifications, to assist the bidders in the preparation of their bids, they should be given access by the buyer to the site and to any additional studies and surveys that have been performed with regard to the nuclear power project. Direct contact of the bidders with local industries and relevant organizations should be promoted.

Further detailed information on the subject of bid specifications is being developed by the IAEA in a guidebook in preparation and expected to be published in 1982/83.
11.5.2. Information provided by the owner

According to the example presented in Table XXXIV, the introduction to the bid specifications would consist of an invitation letter (this letter might also be a separate document).

In the invitation letter a summary is given of the documents and highlights of the bid specifications, giving emphasis to those parts that the owner feels are of particular importance for his project. It should be kept as short as possible and should contain no details of the subjects that are going to be treated in the rest of the bid specifications.

The administrative instructions to the bidders should contain all organizational and administrative procedures for submitting the bid documents. These instructions should only contain matters that are of no importance once a contract has been signed, so that they can be neglected as far as the contract documents are concerned.

The buyer should indicate in the instructions to the bidders the bidding conditions. The bidding conditions normally contain particular instructions for the submittal of the bids, such as the date for submission, the language(s) in which the bid can be submitted, the engineering unit system to be used, the number of copies, etc.

Further, the bidder shall be deemed to have carefully examined all the conditions of the bid invitation and to have fully informed himself of all the conditions locally and otherwise affecting the carrying out of the work. The bidding conditions should also contain instructions regarding the indication of prices in the bids and an indication of the validity of the bids.

In order to inform the bidder on which items particular emphasis is placed, it is important to indicate the bid evaluation criteria that will be applied by the buyer for evaluation of the bids. Clear instructions have also to be given for the presentation of the bids, in particular regarding the separation of the commercial-bid from the technical-bid documents.

Suppliers cannot be expected to prepare complete and firm bids without having been given sufficient and adequate general information on the project, the site, the electric system and the local and national infrastructures available. Any bids based on a bid invitation without this information can only be regarded as preliminary.

The project description provides information about reactor types, unit rating, number of units per site, time schedules for the implementation of units at the site, technical and economical lifetime, expected load factors, operating mode, etc. Environmental data, especially referring to climate and cooling conditions, must also be enclosed.

The site data and information must be as comprehensive as possible and should also include those site conditions that in a first instance may not be considered as directly applicable to the nuclear power project. Preferably,
the same document as prepared for the authorities for obtaining the site review and approval should be used. The requirements for siting studies have been considered in Chapter 9.

The provision of complete site information is especially important for the turnkey and split-package approaches for the power plant. It is less relevant to bidders under a multiple-package approach. The bidders should be offered free access to inspect the site and encouraged to perform their own studies or analysis that they might consider necessary. Ultimately, such an approach can only work out to the advantage of the owner.

The information on the electric system includes a description of the generating units and transmission lines into which the nuclear unit will be integrated, and the operating conditions. This includes information on capacity, voltage, frequency, generator operating and load diagrams as well as electrical supply from the grid to the plant during construction and operation (normal and abnormal conditions). In addition, the behaviour of the unit in case of system faults must be defined. Of importance are the requirements for base load or load-following operations.

The information on the national infrastructure should be as complete as possible and may deal with the following subjects:

- National participation policy and strategy
- Engineering firms
- Construction and erection industry
- Electrical industry
- Mechanical industry
- Electronics industry
- Applicable national codes and standards
- National labour legislation
- The nuclear regulatory system, codes, standards, rules and guides.

The relevant results of the previous surveys and studies (nuclear power planning, feasibility study) should be included in this section of bid specification as basic information for the bidders.

In addition, if there is a policy for promoting national participation, the bid specifications should contain clear indications to that purpose. It is advisable to include lists of what equipment, components and services the owner expects to be supplied by national sources. Furthermore, the proposed procedures to implement the national participation goals should be clearly outlined.

It should be recognized that suppliers will only bid according to their available standard designs, with the modifications needed to fulfil the buyer’s general requirements and local conditions.

Taking into account this limitation, the technical requirements and criteria included in the bid invitation should be, whenever possible, functional specifications.
that specify the general and particular requirements imposed on the equipment with regard to basic function, performance, redundancy, automation, etc. Functional specifications should provide the utility with maximum protection on performance of equipment and systems, but should also allow the bidders the freedom to offer their standard type of equipment and systems if they consider that these conform to the owner's requirements. Equipment specifications are only suitable if a particular type of component is required for the completion of a certain system or group of systems. The application of this latter type of specification should be limited to multiple-package approaches.

The main purpose of the technical requirements and criteria is to provide the bidders with information on what the buyer wishes to acquire. The technical requirements and criteria should be clearly stated, possibly along the lines contained in Table XXXIV.

As an example, design requirements and criteria in the bid specifications constitute the basis for the layout of the plant, ensuring an optimum use of the space available and taking into account access to the plant and possible future extensions. The layout should ensure safe and economical operation of the plant, access to the controlled areas, adequate capacities of areas for the storing of wastes and consumables, and the temporary storage of equipment during maintenance. The layout criteria should also contain a section on the zoning criteria that will be applied in the plant. The seismic design criteria to be adopted and applied to the plant should be specified, as well as the basic design rules that have to be applied for a proper seismic design. Operation requirements and criteria should include details on base load or load-following capabilities, minimum continuous load, capabilities of the plant to operate isolated from the grid, start-up and loading of the unit, step and ramp load changes, operational cycles, stretch-out capabilities, etc.

The requirements of the buyer of a nuclear power plant regarding documentation to be provided by the supplier are more extensive than would be the case for a fossil-fired plant, owing to the nuclear safety implications as well as to the complexity of such a unit. The documents usually requested from the supplier as part of his scope of supply are the following:

(a) Schedule of execution and progress reports, together with project routines which the supplier must develop for the project;
(b) Technical descriptive documentation, which consists of descriptions, specifications, drawings, technical data, flow sheets and other technical information of equipment and systems. This documentation must be updated continuously in the course of the project;
(c) Information on interfaces to enable the owner to design those items that have been excluded from the supplier's scope of supply;
(d) Operation and maintenance manuals;
(e) Safety analysis reports and additional information as might be required by the authorities for licensing the plant.

The owner must have the right to review the documents received from the supplier in order to check that the station is being built according to the requirements laid down and in compliance with the codes and standards of the licensing authorities.

The scope of supply requested by the buyer has to be clearly specified. In addition, the owner's scope of supply has also to be specified. Should the buyer have any specific requirements regarding technology transfer, he should state them in as much detail as possible.

11.5.3. Terms and conditions (draft contract)

The buyer should always include in the bid specifications a draft contract with the terms and conditions he wishes to agree to with the successful bidder. The draft contract should be clear and precise and should contain reasonable terms and conditions designed to protect the owner, but also equitable and acceptable to the bidders. The bidders must provide comments and justifications regarding their deviations from and exceptions to the buyer's terms and conditions. The draft contract, together with the comments of the successful bidder, will form the basis for the contract negotiations. Part of the bid evaluation procedure will consist in analysing the bidders' comments about deviations and exceptions.

The draft contract should deal with the administrative, organizational, commercial, legal and technical matters that are of overall importance to the project and that need to be settled in the final contract document.

The draft contract should define the responsibilities of the supplier regarding his supplies and services to be provided from abroad as well as through local sources. The supplies and services comprise studies and technical documents, design, manufacture, inspection of manufacture, tests, transport, insurance and storage, erection and testing of material and equipment, pre-operational testing, commissioning, demonstration run, compliance with the guarantees and warranties, and assistance and services during operation and maintenance.

Usually, the draft contract includes the following items:

- Basis for the contract
- Scope of supply and services
- General agreements
- Risks, liabilities and title
- Insurance
Licensability and licensing conditions
Inspection and control
Delivery times
Technical guarantees and warranties
Acceptance and final take-over
Price, price revisions, terms of payment
Changes and modifications
Force majeure
Contract modifications or cancellation
Applicable language, laws and arbitration.

The draft contract should in particular deal with the various aspects of risk of loss and damage, liabilities and transfer of title. With a turnkey approach the supplier should carry the risk of any loss or damage until the date of take-over, except the nuclear risk, which is always borne by the owner. In the event of injury suffered by persons, or loss or damage sustained by or occasioned to third parties, their properties or possessions, the liability of the supplier and the owner should be determined by the law of the country where the injury, loss or damage occurred. The transfer of title and property in all or any materials, goods, equipment or systems intended for inclusion in the nuclear power plant should pass to the owner upon the same being delivered to or received at the site or on take-over of the plant.

Guarantees and warranties should cover design, material, workmanship, delivery and performance, following the usual practice.

All matters, such as prices, price revisions, terms of payment, force majeure, cancellation of the contract, applicable law and arbitration courts, can be dealt with in a conventional way as for any other contracts. It is emphasized that the draft contract must be prepared with extreme care by specialists in this field, including good industrial lawyers with international experience. It is further advisable to provide a set of definitions that are used consistently throughout all documents.

11.5.4. Information requested from the bidder

This part of the bid specifications contains the buyer's requests for information to be provided by the bidders in a manner that facilitates the buyer's bid evaluation (see Table XXXIV).

In principle, the bidders are requested to provide a complete technical description of their precisely defined scope of supply. They are also requested to present information on their compliance with nuclear safety requirements, and the quality assurance programme to be applied. In addition to the technical aspects, the bidders are requested to provide all information on the
commercial aspects of their bids as well as all deviations and exceptions (including justification) they may have regarding the buyer's terms and conditions as contained in the bid specifications (draft contract).

As international competitive bidding entails receiving bids with different approaches and contexts, the buyer should request a summary of selected information along the lines presented in Table XXXIV. This summary information should be presented in standard formats provided by the buyer in the bid specifications.

Finally, the bidders should be requested to provide extensive information on their relevant experience and capability to provide the goods and services they offer.

11.5.5. Nuclear fuel cycle and reactor core bid specifications

Nuclear fuel, fuel cycle services and reactor core components such as control devices, fuel channels and in-core instrumentation should be acquired at the same time as the nuclear power plant is acquired. In principle, it would be desirable to have these specifications as part of the bid specifications for the nuclear power plant, but in most cases the reactor or power plant suppliers only supply the fuel fabrication service and core components, either directly or through subcontracting. Thus, the owner would have to acquire from different sources:

(a) Uranium
(b) Conversion to UF$_6$ and enrichment services (for enriched-uranium reactors)
(c) Reactor core (including fuel element fabrication)
(d) Spent fuel management (transport, storage, reprocessing, waste disposal).

Uranium is acquired either within the country (if available) or in the world market in the form of yellowcake, which is a commercial product. If a competitive bidding procedure is adopted, the bid specifications would include an invitation letter, instructions to the bidders, draft contract and technical requirements. The technical requirements are relatively simple and consist of the chemical and physical composition and concentration of the material with particular attention to the admissible content of impurities.

The acquisition of conversion (to UF$_6$) and of uranium enrichment services is either done through a competitive bidding procedure, or through a direct negotiation approach where formal bid specifications are not required.

The provision of natural uranium and of conversion and enrichment services (if needed) would thus become part of the owner's scope of supply in the bid specifications for the acquisition of the reactor core (including
components and fuel element fabrication). The reactor core specifications can either be a part of the bid specifications for the nuclear power plant (or NSSS) or can be dealt with separately. It is in general recommended to include the first reactor core (with options for subsequent reloads and/or core components) as a part of the bid specification for the power plant (or NSSS). The core specifications should, however, be of such a structure and so complete that they can easily be separated, because reloads and replacements of core components will be acquired at later dates.

The reactor core specifications would have a similar structure to the plant or package specifications of Table XXXIV; however, there would be differences in the content owing to the scope of supply. It is important to request the integral supply of all consumable elements of the reactor core, such as control devices and in-core instrumentation, in addition to the fuel elements, because both they and their replacements must be compatible with each other and with the reactor itself. It would also be desirable to include in the scope of supply of the reactor core the fuel and the fuel cycle services (front and back-end), at least those that might be available from the plant or NSSS suppliers. In particular, in-core fuel management services and codes (optimization and reloading schedules) should always be included in the requested scope of supply.

Even if the reactor core is acquired separately from the power plant or NSSS, it is essential to combine both specifications and later on both contracts. The nuclear fuel elements and core components must be designed and manufactured to be fully compatible with the reactor performance, physical characteristics and all other interrelated features. The technical requirements imposed on the nuclear power plant must also apply to the nuclear fuel, wherever appropriate. The need for combined guarantees and warranties is possibly one of the principal factors supporting the recommendation to include the first reactor core in the scope of supply of the nuclear power plant (or NSSS).

11.6. THE BID PREPARATION PHASE

Once the bid invitation has been issued, the suppliers will start preparing their bids. This task will require six to eight months for a turnkey project and somewhat less (four to five months) for each of the principal packages in non-turnkey approaches. If harmonized or sequential bidding procedures are adopted (section 4.4.2), the bid preparation phase will overlap with bid evaluation and will last considerably longer. The cost of preparing a bid for a nuclear power plant is of the order of several hundred thousand dollars.

Though the main activity, i.e. the preparation of the bids, will be performed by the bidders during this phase, there are also some tasks for the buyer, consisting of:
(a) Proceeding with additional studies that might be required for site evaluation
(b) Maintaining contact with the bidders and providing them with additional or clarifying information as required
(c) Preparing for bid evaluation.

It is intended that the bid specifications should be complete, clear and unambiguous, but it must be recognized that the bidders will undoubtedly find mistakes and omissions which will require clarification by the buyer. The bidders will also find at least some of the buyer’s requirements unacceptable or too difficult and expensive to comply with and will approach him with requests for modifications. As it is desirable that the bids should correspond as far as possible to the bid specifications, the buyer might want to reconsider his requirements and modify the specifications accordingly.

This will generate a constant correspondence and flow of information which has to be channelled by the buyer to all holders of the bid specifications simultaneously. Every communication of the buyer that refers to the bid specifications, clarification, modification or addition must be in writing and must be incorporated into the specifications.

Finally, the bid preparation period should be used by the buyer to prepare himself for the evaluation of the bids. The bids will have a limited validity and the evaluation should proceed as smoothly and rapidly as possible. Preparatory action that will facilitate the performance of the bid evaluation includes:

(a) Organization of the evaluation team
(b) Assignment of responsibilities
(c) Development of evaluation methodology
(d) Analysis by the evaluation team of the available technical information on the bidders’ products
(e) Pre-evaluation of the bidders
(f) Cost estimates of items within the owner’s scope of supply.

11.7. BID EVALUATION

The evaluation of the bids received from suppliers in response to the bid invitation is a major task leading to the selection of the supplier(s) and the final decision to construct the nuclear power plant.

The buyer has a direct responsibility to perform the bid evaluation within his organization and with his own staff. As expertise is needed in many different fields and disciplines, assistance from an experienced and impartial consultant might be required for specific tasks, especially for a first nuclear power project.
The period required for bid evaluation is usually six months to a year. About 30 experienced professionals will be needed, most of them engineers in various disciplines, but also lawyers and economists. A core of top-level management staff will have the task of directing and co-ordinating the evaluation effort.

The overall bid evaluation can be subdivided according to different aspects:

- Technical
- Safety
- Economic
- Financial
- Contractual conditions
- Organizational and management
- National participation and technology transfer.

Some of these aspects could be linked; the safety evaluation could be part of the technical evaluation or the economic evaluation could include the financial factors; others might be subdivided further, considering aspects such as assurance of supply, reliability of the supplier, completion schedule, etc. separately.

The first task of the bid evaluation is to establish the evaluation factors to be considered. The establishment of their relative importance or weight is extremely difficult and in some cases might be beyond the scope of responsibility or capability of the owner's evaluation management. Some aspects, especially those affecting national policy and financial matters, would probably involve high governmental levels.

The technical (including safety), economic and financial evaluation of bids is covered in two IAEA guidebooks, "Technical Evaluation of Bids for Nuclear Power Plants", Technical Reports Series No.204 (1981), and "Economic Evaluation of Bids for Nuclear Power Plants", Technical Reports Series No.175 (1976). Accordingly, these subjects will not be discussed in detail in the present Guidebook. However, for the sake of completeness, a few general comments are included.

The main objective of the technical bid evaluation is to determine the technical acceptability of the bid, which means the assurance of adequate conditions of safety and reliability. The nuclear power plant must be licensable in the country with known risks of anticipated extra costs for additional licensing requirements during construction and should further give assurance of adequate operability and maintainability.

The technical bid evaluation is essential and independent of the acquisition approach adopted (competitive bidding, direct negotiation, turnkey, non-turnkey). It should be kept in mind that the success or failure of the project ultimately depends on the overall technical performance of the plant.
In general, the scope of the technical bid evaluation includes:

1. Checking the bid for completeness of the information requested.
2. Checking the scope and limits of supply and services and of interfaces.
3. The evaluation of the technical features of the equipment and structures as well as the adequacy of the services.
4. The preparation of questionnaires, evaluation reports (including the identification of problem areas) and of suitable technical documents.

The main objective of the economic evaluation is to establish the cost of the plant and to rank the bids in accordance with an economic figure of merit. Frequently the construction of the first nuclear power plant is among the largest single projects ever undertaken by the country. Hence, the economic and financial analysis of the bids should be carried out from a national point of view. Due consideration should also be given to the fact that the construction of a nuclear power plant is not an isolated event but part of a more comprehensive nuclear power programme which will involve the construction of several future nuclear power plants.

It will depend on the particular situation whether the total investment required, the unit energy cost, the present worth of lifetime expenditures, the expenditures to be paid before start of operation, the expenditures in foreign currency, the internal rate of return, the cost/benefit ratio, or some combinations of these yardsticks are regarded as decisive for the economic order of merit.

The basis for the economic and financial bid evaluation is a combination of data contained in the bids and data developed by the buyer. The bids contain price, payment schedules, escalation, possibly also financing terms and conditions, within the defined scope and limits of supply. The buyer will have to provide economic parameters, such as present-worth rate (or discount rate), economic life of the plant, exchange rates of foreign currencies, and the cost estimates of his own scope of supply which is needed to complete the nuclear power plant. This last involves interfacing with the technical bid evaluation. In addition, he will have to provide long-term predictions regarding fuel costs. Most of these parameters and data involve elements of judgement and/or estimates. Taking this into account, the results corresponding to the economic ranking of bids should be interpreted as ranges. Also, the order of merit might change if a different set of parameters and data are applied within the estimated range of accuracy.

The general methodology applied for the economic and financial evaluation of the bids is fundamentally similar to the one used for planning and feasibility studies. Further information on this subject can be obtained from the IAEA Guidebook on “Economic Evaluation of Bids for Nuclear Power Plants” (Technical Reports Series No.175) published in 1976.
The evaluation of the contractual conditions fundamentally consists of identifying any exceptions or deviations contained in the bids with respect to the owner’s bid specifications and of evaluating their effect and importance.

Most of the differences between the requests specified by the buyer and offers of the bidders can be resolved during contract negotiation reaching compromises and agreements, but some might be of such fundamental nature that they could eliminate the prospective supplier from the bidding procedure, unless he is willing to modify his position. It is desirable to identify such fundamental exceptions or deviations at an early stage of the bid evaluation procedure. Negotiations should be immediately started to resolve the differences, because if the positions of the buyer and bidder are not reconcilable and mutual agreement does not appear likely, further evaluation of the particular supplier’s bid would be useless.

The evaluation of organizational aspects could be considered separately or included in the scope of the technical evaluation. Its main purpose is to establish a measure of confidence based on technical judgement on whether the project can be implemented within the schedule and cost commitments of the bid. Project management is possibly the most relevant aspect to be analysed in detail, together with the proposed organizational structure to handle subcontracting and interfacing.

The detail and depth of the evaluation of national participation and technology transfer depends strongly on the national policy in this matter. Should there be ambitious national participation goals and a serious commitment to implement them, then this aspect could become one of the decisive evaluation factors. In this case, ‘good will’ clauses or expressions of ‘best effort’ on the part of the bidder are certainly not sufficient. The evaluation must include detailed quantitative and qualitative assessments of the commitments contained in the bid.

Finally, the evaluation of the policy and political aspects of the bids can probably not be performed by the bid evaluation team. However, the team does have the task of providing the national decision makers with all relevant information on the issues involved, pointing out advantages, disadvantages and potential problem areas, such as international commitments and agreements, export licensing, and assurance of supply.

The overall bid evaluation is normally performed by several specialist teams working in parallel on the different aspects, directed and co-ordinated by a manager. The evaluation (project) manager reports directly to the decision-maker level of his organization. Setting up an ad hoc bid evaluation committee to assist and advise both the decision makers and the manager is advisable, in view of the magnitude of the project as well as the interdisciplinary character of the work.

It is emphasized that bid evaluation not only requires a high level of technical competence, but also and especially absolute integrity and impartiality.
of all the persons involved. Bid evaluation is one of the most delicate phases of the plant acquisition process; it leads to decisions involving large amounts of money and diverse commercial interests. Hence pressures and attempts to influence the evaluators are not uncommon. Bids also might require confidential treatment, especially regarding the economic and financial contents which usually are presented in separate documents. The procedures adopted for the organization, staffing and carrying out of the bid evaluation process should take into account the above-mentioned factors.

Regarding the evaluation approach in a competitive bidding, the two-stage approach is in general recommended. This means a first preliminary and a second detailed evaluation phase. The preliminary evaluation, which can be performed in a month or two, has the objective of selecting the preferred bids (possibly two or three, if a larger number of bids has been received), which will then be evaluated in detail during the second phase. This approach helps to reduce the work load while maintaining the competition during the contract negotiation period. During the whole evaluation phase there will be constant communication with the bidders, preferably written but also oral, with the objective of completing the information contained in the bids and clearing-up doubts. To this effect, both the bidders and the buyer must have duly authorized representatives with adequate authority and technical qualifications to expedite a fast and efficient information flow.

11.8. SELECTION OF SUPPLIER(S)

Except for the direct negotiation approach where the supplier(s) have been pre-selected without competitive bidding, the selection of the successful bidder(s) who will be awarded the contracts to become the supplier(s) of the plant is based on the results of the evaluation of the bids received, as well as the results of the contractual negotiations that have been held before this final decision is taken (see also section 11.10).

As a result of the evaluation, the bids can be and usually are ranked in order of merit according to each specific aspect. The ideal case would be if a bid could be classified in a top position in every aspect, i.e. technically the best, the least expensive, with lowest kW·h costs, best financing terms, etc. This, of course, would be too much to hope for. In practice, the selection will have to be based on a compromise solution where some minimum conditions must be met by any potential winner. Such minimum conditions are:

- The scope of supply must be such that together with the owner's clearly defined contributions there is assurance that the project can be completed successfully
- The bid must be technically sound and acceptable
— The commercial risk must be acceptable (see also ‘provenness’, section 10.3.2)
— The nuclear power plant must comply with the applicable safety criteria and must be licensable in the buyer's country
— The bid must have satisfactory economic conditions and assured financial viability
— The owner's fundamental contractual terms and conditions must be met and basic agreements reached on all important contractual matters
— The organizational aspects must give reasonable assurance of efficient project implementation
— The political viability of the bid in particular, and of the nuclear power plant including its fuel in general, must be assured.

The concepts of ‘assurance’ and of ‘acceptability’ have been used in the above listing of minimum conditions. It must be realized that these concepts can be interpreted in different ways and what might be satisfactory to one buyer might not be for another. There are always value judgements involved, but what is important is that these value judgements must be made by the buyer (utility/owner and/or government) with full understanding of the issues, risks and commitments involved and the capability of making the right judgements. In the present Guidebook emphasis has been placed on the need for a substantial intervention in a leading role in all pre-contractual activities of the owner/utility and of governmental organizations of the buyer country. One of the reasons for this is that only through active participation and by accepting responsibilities can a national decision-making capability be developed to the degree necessary for nuclear power.

Having made the selection of the supplier(s), usually a letter of intent is issued, which communicates the buyer's intention to the supplier(s) for proceeding with the contractual arrangements. This letter of intent should contain a brief summary of the principal aspects of the supply to be contracted and should make reference to the documents that are to be used as a basis of the contract to be developed. The letter of intent might also contain a limited authorization for work to be performed by the supplier, such as ordering the heavy components which involve long delivery times, before the contract is concluded. This authorization in effect already constitutes a limited contract and as such commits both the buyer and supplier. Its issue will depend on the buyer's confidence in reaching a satisfactory conclusion of the contract within a reasonable period and on his urgency in starting (and finishing) the project.

11.9. ARRANGEMENTS FOR FINANCING

The financing requirements, constraints and sources have been discussed in Chapter 5, section 5.10. Obviously, a nuclear power project is only viable
If assured financing is available. This might constitute a major constraint to countries poor in capital and financial resources or where many different investment requirements compete for the available resources.

Because of the relatively large investment requirements of a nuclear power plant, its financing should be viewed within the framework of the electricity and energy sector, and even within the whole economic activity of the country if it represents a sizeable portion.

Whenever financing is a major constraint, it is customary to request financed offers in the bid specifications. It would not be reasonable to expect the reactor or nuclear power plant vendors to directly finance their supplies, though they might offer some partial financing, but probably not on preferential terms.

The vendors, however, do have access to their national export financing institutes, whose objective is to facilitate exports and where preferential terms might be obtained. There is, thus, a common interest between the vendor and his national financing institute to promote the sale.

The two parties in a financing arrangement are the financing institute and the buyer of the power plant. The vendor is not a party, though the funds of the loan are ultimately channelled to him. Thus, the financing arrangements have to be negotiated directly between the buyer and the financing institute. The vendor can only provide assistance, but this could be of fundamental importance for obtaining loans on the best possible terms.

Financial institutes are usually reluctant to commit themselves before a supply contract is finalized between the buyer and the vendor. However, if the acceptability of the bids is subject to being accompanied by a financing offer, they might issue a conditional letter of intent.

Preliminary discussions can and should be held with the financing institutes during and even before the bidding process, but in practice, financing contract negotiations are only started after the supplier is selected and at least a letter of intent for the supply is issued. Financing institutes may even insist on there being a signed supply contract available before the start of financing contract negotiations. The buyer, on the other hand, would normally be reluctant to commit himself to a supplier before having a clear understanding of at least all principal terms and conditions of the financing contract. This conflicting situation is usually resolved by a compromise solution which makes the letter of intent and contract for the supply conditional to the finalization of satisfactory (to the buyer) financial arrangements.

Financial institutes do have standard contract forms, but for the large amounts involved in a nuclear power plant and if preferential loans are involved, special contracts are usually drawn up containing terms and conditions, some of which might not be acceptable to the buyer and consequently have to be negotiated. Lawyers and economists of the utility/owner and probably also of the Ministry of Economy would perform the contract negotiations. Technical knowledge regarding the nuclear power project is practically not required.
Financing arrangements culminating in the signing of the financing contracts might require several months and sometimes even a year or more. If the supply contract is conditional to the financing arrangements being completed, there is an evident urgency involved, because the supply contract does not become effectively valid and major work on the project cannot start until financing arrangements have been completed.

11.10. NEGOTIATION AND FINALIZATION OF THE CONTRACTS

All the tasks performed during the acquisition phase lead up to the finalization of the contracts.

The primary task to be performed in contract negotiations is to set out precisely and clearly the contractual terms and conditions, and to define the responsibilities of the supplier as regards to the scope of supply, services, warranties, guarantees and compliance in general with the codes, standards and regulations adopted for the plant. The major difficulty encountered is that most suppliers today limit their scope and responsibility, leaving extensive areas of undetermined extent in the owner's scope. This situation can lead to considerable increases in the cost of the project as well as difficulties in the management and execution of the work and maintaining a firm schedule.

The bid specifications and in particular the draft contract (section 11.5.3) contained in the bid specifications, together with the bid prepared in response to the invitation constitute the basic documents for the elaboration of a contract. For a nuclear power project there will always be several contracts. Even under a turnkey approach, in addition to the main contract for the supply of the plant, there will be contracts for the owner's scope of supply and probably for fuel and fuel cycle services and for financing. For a split-package approach a contract will be needed for each package and for a multiple-package approach there might be as many as a hundred contracts involved. Each contract needs careful preparation because these documents will precisely define the activities to be performed and the goods and services to be supplied as well as the terms and conditions under which this will be done.

The bid specification and the bid have to be combined in each case into one single document, the contract, which should be clear, precise, complete, fair, equitable and to the ultimate benefit of both parties. If any of these conditions are not fulfilled, the relations between buyer and supplier may deteriorate and the partnership, which is the desired aim of the relationship, may not be achieved. Good contracts, though not a guarantee, do constitute an essential condition of success of the project.

Contracts are not imposed unilaterally; they constitute agreements between the parties, which are arrived at through negotiations.
The most important contractual negotiations should be carried out during the bid evaluation phase, because improvements on the bids and mutual agreements are much easier to be obtained before the buyer has definitely selected his supplier. The selection of the supplier is fundamentally equivalent to the acceptance of the supplier’s bid, with the amendments and modifications that might have been agreed upon and included at that date. Afterwards, it would not be reasonable to expect the supplier to alter substantially his position as expressed in his accepted bid, nor would it be reasonable for the buyer to request major additional improvements.

In a competitive bidding contracting can be divided into the following stages:

(a) Contract negotiation: all major terms and conditions are clearly stated and agreed;
(b) Contract finalization: on the basis of the previous agreements reached, the final contract documents are prepared;
(c) Signing of the contract by duly authorized representatives of the parties;
(d) Compliance with all conditions to have the contract effectively validated.

All main contract negotiations, as has been stated above, should preferably be carried out before selecting the supplier, in parallel and as part of the bid evaluation. Contract finalization usually requires about six months for a turnkey contract or three to four months for a package. Though there is always pressure to reduce the time as much as possible, absolute priority should be given to quality. In principle, nothing should be left open and the temptation to leave details ‘to be mutually agreed on later’ should be thoroughly resisted. This would only create potential trouble-spots.

The signing of the contract represents the commitment of the parties, but there are usually some conditions included in the contract itself that have to be complied with before the contract effectively becomes valid. Such conditions might be:

- Financing agreements
- Down payments
- Governmental ratification or approval
- Bilateral international agreements
- Safeguards agreement
- Export licence
- Regulatory and licensing requirements.

Compliance with such conditions, if required and not yet fulfilled, might need several months. In an extreme case they might delay the project indefinitely and, if no mutually satisfactory solutions can be found, this would ultimately lead to cancellation of the contract.
Contract negotiation and finalization should be performed by relatively small highly qualified teams (8 to 10 professionals) with the necessary authority to make decisions on behalf of their respective organizations, except possibly on the most crucial items where they might have to refer to a higher level. The supplier’s and the buyer’s technical staff involved in the bid preparation and the bid evaluation respectively will have to assist the contracting teams on request. Some of this staff might be members of the contracting team.

Some potential problem areas in contracting are commented on in the following paragraphs.

Minutes should be taken of all meetings. A language problem may be involved if the languages of the supplier and buyer country differ. Discussions might be held in any common language, but there must be one accepted official language for all written documents and communications. In principle, this should be the language of the buyer. Translations will have to be prepared and extensively used, but for all contractual matters only the adopted official language should be valid.

The two basic documents for the contract are the bid specifications and the bid. Both, however, will have been amended and modified during the course of the bid preparation, bid evaluation and contract negotiation, through written communication from both the buyer and the supplier. Basically, there are two possibilities for incorporating the changes. Either one can leave the original documents unchanged and list all agreed amendments and modifications in a separate document which is attached, or one can modify the original text with the changes agreed upon. In general, it is recommended to follow the latter procedure.

Because of the extent of the technical information, it is in most cases not possible to finalize the technical contract specifications before placing a letter of intent. This can be acceptable if the basis for completing the technical specifications is clear and agreements have been reached during the technical contract negotiations on those parts that need completion. It is, however, important to lay down the agreements reached during such technical contract negotiations in corresponding minutes which would form the basis for completing the technical specifications later on. The technical contract specifications must, however, be agreed upon before the contract is signed.
Chapter 12

OVERVIEW OF DESIGN,
CONSTRUCTION AND OPERATION

12.1. INTRODUCTION

The ultimate purpose of all the studies and activities performed during the pre-construction stages of a nuclear power project is to permit the successful implementation of the design, construction and operation of the plant. While practically all major decisions regarding the project are taken during the pre-construction stages, most of the money and effort involved in the project will be expended after the start of construction.

The present Guidebook is intended to provide specific guidance for the pre-construction phases of the first nuclear power project of a country and, thus, the activities after the start of construction have been excluded from its scope. Nevertheless, for the sake of completeness, a brief overview of design, construction and operation will be presented in this chapter.

For further information, consultation of the IAEA Guidebook on "Manpower Development for Nuclear Power" (Technical Reports Series No.200), which contains outlines of all the principal activities involved and their manpower requirements, is recommended.

For a first nuclear power plant in a country it is assumed that the technology, know-how and a substantial portion of the equipment, goods and services will be imported from abroad. Assuming the contrary, i.e. local development of the design and engineering, the domestic manufacture of most of the equipment, and the complete construction and erection of the plant, would be unreasonable. Independent local development would require a very great effort, beyond the possibilities of even many highly industrialized countries and would involve costs certainly placing the nuclear plant outside the competitive range.

It is furthermore assumed that the country introducing its first nuclear power plant has a nuclear power programme involving a sequence of nuclear units on a reasonable time scale, as well as a policy of not only using its national capability and infrastructure wherever possible, but also of increasing it on successive units.

National participation in the design, construction and erection of even the first nuclear power plant is not only convenient to the country, but is also necessary. There are some essential activities, for which full responsibility has to be borne by national organizations and which should be primarily executed by national manpower, whatever the contracting arrangements. There are also materials, goods and services that have to be supplied locally, because importing
them would not be feasible. This means that the country must have an important active participation through its utility/owner, regulatory body, national industry and other relevant organizations.

The utility/owner of the plant has to take full responsibility for operation and maintenance, even for a first unit and without any previous experience. He will be able to obtain advice and assistance, and he certainly will require and obtain foreign services for training his operations personnel, but he must develop his own capability to fulfil his responsibilities successfully.

Though the construction and the operation of a nuclear power plant refer to clearly defined stages in the development of the project, preparations for these activities do start earlier during the planning and acquisition phases of the project. The organizations involved in the country intending to introduce nuclear power need to have a clear understanding at an early date of what effort will be required from them in the design, construction, manufacture, erection, testing, commissioning, licensing, operation and maintenance of a nuclear power plant.

In general, it can be stated that the best way a country can prepare itself consists in directly performing all the pre-construction tasks and activities, or at least of being heavily involved in them and accepting full responsibility.

12.2. PROJECT MANAGEMENT

The overall direction and co-ordination of all the different project implementation tasks and activities is the function of project management. The utility/owner would normally delegate this function to a main contractor under the turnkey approach, or to an experienced architect-engineer under a non-turnkey approach. With a first nuclear power project, retaining full responsibility for overall project management would constitute a very large and probably excessive risk for an inexperienced utility. The utility/owner, however, does retain under any type of contractual approach the direct responsibility for control and supervision of the project. To carry out this responsibility, it has to set up its own project management organization headed by an experienced project manager and staffed with about 30 qualified people (mostly professionals) before construction starts. During construction of the plant the utility project management staff will increase to some 50 to 60 professionals. The assistance of experienced consultants, familiar with the suppliers' product and organization, might be needed to complement the utility staff, if a sufficient number of qualified local people cannot be found. But the services of foreign consultants can only be advisory and they must be in turn controlled and supervised by the owner's project management staff.

Project management is possibly the most critical activity to ensure successful project implementation. The decisive factor of good and efficient project
management is the quality of the manager and his staff. The project management organization should be set-up when the decision is made to proceed with the acquisition of the plant, based on the positive results of the project feasibility study.

The first tasks of the utility/owner's project management consist in the performance of the acquisition activities discussed in Chapter 11. After contract finalization, the main tasks will be:

Management of the owner's scope of supply
Co-ordination of QA/QC programmes and audits
Schedule control
Cost control
Control of compliance of the supplier(s) with the contractual terms and conditions
Design review and approval
Construction and erection supervision
Equipment and component manufacture supervision
Plant commissioning supervision
Review and approval of operation and maintenance procedures and manuals
Management of overall project documentation
Management of the training of operations personnel
Procurement of nuclear fuel and fuel cycle services
Licensing applications.

An IAEA guidebook on “Nuclear Power Project Management” is being prepared and is expected to be published in 1983.

12.3. QUALITY ASSURANCE AND QUALITY CONTROL

The requirement of high quality is one of the main special features of nuclear power. Safety and reliability in operation of nuclear power plants can only be ensured by proper implementation of the QA programme and procedures. These have been briefly discussed in section 5.9.

The utility/owner is responsible for implementing the overall QA programme for the plant. It will fulfil this responsibility either directly, or through contractual arrangement with the supplier(s) by delegating to them the constituent activities of the programme. Even assuming such delegation of activities, the utility will still require a QA group to perform overall QA co-ordination and supervision. In addition, the regulatory body of the country will also be involved in supervising the owner by performing inspections and audits, to see that nuclear safety is effectively ensured.
QA activities are already performed during the pre-contract phase as part of bid specifications and bid evaluation. The principal volume of QA/QC work, however, will be performed during the construction and commissioning phase of the project, but it also continues during the entire operating life of the plant.

The relevant publications of the IAEA’s NUSS (Nuclear Safety Standards) programme should be consulted for guidance in this field.

12.4. DESIGN AND ENGINEERING

The design and engineering services include preliminary and conceptual designs and their review, the preparation of licensing documentation, basic and detailed designs, equipment and component specifications, construction, manufacturing, erection and commissioning support, and as-built documentation. The overall effort of designing and engineering a nuclear power plant (not first of a kind) is about three million man-hours, involving 300 to 400 qualified professionals and technicians.

Most importing countries have not participated in a major way in this activity for their first nuclear power project. Part of the tasks, however, fall under the direct responsibility of the utility/owner, while limited contributions by national industry are usually feasible.

During the acquisition phase of the project, preliminary designs (outlines) have to be developed. These are relatively simple for a turnkey approach, but become progressively more complex for split-package and multiple-package approaches. Preparation of the preliminary designs is the utility/owner’s responsibility; it may be delegated to experienced architect-engineering firms.

Conceptual, basic and detailed designs and engineering are usually tasks of the main contractor (turnkey) or of suppliers and architect-engineers (non-turnkey). The utility/owner is responsible for design review, surveillance and control, which require adequate and qualified staff. During engineering review the utility/owner will not only verify that the supply is within the established scope and contractual terms and conditions, but also in strict conformity with the criteria, rules, standards and regulations applicable for licensing compliance. The utility/owner bears the ultimate responsibility for all actions that are relevant to ensuring plant safety.

Areas for national participation in design and engineering can be found in most countries in the civil and steel construction sectors. Further areas could be the power supply and electric system interconnection, cooling water systems, demineralizer plant, air circulation system, conventional auxiliary systems and facilities in general. In engineering, most of the national participation possibilities are in the detailed design phase.
National participation in design and engineering can either be carried out by the utility/owner directly, or by national engineering firms under subcontract to the owner or the foreign supplier. In this last case, national participation in design and engineering could be an integral part of the supplier's scope of supply, subject to whatever contractual conditions have been agreed between the owner and supplier.

The design and engineering activities in a utility are normally carried out by a separate organizational unit because of the high degree of specialization needed. However, in order to keep all project activities for a nuclear power plant under close control, the engineering staff can be incorporated into the project management group.

12.5. CONSTRUCTION OF BUILDINGS AND STRUCTURES

Civil works represent the largest item in the construction of a nuclear power plant and national participation is essential. Management, engineering and special materials could be imported if not available within the country, but the provision of the usual construction materials and the actual performance of the works should be a domestic effort.

By the time a country is able to add a nuclear power plant of commercially available size to its electricity system, it will have a substantial electric load, which in turn implies some industrial infrastructure. It will also have experience in building conventional electric power plants. This means that there should already exist an industrial capacity for construction, even if it might not have the required quality standards or necessary know-how in the special techniques used in building nuclear power plants. Improvements, however, to develop the construction industry to the required level can be introduced without undue effort and in a relatively short time, as experience has shown in a number of developing countries that have introduced nuclear power in the past.

The erection of plant buildings and structures is preceded by site preparation and the provision of the necessary site infrastructure. This involves provision of access to the site for heavy loads; site clearing and levelling; flood protection (if needed); construction of temporary warehouses, office buildings, housing, workshops, fencing; installation of communication systems; fire protection; provision of electric power, fresh water and auxiliary services such as first aid, hospital, security, canteen, parking, etc. All this is usually within the scope of supply of the owner, even with a turnkey approach. To avoid delays in the start of the construction of the nuclear power plant, it is in the best interest of the owner to finish site preparation and provide the site infrastructure in the shortest possible time. He might start with this work even before the contracts are finalized. For difficult sites (the ideal site is only a theoretical concept) an early start is especially desirable.
Site preparations do not demand special 'nuclear' knowledge or know-how, except information on the site infrastructure requirements for a nuclear power plant. What is mostly needed is early planning, an efficient organization, project management and administrative support and a qualified workforce consisting of about 10 to 20 professionals and perhaps 100 to 150 craftsmen and labourers.

Among the construction materials, cement, structural and standard steel might need special attention, the rest should not be difficult to supply from national sources, preferably close to the site. The work force during construction will probably amount to about 1000 to 1200 skilled workers during the peak period, which occurs in the second and third year after construction starts. Up to twice as many might be needed because of local conditions and the qualifications of construction workers.

Erection of plant buildings and structures will be a new experience for a country building its first nuclear power plant, so certain preparatory actions should be taken to avoid unpleasant surprises later on, which might result in delays and/or higher costs.

Attention is drawn to potential problem areas in:

- Sufficient availability of construction materials in quantity and quality;
- Availability of major construction equipment (hoists, cranes, heavy transport vehicles) of adequate capacity;
- Qualification of the construction firms regarding size, capability and reliability to undertake the job;
- Qualification of the supervisory personnel of the construction firms (management, professionals and foremen);
- Availability of qualified manpower in the technician and craftsmen categories, such as welders, pipefitters and electricians.

Any programme aimed at improving deficiencies will undoubtedly have beneficial effects on the overall level of the national construction industry. In view of this, early actions might be justified even before final commitments are made regarding the nuclear power project.

12.6. MANUFACTURING OF EQUIPMENT AND COMPONENTS

Equipment and components represent about half of the cost of a nuclear power plant; hence, there is an evident interest in national participation. It should be also recognized, however, that for manufacturing most of the equipment and components of a nuclear power plant a high level of development of the industrial infrastructure is necessary with all its experience, technology, know-how and qualified manpower.
A relatively lower degree of development of the industrial infrastructure of a country would constitute the main constraint on national participation in this item. This does not mean that all equipment and components must be imported by definition; on the contrary, when the introduction of nuclear power becomes feasible in a country, there is already some industrial infrastructure and this can and should be used as much as possible to provide all it can reasonably supply within the constraints posed by the high quality requirements, safety, competitive costs and delivery schedules. Depending on the country, 10 to 15% of the equipment and components for a first nuclear project could be expected to come from local sources. Subject to national policy and the efforts invested in implementing such policy, this can be gradually increased for successive projects.

Assuming that the country introducing nuclear power adopts a policy promoting national participation, the inclusion of a statement to this effect in the contract of the nuclear power plant, as mentioned in Chapter 11, certainly is not enough to achieve the desired goals. Preparatory action is also needed.

The first preparatory action which should be performed within the scope of the feasibility study is a preliminary survey and evaluation of the national manufacturing industry. The results of an updating of this survey and evaluation should be included in the bid specifications, with a clear indication to the prospective bidders that they should include in their offers a detailed list of which specific items will be provided by national industry. The contract will have to contain such a list, which defines the scope of supply from national sources. So called ‘good-will’ or ‘best-effort’ statements are not adequate and should be avoided.

In addition to ensuring the maximum use of the existing industrial infrastructure of the country, further activities should be undertaken to promote industrial development and an increased national participation, if this is consistent with national policy. Such promotional activities should start at the feasibility study stage of the project and would continue throughout project implementation. They would involve:

- Development of a consistent set of governmental measures and incentives
- Overall manpower development
- Promotion of technology transfer
- Standardization within the nuclear power programme.

12.7. INSTALLATION OF EQUIPMENT, COMPONENTS AND SYSTEMS

The magnitude of the effort involved in installation of equipment, components and systems is similar to that of the civil works. Installation of plant equipment, components and systems follows and partially overlaps the erection of plant
buildings and structures. A peak workforce of the order of 1000 to 1500 people (mostly technicians and craftsmen) would be required. The peaking usually occurs during the fourth year after the start of construction. In addition to management and QA/QC, mostly mechanical, electrical and instrumentation crafts are required.

This activity makes important demands on the national industry. Success in performing the installation of the plant equipment, components and systems mainly depends on efficient management and co-ordination, which might be provided from outside, and on a well-qualified workforce, which should be available within the country. Importing hundreds of technicians and craftsmen for the job would certainly involve very high costs and would also lead to a continuing substantial dependence on foreign sources during the subsequent operation and maintenance of the plant. The desirability of the introduction of nuclear power in a country may be questionable if the country does not possess a national manpower infrastructure able to perform at least a substantial portion of these activities.

Of course, there is never any difficulty in having an adequate number of people; the problem consists in having an adequate number of qualified personnel. High quality requirements constitute one of the specific features of nuclear power and in matters of quality there can be no compromise if safe and reliable operation is to be assured.

Here again, preparations prior to construction have to be made. Survey and evaluation during the feasibility study phase are to be followed by a manpower development programme, if problem areas are identified. A need for upgrading the existing training systems and programmes is to be expected as is some specialized training.

A thorough knowledge of the level, potential and constraints of the national labour market in this field is a prerequisite.

12.8. NUCLEAR FUEL

Fossil-fired power plants have been usually acquired without any special provisions or measures regarding fuel supply. This attitude, which was normal and perfectly acceptable in the past, is still followed in most cases even though the world market for fossil fuels has changed and a long-term assurance of fuel supply is becoming more and more necessary not only on a national but also on a utility level.

Regarding nuclear fuel (see Chapter 3), whatever fuel cycle is selected there are a series of steps and processes involved both before and after burning the fuel in the reactor, each of them requiring a period of time as well as a certain lead time and different sources of supply. The world market in uranium and in
fuel cycle services is not what might be called a 'free market' defined by an
unrestricted interplay of demand and supply. There are conditions and constraints
beyond the commercial aspects, which must be taken into account.

Before the acquisition of a nuclear power plant, the supply of fuel and of
fuel cycle services must be reasonably assured. This will involve in addition to
the utility/owner, the government of the country.

One way of assuring supply consists of developing national sources of supply
for the whole fuel cycle or for parts of it. To do so, the country must have
uranium mineral resources and a nuclear fuel cycle programme involving relatively
large investments, lead times and technology. This might be either beyond the
possibilities of the country or not considered as a convenient policy, and in these
cases, reasonable assurance from foreign sources is needed.

Should the country decide to embark on a national nuclear fuel cycle
programme, each major part of such a programme is to be handled as a project
involving all the corresponding activities. If the choice is for foreign supply,
procurement will be the fundamental activity to be undertaken.

The analysis of the nuclear fuel cycle will be part of the feasibility study of
the nuclear power project. As a result, a policy decision will have to be made
and a strategy developed. Any international commitments and agreements that
might be needed will have to precede the commercial contracts.

There will be continuing fuel cycle activities throughout the construction
and the whole operating life of the nuclear power plant. How many and which
activities a particular country wishes to embark on are matters of national policy,
but some of these activities must be carried out domestically. These minimum
essential activities are:

- Procurement of uranium
- Procurement of conversion and enrichment services (when needed)
- Procurement of fuel element fabrication
- Quality assurance
- Fuel management at the power plant
- Disposal of spent fuel
- Waste management.

12.9. COMMISSIONING

Commissioning of a nuclear power plant covers a period of about two years,
starting after the finished erection of the first systems and ending at the initiation
of commercial operation of the plant. It involves all activities required for testing
the operational capability and for determining the safety, efficiency and reliability
of each individual system and component as well as of the complete plant.
The performance of the tests themselves is preceded by a major effort in preparing them, and it is essential that all commissioning activities be documented and evaluated.

Commissioning is carried out by a well-qualified staff of 40 to 50 professionals and some 120 to 180 technicians and craftsmen of the utility/owner and the supplier(s). In addition, staff of the equipment and component manufacturers' are involved as well as the plant operations and maintenance personnel, for whom active participation in this activity is considered the last essential part of their training.

Detailed preparations for commissioning (mostly written procedures and instruction, their approval and training of staff) are normally performed during the erection of equipment, components and systems. Before the start of construction only general provisions have to be made involving the distribution and assignment of responsibilities and the setting-up of the organizational framework to carry out the tasks later on.

Nuclear fuel is an area that requires special preparation. Nuclear fuel will arrive on site and will be loaded into the reactor during the commissioning phase. It is to be noted that the utility/owner is always fully responsible for any nuclear liability, and therefore provisions must be made to fulfil this responsibility. The legal provisions should be established before the acquisition of the plant and its fuel, and special security measures have to be adopted prior to the arrival of fuel. There are international conventions, and adherence to these must be considered at an early date by the national authorities.

12.10. LICENSING AND AUTHORIZATION

The safety and environmental considerations have been discussed in Chapter 6. Extensive further information is available from many sources, and in particular from the IAEA's publications within the framework of the NUSS (Nuclear Safety Standards) programme.

It must be understood that nuclear power can only be a viable energy source if it is safe and if it is perceived as being safe by the public.

Full responsibility for safety lies with the utility/owner. Safety consciousness and its encouragement and enforcement has to permeate the entire planning, engineering, manufacturing and operations manpower of the utility/owner and of its supplier(s).

The regulatory authority of the country has the responsibility for ensuring the health and safety of the general public against possible adverse effects arising from the activities associated with nuclear power. To that purpose, it establishes regulatory standards, codes and criteria, reviews and evaluates the safety analysis and environmental reports submitted by the utility/owner, issues licences or
authorizations and conducts a programme of inspections to ensure that every­
thing conforms to the established rules and regulations.

All partners, the utility/owner, the supplier(s) and the regulatory body, have
the common goal of ensuring safety. The word 'partner' is used intentionally,
because mutual co-operation, assistance and the sharing of a common objective
are essential aspects of the relationship between them. Any antagonism or unco­
operative spirit that might exist or develop would certainly have negative effects
that must be avoided.

It is the utility/owner's task to apply for licences or authorizations. The
supplier(s) have to provide the utility/owner with all necessary data and information
in order to complete the licence/authorization applications, to be reviewed and
evaluated by the regulatory body.

These activities of the licensing/authorization process start together with the
project activities and follow the project throughout its lifetime. Practices vary
somewhat among different countries, but there are usually licences or formal
authorizations (permits) to be issued for site, construction and operation of the
plant as well as for the plant personnel directly responsible for operating the
plant.

It is emphasized that the whole purpose of the licensing/authorization
procedure can only be achieved if carried out by adequately qualified personnel.
Furthermore, it must be done within the country where the plant is built. It is
possible to obtain expert assistance and advice from abroad, but the responsibility
cannot be delegated.

12.11. OPERATION AND MAINTENANCE

The operation and maintenance of a nuclear power plant is always the full
responsibility of the utility/owner. It cannot share this responsibility with
anyone else, though it can and normally does obtain some assistance from the
plant designer and constructor, especially in the early stages of plant operation
and it will most likely resort to contractors and subcontractors as well as
manufacturers of equipment and components for plant maintenance purposes,
in particular during major overhauls and revisions as well as for repairs and
modifications.

During the feasibility study phase of the project only general outlines of
plant operations and maintenance have to be analysed. Specific preparations
for operation and maintenance will start with the bid specifications, where an
input is required from experienced plant operations staff. During bid evaluation
and contract negotiation, the involvement of experienced operations staff is
especially important. This is the stage where all major characteristics and
technical aspects of the plant will be defined, which include its operability and
maintainability features. It is best to provide for those features at this stage, otherwise to include them later during design and construction of the plant will involve additions or modifications which are always very expensive to the owner and usually difficult for the supplier.

Safe and reliable operation of a nuclear power plant will be ensured by having a plant that has been well designed and built, and by having a well-trained, competent and dedicated operations and maintenance staff. Both conditions have to be fulfilled.

Assurance regarding the design and construction of the plant starts with the preparation of bid specifications and proceeds throughout the evaluation of bids, selection of the supplier(s) and all stages of project implementation, plant erection, manufacturing of equipment and components, their installation, testing and final plant commissioning.

To ensure the availability of a well-trained, competent and dedicated operations and maintenance staff, timely recruitment and careful selection of personnel is the first condition to be fulfilled; intensive training of this personnel under constant control and supervision is the next task. Furthermore, a clearly defined organizational structure as well as comprehensive operations and maintenance procedures and documents are needed. All this, within the framework of a personnel management policy ensuring the retention of trained personnel as well as good and efficient working conditions.

It is the utility/owner's project management that has the leading role in directing and co-ordinating all these tasks during project implementation, until plant operation is started. From this stage on, full responsibility for operation and maintenance will be in the hands of the plant superintendent and his staff. There should be a smooth transition of responsibility, which can only be provided for by early involvement of the plant superintendent, his top level staff in the project, and by effective co-operation between project management and the operations and maintenance organization.

For a country introducing its first nuclear power plant, a generous approach towards the number of people to be trained and the length and depth of their training is recommended. Not every trainee will qualify for the post he is intended for, and losses due to attrition during as well as after training are to be expected. Replacements constitute a difficult problem for a country on its first nuclear project. If the losses occur at a late stage within the project, there might not be enough time to train replacements properly.

Salaries and training expenses may constitute a sizeable portion of the owner's scope of supply and costs, but the temptation to make economies in this item should be resisted.

The number and qualifications of the operations personnel needed are practically independent of the size of the unit and type of reactor. Usually there will be about 40 to 60 professionals as well as 150 to 200 technicians and craftsmen. Personnel for routine maintenance of the plant are included in these numbers,
but for major overhauls and revisions, repairs or modifications, the off-site support of several hundred to a thousand people would be required.

The training and retraining of operations personnel is a constant activity during the lifetime of a nuclear power plant. The utility/owner should make provisions for the performance of this activity both to fulfil the needs of the first plant and those of the follow-up units of its nuclear power programme. Experience has shown that the first nuclear power plant in a country constitutes possibly its most valuable training ground.
BIBLIOGRAPHY

(A listing of IAEA publications relevant to the subject of the Guidebook is provided. Some of these are referred to in the text. Publications other than IAEA publications used as reference material are specifically mentioned in the text. Further information on the IAEA publications, including a brief description of contents, can be obtained from the IAEA publications catalogue.)

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50-SG-QA7 Quality Assurance Organization for Nuclear Power Plants
50-SG-QA11 Quality Assurance in the Procurement, Design and Manufacture of Nuclear Fuel Assemblies
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Consultants' Meeting, 12–30 January 1981
Advisory Group Meeting, 9–20 November 1981

The participants at these meetings were:

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4 (C) and (A) after name denotes participation in the Consultants’ and Advisory Group Meeting, respectively.
5 Chaired both meetings and also served as consultant to the IAEA from May 1980 to February 1981 and in September 1981. Was in charge of the Guidebook including the preparation of its first draft until February 1981.
6 Secretariat Abbreviations: AD - Department of Administration; ADLG - Legal Division; SG - Department of Safeguards; TONF - Division of Nuclear Fuel Cycle; TONP - Division of Nuclear Power; TONS - Division of Nuclear Safety.
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7 Responsible Officer for both meetings and in charge of the preparation of the Guidebook since February 1981.
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