IAEA-TECDOC-347

SMALL AND MEDIUM POWER REACTORS: PROJECT INITIATION STUDY PHASE I

REPORT PREPARED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE
OECD NUCLEAR ENERGY AGENCY

A TECHNICAL DOCUMENT ISSUED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1985

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Printed by the IAEA in Austria
July 1985

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FOREWORD

In conformity with the Agency's promotional role in the peaceful uses of nuclear energy, IAEA has shown, over the past 20 years, assisting Member States, particularly developing countries, in planning for the introduction of nuclear power plants in the Small and Medium range (SMPR). However these efforts did not produce any significant results in the market introduction of these reactors, due to various factors.

In 1983 the Agency launched a new SMPR Project Initiation Study with the objective of surveying the available designs, examining the major factors influencing the decision-making processes in Developing Countries and thereby arriving at an estimate of the potential market. Two questionnaires were used to obtain information from possible suppliers and prospective buyers. The Nuclear Energy Agency of OECD assisted in making a study of the potential market in industrialized countries.

The information gained during the study and discussed during a Technical Committee Meeting on SMPRs held in Vienna in March 1985, along with the contribution by OECD-NEA is embodied in the present report.

It is hoped that this report would serve as a useful guide for future case studies which can be undertaken with the Agency's assistance by Member States with definitive plans for nuclear power programme.

EDITORIAL NOTE

CONTENTS

1. EXECUTIVE SUMMARY

To assist primarily developing Member States to introduce nuclear power earlier, the IAEA has since more than 20 years tried to promote the industrial production of nuclear power plants smaller (100 to 500 MW(e) range) than were generally available on the international market. These efforts were not successful and no SMPR was exported as a result, although 200 and 400 MW(e) nuclear power plants are being built and operated economically in India and the CMEA countries, respectively. Up to 1975 the reactor suppliers in the market economy countries had an ample stock of orders for big plants and there was little interest in new efforts to produce an SMPR design for what was perceived to be an uncertain market. It was at that time that the argument was formulated that a domestic market is required for a plant before it can become available for export.

In recent years however two new factors have appeared which could alter the situation. Firstly, the suppliers, faced with diminishing and uncertain future home markets are compelled to take a new look at the potential future export markets. There also seems to be some interest, in at least some industrialized countries, for smaller, standardized nuclear power plants as an alternative to the large ones for situations involving lower load growth rates and for limiting the financial risks of individual investments. Whether these smaller plants would be in the SMPR or rather in the 600 MW(e) range still is uncertain. The use of small nuclear power units is also under review also for applications other than electricity e.g. cogeneration, district heating, process heat or desalting.

These two new factors seemed to justify a new effort, and in 1983 IAEA launched a new SMPR project initiation study with the objective of surveying the available designs, examining the major factors influencing the decision-making processes in developing countries and thereby also arriving at an estimate of a potential market. The Nuclear Energy Agency of OECD offered its assistance in making a study of the potential market in industrialized countries.

<u>The SMPR Supply Situation</u>

Two questionnaires were used to obtain information from potential suppliers and buyers. Suppliers responded with an overwhelming 23 design concepts which could be offered for export but with varying levels of readiness and provenness. From potential buyers 17 responses were received, 16 of which were from the developing countries.

In reviewing the suppliers' proposed design concepts, no in-depth evaluation of provenness and safety aspects could be performed, as the information provided in most cases would not permit this. The following notable design trends could, however be discerned from these proposals:

- An emphasis on a shortened and tightly controlled construction schedule. This is evident in many proposals, and is the principal theme of two designs.

- Efforts to satisfy provenness criteria through utilization of systems, components, and concepts proven by commercial operation. This is evident in many designs including the Magnox and PWR concepts. Two designs share all key component designs with current larger reactors.

- A high level of prefabrication/shop fabrication. This is emphasized in several designs, and is maximized in a barge-mounted unit.
- Recognition of site conditions in some developing countries. Most of the SMPR designs presented incorporate a relatively high seismic design level, and would also function satisfactorily with relatively high cooling-water temperatures.
- Several of the design concepts are aimed at operation in smaller and weaker grids including features of load following and self-powered start-up.
- Several of the design concepts include at-reactor storage of spent fuel for the entire foreseen lifetime of the plant (up to 40 years) or easily expandable storages, recognizing the present uncertainty in the back end of the fuel cycle.

These trends are notable for the plants proposed to be offered immediately or in the near future. For the longer term, some suppliers referred to on-going development work on inherently safe smaller reactors but also stated that these could not be offered for bids until well into the next decade.

Only very few of the potential suppliers gave any indications of the costs of the plants offered. They must be considered as carefully made estimates but not applicable to any specific site. It is still interesting to see that all estimates are low in comparison to costs extrapolated from equally generalized IAEA estimates for the size range above 600 MW(e). It would indeed appear that SMPR specific designs and fabrication methods would have managed to supercede the usual scaling laws.

The Potential Market for SMPRs

In the IAEA study a series of factors which would influence the choice between a smaller or larger nuclear power plant have been identified:

FOR SMPRs

- o Lower absolute capital cost, with smaller financial burden
- o Distribution of economic risk through several smaller plants.
- o Better controlled construction schedule due to the less on-site work and smaller size of components
- o Earlier introduction of nuclear power will give environmental protection vs. fossil fired units
- o Lower absolute heat rejection permits better adaptation to cooling capacity and extends the number and location of possible sites

AGAINST SMPRs

- o Larger units have lower specific capital cost per kW(e) and better economic viability
- o In many cases non-standard design, with provenness, licensing, and commercial availability questions
- o Break in normal technology devlopment for industrialized countries which are used to larger units
- o More limited possibilities for domestic participation due to trends for shop prefabrication but the smaller size of components vs. larger nuclear power plants can bring an increase in domestic participation

FOR SMPRs	AGAINST SMPRs
o Better fit to smaller and weaker grids and lower requirements on grid	o Domestic participation targets and seismic design requirements can work against construction time
o Fit to low load growth rate situations	o Essentially the same infrastructure requirements as for big plants
o Better past performance records than for larger plants	
o High degree of shop fabrication and potential for series production	
o Earlier introduction of nuclear power with potential for longer term technology transfer if the introduction does not come too early.	

It must be recognized that these factors will be judged very differently in, on the one hand, developing countries considering nuclear power introduction and, on the other, industrialized countries or advanced developing countries with on-going nuclear power programmes. In the latter the lower absolute capital costs with their potential for better financial risk management in situations of slow load growth must be expected to carry more weight than any grid-related considerations. Some of the advantages can also be translated directly into monetary terms. For developing countries it can mainly be a question of timing of nuclear power introduction. In many developing countries the existing grid limits the size of plants which can be introduced. The smaller total capital cost of an SMPR is certainly very important but in the present investment climate and with the competition from other investment needs in the country the financing becomes a major issue of national policy. In addition the available infrastructures (organizations, availability of qualified manpower and domestic industrial support) are often weak and may jeopardize the successful execution and operation of an early nuclear power plant. Thus it becomes necessary to weigh carefully the advantages of an early introduction of nuclear power with an SMPR against later introduction with bigger units, permitting an orderly assessment and strengthening of the required infrastructures.

Investment decisions are always taken with a certain economic risk, which is particularly large in the case of a nuclear power plant because of the long lead time until the plant is in operation. This risk may however be reduced by the choice of a serie of several SMPRs with short construction time instead of a single large plant with a long time schedule.

In reviewing the potential market for SMPRs not only the economics but also the infrastructures in potential customer countries had to be included in the evaluation. The varying contents of questionnaire responses made it necessary to seek additional information from IAEA files, World Bank reports and in some cases also through IAEA missions. In this manner some 25 countries which are expected to have grids with a capacity of 2000 - 6000 MW(e) in the period 1991 - 2001 could be included.

The potential market assessment focussed on 300 MW(e) plants as most of the plants offered by the suppliers were in this size range and as it also gives a distinct alternative to the already available 600 MW(e) plants and would include a significant number of countries unable to accept the larger plants.

A primary consideration must, of course, be economic competitiveness of the nuclear plant. If an economically viable hydro potential is available in a country it was assumed that this will probably be chosen and it also offers easier financing conditions in most cases. Oil is not competitive with a nuclear plant even in the 300 MW(e) range for any oil-importing country and, from national economics considerations, also for oil-exporting countries. In the major oil-exporting countries it was, however, assumed that because of existing oil resources there would be a tendency to set national development priorities so as not to favour an early introduction of nuclear power. The existence of significant reserves of non-associated gas was in general assumed to provide a time delay for the introduction of nuclear power but not to compete over a longer term, because of the value of natural gas not as an energy source but rather as a raw material for industrial development. The remaining competitor with nuclear power thus was coal-fired plants.

Economic competitiveness must, of course, be decided in country- and site-specific planning studies with good estimates of capital costs, future fuel costs, expansion requirements and levellized lifetime costs for all alternative generation capacity additions. In the SMPR study, however, such detailed studies were not possible, and it was necessary to use a simple screening test of levellized generation costs to determine whether SMPRs can be competitive with coal-fired plants. The first step in this screening test was the calculation of "breakeven" fore costs for SMPRs, that is, the SMPR fore cost which would lead to levellized generation costs equal to those obtainable from coal-fired plants with coal costs of 45, 65 and 85 US$/t and fore cost estimates given by the suppliers were then compared with those calculated breakeven fore costs. Figure 4.3 (p.47) shows the result where suppliers' fore cost estimates and construction times with a fairly high interest rate of 10% in constant 1985 money are used. It shows that 300 MW(e) SMPRs could be competitive with coal-fired plants in the $65 - 85/t coal cost range and 960 to 1200 US$/kW fore costs, which are the cost ranges for many coal-importing developing countries. It thus indicates that further specific studies would be justified to take into account local conditions.

As the economic competitiveness of SMPRs has to be proven against alternatives electricity generation (hydro and coal) and vs. larger nuclear power plant, the economic competitiveness is not the only decision making factor. Some countries want to introduce nuclear power also because of its other characteristics. The advantages of SMPRs against larger plants are shown above (see "For SMPRs") and the advantages versus alternatives may be among others the independent fuel supply such as given by natural uranium fuel cycle, environmental protection, spin-off for national industry etc.

With the above very simple determination of a possible economic viability of proposed SMPR designs, the potential market for them in developing countries was surveyed using a qualitative rather than a detailed quantitative approach. Developing countries were first divided into groups from the point of view of their likely interest in procuring SMPRs:

- countries with on-going nuclear power programmes (outside CMEA);
- countries with large grids considering nuclear power;

- some CMEA countries;

- countries without on-going nuclear power programmes but with grid sizes unable to take plant sizes above 600 MW(e), during the study period.

The study period was defined as the 10 years between 1992 and 2001, as 1992 would correspond to the earliest date when a plant could conceivably go on line, with 10 years being a reasonable period for a potential market.

It was not excluded that the first two groups of countries would procure SMPRs. Their choice would then be dictated by much the same considerations as for a utility in an industrialized country and it was estimated that the market could be up to 5 units during the study period.

In the CMEA countries fifteen 440 MW(e) PWR plants are now under construction and it would appear that they would have a continuing market with 5 - 6 additional plants to go on line in the 1990s.

For the last of the above groups all countries were selected for which available data indicated that they would have grids in the 2000 - 6000 MW(e) range during the study period.

Three types of parameters were used as indicators for the assessment of the potential market in these countries.

(a) Parameters which indicate the technical feasibility of introducing SMPRs at all, i.e. grid size and projected annual capacity addition rates 1992 - 2001. (The "10% rule" was used in relation to grid size, recognizing that a case can be made for a different size limitation).

(b) Parameters which indicate the urgency with which the country's authorities should consider introducing nuclear power plants in the electric energy supply system:

  - Cost of oil imports as % of total exports of merchandise for net oil importers;

  - An estimate of how long domestic coal and hydro resources will last.

(c) An assessment of the infrastructures of the country in qualitative terms. (A certain level of expressed interest by national authorities in considering nuclear power for the future energy supply was used as a first indicator).

  - Organizational structure for nuclear power including legislation. The basis for assessment has been the existence of appropriate legislation, a regulatory body and an organization with experience from the construction and operation of large power projects, etc.

  - Availability of qualified manpower. Basis for assessment: e.g., the availability of qualified engineers (mechanical, electrical and civil), engineering consultants, qualified technicians, code licensed welders.

- Availability of industrial support. Basis for assessment: domestic production of, e.g., heavy rebars, boilers, cables, valves, gauges to specified standards.
- Capacity for financing as indicated by present external debt as % of GNP; the cost of servicing debts as % of exports of goods and services; also by the total GNP, as energy sector investments normally fall in the range of 2-3% of GNP, with electric system investments at a maximum half of this.

It was assumed that major oil exporters, with the exception of those that have stated an interest in nuclear power, would most probably set national development objectives which would not include introduction of nuclear power. All countries were carefully screened to detect situations of abundant and cheap hydro power, dams built for joint or export production purposes, major dams built for specific industries, etc.

The screening finally left a small group of 10 countries which were considered likely to consider seriously introduction of nuclear power during the study period and which could decide in favour of SMPRs if the economics can be demonstrated. Using experience gained in IAEA electricity expansion studies, it was deduced that for the some 21 000 MW(e) new generating capacity which would be needed in these countries, about 50 of the new plants could be base loaded units in the SMPR power range. If 15-20% would be nuclear this would mean a potential market of 7-10 units in these countries.

With the additional 5 units in other countries, the total potential market in the developing countries could be some 10-15 units during the 10-year period.

If authorities in a country were to decide to wait with nuclear power introduction until a 600 MW(e) unit would be acceptable in the grid, this would mean a delay of, on the average, some 7-10 years.

It is clear that many could have a different view of the screening process, e.g. in the choice of a unit size limit of 10% of the grid's installed capacity. There are in addition uncertainties, e.g., in respect of availability of financing. Thus no really accurate estimate of the market can be made but only an indicative one under specified assumptions.

It is also clear that the estimate is for a potential market, further definition of which would require more detailed country-specific studies with more accurate data from both potential suppliers and buyers. This will also require a willingness and a commitment from both sides and also from the financing community to enter into discussions of specific projects. The Agency can assist in this but the major effort would have to come from the project partners.

The NEA study of the potential market in the OECD Member States concluded that "the maximum market for units of 200-400 MW(e) (all types - fossil and nuclear) may be in the order of 10 units or more per year. Part of this market could be served by SMPRs".

Second TCM on the SMPR Project Initiation Study

The draft of the present report including the OECD/NEA part was discussed during the second Technical Committee Meeting held in Vienna in March 1985.

The meeting was characterized by a strong supplier interest but also by hesitation of potential buyers to make any kind of commitments relating to the market introduction of SMPRs.

Most of the suppliers provided up-dated information on their technical designs, possibilities of reducing construction time and on economic comparison between nuclear and coal fired plants. Two developing countries presented papers on their SMPR market situation. Detailed information was presented about economic comparison of nuclear and coal-fired plants, based on experience in India and Canada, which clearly indicates the advantages of a nuclear power programme with small reactors. Other participants expressed doubts about the use of nuclear power versus other power sources, especially coal in the size range below 600 MW(e).

All new information has been incorporated into the report together with a number of expressed comments, especially related to the presentation of the economics of SMPRs, the necessity of a reference plant, provenness of major components and systems etc.

The meeting gave the following conclusions and recommendations:

Conclusion

The SMPR is a state-of-the-art technology which benefits from a very broad experience in design, construction, operation and export of nuclear power plants and related components. The technical information received from the suppliers was adequate and sufficient for the purpose of the study.

The number of returned questionnaires from potential buyers indicates a significant interest in the SMPR concept. Also the number of SMPR designs submitted is interpreted as a clear indication of vendors' perception of economic viability. Real examples presented during the second TCM on SMPR show that for certain given situations (e.g. India and Canada) there are economic advantages for SMPRs over coal-fired-plants of the same size for electricity generation.

The data presented indicate that over 10 years period (1992-2001) there could be a need for SMPRs in a significant number of countries. However, there is a large number of uncertainties including financing which prevent an accurate estimate to be made of a potential market.

Recommendations:

The present step should be completed by publication of the final version of the present report by the end of June 1985. The report should include an updated analysis of the responses from potential buyer countries. The report should be regularly updated by the IAEA.

The Agency should make an attempt to define better specific constraints which hinder the introduction of SMPRs in those countries which have replied, or intend to reply, to the buyers questionnaire.

In addition the IAEA should:

- provide the banking side with the latest information now available regarding SMPR,
- in its normal technical assistance programme dealing with long-term energy planning take into account the SMPR option,
- encourage considerations of SMPR for other applications such as district heating, process heat, desalination.

2. BACKGROUND

2.1. The SMPR Issue

Nuclear power, like many other technologies, has been characterized by substantial growth not only in numbers but also in plant sizes, with economies of scale favouring the large plants. Small- and medium-sized nuclear power plants, or SMPRs, are generally understood to be plants below the sizes now being built for power generation in most industrialized countries. For statistical purposes an upper size limit of 600 MW(e) has been in use by the IAEA for some years to define the SMPR range. By this criterion some 140 nuclear power plants, or more than 40% of the total number of nuclear power plants in the world, are SMPRs. However, most of them are of rather old vintage.

2.1.1 Viability of Nuclear Power

Nuclear power has, in spite of some accounts to the contrary, maintained its position as a safe, economic and reliable source of electric energy. In 1984 alone, 33 new nulcear power plants went into operation, the total today being 344. Nuclear power plants now account for about 12% of all the electricity generated. Ten Member States of the IAEA produced more than 20% of their electricity by nuclear power in 1984, with France and Belgium producing even more than 50%. There were set-backs in recent years, however, caused mainly by lower than expected increase in demand for electricity, by political and public-attitude constraints, by very long construction times in some countries and by financing problems. 20 plants planned or already under construction were cancelled or construction suspended in 1984, mainly in the USA.

In most of the industrialized countries the orders for new plants have declined, in some because nuclear is already filling a maximum economic role, in others because the problems encountered have made utilities refrain from ordering any new plants. As a result most nuclear power plant suppliers have overcapacities for new plants and are reviewing the future market potential carefully. One line being investigated by several is inherently safer plants. Another is the possibility of new markets through the inclusion of district heating and process heat production schemes. Also, ways of further improving the efficiency and performance of power reactors are being examined.

In the longer term, however, a resumption of economic growth will increase electricity demand and will probably lead to new orders for nuclear power plants even in countries where ordering has now been suspended, if the main problems associated with nuclear power can be resolved, i.e. construction times kept under control and thereby also costs. Under the same conditions the fact that in a few years old fossil fired plants and the first nuclear power plants have to be replaced may also bring new orders. There is also a growing awareness of the need to reduce emissions of sulphur oxides and other pollutants from fossil fuel plants, and one means of doing this is to include more nuclear plants in the energy mix.

The nuclear power trends in developing countries remain uncertain. Although there are now 12 developing countries with nuclear power plants in operation or under construction, only one new unit was connected into a grid during 1984. While the economic desirability of nuclear power and its technical feasibility can be shown for a number of countries with large enough grids, decisions to launch nuclear programmes and projects are not being taken. The main reason appears to be the infrastructures, i.e. the lack of qualified manpower, organizational structures, industrial support and financing.

2.1.2 Need for SMPR

In the market economy countries the nuclear power plant sizes rapidly increased to the 900-1300 MW(e) size range and with strong domestic markets there were no strong reasons for suppliers to continue to offer plants in the SMPR range for smaller grids abroad. Only, the CMEA countries and India continued with the installation of SMPR size units.

Recent trends, however, indicate a revived interest in smaller plants. Plant suppliers, faced with diminishing or uncertain home markets, appear to be taking a new look at the future export markets and assess the SMPR range as an important portion of potential markets. Developing countries are giving closer attention to long-term energy planning, with infrastructure assessment and corresponding manpower and industrial support development plans playing important roles. Spurred by new market prospects, the development and maturing of concepts has advanced considerably.

In addition, some industrialized countries are showing interest in using SMPRs, particularly those with smaller utilities and low load growth. One motivation is the possibility of better financial risk management both because of the smaller total amounts of capital involved and the potential for stricter control of construction times which some of the new SMPR concepts could offer.

There are also industrial processes for which the use of dedicated nuclear power plants either for process heat or electricity could be attractive. An economically competitive SMPR would open a wider range of such uses, since the requirements of such industries for both heat and power are generally lower than the power provided by large plants. Examples of electricity-intensive industries are aluminium and magnesium production, which require more than 100-200 MW(e) for an efficient plant with modern technology (see also Section 5.3.2).

The economics for special industrial plants may be quite different from those for utility electricity distribution and would have to be examined on a case-by-case basis. Nevertheless, such industries may present SMPR opportunities.

Some SMPRs may also be uniquely suited to opportunities in district heating, cooling, and the supply of process heat to various industries (e.g. desalting). Single-purpose heat plants, however, tend to be conceptually different from the power-generating SMPRs and possibly share only some components with them. Opportunities for their use are likely to occur more often in the more highly industrialized countries. Another potential market for SMPRs could be in dual-purpose plants for both process heat and electricity production. There are already numerous examples of fossil-fired electric power plants with various degrees of co-generation of heat, both in both industrialized countries and developing countries. Desalination facilities are in operation in the Mid-East, in combination with fossil power plants, and in the USSR with a 300 MW(e) nuclear power plant at Shevchenko. Nuclear plants are already delivering electricity and process heat to industry, homes and offices in France, Canada, Czechoslovakia, the Federal Republic of Germany and the Soviet Union.

In the future, the spectrum of co-generation possibilities may widen, as reactor types with different temperature levels are becoming available and smaller-sized plants could open new applications. New schemes for co-generation are being developed, such as using most of the so-called waste heat, slightly upgraded via adjustments in the secondary system of the plant, for process steam or a desalination plant. The electric power output in such a case will be less than the maximum achievable. The current plans for a Libyan power plant with an SMPR of the WWER-440 type are precisely of this nature. There is also experience with a flexible mix between process heat production and electric power production, such as at the Bruce plant in Canada.

2.1.3 Small vs. Large Units

Variation with plant size of the cost parameters of nuclear power plants has been the subject of many investigations and controversies. The SMPR range has recently not been explored systematically in that regard. To gain more information on this a meeting on "Scaling Factors for SMPRs" was held at the IAEA in May 1984 within the framework of the present study. The meeting indicated that the scaling exponents for fore costs for nuclear power plants, including SMPRs, would lie in the range 0.4-0.6. Using IAEA data for 600 MW(e) plant fore costs, this would indicate a range for 300 MW(e) plant fore costs of US$0.63-1.1 x 10^9. At the upper range of these fore costs SMPRs would hardly be competitive with coal even in the $90-100/t range, and it was obvious that plant designers would have to stress the attainment of low total capital costs to make SMPRs viable except in very special locations.

There were, however, a number of additional size-dependent factors identified by that meeting which could change the comparative advantages between large and small plants. These are given below:

- Fore cost, smaller in absolute terms but higher in $/kWe.
- Potential for series production of standardized plants.
- Construction schedule, which for a smaller plant could be kept shorter and under tighter control as a result of the design.
- Smaller reserve capacity requirements in grid operation.
- Transmission system requirements which could be less stringent.
- Financing, as availability and terms could be easier for a smaller total package.
- Better flexibility to meet a potential low load growth.

These facts could lead to cost-benefits for a small plant which, in some cases, could cancel the relative capital cost disadvantage (in $/kWe installed). Some of the influences are explained below:

- Series production of several standardized units should give savings in fore costs and improved certainty in a short construction schedule.

- Several factors and influences other than fore costs were identified which are also subject to scaling and can influence comparative overall evaluations of large and small plants significantly. Among them reserve margin requirements, savings from the shorter construction schedules, and reduced financing requirements appear to be important and generally favor SMPRs.

- Bigger plants will require more funds and generally pose a higher financing risk with consequent problems on cash to coverage ratio (ratio of revenues over debt charges). This can result in higher fees or interest rates or in a reduced bond rating, or both.

The factors which will influence a decision in favour of an SMPR or in favour of a bigger plant have been summarized as follows:

FOR SMPRs

- o Lower absolute capital cost, with smaller financial burden
- o Distribution of economic risk through smaller plants
- o Better controlled construction schedule due to the less on-site work and smaller size of components
- o Earlier introduction of nuclear power will give environmental protection vs. fossil fired units
- o Lower absolute heat rejection permits better adaptation to cooling capacity and extends the number and location of possible sites
- o Better fit to smaller and weaker grids and lower requirements on grid
- o Fit to low load growth rate situations
- o Better past performance records than for larger plants
- o High degree of shop fabrication and potential for series production
- o Earlier introduction of nuclear power with potential for longer term technology transfer if the introduction does not come too early.

AGAINST SMPRs

- o Larger units have lower specific capital cost per kW(e) and better economic viability
- o In many cases non-standard design, with provenness, licensing, and commercial availability questions
- o Break in normal technology devlopment for industrialized countries which are used to larger units
- o More limited possibilities for domestic participation due to trends for shop prefabrication but the smaller size of components vs. larger nuclear power plants can bring an increase in domestic participation
- o Domestic participation targets and seismic design can work against construction time
- o Essentially the same infrastructure requirements as for big plants

It must be recognized that these factors will be judged very differently in, on the one hand, developing countries considering nuclear power introduction and, on the other, industrialized countries or advanced developing countries with on-going nuclear power programmes. In the latter the lower absolute capital costs with their potential for better financial risk management in situations of slow load growth must be expected to be more important than any grid-related considerations. Some of the advantages can also be translated directly into monetary terms. For developing countries it can mainly be a question of timing of nuclear power introduction. In many developing countries the existing grids limits the size of plants which can be introduced. The smaller total capital cost of an SMPR is certainly very important but in the present investment climate and with the competition from other investment need in the country the financing becomes a major issue of national policy. In addition the available infrastructures (organizations, availability of qualified manpower and domestic industrial support) are often weak and may jeopardize the successful execution and operation of an early nuclear power plant. Thus it becomes necessary to weigh carefully the advantages of an early introduction of nuclear power with an SMPR against later introduction with bigger units, permitting an orderly assessment and strengthening of the required infrastructures. Investment decisions are always taken with a certain risk. It is particularly large in the case of a nuclear power plant because of the long time delay until the plant is in operation. The risk may however be reduced by the choice of a serie of several SMPRs with short construction time instead of a large unique plant with long schedule.

2.2 Previous IAEA Activities

Promotion of the availability of SMPRs for, in particular, developing countries been a programme item in Agency activities for more than two decades. Efforts have involved many meetings, missions, reports and even a research contract with a supplier. This was initially to help start and coordinate SMPR development and later to explore and update information on important technical and economic aspects.

In the early 1970s, substantial work was invested in an overall market survey in developing countries and in detailed evaluations of a number of candidate Member States. A partial but important objective of this survey was to demonstrate the existence of an SMPR market if the reactors would be available at certain costs. Detailed assistance also was provided in the case of two bid evaluations, namely for Kuwait in 1975 and Bangladesh in 1978.

An SMPR information meeting held in 1981, in conjunction with the 25th IAEA General Conference, provided a summary of the status and recent thinking on SMPRs, but also pointed out important factors which must be taken into account such as the complex decision-making process, financing constraints, and infrastructure considerations. Such meetings and many studies performed elsewhere, however, have only confirmed the desirability of SMPRs being considered a potential power source for developing countries and also for industrialized countries in some situations.

This historical experience and the recent trends were taken into account in launching a new study -- the IAEA Small and Medium Sized Power Reactor Project Initiation Study -- conceived as a joint effort between buyers, suppliers and the financing community. In September 1983 a first Technical Committee Meeting was held with participants from the buyer and supplier sides. The first meeting generally endorsed the overall concepts of the new study and a phased approach for its implementation was recommended. In October 1984 a Consultants' Meeting on Nuclear Power Plants Financing was held in Vienna. The main findings of this meeting are shown in paragraph 4.3.3 of the present report. The banks responded favourably to becoming more involved in this matter.

According to the main objectives of Phase I of the study, clarification is being sought of the major factors and inputs to the decision-making processes before a SMPR project can be launched. This includes basic energy resources, power system expansion plans, available plant technology, possible contractual conditions, infrastructure and manpower availability, financing aspects, as well as market prospects. The necessary information was collected from both the buyer and supplier sides via a rather comprehensive two-part questionnaire and has been supplemented considerably by data from IAEA files. The OECD-NEA has shown a keen interest in this study and has provided a survey of the potential industrialized country market for SMPRs (Section 5.4).

3. SMPR SUPPLY SITUATION

3.1 Design Summaries

The surprisingly high number of 17 potential suppliers answered the questionnaire, presenting 23 design concepts. It was to be expected that these concepts are at very different levels of maturity and also that the responses give information at very different levels of detail. Table 3.1 gives a summary of the responses.

Some of the concepts would not be ready for a commercial bid within this decade (the B & W. CNSS, CNSG, the ASEA-ATOM PIUS and the GE MPR and HTG). For these a design summary has been provided but essentially no further information.

The GEC/U.K. Magnox concept is a single purpose process heat plant aimed at oil recovery. A reference plant for this has been given.

While additional information would have to be sought in several cases, it is clear from the questionnaire responses that a new situation has developed in which several suppliers are prepared to bid immediately or soon on plants, from 100 to 500 MW(e) but generally in the 300 MW(e) range, with well-defined reference plants which should make it possible to form some judgment on plant provenness, safety and attainable operating performances.

Three suppliers gave information on plants in the 600 MW(e) range (ASEA-ATOM, Sweden, GE, U.S.A. and WESTINGHOUSE, USA). While the SMPR range definition excludes plants of 600 MW(e) and above it should be recalled that a number of suppliers have designs of plants in the 600 MW(e) range ready for bidding. They include:

AECL, Canada	PHWR 600 MW(e)
FRAMATOME, France	PWR 600 MW(e)
KWU, Germany, F.R.	PWR 600 MW(e)
ASEA-ATOM, Sweden	BWR 650 MW(e)
GE, U.S.A.	BWR 600 MW(e)
Westinghouse, U.S.A.	PWR 600 MW(e)

Brief summaries of the SMPR designs offered or proposed by the various vendors in alphabetical order are shown in Annex I together with basic data and information on suppliers provenness and readiness. These summaries are necessarily brief in the context of this report but could be supplemented by extensive reports from the suppliers, upon request. Key parameters for the SMPR designs presented here are summarized in Table 3.1.

At this stage no attempt has been made to give any assessments of the designs proposed, e.g., as regards provenness, but only information provided in response to the questionnaires has been supplied.

3.2 Design Trends

The most significant, and consistent design trend evident from the questionnaire responses is the concentration of the presented designs or concepts in the 300 MW(e) size range. 12 out of 23 designs are for power plants near 300 MW(e) output.

Table 3.1: SURVEY OF SUPPLIER QUESTIONNAIRE RESPONSES

Supplier	Concept Name	Information given on Design	Reference (R) or Prototype (P)	Costs	Technol. Transfer	Contract
AECL, Canada	CANDU 300	Yes 1)	R	Yes	Yes	Yes
FRAMATOME, France	NP 300	Yes 1)	P	P	Yes	P
KWU, FRG	PHWR 300	Yes 1)	R	-----	Yes	Yes
HRB, FRG	HTR 100	Yes 1)	P	P	Yes	P
	HTR 300	Yes 1)	R	P	Yes	P
	HTR 500	Yes 1)	P	P	Yes	P
INTERATOM, FRG	HTR M80 to 640	Yes 1)	P	----	Yes	P
ANSALDO/NIRA, Italy	CIRENE 300	Yes 1)	P	Yes	Yes	Yes
	PWR 300	Yes 1)	R	Yes	Yes	Yes
MITSUBISHI, Japan	PWR 300	P	R	----	----	P
TOSHIBA, Japan	BWR 500	P	R	----	----	----
	BWR 200/ 300	P	----	----	----	----
HITACHI, Japan	BWR 500	P	R	----	----	----
ASEA-ATOM, Sweden	PIUS 500	Yes 1)	----	P	----	----
NNC, U.K.	MAGNOX 300	Yes 1)	R	Yes	Yes	Yes
ROLLS ROYCE, U.K.	PWR 300	Yes 1)	----	P	----	----
GEC, U.K.	MAGNOX	Single purpose process heat plant				
B & W, U.S.A.	CNSS	Yes 1)	----	P	Yes	P
	CNSG	Yes 1)	----	P	Yes	P
GE, U.S.A.	Small BWR	Yes 1)	2)	3)	Yes	Yes
	MPR	Yes	----	----	----	----
	HTG	Yes	----	----	----	----
Atomenergo- export, USSR	VVER-440 PWR	Yes 1)	R	----	Yes	P

P = Partial

---- = No Response

1) Design summaries for these plants are included in Annex I.

2) GE has given several BWR plants as reference.

3) Costs for 600 MW(e) BWR are given.

Some other objectives and trends common to several of the designs include:

- An emphasis on a reduced construction schedule. This is evident in many proposals, and is a principal theme of the Rolls Royce and CANDU designs.

- Efforts to satisfy provenness criteria through utilization of systems, components, and concepts proven by commercial operation. This is evident in many designs including the Magnox and BWR concepts. Some BWR concepts essentially adopt a current pressure vessel for use in the smaller power plant, and the CANDU-300 design shares all key component designs with current larger reactors.

- Simplification of process and safety systems by taking advantage of particular inherent small reactor characteristics. For example, natural circulation in some BWR concepts (not practical in large-size units because of pressure vessel size limitations); taking advantage of the high heat sink capacity/capability of small gas-cooled reactor cores.

- A high level of prefabrication/shop fabrication. This is emphasized in several designs, and is maximized in the barge-mounted Rolls Royce 300 MW(e) unit.

- Recognition of site conditions in some developing countries. Most of the SMPR designs presented incorporate a relatively high seismic design level, and would function satisfactorily with relatively high cooling water temperatures.

- Several of the design concepts are aimed at operation in smaller and weaker grids including features of load following (e.g., NP 300 and PHWR 300) and self-powered start-up (e.g., CANDU-300).

3.3 Process heat and cogeneration plants

Several of the proposed designs are explicitly stated to be usable for process heat generation in single purpose plants, notably the GEC/UK Magnox plant, the BBC/HRB and the Interatom high-temperature reactors, although others could also be used in this manner.

Several suppliers have stated that dual-purpose applications, such as in desalting plants are foreseen (Rolls Royce PWR 300, HRB 100-500 and Atomenergoexport VVER-440). It is not proposed to obtain an optimized design through a back pressure turbine but simply to bleed off high-pressure steam at the high pressure turbine. This is in itself a proven and simple method.

For the VVER-440 plant, the supplier quote economical dual-purpose applications in the areas of district heating, seawater desalting and industrial processes.

One supplier estimates that there may be a potential market for about 48 cogeneration modules of HTR for the Federal Republic of Germany's internal market. In China there are preliminary feasibility studies under way for district heating in North-East China and also for a dual purpose nuclear power plant for the Shanghai Petrochemical Complex.

SMPR for these applications would be less sophisticated than for the electricity generating reactors. Countries having industrial capabilities to design and construct test reactors may reach the goal of series production of low temperature heat only reactors in a relatively short period of time.

3.4 Implementation Schedule

In the "Guidebook on Nuclear Power Introduction, TRS-217", the IAEA has published a model schedule for all activities involved in planning, launching and implementing executing a nuclear power plant project. This schedule is given in Fig. 3.4.-1 The time periods given must, of course, be considered as indicative only and will vary from one project to another, but the activities are essential and have to fit into an overall schedule. In Fig. 3.4.-1 the schedule has been divided into four major parts

- pre-project activities ending with a decision to embark upon the project;
- pre-contractual activities including the bidding, bid evaluation and contract negotiation and also the site selection and qualification (A);
- pre-construction activities (B);
- the construction itself, defined as the site work from the first major placement of concrete to the time the plant goes into commercial operation after completed trials at full power.

In the case of an SMPR project it is necessary to review in more detail phases A and B. In the precontractual activities, the model schedule assumes a letter of intent and the submission of a preliminary safety analysis report (PSAR) to obtain the construction license as a pre-requisite to the final contract signature. Depending upon the state of readiness of an SMPR design this may or may not be possible to perform within the one year shown, and it could in some cases extend up to five years, i.e. until the supplier has been selected, the PSAR has been prepared and the construction licence given.

The pre-construction phase B allows for the plant owner's work on site infrastructures before the construction proper can start. It also gives time for the supplier to prepare the construction effort for plants of a more or less standardized design. It is foreseen that the supplier would place orders for some major components, e.g. big forgings or the whole reactor vessel and steam generators, already after the letter of intent. This may not be possible for many of the SMPR concepts, as the detailed designs still have to be completed. In this case the supplier could require and extension of the preconstruction phase by possibly several years. The schedule given by Rolls Royce (Fig. 3.4.-2) for the completion of a series of SMPR projects demonstrates these points very, well with delays in these phases for the first plant not recurring for in subsequent ones.

As regards the construction phase itself it is notable that several suppliers have stated remarkably short construction times of 48 months, with tight control and considerable confidence that these short times can be kept in a project abroad. This is, of course, a most important element for the possible viability of an SMPR in comparison with a coal fired plant.

In the Table 3.4.-1 the responses to the questionnaires have been summarized. Where suppliers have indicated a time requirement for detailed engineering or pre-construction work, this has been interpreted

Table 3.4.-1. RESPONSES ON IMPLEMENTATION SCHEDULE

Supplier and Plant	Preconstruction time requirements "B" (months)	Construction schedule (months)
AECL, CANDU 300	-	48 4)
FRAMATOME, NP 300	-	48
HRB, HTR 300	-	72
INTERATOM, HTR MOD	18 - 42	48
KWU, PHWR 300	-	48
Ansaldo, CIRENE 300	27	69
Ansaldo, PWR 300	22	67
Mitsubishi, PWR	-	36 & civil works
Toshiba	-	50
NNC, Magnox	-	66
Rolls-Royce, PWR 300	1)	96 1)
GEC, UK, Magnox process steam	2)	72
B & W	-	60
(GE/BWR 6)	(18)	(54)
Atomenergoexport	(80-90) 3)	

- indicates that no special requirement was given.

1) 66 months needed before a contract, 96 months applies to first plant only, later plants could be constructed in 72 months.

2) 72 months required before a contract.

3) From receipt of site engineering data.

4) Later information indicates 42 months.

in the table as meaning the pre-construction phase "B" as defined above, even though this may be an overestimate in certain cases.

It should be noted that several suppliers have indicated a time requirement before a bid could be submitted. This has been shown in the Annex to Sections 3.5 and 3.6.

3.5 Supplier Readiness

The "readiness" of the various SMPR suppliers must be assessed in a number of ways. In this report the following has been excerpted from each supplier's answer to indicate how ready each would be to enter a competitive bidding process:

- At what date has the supplier stated that he would be prepared to submit a realistic firm price bid for the nuclear power plant?

- At what date will the detailed design of the power plant be at a stage to permit construction to begin?

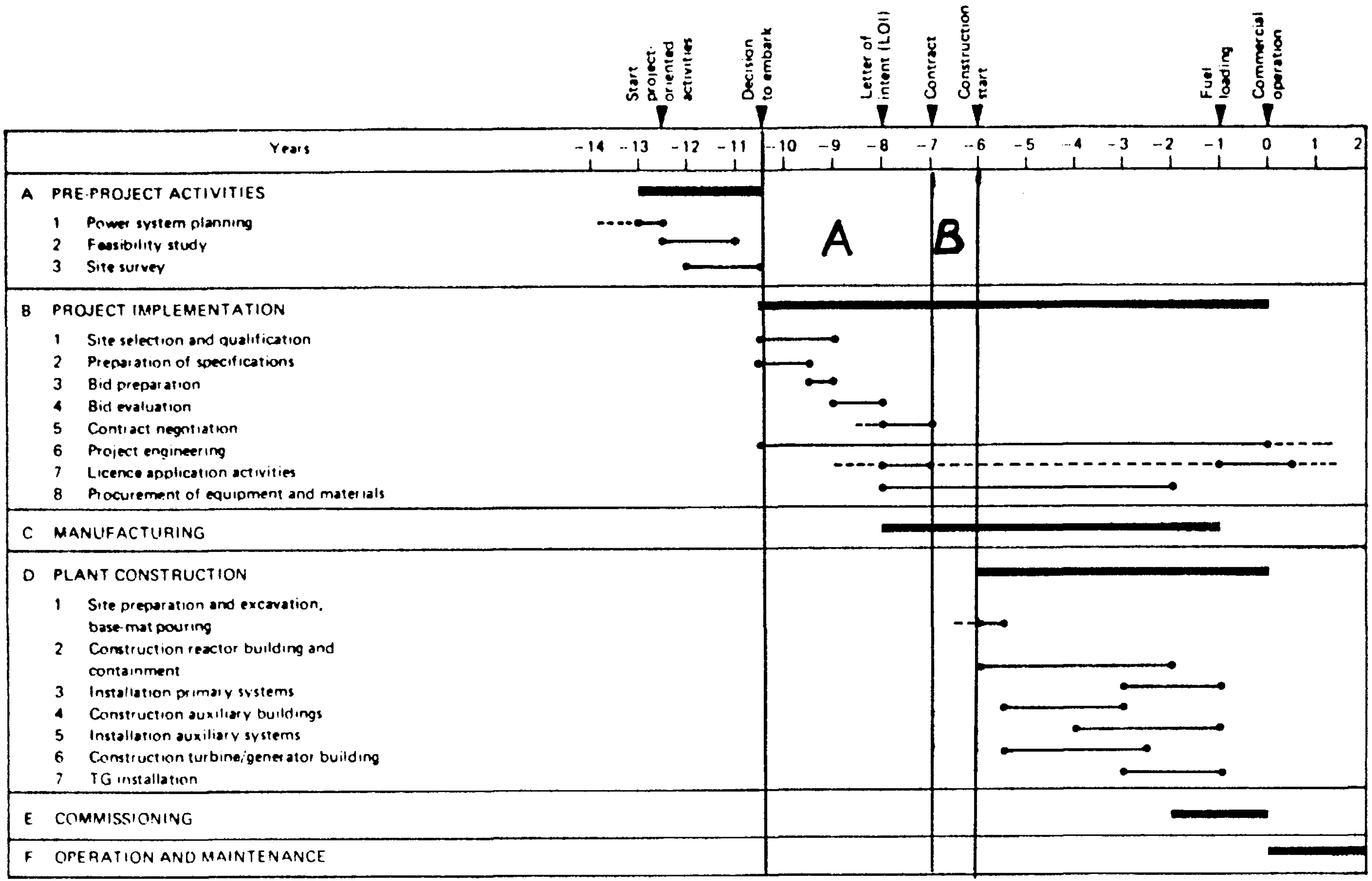

Fig. 3.4.1: Schedule for a Nuclear Power Plant

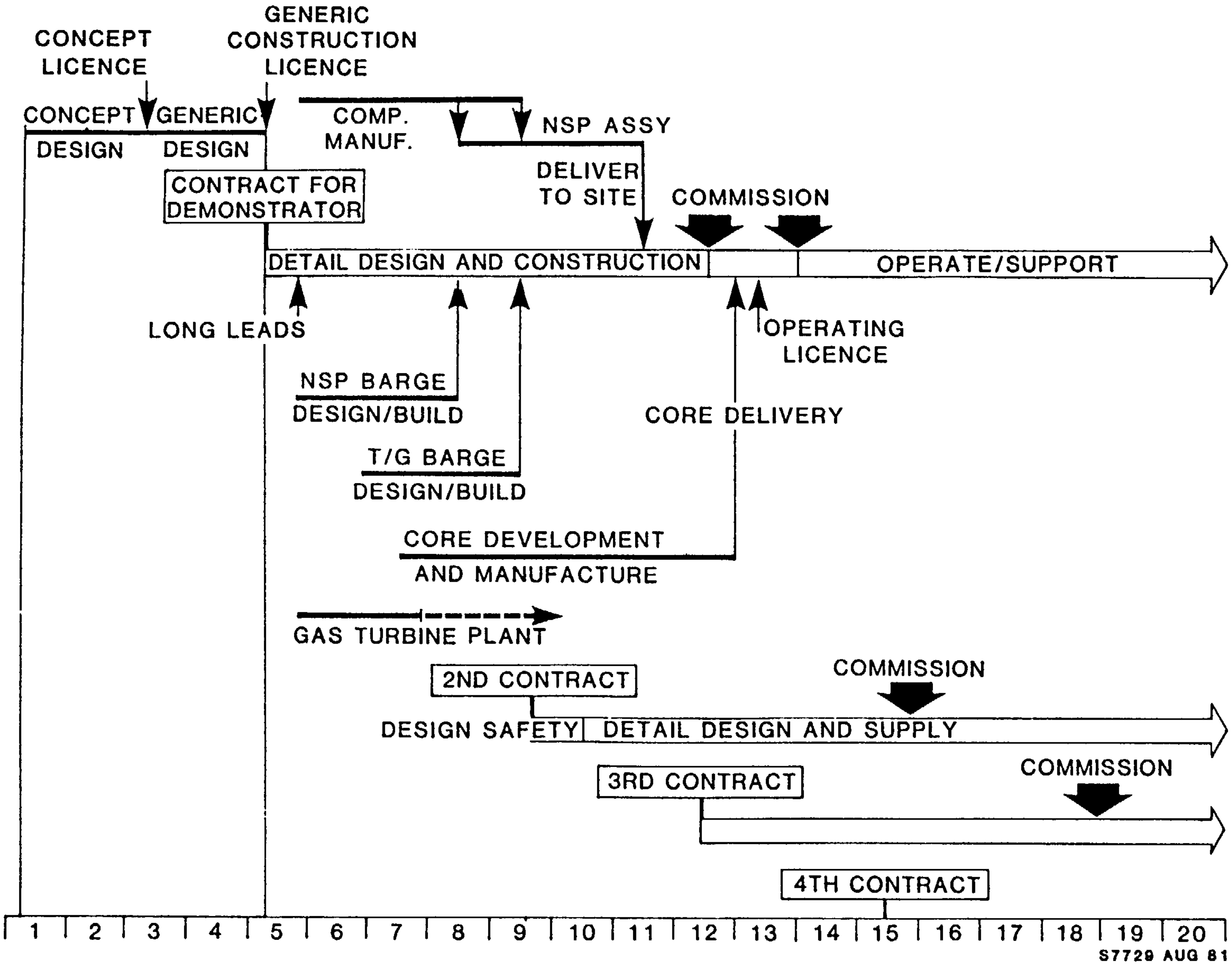

Fig. 3.4.2: Schedule of Rolls-Royce barge-mounted SMPR

- What are the pre-construction and construction schedules for the proposed plant?
- What is the status of the regulatory review of the design?

The "readiness" of the various SMPR designs currently offered or proposed by the nuclear suppliers, and their respective design and availability schedules are given in the Annex I to the report. A final definition of readiness, however, would only be achieved when a bid is requested.

3.6 Provenness

The purchaser of any nuclear power plant will require high station availability/performance from the start of operation as the plant is capital intensive, but with low operating costs. Economic considerations therefore necessitate operation at a high capacity factor.

In the case of an SMPR it is in addition necessary to consider that it is likely to be purchased by a relatively small or developing country or utility, and to be the first nuclear unit. Such countries or utilities are unlikely to have the qualified manpower and other infrastructures necessary to resolve major or frequent station performance problems.

The concept of "provenness" is therefore important; the performance and availability of the nuclear power plant, particularly during the early years of operation, can be expected to be related to the degree of its "provenness".

Obviously, there are various degrees of "provenness" that could be assigned to a proposed small or medium size nuclear power plant, ranging from a very high degree of "provenness" if the proposed power plant is nearly identical to one or more stations in successful commercial operation, to a very low degree of "provenness" if the power plant design to a major degree encompasses novel or unproven concepts or components.

In general, it is the performance of a number of key components (including fuel, primary pumps, control devices, steam generators, and reactor vessel or pressure tubes) that dictates the performance of the nuclear steam supply system. Except for fuel, malfunction of these key components inevitably leads to a unit outage, and repair or replacemnt is difficult, time consuming and costly. Fuel failures also pose operating problems, particularly for reactors that are fuelled off power.

Commercial nuclear power plant operating experience over the past decade, as reflected in the IAEA Power Reactor Information System, has demonstrated that new designs or design modification of the above components or modifications in system designs have to be introduced with the greatest of care.

The integration of components of proven performance to constitute systems based on proven concepts is, however, likely to produce a reactor/plant design capable of high performance/capacity factor.

This philosophy has led to the IAEA minimum requirements proposed for provenness cited below:

1) The reactor and plant systems and concepts must have been demonstrated in an integrated manner in at least one power reactor at comparable ratings,
or

2) All key components, of the design and capacity proposed, must have significant operating experience in the offered size under comparable operating conditions, in nuclear power plants or test facilities. It would be necessary to define individual provenness criteria for fuel, reactor vessel and other components (which could require an experience in excess of 10 000 h of operation time or a significant number of operation cycles). Key components in the nuclear steam supply system may include:

- fuel
- refuelling system
- primary pumps
- control and protection systems and their components
- steam generators
- reactor vessel or pressure tubes and
- critical valves.

Experience indicates that the Balance of Plant (BOP) is a major contributor to the unavailability of nuclear power plants. It is, therefore, appropriate to apply the proveness criteria to key BOP components, including the turbine-generator, condensor, and feedwater pumps. If some parts are "first-of-a-kind" it could be useful to have spare parts of them.

A judgment on provenness requires a careful and detailed design review and the questionnaire responses did not, of course, provide enough information for such a review. The responses did, however, contain information on reference or prototype plants which would give a possibility to judge the general status of provenness. In this context a prototype plant is defined as one in which the plant concept has been demonstrated, usually at a much lower plant capacity than in the proposed plant but most of the components have to be optimized. On the other hand a reference plant is one in which all major plant systems and components have been or will be proven in operation well ahead of the construction of the proposed plant. This reference plant has to be a mature and industrial one and its overall design capacity must be nearly the same than for the proposed plant. All design changes with respect to the reference plant must be easily identifiable. A modular design approach can make it possible to have a reference plant with a significantly different capacity. The information which was provided in the questionnaire responses is given in Annex I of the report, together with pertinent experience and performance data taken from the IAEA Power Reactor Information System. At this stage no judgments have been made based on this information.

It should be noted that while a reference plant can be very helpful in demonstrating provenness, it should not be regarded as the one and only solution to the provenness problem. Several plants have been built in developing countries without a reference, e.g., Atucha-1 and KORI-1. In these cases the buyers appear to have put greater stress on the demonstrated experience of the supplier, rather than on component and system provenness.

It is in this context particularly useful when the safety concepts are of proven design and that the suppliers have proven their ability to supply safe and available plants. These two last items may be helpful to judge provenness in the cases where the plants show some differences with the prototype or reference plant.

A safety analysis report of the proposed concept (or an updated safety review if based on an old existing plant) by the supplier's country regulatory body is usually considered a convenient, but not sufficient, aspect of the provenness assurance.

3.7 Cost Information

Only a few of the suppliers gave any information about capital costs in their responses to the questionnaires.

It is clear that all suppliers who gave information want it be seen as very preliminary and of the nature of an estimate only and that the final costs will be dependent on the location of a future plant, contract type, available infrastructures, etc.

The information given must be used with care for the following reasons:

- fore costs were generally given without owners costs
- some fore costs were given in suppliers national currencies
- it is not absolutely clear what is included with regard to services, training and other options which the final contract would include
- the costs depend on the size of the final programme.

With all these reservations it is still interesting to see which trends the information can show. Thus the information was used after some corrections (owner costs, exchange rates) in section 4.3 to show a comparison with coal-fired plants.

A Technical Committee Meeting on Scaling Factors of SMPR held 28 May to 1 June 1984 discussed the possibility of obtaining information about the capital costs of smaller plants from better known costs in the range 600 MW(e) and above. The meeting was very useful in defining several factors which are likely to influence the total project cost of SMPRs but it was inconclusive as regards the fore costs, although it gave some general directives for scaling down. The data shown would lie in the lower part of a range obtained through such a scaling down.

Several suppliers have, however, opposed the use of scaling factors, as they would not take into account the specific design approaches used for SMPRs to keep specific fore costs as low as possible. The location of the points, all on a low end of any extrapolated range could confirm this.

In summary it can be stated that the cost information given has, naturally, a preliminary character but that it is based on quite carefully made estimates and that it would give some indication that SMPRs could indeed be competitive with coal (cf. Section 4.3). Better estimates cannot be expected to be obtained until a bidding process has been launched for a plant at a specific site.

3.8 Supply of Fuel, Spares and Services

a) Fuel Supply:

The suppliers are naturally aware of the limitations imposed by national nuclear export policies, e.g., in connection with non-proliferation conditions. All suppliers obviously expect to deliver the first core with the reactor. For later reload fuel, almost all declare that it will be available, but with explicit or implicit reference to exports being subject to national laws or the obtaining of export licenses. AECL alone makes reference to long-term guaranteed supply. Mitsubishi states that only fuel fabrication services would be provided, implying that the buyer would have to arrange for uranium supply, conversion and enrichment services. This is, however, a quite standard practice, especially for plants requiring enriched uranium.

None of the suppliers offers complete back-end services, but two (Framatome and NNC) indicate that reprocessing could be arranged through undertakings with other enterprises or entitites in their countries. Several (e.g. AECL, KWU, HRB and NNC) indicate that reprocessing of the spent fuel is not required for economic reasons and may indeed not be desirable. None of the suppliers offers to take over management and disposal of the high-level wastes, and none mention explicitly that this could be done in the supplier's country, reflecting the present general unwillingness to accept high-level wastes from any other country. The only known exception to this rule now is the USSR. Several suppliers offer to work with the buyer to resolve the problems of the back-end of the fuel cycle through technology transfer (e.g., AECL, Framatome, NIRA). Other suppliers have offered to assist in negotiations with other entities which would provide reprocessing services.

It is notable that some suppliers are providing for large storage capacities of spent fuel at the reactor in their proposed designs to avoid operational problems from overfilling of storage pools, as shown in the following table:

Supplier	Foreseen Capacity	Expansion Possibility
AECL	1 core + 10 years operation	20 years possibility
FRAMATOME	1 core + 10 years operation	Timelife of reactor operations
HRB	10 years operation	Dry storage casks
KWU	40 years operation	
NNC	10 years operation	Optional additional storage capacity
ASEA-ATOM	15-30 years operation	

b) Spares:

It appears from the answers on this point that the supply of spare parts and equipment with the plant is considered a routine matter by the suppliers. They have in several areas also indicated that special spare parts lists would be defined taking into account the local supply situation in a developing country so that plant availability or safety would not be jeopardized by the failure of single items of equipment. A few indications were given that spare part costs were some 2.5% of the price for the complete plant.

As regards the long-term supply of spare and substitute parts, most of the suppliers who answered this point (10 out of 14) are prepared to assume long-term supply of spares, while e.g. AECL, KWU and INTERATOM give categoric assurances. NNC points out that this has not been a problem during the more than 20 years of experience gained with operation of the Magnox GCR plants.

c) Services

Without exception the suppliers are prepared to offer training of the buyer's operations staff. Some offer specific and broadly scoped programmes covering all stages of the project (planning, design, construction, commissioning and operation and maintenance) within the

Table 3.9. PERFORMANCE GUARANTEES

Vendor	Elect. Output	Net Heat Rate of NSS	Fuel Burnup	Fuel Integrity	Material and Workmanship	Completion Schedule	Efficiency	D_2O Loss	"Linked with customers demand and scope of supply"	"Usual guarantees or current practice"
AECL	Yes	Yes	Yes	Yes	Yes	----	----	Yes	----	----
FRAMATOME	Yes	Yes	Yes	Yes	Yes	Yes	Yes	n.a	Yes	Yes
BBC/ HRB	----	----	----	----	----	----	----	n.a	Yes	----
INTERATOM	----	----	----	----	----	----	----	n.a	----	Yes
KWU	----	----	----	----	----	----	----	----	Yes	----
ANSALDO-NIRA (Italy)	Yes	Yes	----	Yes	Yes	Yes	Yes	n.a. for PWR 300 Yes for CIRENE	----	----
HITACHI	----	----	----	----	----	----	----	n.a.	Yes	----
MITSUBISHI	----	----	----	----	----	----	----	n.a.	Yes	----
TOSHIBA	----	----	----	----	----	----	----	n.a.	Yes	----
PIUS	----	----	----	----	----	----	----	n.a.	Yes	----
GEC, UK	----	----	----	----	----	----	----	n.a.	----	----
NNC	Yes	Yes	Yes	----	Yes	Yes	Yes	n.a.	----	----
Rolls Royce (UK)	Yes	Yes	----	Yes	Yes	To be Negotiated	----	n.a.	----	----
B & W	----	----	----	----	----	----	----	n.a.	----	Yes
GE, USA	Yes	Yes	----	Yes	Yes	----	----	n.a.	----	----
Atomenergoexport (USSR)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	----	----	----

---- = not mentioned in response.

N.B. Performance guarantees, applicable to contracted scope and services, are always included in plant contracts, and would presumably also be included in the case of an SMPR. Experience has, however, shown that this guarantee can take very different detailed forms, and will depend very much on the contract negotiated.

scope of technology transfer programmes which would be negotiated for each specific case.

All suppliers are also prepared to offer services for refuelling, operational assistance, in-service inspection, maintenance and backfitting.

A specific question asked was whether the suppliers would have "an optional service available which provides for complete plant operation by the supplier." The answers to this showed large variations, as can be seen from the following:

- Only INTERATOM would be prepared to offer this over the plant's lifetime.

- Mitsubishi, Hitachi, B & W and GE clearly state that this service would not be offered.

- The remaining answers indicate either that the supplier could negotiate such an offer (AECL), that a national organization which operates nuclear power plants might do it (Framatome-EDF, NNC-CEGB), or that some supervisory functions and additional training could be provided after turnover of the plant to the buyer. None of the suppliers contemplated a situation in which ownership of the plant would remain with the supplier while such operational services were offered. This point is of some actual interest as it also has a bearing on financing of the plant (see also Section 4.3.3), and also because Turkey in late 1984 requested bids for a larger plant which would also include operation of the plant by the supplier over an initial period (final negotiations of such a bid are now going on (early 1985)).

3.9 Performance Guarantees

Safe and reliable operation of a nuclear power plant can only be ensured by having a plant that has been well designed and built. Any amount of competence and dedication by the operation and maintenance staff will in no way compensate for poor engineering design and workmanship of the manufacturing and construction personnel. Quality consciousness and its encouragement and enforcement has to permeate the entire planning, engineering and manufacturing of the owner as well as the supplier.

The SMPR suppliers were asked to send their responses on the type of guarantees and warranties offered on plant safety, performance and completion schedule. The responses received vary from precise answers to more general conditions such as "Linked with customers demands or scope of supply" or "Usual guarantees or current practice". Table 3.9 shows these responses.

4. MAJOR FACTORS INFLUENCING DECISION MAKING

4.1 Infrastructures

4.1.1 Introduction

Introduction of a nuclear power plant in a country cannot be conceived as an isolated project. The first nuclear plant should always be seen as part of a continuing nuclear power programme in which nuclear power will be providing a significant part of the country's electric energy. The decision to launch such a nuclear power programme has to be made taking into account the country's industrial development status and objectives, its technological infrastructure/capabilities, its energy policy, as well as the alternative electric power generation sources.

A key factor to be evaluated when considering a nuclear power programme is the infrastructure requirements which the IAEA has defined in the following four categories:

i) Electric grid
ii) Organizations for:
- regulation with its legal background
- programme planning
- project implementation
- plant operation and maintenance.

iii) Availability of qualified manpower.
iv) Industrial support.

A nuclear power plant of any size imposes certain requirements on each of these infrastructures. They have been discussed extensively in IAEA guidebooks (e.g. TRS 200 and 217). These requirements need not delay the introduction of nuclear power in a developing country, if properly recognized at an early stage with corresponding decisions and actions on meeting them. Enhancement of infrastructure is an essential part of modernization and industrialization. Alternatives to nuclear plants also have infrastructure requirements, e.g. for coal mining, transport and handling. These may be quantitatively very important, but nuclear power will have very high qualitative requirements.

It must be recognized that an SMPR will have essentially the same infrastructure requirements as a larger plant, with the exception that it can be introduced into a smaller electric grid. An SMPR is likely to be considered as a first plant to introduce nuclear power in countries with very weak infrastructures. The following sections review those aspects which are specific to SMPR procurement in this context, with references made to the relevant IAEA guidebooks for general background and more detailed discussion of these topics.

4.1.2 Electric Grid Requirements

The electrical power system of a country or utility consists of two principal components, the electricity generating system and the high-voltage transmission system or the electric grid. Both systems must be kept "in-step", since the quality of the electric power provided to the users requires both available generation and reliable dispatching of the electrical output.

The power grid is a fundamental consideration in the sizing and siting of new power generating units. A general rule-of-thumb states that the addition of ten per cent generating capacity in a single unit to an existing interconnected grid is the maximum permissible, if the dynamic stability of the system is to be ensured. This is, however, very much a function of the individual grid and load characteristics. A case can also be made that in a system with fairly low reliability the biggest unit size can be much higher than 10% of the total installed capacity, even as high as 20%, provided that the frequency variations due to the low reliability of the grid is corrected by load shedding in order to keep the frequency in a range which is admissible by the nuclear power plant without power trip. On the other hand a power trip of a nuclear power plant which has a high fraction of the grid capacity cannot be compensated by the immediate power increase of the reserve capacity and may be followed by a collapse of the whole grid if load shedding is not able to counterbalance immediately the loss of power by cutting out a large part of the power demand. Such a load shedding has to be effective and reliable and therefore adequately engineered and accepted by the users. Direct and indirect (i.e. loss of productivity) costs have to be taken into account in such a case. [Current projections for electricity generation capacities in IAEA Member States are considered in the market assessment in Section 5, where the projected grid sizes have been used as a fundamental parameter to assess the feasibility of introduction of SMPRs using the 10% rule].

A number of suppliers are now offering nuclear power plants in the 300 MW(e) range. In spite of the quoted 10% rule-of-thumb it must be recognized that in many of the developing countries with grids in the 3000 MW(e) range, the characteristics of the grids may be such that even a 300 MW(e) plant would need to be operated in a load-following mode some times. Recent experience has demonstrated the feasibility of such operation of PWRs.

In many developing countries the electricity supply is in addition lagging behind the demand (situation of "suppressed demand"). This has most often resulted in grids with poor voltage and frequency stabilities.

At the same time, the economics of nuclear power requires that a high load factor of the plant be achieved, thus requiring a grid quality which would not adversely affect the operating performance of the plant.

These basic, and to some extent conflicting, requirements emphasize the need for a careful study of the grid characteristics and the consequent specifications of the prevailing conditions under which the plant is expected to operate reliably, which must be clearly detailed in the bid specification. It is likely that the grid into which an SMPR is planned to be introduced will require very careful study in this respect. In the final instance, a study must be made of the interaction between the existing grid and a specific plant for which the essentialoperational characteristics must be known. In this context it can be recalled that several of the SMPR designs presented for this study specifically address operation in smaller and weaker grids (Sections 3.1 and 3.2). The example of India shows that in the case of a weak grid it is difficult to connect a big plant and that it will be more useful to split the capacity in several smaller plants which may be distributed in different points of the grid near the consumption centres.

The safety of a nuclear power plant should not generally impose very rigorous demands or requirements on grid performance or availability. Following a loss of grid, most current nuclear power stations are designed automatically to reduce electrical power output to a level sufficient to maintain the station operating loads. All current nuclear power plants have their own support systems to maintain safe operating conditions for several hours following a loss of grid and station turbine-generator output; some designs can sustain safe operating conditions indefinitely without the grid connection through inherent heat sink features, as shown in several of the SMPR design concepts presented for this study. Considerations of the reliability of the grid and of the emergency power supply systems of the power plant (typically diesel generators) may, however, call for extra redundancies of the latter.

It is likely that the grid studies will lead to specific plant specifcation requirements, e.g. load-following operation capability and capability to accept higher than normal frequency and voltage variations. These may call for additional engineering and plant features, with the resulting additional capital costs.

Plant-grid interaction studies may also likely conclude that improvements must be made to the electrical transmission system to correct deficiencies. This may result in extra investments that must be carefully evaluated. In its essence the problem is that when the NPP comprises a large share of the total installed capacity of a weak grid, its trip due to a plant-internal reason is likely to provoke the collapse of the local grid, hence leading to a situation of station black-out. In these conditions the heat decay removal system can only rely on the availability of the on-site emergency power supply (diesel generators). The higher probability of station black-out likely to occur in a weak grid system may require increased reliability (additional redundancy, increased frequency of start-up etc) of the on-site power supply.

In parallel with this, efforts should be made to improve the outside grid characteristics. These include construction of new tie-lines and/or duplication of those lines which would become overloaded during perturbed system conditions, installation of more effective controlling equipment and engineering of an effective, reliable load-shedding scheme. While the first solutions may require large extra investments by the utility, the last is more within reach and should be implemented as soon as possible. However, all improvements made on the electric system of a country have as consequence better service and greater reliability of supply to the consumer. High-quality service is not only a NPP requirement but also modern industry's need in general, and investments in the improvement of the grid must be made sooner or later in a developing country which wants to progress. Hence, additional investments required for the grid need not necessarily be charged to the introduction of a nuclear power plant.

The IAEA Guidebook, "Interaction of Grid Characteristics with Design and Performance of Nuclear Power Plants" (TRS 224) gives an overview of the associated problems and their solution. Other relevant informtion is presented in the IAEA Guidebooks, "Introduction of Nuclear Power (TRS 217) and "Expansion Planning for Electrical Generating Systems" (TRS 241).

4.1.3 Organizational Requirements

Various organizational structures are required to provide the legal and administrative framework necessary for the start and implementing of a successful nuclear power programme. These structures are essentially independent of the size of the initial nuclear power plant constructed, but generally evolve or are modified as the nuclear power programme develops.

When considering organizational requirements, manpower requirements must also be taken into account (see Section 4.1.4.). The organizational structures require some highly qualified indigenous staff but not necessarily in very large numbers; in many cases the necessary effort and functions can be accomplished with the help of imported manpower.

The organizational requirements encompassing the start and implementation of a nuclear power programme can be considered under three general categories:

- Electrical system development and planning organization
- Regulatory organization
- Plant procurement, construction and operating organization.

Each of these organizations is discussed briefly below. Further information is available in Section 5.5 of the IAEA Guidebook, "Introduction of Nuclear Power".

Electrical System Development and Planning

It is essential to have organizational entities which are able to perform electrical capacity and electrical transmission and distribution system planning, consistent with various national requirements and objectives. The functions of these organizations include electrical system expansion planning, and manpower and industrial capability assessments.

The responsibilities, functions, objectives and method of operation of these organizations must be well defined and recognized by the country/utility.

Regulatory Organization

Adequate licensing and regulatory functions are a key to the safe operation of a nuclear power plant. A well-defined organization charged with the licensing and regulatory responsibilities is therefore essential; the authority and responsibilities of this organization must be well defined. The authority of the licensing and regulatory organization should be defined within national legal statutes.

The importance of licensing and regulation justifies a dedicated and qualified core staff, even if moderate in size. In many cases in the past, bilateral intergovernmental agreements have provided the framework for assistance to the licensing body in the buyer's country.

Plant Procurement, Construction and Operating Organization

Organizational structures are necessary for the procurement, construction and operation of a nuclear power plant. The nature and size of these organizations can vary widely, and depend on the level of local participation, type of contractual arrangements, and station operation needs (e.g. in-house versus a service contract for maintenance). In each case, however, the organizational structure must be appropriate to the functions required, and be well defined.

4.1.4. Manpower Requirements

The availability of adequate qualified manpower at the time when it is needed is one of the essential requirements for the success of any nuclear power programme. Without qualified manpower no nuclear power plant can be planned, built or operated with assurance of safety and reliability. Whatever the contractual arrangements for a nuclear power project, there are certain activities for which full responsibility has to be borne by national organizations and which have to be performed primarily by qualified local manpower. There is a worldwide recognition of the need for a competent manpower infrastructure as a basis of nuclear power development, derived from the experience of those countries and organizations that have launched nuclear power programmes. Experience has also shown that, in some of these countries, the availability of competent manpower continues to pose a problem. In some cases it has been a constraint on the nuclear power programme. In all cases, sustained efforts are being expended in manpower development to satisfy the need for qualified personnel. It should be recognized that the manpower requirements are essentially the same for an SMPR as for a larger nuclear power plant.

Activities which have to be performed under the full responsibility of national organizations and primarily by local manpower under all circumstances include the following:

- Establishment of regulatory requirements and licensing criteria for the power plant and their enforcement;
- Planning the introduction of the nuclear power power programme in step with national development programmes;
- Negotiating the bilateral intergovernmental agreements;
- Procurement of the nuclear power plant(s) and its fuel;
- Surveillance of the execution of the contract(s);
- Operation and maintenance of the nuclear power plant(s).

The Agency's Guidebooks on "Manpower Development for Nuclear Power" (TRS No. 200) and "Qualification of Nuclear Power Plant Operations Personnel" (TRS-242) contain detailed information on manpower and qualification requirements, and on the planning and implementation of manpower development.

In meeting the manpower requirements of nuclear power plants a country may follow several options, depending on the local conditions. Developing countries which have embarked on nuclear power programmes in the past have generally tried to maximize the domestic participation in regulatory activities, construction supervision, operation and maintenance. These strategies have not always been implemented in an optimal manner and have even in some cases affected the costs and schedule of the first project negatively, but they have generally helped the country, at least in the longer term.

If qualified local manpower is not available for a particular task, these personnel requirements can in many cases be met by hiring competent people or organizations from abroad, or through appropriate service contracts. Although such practices are common in some countries in a variety of industries, all countries that have currently introduced nuclear power have done so without applying these approaches on any significant scale.

In the case of the possible introduction of an SMPR, the authorities must carefully consider what the national priorities should be: at one extreme there may be a need and decision to obtain electric energy at minimum costs with reasonable national participation, and at the other to maximize transfer of technology as soon as possible in step with domestic industrial development programmes but with increased risks for delays and cost escalations in nuclear power production. Manpower considerations are central to decisions on this issue.

An SMPR may be considered by a developing country with weak manpower infrastructure. In such a case it is essential that an early assessment is made of the availability of qualified manpower to form a basis for:

- Decisions on whether to go ahead with the project in view of overall national policies;
- Setting up staffing and personnel management policies for the project, and
- Establishing a manpower development programme to meet the demands of the nuclear power programme.

Assistance from the IAEA can be requested for performing an assessment of the availability of qualified manpower and for formulating a manpower development programme. It should be stressed that the cost of such a programme will be very small compared to the planned plant investments and that it nevertheless represents one of the most critical and necessary investments of the nuclear power programme, as it will help to avoid costly mistakes, delays and overruns, and ensure safe and reliable NPP operation.

If the manpower requirements are not recognized and dealt with at an early stage, experience shows that this can cause serious problems and delays. Early assessment and a judicious use of the options available to meet manpower requirements could prevent these requirements from becoming a constraint to the successful implementation of the nuclear power programme.

It should be noted that the shorter-than-usual construction times quoted for many of the SMPR concepts in this study would emphasize the urgency for early assessment of availability of qualified personnel and for consequent decisions and actions.

4.1.5 Industrial Support Requirements

A very large and diverse array of requirements for support from industries is inherent in the construction, operation and maintenance of a nuclear power plant.

However, in order to minimize costs, the SMPR concepts provide for an extensive degree of foreign supply standardization and pre-fabrication which may limit the scope for local manufacturing.

In the information from suppliers, all have indicated that turnkey contracts could be provided, and in some cases a high degree of shop fabrication as well, the extreme case being a barge-mounted plant which would be towed to the site. An SMPR can be procured with no participation of domestic industry except some civil construction work. This type of procurement, together with provisions for an extensive guarantee for plant performance and licensability, and the expectation of good cost and schedule control would be in the interest of the buyer organization. Still, most buyer countries would want domestic industries to be involved in providing some of components and also to participate in the plant erection as a preparation for later, more extensive participation. A good supply contract will strike a balance between these conflicting requirements.

It is important to note that, if domestic production of some component is contemplated, the smaller sizes often involved for an SMPR would ease some problems of manufacturing but the requirements for quality will remain very high. Manufacturing processes such as casting, forging, etc. could indeed be easier for small-size components but tooling, finishing to close tolerances and welding would remain highly demanding in quality. Construction materials, structural steel and labour for civil construction could most often be procured locally, but strict quality standards have to be met. The easier introduction of SMPR components in the domestic production can provide a spin-off for the domestic industry which will increase manufacturing quality. This quality increase can be used to develop other products which also need high quality.

Early in the evaluation of a nuclear power programme the prospective buyer organization should develop a thorough understanding of the industrial requirements of a nuclear power plant, and make a detailed assessment of the indigenous industrial capabilities in terms of both "quality" and "quantity". The extent and nature of technology transfer to local industries available from supplier countries should also be established during the bidding stage.

At the same time the scope and capabilities of national R&D organizations must be assessed to help define their possibilities to assist technology transfers to the local industries.

Experience has shown that too high ambitions for local participation in a first nuclear project can have negative consequences for the schedule and costs of the nuclear power project. Realism in assessments of national participation capabilities and in national participation policies must therefore be stressed.

4.2 Siting Considerations

The principal considerations in selecting a site for a "conventional" thermal power station include proximity to load, availability of cooling water and proximity to the fuel supply. The first two of the above considerations are equally valid for a nuclear power station; the third is unimportant for a nuclear power station, owing to the small volumes of fuel consumed.

There are also, however, a number of other considerations, which have special or increased importance for nuclear power stations. These include:

- Site-related natural phenomena that are important to the safety of the plant. Such phenomena include earthquakes, floods, tsunamis and hurricanes.

- Site-related man-made phenomena that are important to the safety of the plant, for example, gas clouds (potentially released by chemical complexes, etc), aircraft crashes, and explosions (which could occur at nearby highways or railways).

- The environmental impact of the nuclear plant, particularly as related to the potential release and distribution of radioactive material into the environment (air and water).

- Safety-related considerations related to the surrounding population, particularly under accident conditions.

In general an effort should be made to select a site for a nuclear power station that avoids the difficulties suggested above. For each site however, the specific nuclear power plant characteristics and performance must be addressed relative to the site and the local infrastructure (transportation systems, population, etc.), to assess the suitability of the site.

Except for heat rejection capacity (cooling water requirements), which are primarily a function of power plant size, the siting requirements for SMPRs do not differ substantially from those of the larger nuclear power plants.

The SMPR designs proposed are generally made to relatively high seismic loads as compared to some of the current larger units.

A comprehensive discussion on "Siting of Nuclear Power Plants" is provided in Chapter 9 of the IAEA Guidebook, "Introduction of Nuclear Power", and detailed safety rules are proposed in the IAEA Nuclear Safety Code and Safety Guides on Siting (see Appendix I).

4.3 Economics and Financing

4.3.1 Planning for nuclear power introduction

Nuclear power plants are and will continue to be used mainly for electricity production, even if process heat or dual-purpose applications are also possible and potentially locally important, as shown by the questionnaire responses (see Section 3.3).

The introduction of nuclear power must be based on careful estimates of a country's future energy requirements in the various sectors and on qualified studies* of economically optimized electric system expansion plans, taking into account all available supply alternatives. The planning for introduction of nuclear power shall also be based on a programme study which has to establish if the introduction of the first nuclear power plant will be followed by other nuclear power plants of same size and design or with increasing power capacity as a function of future power growth rate. At least equally important is an assessment of the domestic infrastructures and the related development programmes which will be necessary. This planning is a continuing process, within the utility or electricity generation authority, in which master studies are continually revised and updated. It is extensively discussed in the IAEA Guidebooks on "Introduction of Nuclear Power" and on "Expansion Planning for Electrical Generating Systems".

The electric system expansion studies require good data on capital costs, which for fossil-fired and hydro plants should be available in a country from experience, recent bids and feasibility studies, but cannot easily be generalized from one country to another. For the nuclear power plants in the SMPR range the available fore cost data must be regarded as carefully made, but generalized, estimates which are not tied to any specific site conditions. Thus, they should not be used directly in any planning studies without associated parametric sensitivity analyses over a fairly wide range of capital costs.

The second main cost used in the planning process, the fuel costs, must involve an educated estimate of future trends, which is, of course,

* A qualified planning study must involve a comparison of levellized lifetime costs with estimated future fuel costs for all generation alternatives operating within future load diagrams.

difficult as this refers to a time from after the plant has come on line and up to the end of its life. There now seems to be a general concensus that, over the long term, coal prices in the international market are likely to increase slowly at a rate above inflation. Uranium and fuel cycle front-end service prices should remain constant at least well into the 1990s. For nuclear plants the influence of changes in the fuel prices are also much smaller than for fossil-fired plants.

There are, however, other factors which should be taken into account in the decision on the introduction of a new energy technology. They include:

- Preparing to meet the demands of a long-term (20-30 years) energy policy based on the future availability of diversified and economic energy resources;
- If nuclear power is indicated as needed by the country in the future, the possible advantages or disadvantages should be taken into account of an early introduction involving an SMPR rather than waiting until a larger unit can be introduced;
- The technology transfer requirements and the potential benefits of the introduction of a new technology.

These considerations will go beyond those normally made by the electricity generation authority. They require the involvement of several authorities and ministries and will require decisions at a high - most often governmental - level.

4.3.2 SMPR Economics

It can generally be stated that nuclear power plants in the power range above 900 MW(e) are well competitive worldwide with oil-fired plants at current prices. They are also competitive with coal-fired plants except possibly at mine-mouth locations, especially in the USA.

For SMPRs the situation is less clear. Fig. 4.1. shows the general situation of expected generating costs for oil- and coal-fired plants; the fuel cost has been used as a parameter, as the capital cost variations are less important. The IAEA estimates for nuclear power plants with the present variations in capital costs are shown in the middle band for the sizes 600-1200 MW(e). Extrapolating this band into the SMPR range would indicate doubtful competitiveness with coal and even with oil in a lower price range of $ 25-30/bbl.

This type of assessment should not be taken as basis for the planning procedure referred to in Section 4.3.1 which requires much more sophisticated approach, but only as general screening test for whether further studies are worthwhile or not. It is in this same sense of a first screening that the following discussion of the potential economics of SMPRs based on the few cost data submitted with the questionnaires must be taken.

In order to have a better comparison between SMPR and coal-fired plants of the same size range the following analysis has been made:

- what will be the fore cost for a nuclear power plant which would give the same levellized kWh cost as a coal-fired plant, based on the reference data given hereunder?

- compare this "breakeven" capital cost with the cost data submitted with the questionnaire responses (some data have also been given for 600 MW(e) and 650 MW(e) and it seems interesting to compare also with this data).

The basic assumptions are as follows:

- o plants are standardized plants in a series
- o all costs given in US$ of January 1985
- o in-service date: 1992 for all plants

The cost data for coal-fired plants are:

- fore costs for 300 to 600 MW(e) plants: US$ 800 to 1000/kW (e) without desulphurization and US$ 960 to 1200/kW (e) with desulphurization
- O & M costs: 3 mills/kWh without and 8 mills/kWh with desulphurization
- coal costs parametric studies on US$ 45, 65, 85/t delivered at the plant
- for levelized costs include 2%/a increase in constant money for coal cost from 1990
- construction time 48 months
- interest rate 8%/a
- discount rate 10%/a
- load factor 70%
- life time 30 years.

o cost data for nuclear plants:

- same interest and discount rate, load factor and life time as above
- fuel costs: . 5.0 mills/kWh for natural uranium and 10.00 mills/kWh for enriched uranium.
  . 1%/a increase from 1990
- construction time: see Table below

The cost data given in the suppliers questionnaires responses are as follows:

Plant	Size MW(e)	Fuel	Fore cost 10^6 $	Constr. Time month
# 1	300	nat. U.	770	48
# 2	300	enrich. U.	540	48
# 3	300	enrich. U.	520	60
# 4	300	nat. U.	690	66
# 5	300	nat. U.	660	69
# 6	500	enrich. U.	644	55
# 7	600	enrich. U.	745(1)	72
# 8	600	enrich. U	1250(1)	72
# 9	650	enrich. U	790	63

The results are given in figures 4.2 and 4.3. Figure 4.2 shows that if the coal plant has no desulphurization it may be more competitive than the nuclear power plant.

(1) These two data show that all the fore cost information presented here should be taken with care, as the spread in cost data is very large.

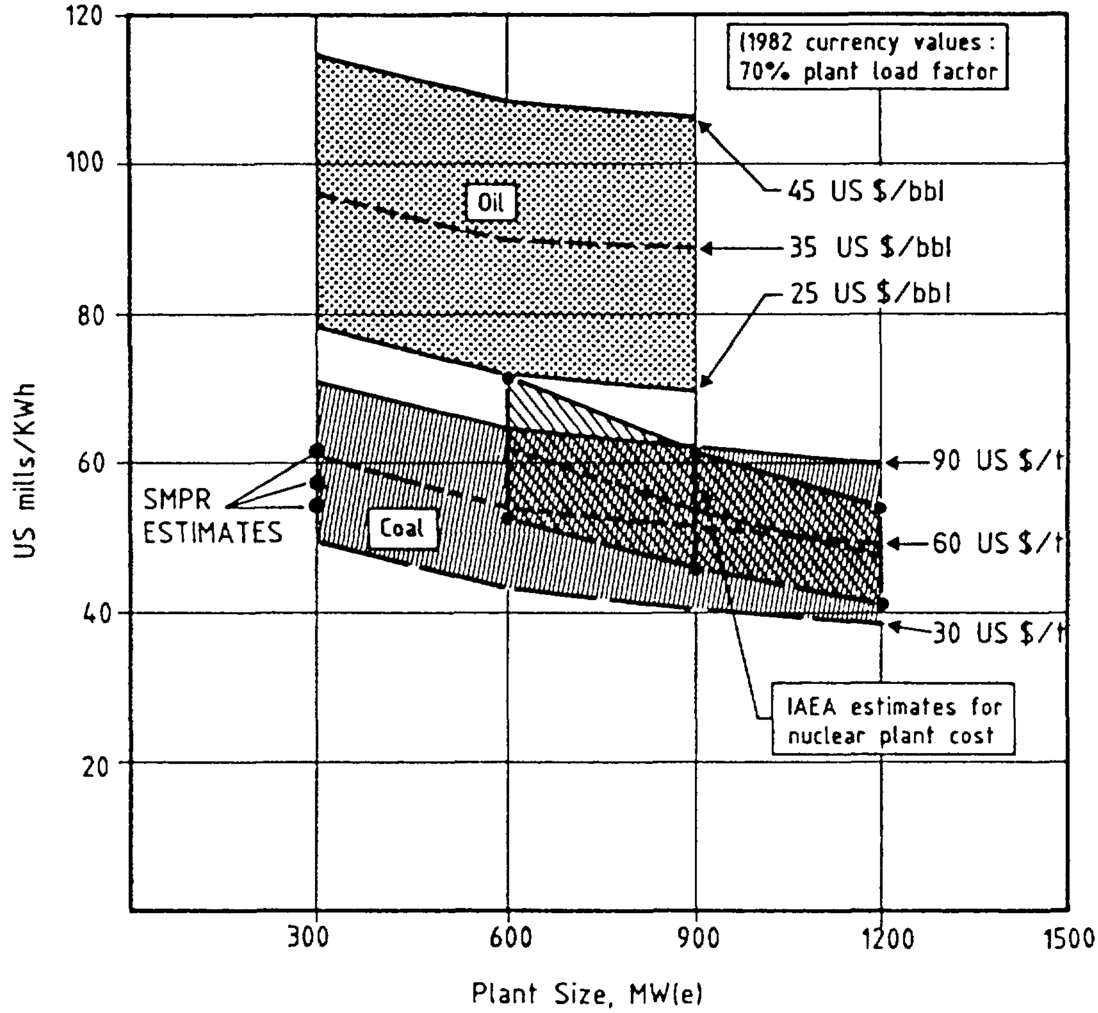

Fig. 4.1: Estimated Cost of Electricity Generated by Nuclear, Coal and Oil Power Plants Starting Operation in 1990

However, to take into account similar levels of environmental protection for both nuclear and coal-fuelled plants, it is more useful to take as reference the coal-fuelled plant equipped with a flue gas desulphurization system. Figure 4.3 shows that in the competition with coal-fired plants equipped with desulphurization the nuclear power plant may be well competitive with coal-fired plants which show the given coal prices and fore costs.

Plants 6, 7 and 9 confirm that larger power plants are well competitive with coal-fired plants.

Still, these very simple screening tests would only indicate that SMPRs in the 300 MW(e) range may be competitive with coal-fired plants but it is inadequate for a decision which needs further investigation. A better cost estimate can only be expected as a result of a detailed feasibility study for a plant at a specific site. A proper planning study should also take into account other cost elements such as:

- Costs of grid reinforcement or development;
- Potential costs of special infrastructure development if not seen as part of general development programmes;
- Possible penalties for alternatives, e.g. detrimental environmental effects of fossil fuel burning, large scale

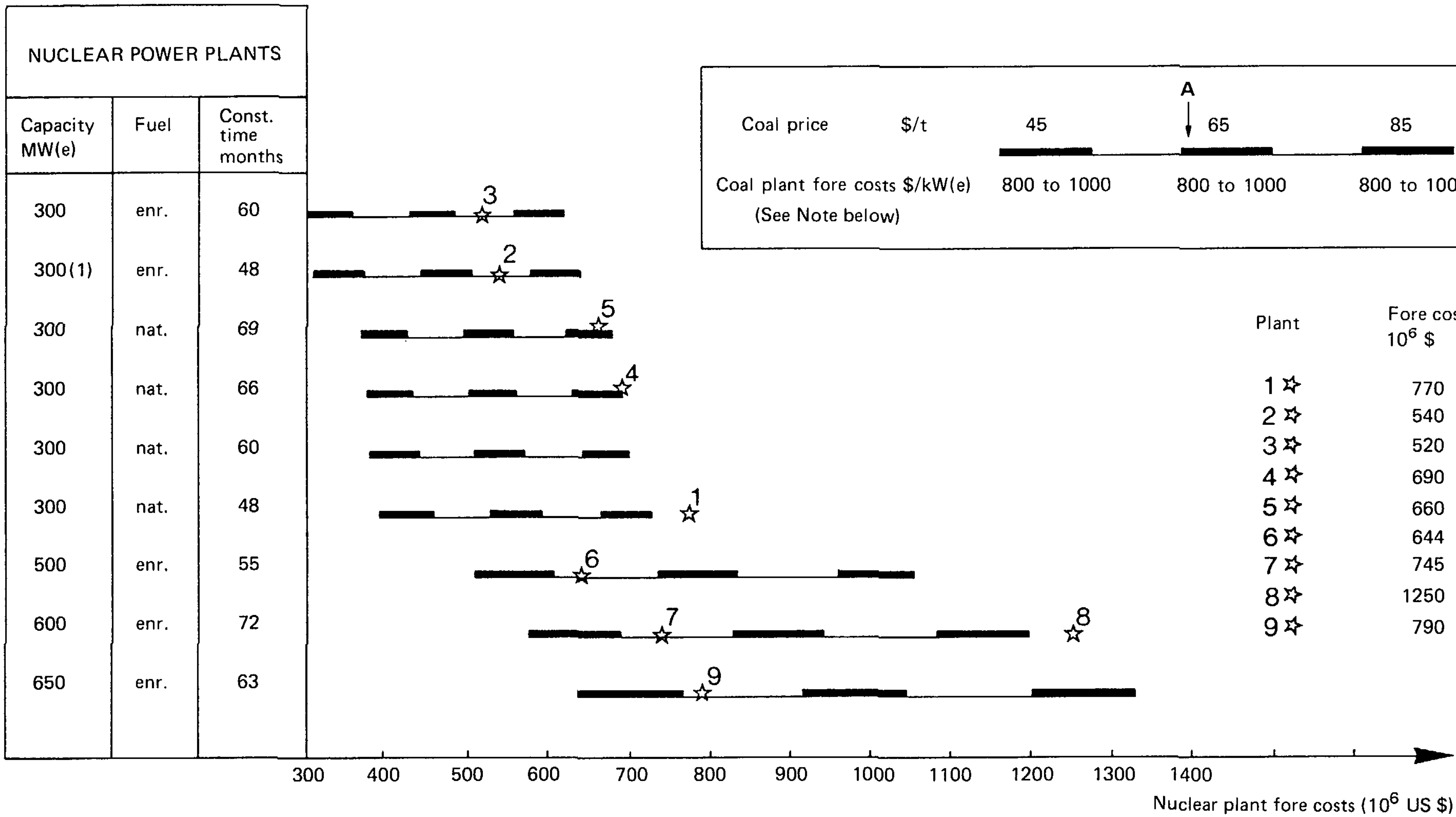

FIG.4.2. *Competitivity of nuclear to coal fired plants. Case 1:* Coal fired plants without desulphurization — (1) Fuel costs 8 mills/kWh(e) in this case instead of 10.

Note: The bars show the nuclear plant fore cost which will "breakeven", that is, have the same levelized generation cost as a coal-fuelled plant having the indicated coal price and fore costs.
For example: a nuclear power plant whose fore cost is A is competitive with a coal fired plant whose fore cost is between 800 to 1000 US $/kW(e) and which uses coal at 65 US $/t. The point ☆ is the supplier's estimate of the fore cost for the particular plant.

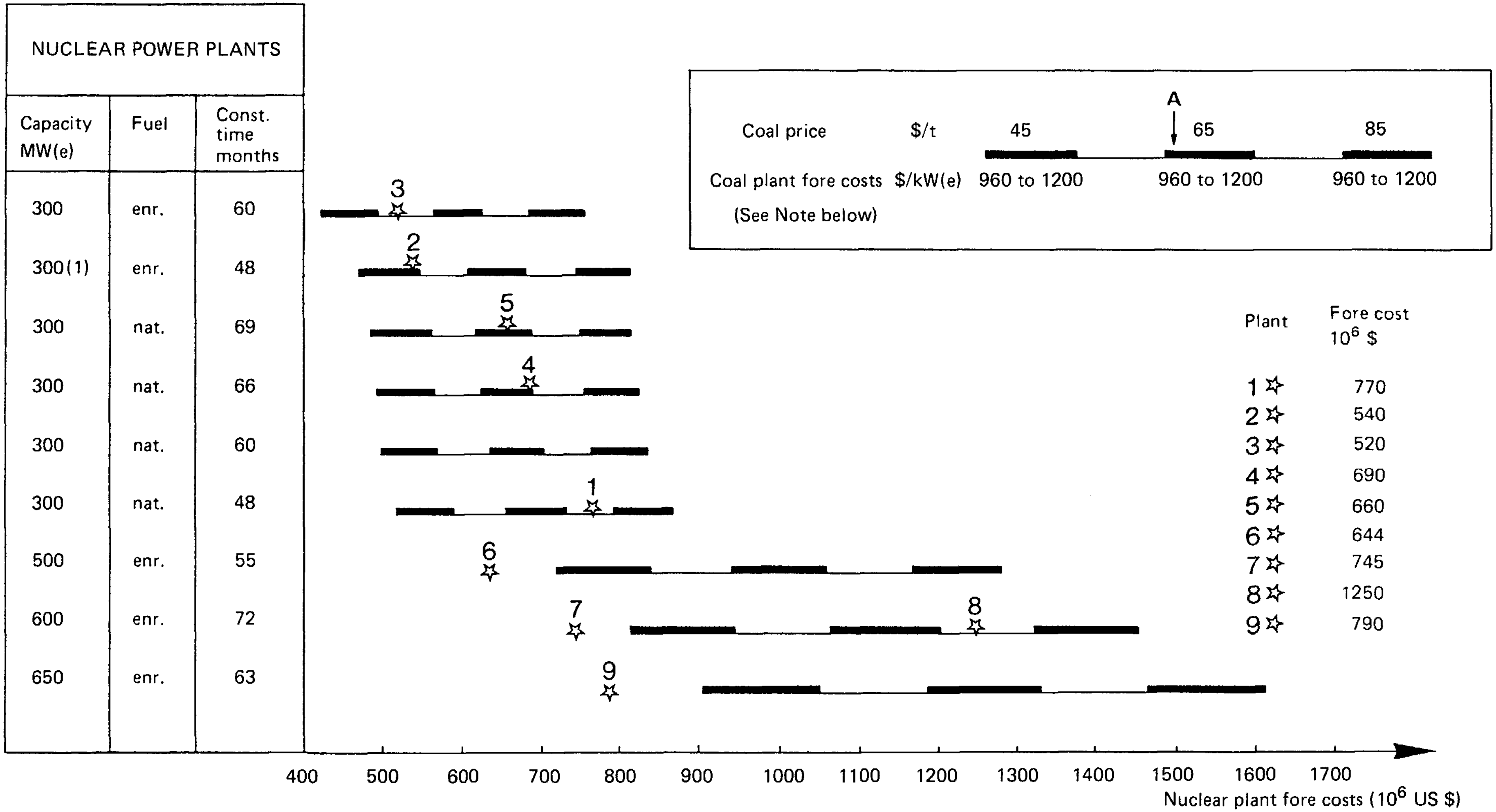

FIG.4.3. *Competitivity of nuclear to coal fired plants. Case 2:* Coal fired plants with desulphurization.

(1) Fuel costs 8 mills/kWh(e) in this case instead of 10.

Note: The bars show the nuclear plant fore cost which will "breakeven", that is, have the same levelized generation cost as a coal-fuelled plant having the indicated coal price and fore costs.

For example: a nuclear power plant whose fore cost is A is competitive with a coal fired plant whose fore cost is between 960 to 1200 US $/kW(e) and which uses coal at 65 US $/t. The point ☆ is the supplier's estimate of the fore cost for the particular plant.

harbour and transport infrastructures needed for coal-fired plants, and in some cases, e.g. China and India, capital costs to open new coal mines.

The conclusion is still that the reported data would support the possible competitiveness of nuclear plants in the 300 MW(e) range in many countries and that further studies are justified.

As example a study made by the Department of Atomic Energy[(1)] of India shows that in actual conditions the economic comparison between the Madras Atomic Power Station Unit I (235 MW(e)) and the Singrauli Super Thermal Power Station (3x200MW(e)), both commissioned in 1982, gives the following generation costs in Paisa (10^{-2} Ruppees) per kWh(e) with a capacity factor of 75%:

- 30.90 p/kWh(e) for the nuclear power plant
- 33.14 p/kWh(e) for the Singrauli power plant located at the pithead
- 41.59 p/kWh(e) for the same coal-fired plant as Singrauli but located at 800km from the pithead.

4.3.3. Nuclear Power Plants Financing

Because of the sheer magnitude of the capital needed and the time over which it is needed, the financing of a nuclear power plant project poses particular problems wherever it is to be constructed. Even a power plant in the 300 MW(e) range would require a total capital investment of some US$ 800 millions for a standardized plant in a serie including interest during construction; the period of repayment would be some 15-20 years after the year of commissioning of the plant. These are conditions which go beyond normal export credits.

A parallel is often drawn between big hydro-power and nuclear projects, as the former may well be more capital intensive and take longer to build. There is, however, a fundamental difference as far as export credits are concerned, as the civil works for hydro projects are most often financed domestically, and the foreign component of equipment is only delivered in the last years of the construction, making the repayment period shorter than for a nuclear power plant.

The cost information received from three potential SMPR suppliers indicate that capital costs for a 300 MW(e) nuclear power plant would not be more than 50-70% higher than for a coal-fired power plant of the same size. The financing institutions do, however, have more experience of coal-fired plants and tend to consider them as projects which are more easily controllable and having a smaller risk. Nuclear plants are still perceived as riskier, and not unjustifiably, in view of some notable cases of major schedule and cost overruns in both industrialized and developing countries. Two factors which should favour an SMPR project should thus be the overall smaller package that is to be financed (in comparison with a 600 MW(e) or larger unit) and the shorter and tightly controlled construction schedules cited by several suppliers.

There are three ways in which export credits are normally arranged, viz. supplier's credit, buyer's credit and aid credit. Export banks consider that supplier's credit will not function for nuclear power plants because of the size of the project and the effect that such a

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(1) Department of Atomic Energy, Government of India, Dr. Raja Ramanna, March 1985.

credit would have on the supplier's balance sheet. Aid credits, often on concessionary terms, are as a general rule no longer granted for nuclear power plants, in accordance with an OECD agreement.

For buyer's credits the credit insurance organizations of the supplier countries play a decisive role; indeed they reflect the export policies of the supplier states vis-a-vis its trading partners. Credit insurance will determine the availability of capital from the main export credit institution and also from the commercial banks. Normally, credit insurance organizations will limit their coverage to 85% (or less, perhaps 75%) of the capital cost of the plant (usually taken by the national export credit institution). Thus, an additional 15-25% will be needed from commercial banking sources, to cover local costs, interest during construction, etc. As each of these sources will extend credit only up to a limited amount (say $ 10 -20 million), each project would require a commercial banking consortium with some 20 partners. It is not the total funds which are prohibitive, as they are undoubtedly available in the market economies, but there are very complex problems in arranging this kind of financing package, which will involve getting together a significant number of the some 100 banks worldwide which could be interested in this type of project.

The World Bank (IBRD) and the regional development banks could in principle play an important role for a nuclear power project in a developing country. The total funds available to these banks for loans in the energy sector are, however, too small (for IBRD a total of US$3 billion per year) for them to play anything but a "seed" role in financing, which could still be very important, because their evaluations of the project are seen as providing some guarantee for its soundness. It is, however, to be noted that the World Bank never has been asked to participate in the financing of a nuclear power plant in a developing country.

The evaluation of a nuclear power plant project in a developing country will certainly include the project-specific considerations of economic viabiltiy, debt servicing capacity and project soundness, both the pre-operational and operational aspects, and will draw also on experience from other projects in the country. Still, according to the national export financing institutions, the creditworthiness of the country will be a primary consideration and involves such aspects as:

- Future prospects of the country's economy;
- Vulnerability of the country in its dependence on energy imports and in its export of goods and services;
- The past financial performance of the country.

It should be noted that both in this general assessment and in the specific project evaluations the credit institutions would tend to focus on infrastructures in the same general categories as used by the IAEA (Section 4.1) and, of course, mainly from the economic and financial points of view.

While this short account cannot cover all aspects of the very complex financing problem, it should be clear that this is one aspect which in the past possibly has not been given the attention needed from prospective buyers. The arranging of financing will require active preparation and participation from the buyer's side. It should not be left only to the supplier and it will accordingly also require a time for collection of information and for preliminary negotiation which is of the same order as the bidding process. Besides early discussions with national export and commercial credit institutions, it would probably be useful also to explain the buyers' plans and their soundness to the World Bank and regional development banks. This approach has not been followed in the past, which may to some extent account for the failures in arranging for financing, especially for SMPR projects. More stringent control and assurances on project performance, particularly on schedule and cost, have to be considered in the future to make the nuclear power option more attractive to finance.

4.4 Safety Aspects

Both the acceptability and the economic viability of nuclear power plants depend on their demonstrating a very high level of safety. The safety considerations for a nuclear power plant encompass all normal and postulated abnormal operating conditions. Nuclear safety objectives are twofold:

- Public Safety: to assure that there is a sufficiently low probability of a release of radioactive material that would represent a significant public health hazard, and;
- Occupational Safety: to assure that the radiation exposure of station personnel is as low as reasonably achievable and does not exceed the allowable dose limits.

The nuclear safety philosophy and requirements for nuclear power plants has evolved over the last 30 years in the various supplier countries, and has been accepted, in some cases with minor modifications, in the current buyer countries. Many of these current nuclear safety requirements are now encompassed by the IAEA NUSS Codes and Guides. (Appendix I)

The success and adequacy of current nuclear safety regulation and requirements is amply demonstrated by the world-wide safety record of all nuclear power plants. This record has been the subject of several IAEA Conferences and Symposia over the past 5 years. There is also an annual Nuclear Safety Review, published by IAEA, which gives an up-dated survey of the safety record of nuclear power.

The SMPR designs now offered or proposed by the various suppliers satisfy the same nuclear safety criteria as the larger-size units currently available, and therefore offer the same high level of nuclear safety.

The specific design features, methods or mechanisms for achieving the necessary level of nuclear safety are, however, in some SMPR concepts different from those used in larger-size units of the same type, because advantage has been taken of the inherent possibilities offered by the smaller size of the reactors. Examples are the HTR concepts which utilize the large inherent heat sink capacity.

It must be underlined that overregulation of a design may act against safety.

A common approach adopted to assist the regulatory body of a buyer country in assuring nuclear safety has been to specify that the SMPR design must comply with the IAEA NUSS Guides, and be demonstrated to be licensable in the supplier's country.

4.5 Contractual Arrangements

The contractual arrangements for the design and construction of a nuclear power plant can be grouped into three basic categories, as follows:

- TURNKEY CONTRACT, where a single principal contractor has the overall responsibility for the design and construction of the nuclear power plant. This responsibility often extends to the commissioning and startup of the station, and to the provision of the initial fuel supply. The Turnkey Contractor is most often the nuclear steam supply system vendor, but an architect/engineer/constructor could also performn this function.

- NON-TURNKEY CONTRACTS, where the overall responsibility for the design and construction of the nuclear power plant is divided among a number of contractors/consultants, with the owner (with or without the help of an architect/engineer) assuming the overall responsibility for functional co-ordination, interfaces, and for overall project management. Non-turnkey contracts are often subdivided into "Split Package" contracts which involve a small number of contractors (typically less than 6), and "Multiple Package" contracts which involves a large number of contractors (typically 50 or more).

- OTHER, like the proposed arrangement whereby the contractor would manage the project when it had become operational, until such time as the cost of the plant would be recovered.

The selection of the type of contract (turnkey vs non-turnkey) is one of the key decisions to be taken by the buyer when embarking on a nuclear power project. The decision should, therefore, be carefully considered, based on the analysis of all relevant factors, paramount among which are the experience and competence level of the utility organization in the area of large project management. Since a nuclear project is likely to be the most complex and capital intensive project in the history of most utilities, they will not have sufficient project experience at the necessary level. In this case, a turnkey contract is the advisable form for the implementation of the project, especially the first one.

A turnkey contract has both advantages and disadvantages. Among the advantages are:

- The overall responsibility for design, fabrication, construction and commissioning is assigned to a single, experienced party;

- The scheduling risk is reduced by having the overall responsibility for the time schedule assigned to a single, experienced party.

- Minimizing of technical risks and avoiding of interface problems;

The approach taken by several of the prospective suppliers, using more shop fabrication and stressing construction schedule control, would also tend to favour a turn-key type contract.

The major disadvantage with turnkey contracts has often been stated to be the limited possibilities which the buyer has to influence the project and to have domestic participation. These disadvantages can, however, be mitigated by a careful assessment of project requirements and of local industry capabilities for domestic participation, before the contract is negotiated.

The need for clarity and precision in the contract must be stressed. All terms and conditions must be clearly specified in the contract and vague generalizations must be avoided. The contract should also endeavor to specify exactly which components and supplies are to be furnished by local industry.

Further information on contractual arrangements is provided in Section 1 of the IAEA Guidebook, "Manpower Development for Nuclear Power", and in Section 11 of the IAEA Guidebook, "Introduction of Nuclear Power".

4.6 Technology Transfer

Technology transfer in nuclear power is fundamentally a long-term, programme-oriented activity. As such, it is not specifically related to SMPRs. There are, however, some considerations which take on additional importance for smaller reactors.

SMPRs have to compete economically with other energy sources. Owing to the characteristics of specific installation costs vs. unit size, emphasis has to be given to minimizing investments. This refers not only to the investment in the plant itself, but also to the investments in technology transfer and the development of the necessary infrastructures. Technology transfer will represent considerable efforts for the buyer country, and may involve sizeable investments which will have to be justified by the expected results. It would follow logically that for a first nuclear power plant, and in particular for an SMPR, the technology transfer ambitions should not be set too high.

Success in technology transfer will mainly depend on the country's capability to effectively absorb the technology it is receiving. The type of contract (turnkey or non-turnkey) under which the nuclear power plant is acquired should not have a major influence on this but, on the other hand, specific provisions within the contracts (for plant as well as fuel) and specific additional technology transfer contracts and agreements will have a large impact on the success of technology transfer.

During execution of a nuclear power project, technology transfer takes place, even when no special technology transfer contract has been agreed upon. This transfer takes place through the acquisition of equipment and components from national industry, where nuclear specifications and the essential quality assurance programmes are introduced, qualification of local suppliers is performed and workers' skills improved. There may be an essential local content in the detailed design of the buildings and structures, and construction and erection requires local participation. New materials are introduced together with applicable fabrication procedures. Construction companies will have to accept to work to higher quality standards and, finally, the operations and maintenance personnel is trained. In this way, participation of the local industry is promoted and upgraded, primarily through increased quality awareness.

A more extensive technology transfer could take place in advance of and in parallel with the implementation of a nuclear power project, if established within the broader framework of a nuclear power programme, and if supported by:

- Bilateral intergovernmental agreements;
- Scientific cooperation between buyer and supplier countries in research and development within the energy sector;
- Industrial cooperation between buyer and supplier countries in the design, construction, component manufacturing, operation, maintenance and fuelling of nuclear power plants.

The agreements at the governmental level may cover the entire spectrum of scientific research and industrial development. They are often the basis for a more intensive form of cooperation at the subsequent levels, e.g. between regulatory authorities.

The aim of the industrial cooperation is the introducton of technology on a commercial and industrial scale, for which a market must exist. The scope of industrial cooperation extends from the analysis of national supply potential, through support in the expansion of the national industrial capabilities for supply, to the founding of new companies which might be joint ventures.

The technologies involved and the quality required in the design, construction, operation and maintenance of SMPRs are basically similar to those of larger nuclear plants of the same type. Many of the components, however, are of a smaller size and may therefore be more amenable to production by national industry. In this respect, the initiation of a nuclear power programme with an SMPR would appear to facilitate more domestic participation in future projects via technology transfer, as compared to starting with a large nuclear plant. A viable national manufacturing industry, however, must also have an assured market for its products during a reasonable period. Experience would indicate that it is mainly through improved quality awareness that such a market is assured and this, rather than the introduction of more technically advanced products, has been the main benefit to the domestic industries participating in a nuclear power project.

In summary, it would appear that although no major technology transfer requirements should be attached to procurement of an SMPR for economic reasons, an SMPR project can provide for an earlier preparation for and more orderly introduction of technology in later projects.

4.7 Fuel Cycle Aspects

At the present time (1985) the fuel supply market situation is characterized by an overcapacity in all stages of uranium mining and milling, conversion, enrichment and fuel fabrication. It would thus appear to be fairly easy to obtain supply assurances by diversification of suppliers. For an SMPR it must, however, be recognized that the fuel may be of a special design and that the total quantities needed will be fairly small, which will likely mean that only one fuel fabricator (namely the original supplier) and possibly one or two others might be interested in the supply on a continuing basis. This does not prevent diversification of uranium and enrichment suppliers.

As with all other nuclear supplies, fuel is also subject to the non-proliferation constraints laid down in intergovernmental agreements. A bilateral agreement will have to exist with the government of each supplier, i.e. of uranium, enrichment services (when needed), fuel fabrication and heavy water supplies. The conditions in bilateral agreements are expressions of national policies and these have been known to be subject to change, which, for example, caused some uncertainties in the supply situation in the late 1970s. In addition, there are multilateral treaties, notably the Tlatelolco and Non-proliferation Treaties, which are intended to give additional assurances of both non-proliferation and supply.

Both these factors, the (in practice) limited number of fuel fabricators and changing national policies, have led some countries to make national self-sufficiency in fuel supply a high priority, calling for the early establishment of uranium prospecting and mining and fuel fabrication. It can also lead to the choice of a power plant type which can be fuelled with natural uranium (HWR or MAGNOX). Fuel fabrication is a fairly easy technology, but its introduction locally for an SMPR is hardly justifiable from an economic point of view.

The back end of the fuel cycle is, on the contrary, marked by undercapacity in reprocessing. The costs of reprocessing and of fabricating uranium/plutonium fuel hardly makes this economical for an SMPR, and there is now no general market for the plutonium obtained from reprocessing. On the other hand, there is no urgency to reprocess or to dispose of the fuel as waste. The present situation, which will prevail well into the 1990s, stresses the need for long-term storage capacity of spent fuel at the power plants. Several of the design concepts include at-reactor storage of spent fuel for the entire foreseen lifetime of the plant (up to 40 years) or easily expandable storages, recognizing the present uncertainty in the back end of the fuel cycle.

It is a paradox associated with nuclear power that domestic uranium resources do not constitute an energy resource for the country without a major investment in nuclear power plants and their associated technology. The feasibility of introducing nuclear power is unrelated to domestic uranium availability and is based on entirely different factors.

More detailed information on the fuel supply situation can be found in, for example, the IAEA Bulletin, Vol. 26, No. 3, September 1984 and in the IAEA Guidebook: "Introduction of Nuclear Power".

4.8 Public Acceptance

For information on public information and acceptance regarding nuclear power, see the IAEA Guidebook: "Introduction to Nuclear Power" (p. 156), "Nuclear Power, the Environment and Man", the IAEA Guidebook: "Manpower Development for Nuclear Power (p.73), and other Agency publications.

4.9 Environmental Effects

The environmental effects of nuclear power are discussed in detail in Section 6.7 of the IAEA Guidebook: "Introduction of Nuclear Power", and the IAEA publication "Nuclear Power, the Environment and Man," as well as in other Agency publications.

5. ESTIMATE OF THE POTENTIAL MARKET IN DEVELOPING COUNTRIES

5.1 General

The potential market for SMPRs depends on a number of factors which would make SMPRs attractive and usable. The following are essential:

- They would have to be economically competitive with alternative generating plants, in particular coal-fired plants, in a qualified project evaluation (cf. Section 4.3.1) based on present and assumed conditions and costs at the site of the future power plant. (This condition would always remain necessary); and

- Their introduction on the grid would have to be technically feasible, i.e. as a general indication the plant capacity should not exceed 10% of the total installed capacity in the interconnected grid (although this criterion has known exceptions) which would require site-specific studies (cf. Section 4.1.2).

While on some sites it may be technically feasible to introduce a bigger, and presumably more economic, unit, it may still be desirable to chose an SMPR for the following reasons (cf also Section 2):

- An SMPR could better fit the required capacity additions (situations with low load growths);

- An SMPR could give improved power system reliability and could have smaller reserve capacity requirements;

- Better financial risk management may be possible because of the smaller total financial package;

- Better financing possibilities may exist for the smaller package;

- Site-specific considerations may make nuclear power preferable to alternatives through the smaller environmental effects.

A basic assumption for this market assessment is that an SMPR is available which can be built in a specified and controlled construction time and to specified costs within quite close margins. This would probably require:

- A plant which is standardized and can be accepted without major modifications at a specific site;

- A supplier prepared to offer a turnkey type of contract, at least in developing countries;

- Infrastructures of the buyer country at an appropriate level.

The responses to the IAEA questionnaires from potential buyers and suppliers do not contradict these assumptions.

The arguments quoted apply equally to developing and industrialized country situations. NEA/OECD has made a separate assessment of the potential markets in the industrialized countries (summarized in Section 5.4). In the following, the approach chosen by IAEA to assess the potential market in developing countries is explained against the experience gained in the past.

In the "Market Survey" of 1972-73 a detailed analysis and optimized electricity system expansion plan was made for 14 countries and later (1973) extrapolated more qualitatively to a large number of countries. The methodology used had fundamental importance and is now used as a standard tool for electric system planning. The approach, in retrospect, had some flaws, which included:

- Demand forecasts given by the countries were in general too optimistic, and were later much reduced by the oil shocks and recession during the 1970s;
- Capital costs assumed for SMPRs were too optimistic;
- Experience, gained from later work, that electricity system planning must be a continuing and iterative process and that one isolated study even though very detailed does not necessarily give a better view of the future than a more qualitative assessment;
- Planning methodologies may give results which are very sensitive to even minor changes in cost parameters;
- Infrastructures in the countries were not taken into account; they strongly influence the decision-making process and should thus be considered in determining the timing for introduction of a new technology.

The market survey showed a considerable potential market for SMPRs in developing countries but mature SMPR designs for that market failed to materialize, mainly owing to the supplier's market conditions which at the time prevailed in the industrialized countries.

Based on this experience it was decided to take a different and more qualitative approach for this study. It consists in reviewing economic and energy indicators of a fairly large number of countries, using the knowledge available on the country (from questionnaire responses, past IAEA missions and new SMPR-specific missions, IBRD reports etc).

The time horizon for the market assessment was fixed to 1992-2001 for the following reasons:

- A decision to go ahead with negotiations for an SMPR in 1985 is unlikely to result in a plant on-line before 1992, at the very earliest;
- A fairly sizeable market would be needed over a limited period of time for the suppliers to make the standardized plants available; if the market is not substantial enough over a 10-year period, then the suppliers are unlikely to expend the effort needed to make the SMPRs available on the market;
- Beyond 2001 all uncertainities are simply too large.

5.2 Buyer Questionnaire Responses

The buyer part of the questionnaires was answered by seventeen countries: Argentina, Chile, China, Colombia, Ecuador, Finland, Indonesia, Malaysia, Mexico, Morocco, Nigeria, Philippines, Sri Lanka, Thailand, Tunisia, Turkey and Uruguay. Of these, Argentina, China, Finland and Mexico already have nuclear power plants in the size range above 600 MW(e) in operation or under construcion. China, Indonesia, Morocco, Thailand and Turkey are known to consider procurement of 600 MW(e) or bigger plants. All these could, however, also consider plants in the SMPR range for the reasons given above (Section 5.1).

Some questionnaire responses are collected for comparison purposes in Tables 5.2-1 to 5.2-3.

As the forecast electricity demand and installed capacity are so important for the study of the potential market, it is of particular interest to see how the questionnaire responses compare in this respect with the IAEA assumptions which have been used generally for a much larger number of countries in Section 5.3. In the developing countries concerned it is realistic to assume an exponential increase of electricity demand over the limited time period of the study. This is well supported by experience in a situation without serious economic disturbances.

A comparison of the demand growth rates forecast for the period 1991-2001 gives the following:

Country	Questionnaire response (%/a)	IAEA assumed (%/a)
Chile	6.5	3.4 - 4.4
Indonesia	14	7.7 - 10
Malaysia	7.5	6.7 - 8.7
Sri Lanka	9.6	5.9
Ecuador	7.5	3.0 - 9.0
Tunisia	6.5 - 7.2	7.0
Morocco	7.0	6.5

The growth rates assumed by the IAEA are generally lower than those used by the national authorities, and this has been quite common in the past. The IAEA estimates are, however, not drastically lower and this would support their use in the estimate of the potential market.

5.3 Potential Markets in Developing Countries

The estimation focussed on 300 MW(e) plants, as most of the information obtained from suppliers in the questionnaires is for this size (see Section 3, Figure 3.1).

In order to define more clearly the potential markets, the developing countries were grouped according to some main characteristics which will also have a major influence on the assessment. The groups are as follows:

(1) Countries with on-going Nuclear Power Programmes (outside of CMEA)

The group comprises:

Argentina	Mexico
Brazil	Pakistan
China	Philippines
India	Yugoslavia
Rep. of Korea	(Iran)

India has, of course, announced a major nuclear power programme with 12 reactor plants of the standardized 235 MW(e) type and 10 additional

Table 5.2.-1: BUYER COUNTRY OVERVIEW GENERAL DATA (1982)

Country	Organization Responsible for Power Planning	Population (1982) (10^6)	Growth Rate Population (1980-2000) (Percent)	Area ($10^3 Km^2$)	Urbanization (Cities 1 million) (No./% Total Population)	GNP PER CAPITA: GNP Per Capita (US$)	GNP PER CAPITA: Av. Annual Growth Rate (Rate %) (1960-82)	Primary Energy for Electric Power (%)	Nuclear Power Plans
Argentina	Secretaria de Energia	28.4	1.3	2767	3 83	2520	1.6	18	Yes
Chile	Comision Nacional de Energia	11.5	1.4	757	1 82	2110	0.6	29	Under Review
Colombia	Ministero de Minas y Energia	27	1.9	1139	2 15	1460	3.1	20	Yes
Ecuador	Instituto Natio- nal de Energia	8	2.6	284	1 16	1350	4.8	5.25	No
Finland	IMATRA VOIMA OY Teollisouden Voima oy	4.8	0.1	337	0 62	10870	3.6	44	Yes
Indonesia	Committee on Energy Resources	152.6	1.9	1919	5 24	580	4.2	10	Yes

Malaysia	National Electricity Board	14.5	2	330	0 29	1860	4.6	20	Under Review
Mexico	Comision Federal de Electricidad	73.1	2.3	1973	4 67	2270	3.7	17	Yes
Morocco	Office National de l'Electricite	20.3	2.5	447	1 12	870	2.6	10	Yes
Sri Lanka	Ministry of Power & Energy	15.2	1.8	66	0 27	320	2.6	12	Under Review
Thailand	Electricity Generating Authority of Thailand	48.5	1.9	514	1 10	790	4.5	26	Under Review
Tunisia	Societe Tunisienne de l'Electricite et du Gaz	6.7	2.3	164	0 0	1390	4.7	7	Yes
Turkey	Ministry of Energy & Natural Resources	46.5	2.0	781	3 13	1370	3.4	13	Yes
Uruguay	Ministerio de Industria y Energia	2.9	0.7	176	1 40	2650	1.7	30	Under Review

500 MW(e) plants to be on line before 2000, but India is going to rely on domestic production capabilities for these plants. China has also announced plans for mainly domestically produced 300 MW(e) plants and for low-temperature process heat reactors. These are to be the basis for the development of a domestic nuclear industry and in that context it would seem very doubtful that any SMPRs would be imported but some component may come from the international market.

Iran has interrupted its nuclear power programme and it has been assumed that any reinstatement of it would primarily focus on completion of two 1300 MW(e) units.

Philippines has a 620 MW(e) plant under construction on the Bataan site but has no plans for further nuclear power plants.

(2) Countries with Large Grids Considering Nuclear Power

In this group are a few countries which have considered or are considering nuclear power introduction with units in the 600 MW(e) range or above.

Egypt	Portugal
Greece	Thailand
Indonesia	Turkey

Egypt and Turkey are negotiating contracts for 600 MW(e) or 900 MW(e) units.

In all the countries in groups (1) and (2), 600 MW(e) or larger units can be used. Still, some of the same considerations which would apply to SMPRs in an industrialized country market would apply also to these countries (cf. Section 5.3-2). It cannot, therefore, be excluded that some of them would install a nuclear power plant in the SMPR range in the future. The questionnaire responses from Argentina and Mexico also represent an expression of interest. The potential market would, however, be limited to a few units, possibly up to 5 during the period of the study.

(3) CMEA Member Countries

This group comprises:

Bulgaria	Poland
Cuba	Romania
CSSR	Hungary

All these countries have nuclear power programmes based on the VVER-440 type of plant. In Romania 600 MW(e) CANDU plants are also being built. 15 VVER-440 plants are now under construction in these countries. While a shift to 1000 MW(e) units is being made in Bulgaria and the CSSR for later plants, it would appear that the 440 MW(e) units will have a continuing market with some 5-6 additional units planned to go on line in the 1990s. In addition, the People's Republic of Korea has shown interest in introducing nuclear power.

(4) Countries without on-going Nuclear Power Programmes and with Grid Sizes which would limit Nuclear Units to the 300 MW(e) Range during the Study Period

To define this group extrapolations from the past and current grid sizes have been made to the period 1992-2001. The growth rate was established based on the historical electricity production growth rates experienced in the seven and twelve years before 1982. For some countries there was a substantial difference between these two historical rates and in order to obtain a growth rate to be used for the study period, additional information was used, such as IAEA studies and World Bank reports. Electric energy production projections were then converted into installed capacity using a common 50% system load factor which for several countries could underestimate the installed capacity by 10-20%. The chosen rates are shown in Table 5.3-1, together with the corresponding projected installed capacities for 1992 and 2001. The table includes all countries for which available data would indicate that they would have grids in the 2000-6000 MW(e) range during the study period and also some with larger grids.

Three types of parameters were used as indicators for the assessment of the potential market in the countries in Table 5.3-1.

(a) Parameters which indicate the technical feasibility of introducing SMPRs at all, i.e. grid size and projected annual capacity addition rates 1992-2001. (While the "10% rule" has been used in relation to grid size, data are presented so that other percentages may be applied).

(b) Parameters which indicate the urgency with which the country's authorities should consider introducing nuclear power plants in the electric energy supply system:

- Cost of oil imports as % of total exports of merchandise for net oil importers;
- An estimate of how long domestic coal and hydro resources will last.

(c) An assessment of the infrastructures of the country in qualitative terms. (The level of expressed interest (low - high) by national authorities in considering nuclear power for the future energy supply was used as a first indicator).

- Organizational structure for nuclear power including legislation (weak - good). Base for assessment is the existence of appropriate legislation, a regulatory body and an organization with experience from the construction and operation of large power projects, etc.
- Availability of qualified manpower (weak - good). Base for assessment: e.g., the availability of qualified engineers (mechanical, electrical and civil), engineering consultants, qualified technicians, code welders.
- Availability of industrial support (weak - good). Base for assessment: domestic production of, e.g. heavy rebars, boilers, cables, valves, meters to specified standards.
- Capacity for financing (indicated here by present external debt as % of GNP and the cost of servicing debts as % of exports of goods and services). Also the GNP itself was also used, as total investments in the energy sector usually are in the range 2-3% of GNP and electric system investments are 1/2 of this as a maximum.

Some general assumptions have been made in this context concerning the future use of oil and non-associated natural gas for electricity production. In the major oil-exporting countries a case can be made for nuclear power from the national economics point of view, and in most

Table 5.2-2: ENERGY DATA (1983)

Country	PRIMARY ENERGY CONSUMPTION		INDIGENOUS ENERGY			ELECTRICITY						
	Consumption (10^6GJ)	Main Origin and %	Years of Reserves at Present Rate of Construct	Production (10^6GJ)	Main Source and %	Production (10^6GJ)	Main Origin and %	Average Annual Growth 1960-80	Projected Annual Growth 1980-2000	Consumption Per Capita (KWh(e))	Consumption in Industry and Mining (%)	Installed Capacity 1983 (MW(e))
Argentina	1990	Oil 54		1950	Oil 54	130	Hydro 50	6.7	3.4 L 4.3 H	1064		12920
Chile	390	Oil 31	460	350	Oil 25	42	Hydro 73	4.7	6.5	1000	60	3210
Colombia	388	Oil 75	500	607	Oil 49	77	Hydro 70	9.4	10	645	22	5028
Ecuador	240	Oil 72	1900	550	Oil 88	13	Hydro 73	10.8	7.5	412	33	1400
Finland	800	Oil 47	50	230	Biomass 80	160	Nucl. 37	7.8	2.5 3.5	9300	55	11290
Indonesia	2940	Non Commercial fuels 60	30	5670	Oil 47	48.3	Oil 76	8.1	14	135	34	3930
Malaysia	560	Oil 70	400	900	Oil 70	40	Oil 88	10.6	7.5	775	51	2600

Mexico	4360	Oil 58	100	8520	Oil 69	270	Oil 67	9.5	6.8	828	44	19000
Morocco	200	Oil 87	23	36	Coal 47	20	Oil 69	8.6	7	317	44	1600
Sri Lanka	170	Non Com- mercial fuels 65	80	130	Non-Co mmerc ial fules 82	7.3	Hydro 86	8.7	N/D	112	43	560
Thailand	700	Oil 60	11.7	300	Biomass 57	182	Oil 35	17	5.9	308	63	5845
Tunisia	142	Oil 83	92	255	Oil 90	10	Oil 61	12	6.5-7.2	460	72	929
Turkey	1250	Oil 59	131	564	Coal 64	163	Hydro 64	10.8	11.5	523	73	6929
Uruguay	108	Oil 58	19.7	46	Biomass 56	32	Hydro 62	6.6	5.1	1100	53	1240

cases the grids would be able to accept nuclear power plants of 300 or 600 MW(e) size or above during the study period. This group comprises:

Algeria	Mexico
Iran	Nigeria
Iraq	Quatar
Kuwait	Saudi Arabia
Libyan Arab Jamahiriya	United Arab Emirates
	Venezuela

Of this group Venezuela and Kuwait have in the past expressed some interest in nuclear power but both have decided against this option, at least for the intermediate term. Iraq and the Libyan Arab Jahamiriya continue to show an active interest in a nuclear power programme, potentially with SMPRs. For the other countries in this group, except those included in Group 1, i.e. Iran and Mexico, it is assumed that they probably will set different priorities in their development programmes so that nuclear power introduction is unlikely. In all other countries it is assumed that oil-fired power plants will not be built in sizes in the SMPR range.

Domestic non-associated gas resources and production would in the short to intermediate term up to 2000 require different considerations. Several of the countries considered have significant gas resources (e.g. Bangladesh, Malaysia, Tunisia). Gas is not so attractive to export, requiring a considerable infrastructure and giving a lower price than oil, and in several cases a policy is being shaped to use the gas domestically, also as the primary future power station fuel. Such a policy will give a respite for any decision on other energy sources, but it is still likely that when the country's industry has reached a higher level of development the primary use of the gas will be as a raw material and heat source for industry and not as a power station fuel. The introduction of nuclear power in these countries would therefore be determined primarily by the infrastructure development and the gas pricing policy, and not by the continued availability of the gas.

This means in practice that for all developing countries except the major oil exporters the major sources for electric capacity additions for the future have been considered to be hydro, coal, nuclear and, for an interim period, natural gas if nationally available.

It is natural that with a generalized approach of this type some countries with special characteristics will not fit the general pattern. This is the case for the Ivory Coast, Mozambique, Colombia, and Singapore (Table 5.3-1).

The Ivory Coast has recently made major additions of hydro capacity over the past 15 years. The overall system load factor is exceptionally low (19%). In spite of the recent droughts it still has to be assumed that the installed capacity, with 70-80% hydro power, at the present does not reflect capacity demand and that projections for the 1990s should be lower than shown for 1992. There is also a major hydro potential of 2500 MW (12.4 TWh/a) in about 20 sites. This would more than cover additional requirements well beyond 2000. This country is thus very unlikely to consider nuclear power in any form at the present time.

Mozambique has 85% of its installed capacity in one hydroelectric installation and two-thirds of the energy from this is being exported. The domestic demand is only about 300 MW(e) and the country has major

Table 5.2-3: INFRASTRUCTURE

Country	Projected Capacity (1990)	Current Capacity 1983 (MW(e))	Largest Grid* (1983)	Largest Unit (1983)	Industrial Contribut. to GDP (%)	Steel Production (10^3t/a)	Cement Production (10^3t/a)
Argentina	16300	12900					
Chile	4400	3200			24.6	462	1260
Colombia	6711	5038			20	-	-
Ecuador	2800	1400			-	250	2400
Finland	13400	11300			39.6		
Indonesia	9100	3930			22.1	1720	7650
Malaysia	4200	2600			23	1040	4300
Mexico	29100	19000			42.15	6950	17070
Morocco	2140	1600			31	-	-
Sri Lanka	1000	600			23.3	48	480
Thailand	7634	5845			20	385	7263
Tunisia	1030	929			36	-	-
Turkey	16124	6929			29	4	13.6
Uruguay	1510	1240			22	-	-

hydro resources. It is for these reasons very unlikely to introduce nuclear power.

Colombia has extremely high hydro resources and also coal. A preliminary survey made by the IAEA in 1982 confirmed that it is unlikely that nuclear power be introduced soon. A study is under way to analyse the possibility of introducing nuclear power at the beginning of the 21st century.

Also Ecuador has an abundance of cheap hydro capacity and an IAEA mission confirmed in 1985 that nuclear power would not be an attractive alternative.

In the case of Singapore the need for nuclear power would seem to be imminent but past studies have failed to define an acceptable site for a nuclear plant. Singapore would thus be unlikely to launch a nuclear power project.

Table 5.3.-1. PRESENT AND PROJECTED INSTALLED CAPACITIES

Country	Installed Capacity 1982 (Mw(e))	Projected Future Growth Electr. Energy (%/a)	Installed Capacity 1990	Installed Capacity 2001	Capacity Growth (MW(e)/a) 1992	Capacity Growth (MW(e)/a) 2001
Kenya	556	6.9	800	1600	70	110
Sri Lanka	523	5.9	1200	2200	70	130
Iraq	1105	4.8	1800	2700	80	130
Tunisia	929	7.0	1450	2800	100	200
Ivory Coast	1163	3-11.0	1700	3000	40	300
Ecuador	1200	3.0-9.0	1500	3300	50	300
Syria	1104	6.0-8.0	1700	3700	100	300
Zambia	1728	4.4	2600	3900	120	170
Bangladesh	990	8.0	1800	4300	160	300
Morocco	1600	6.5	2400	4400	160	290
Peru		6.0	3000	5500-6000	200	360
	3281[1]		6200	10500	-	-
Libyan A.J.	1180	3-9.0	2600	6000	80	500
Nigeria	2770	7.0	4000	6700	300	450
Algeria	2006	7.2	3400	6800	250	490
Chile	3210	6.4-4.0	5200	7000	300	300
Singapore	2170	8-4.2	4700	7100	300	300
Malaysia	2508	7.5	4800	8800	270	650
Mozambique	1800	-	-	-	-	-
Colombia	5028		6700	12000	460	630
Indonesia	2860[2]	10.0	7400	17500	740	1700

1) The upper figures refer to the central and northern interconnected grid.

2) The Java grid has about 70-80% of the shown capacity.

Table 5.3-2. URGENCY FOR CONSIDERING NUCLEAR POWER

Country	Net 1982 Energy Balance (Prod./Cons.)	Oil Import Costs as % of Exports of Merchandise	Urgency based on Remaining Hydro & Coal Resources
Kenya	0.04	63	High
Sri Lanka	0.54	47	Low
Iraq	5.2	---	High
Tunisia	1.64	---	High
Bangladesh	0.49	27	High
Syria	1.30	---	High
Zambia	0.95	---	Med.
Morocco	0.45	41	High
Peru	1.50	---	Low
Libya A.J.	5.40	---	High
Chile	0.72	24	Low
Malaysia	1.90	---	Low[1]
Indonesia	2.59	---	Low

1) For Malaysia this includes hydro resources in Sarawak.

Table 5.3-2 shows some parameters which would indicate the urgency with which a country should consider nuclear power. Considering both commercial and non-commercial energy production and consumption gives the country's situation as a net importer or exporter of energy. Only hard coal, and not lignite, has normally been considered to contribute to fossil energy resources as lignite would require burning at mine-mouth plants.

In the last column of Table 5.3-2 the situation in 1992 for each country was estimated with respect to its reserves usable for generating electricty (excluding oil and gas). It was assumed that all hydro reserves would be developed first. Additional electricity demands would be supplied by coal-fired plants with 43% efficiency. In addition, half of the coal resources would be used for heating, industry, steel production as well as non-commercial energy. The remaining resources in 1992 were used to give an indication of the high, medium or low urgency with which a country should consider introducing nuclear power. "Low urgency" was defined as a situation with more than ten years resources remaining.

For hydro reserves, the usable potential was considered to be one third of the potential available if all natural flows were exploited down to sea level with 100% efficiency from the machinery and with water quantities estimated on the basis of atmospheric precipitation and water run off. This is optimistic but it is an often used methodology. (United Nations Energy Statistics Yearbook 1982, p. xii and Table 36).

Malaysia has one particular characteristic. The high energy resource base which would show a low urgency for Malaysia in Table 5.3-2 includes major hydro resources in Sarawak on Borneo. Making these available to Peninsular Malaysia would involve a HVDC transmission 600-800 km underwater. A 1500 MW(e) line has been under study and should be technically feasible but hardly economically competitive with alternatives. If it is decided to go ahead with this project, it would not delay the need to consider nuclear power significantly (only about 2-3 years). Gas resources and delay in formulating a gas pricing policy could, however, influence any decision on nuclear power significantly.

In Table 5.3-3 some assessments of the infrastructures are given, to provide an additional basis for an assessment of the countries likely or less likely to consider nuclear power plants for operation in 1992-2001. The first infrastructure assessments would tend to indicate the level of the country's preparedness for a nuclear power programme, with weak infrastructures tending to delay a decision. The financial parameters would indicate, in the most approximate terms, the possibilities to obtain commercial credits for financing of a power plant. Very high values could, however, also indicate a situation in which a country probably would not be able to find financing for a changed energy supply programme which would need high capital investments. All countries in the table must be considered to have weak industrial infrastructures.

Finally, a general development analysis, using 50 economic parameters, was taken into account in some cases.*

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* F. McGregor Anciola: "Analyse des Structures economico-industrielles et des contraintes associees au developpement des pays dans la definition des programmes energetiques: une proposition methodologique", IAEA, Vienna (1984).

Table 5.3-3. INFRASTRUCTURES

Country	Expressed Interest in Nucl. Power	Organizational Structure	Availab. of Local Manpower	Ext'l Debt as % of GNP	1981 Debt Service as % of 1981 Exp. of Goods & Services
Kenya	Low	Weak	Weak	34.4	17.1
Sri Lanka	Med.	Weak	Weak	36.6	5.7
Iraq	Med.	Weak	Weak	---	---
Tunisia	Low	Weak	Weak	38.0	13.9
Bangladesh	High	Med.	Med.	31.2	6.9
Syria	High	Weak	Weak	15.2	12.1
Zambia	Low	Weak	Weak	73.1	24.0
Morocco	High	Weak	Weak	52.4	30.1
Peru	High	Good	Weak	28.6	44.9
Libya A.J.	High	Med.	Weak	----	----
Chile	Med.	Good	Good	14.1	27.2
Malaysia	Med.	Good	Med.	19.2	3.1
Indonesia	Med.	Med.	Weak	19.0	8.2

Reviewing each country in this manner an additional regrouping was made as follows:

(a) Countries which are likely to consider nuclear power introduction during the period 1992 - 2001 with a positive decision:

Bangladesh
Chile
Iraq
Libyan Arab Jamahiriya
Malaysia
Morocco
Peru
Syria
Tunisia

The decision may, however, in some cases be delayed so that the first plant actually would go on-line only after 2001.

(b) Countries which are unlikely to introduce nuclear power during the period:

Colombia
Ecuador
Kenya
Sri Lanka
Uruguay
Zambia

(c) Major oil exporters which would not seem likely to consider nuclear power during the period:

Algeria
Kuwait
Nigeria
Qatar
Saudi Arabia
United Arab Emirates

It has been assumed that capacity additions will be made in increments corresponding to the system's capacity increase in 1-2 years. In group (a) the capacity additions required in the SMPR range will be about 21 000 MW(e) in some 50 plants of around 300 MW(e) during the period of study. It is not reasonable to expect that a very high fraction of this would be nuclear, but it is felt that 15-20% could be, corresponding to about 7-10 plants.

Delaying the study period by three years would mean that, with a somewhat different group of countries, the potential market would stay about the same over a 10 year period.

An average delay of 7-10 years would seem reasonable to assume if a country were to decide against a 300 MW(e) unit in favour of waiting for the introduction of nuclear power with a 600 MW(e) unit.

Conclusion

The potential market for SMPRs in the 300 MW(e) range in developing countries can, under given assumptions, be estimated to be some 10-15 plants over the 10-year period 1992-2001. There are considerable uncertainties in this estimate. If a standardized design, constructible at specified costs and in a specified time were not available, the market would be non-existent. If the economics prove to be very advantageous it could well be twice the estimate given.

6. ESTIMATE OF THE POTENTIAL MARKET IN INDUSTRIALIZED COUNTRIES

This evaluation of the potential market for smaller-sized nuclear reactors in OECD countries was provided by the OECD/NEA. The scope and methodology used in this section differs in some respects from that used in Section 5.3 (and elsewhere in the report) and care should be taken when comparing data between the two sections.

6.1 INTRODUCTION

The purpose of this section is to provide a broad technical outline of the market potential for smaller-sized nuclear power reactors in OECD countries. Smaller-sized nuclear power reactors are defined as those with net output capacities of 700 MWe or less. This range may be further sub-divided into four categories: mini-reactors of less than 50 MWe, small nuclear reactors (SPRs) from 50 to 200 MWe, small to medium-sized power reactors (SMPRs) from 200 to 400 MWe, and medium-sized power reactors (MPRs) from 400 to 700 MWe. This section focuses on SMPRs and MPRs, with special emphasis on SMPRs.

There are several reasons why industrialized countries may consider building smaller-sized power reactors. Those suggested by a number of sources are reported in this section and the more important of them are evaluated. The section also evaluates the technical capability of countries or regions to finance and to effectively utilize base load electricity generating stations of the size ranges considered. Clearly there are a number of other factors which countries must also consider (economic, financial, social and political circumstances amongst others) before deciding to build or purchase a power reactor, but these are not evaluated in this OECD/NEA section. Vendors of smaller reactors may well start their market studies with evaluations such as those considered here, then apply their judgements on other factors to produce a "short list" of regions they believe to be potential customers. The "short list" of one vendor may well differ from that of another due to different perspectives on some of the subjective factors. This final, subjective stage of defining potential markets has not been attempted in this evaluation. Therefore, readers must recognize that some of the regions, shown to be potential markets on technical grounds, will not consider smaller (or perhaps any) nuclear power stations at least in the near future.

One key factor which must be evaluated by any utility considering a smaller nuclear reactor is its economics relative to alternatives such as coal-fired plants or perhaps larger nuclear plants. These relative economics are not addressed in detail in this section but are covered in Section 4.3.2.

6.2 NUCLEAR ENERGY AND SMALLER NUCLEAR POWER REACTORS IN OECD COUNTRIES

Nuclear power stations in OECD countries provided an average of 12.8 per cent of electrical generating system capacity and 17.9 per cent of electricity generation in 1984 and are expected to provide about 19 per cent and 26 per cent respectively by the year 2000[1] (Table 6.1). Nuclear power supplied more than 20 per cent of the total electricity generation in Belgium, Federal Republic of Germany, Finland, France, Japan, Sweden and Switzerland in 1984.

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1. Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries, NEA/OECD, Paris, April 1985.

TABLE 6.1 INSTALLED ELECTRICAL AND NUCLEAR CAPACITY IN OECD COUNTRIES

Country	Installed Electrical Capacity (GWe)		Installed Nuclear Capacity (GWe)		Nuclear Share of Inst. Capacity	
	1984	2000	1984	2000	1984	2000
Australia	31.2	54.0	0	0	0	0
Austria	13.0	19.9	0	0	0	0
Belgium	12.1	13.3	3.5	5.5	28.9	41.4
Canada	96.4	124.3	9.5	15.8	9.9	12.7
Denmark	7.9	9.4	0	0	0	0
Finland	11.0	14.0	2.3	3.3	20.2	23.6
France	85.6	129.4	33.2	77.0	38.8	59.5
Germany F.R.	91.6	94.2	16.1	24.3	17.6	25.8
Greece	6.4	15.5	0	0	0	0
Iceland	0.9	2.2	0	0	0	0
Ireland	3.1	4.1	0	0	0	0
Italy	54.0	85.6	1.3	12.8	2.4	15.0
Japan	142.5	223.0	21.8	59.5	15.3	26.7
Luxembourg	0.2	0.2	0	0	0	0
Netherlands	13.5	13.1	0.5	2.5	3.7	19.1
New Zealand	6.6	9.1	0	0	0	0
Norway	22.8	29.0	0	0	0	0
Portugal	5.6	12.4	0	0	0	0
Spain	37.0	49.0	4.6	10.7	12.4	21.2
Sweden	31.0	33.7	7.3	9.4	23.6	27.9
Switzerland	14.7	17.7	2.9	3.9	19.7	22.0
Turkey	7.7	41.0	0	2.8	0	6.8
UK	63.7	67.0	6.5	18.0	10.2	26.9
USA	665.4	908.0	71.1	122.7	10.7	13.5
TOTAL OECD	1424	1969	182	368	12.8	18.7

Source: OECD/NEA[1]

TABLE 6.2 NUMBER OF NUCLEAR REACTORS IN OECD COUNTRIES (As of end 1984)

Country	Operable Power Reactors	Reactors under Construction	Total Power Reactors (a)	Reactors of 200-400 MWe (b)	Reactors of 400-700 MWe (b)	Operating Research Reactors (c)
Australia	0	0	0	0	0	2
Austria	(1) (d)	0	(1)	0	(1)	3
Belgium	5	2	7	2	0	5
Canada	16	7	23	1	10	12
Denmark	0	0	0	0	0	2
Finland	4	0	4	0	4	1
France	41	21	62	4	3	20
Germany, F.R.	19	7	26	3	2	28
Greece	0	0	0	0	0	2
Iceland	0	0	0	0	0	0
Ireland	0	0	0	0	0	0
Italy	3	4	7	1	0	12
Japan	31	11	42	3	11	22
Luxembourg	0	0	0	0	0	0
Netherlands	2	0	2	0	1	2
New Zealand	0	0	0	0	0	0
Norway	0	0	0	0	0	2
Portugal	0	0	0	0	0	1
Spain	7	7	14	0	2	5
Sweden	10	2	12	1	4	1
Switzerland	5	0	5	3	0	5
Turkey	0	0	0	0	0	3
UK	32	10	42	11	16	25
USA	86	44	130	1	18	81
OECD TOTAL	262	115	377	30	72	235
Average number	11	5	16	1	3	10

a. Total of operating and under construction
b. Included under total power reactors
c. Not included under total power reactors
d. Out of service

Source: IAEA-OECD/NEA[1]

To a large extent the early evolution of nuclear power took place in OECD countries. Early nuclear power programmes were initiated in Canada, France, the United Kingdom and the United States. One of the world's first commercial nuclear power plants, a 50 MWe reactor, entered service in the United Kingdom in 1956. Active programmes were instituted through domestic development and offshore licencing in Austria, Belgium, Finland, France, Federal Republic of Germany, Italy, Japan, the Netherlands, Spain, Sweden and Switzerland. At the end of 1984, fourteen OECD countries had 262 operable reactors, with another 115 under construction (Table 6.2). Another six OECD countries which have yet to adopt nuclear power are carrying out active nuclear R&D programmes involving research reactors.

Indeed, the present generation of nuclear power plants has been developed principally to satisfy the needs of electrical utilities in OECD countries. The electrical systems of many of these countries are large and highly interconnected with those of neighboring countries. Such systems can readily accommodate large units.

This capability, coupled with economy-of-scale considerations, led to reactor sizes quickly increasing in the past. But even as large units were being built, many of the conditions that favored them were changing in many countries. Perhaps the most important change generally experienced has been a sharp decline in electrical load growth and increasingly uncertain predictions for future demand. Adverse public opinion, high interest rates, extended construction schedules and escalating costs have added to the nuclear industry's problems. While the absolute contributions of nuclear energy continue to increase as reactors ordered during the 1970s enter service, few new orders for nuclear plants are forthcoming at this time.

Nevertheless, nuclear power is still flourishing in OECD countries such as France and Japan and its use is increasing rapidly there as well as in Canada, the Federal Republic of Germany, Sweden and the United States. Although rates of electricity demand growth are expected to be lower in the future than they were before 1973, significant growth continues to be forecast for OECD countries. Nuclear can be expected to provide for some of the new capacity; smaller reactors could well play a role in some circumstances.

OECD countries have considerable experience with reactors below and within the SMPR size range. Today in thirteen of the twenty-four OECD countries there are 27 operable units of under 200 MWe, 27 in the 200 to 400 MWe SMPR range and 64 in the 400 to 700 MWe MPR range. In addition, three more SMPR and 8 MPRs are under construction (including two LMFBRs and one HTGR prototype), raising the total to 30 SMPRs and 72 MPRs. Many of these plants are older units built before the rapid scale-up in sizes but others are of more recent vintage and/or are prototypes of new designs.

Vendors in two OECD countries can point to SMPRs based on operating plants of about the same size. These SMPRs are the UK's Magnox and the FRG's PHWR (based on Atucha 1 in Argentina), both of about 300 MWe. A similarly-sized HTGR is under construction in the FRG. In the MPR size range, vendors in Canada (600+ MWe range CANDUs), Sweden (a 660 MWe BWR in Finland), Japan (a 500 MWe BWR and 500 to 600 MWe PWRs), the United Kingdom (600 to 660 MWe AGRs) and the United States (600 MWe range PWRs) have sold reactors in their own countries and/or abroad which have come on stream after 1980, or will do so shortly.

Supplier interest in the SMPR study is high (see Chapter 3), with vendors from several OECD countries offering advanced designs (Canada, France, the Federal Republic of Germany, Japan, Sweden, the United Kingdom and the United States). As with proposed advanced reactors of larger sizes, such SMPRs, along with newer MPRs, will build on the combined experience and latest technological advances of the nuclear programmes of OECD countries. Therefore they will incorporate better reliability, improved instrumentation and control, increased fuel cycle lengths and other improvements.

Table 6.3 shows actual and proposed SMPRs and MPRs in the context of nominal products offered, or proposed to be offered, by OECD vendors. This table complements Table 3.1.

6.3 COMPARISON OF SMALLER NUCLEAR REACTORS FOR INDUSTRIALIZED AND LESS INDUSTRIALIZED COUNTRIES

In evaluating the potential markets for SMPRs and MPRs throughout the world, cognizance must be taken of the fact that the considerations in making a decision about purchasing a smaller reactor, or any reactor for that matter, may be quite different in industrialized countries than in less industrialized ones. Table 6.4 outlines qualitative comparisons between industrialized and less industrialized countries. The comparisons do not apply in all cases and none are absolute. They are, however, intented to be indicative.

TABLE 6.3 NUCLEAR POWER REACTORS AVAILABLE FROM OECD NUCLEAR VENDORS

			Approximate Size (MWe)[a]				
			<50	50 to 200	200 to 400	400 to 700	>700
COUNTRY	VENDOR	TYPE	Mini Reactors	SPR	SMPR	MPR	Larger Reactors
Canada	AECL	CANDU			300--400	600--700	950-1050
Finland	IVO/AEE	PWR			400-	500	
France	Framatome	PWR			300	600	900 1300 1400
Germany, F.R.	KWU	BWR				600	800 900 1000 1300
	KWU	PWR			300------	500 600	800 900 1000 1100 1300
	KWU	PHWR			300		750
	HRB/BBC	HTGR		100	300		
	Interatom	HTGR		80 160	240 (320 (400	560	
Italy	Ansaldo	BWR				600	900
	Ansaldo	PWR				600	900
	Ansaldo	HWLWR			300		
Japan	Mitsubishi	PWR				500	800 1100 1300
	Toshiba	BWR				500	800 1100 1300
	Hitachi	BWR				500	800 1100 1300
Sweden	ASEA-Atom	BWR				650--700	900 1050
(b)	ASEA-Atom	PWR		(200)	400	600	(800)
United Kingdom	NNC	GCR			300	600--700	
	Rolls Royce	PWR			300		
United States	GE	BWR			300	600	800 900 1100 1250
	Westinghouse	PWR				600	900 1150 1280
	B & W	PWR		90	400		800 900 1200
	C-E	PWR					800 900 1100 1300
	GA/Bechtel	HTGR		100	300	500	

a. Nominal sizes based on publications in the literature. Actual outputs may vary significantly and other sizes may be available.

b. PIUS/SECURE.

Source: IAEA-OECD/NEA

Table 6.4 COMPARISON OF INDUSTRIALIZED AND LESS INDUSTRIALIZED COUNTRIES

Aspect	Industrialized Countries	Less Industrialized Countries
GNP/capita	higher range	lower range
Electricity consumption/capita	higher range	lower range
Electrical growth rates	lower	higher
Nuclear infrastructure	usually well-developed	often less well developed
Number of electrical utilities	often several	usually one
Size of electrical system	usually larger	often small
System continuity & interconnectivity	often good	often poor
Experience with large projects	usually extensive	can be small
Importance of front-end capital cost	levelized energy cost as important	often paramount
Access to capital markets	better	worse
Energy options available	usually coal	only options may often be more expensive oil and gas
Domestic nuclear vendors	several	few
Industrial tradition	established	being developed
Nuclear power acceptance	divided opinions in some cases	usually well accepted as a potential major source of electrification

Energy consumption per capita in industrialized countries such as those of the OECD is, on the average, much higher than that in most less industrialized countries. Their industrial and service sectors typically make high proportional contributions to the GNP and, with few exceptions, the degree of organization is high. Electricity intensiveness in industrialized countries is greater than that in the less industrialized ones, with usually well-interconnected regional, national and even international electrical grids involving high voltage transmission systems. Further, while projected future rates of load growth may be smaller than those for the less industrialized countries (2 to 4 per cent vs 7 to 10 per cent on average), absolute demand is much greater and the annual increase in peak demand for the electrical systems in industrialized countries is usually much higher.

More than half of the OECD countries have built nuclear reactors and their nuclear industry infrastructures and know-how are therefore relatively more extensive. Most, if not all, active export vendors outside of the USSR countries are from the OECD and these are supported by broad industrial and institutional capabilities. These advantages are lacking in most less industrialized countries.

In many less industrialized countries a nuclear power project may be the largest industrial endeavor yet attempted, requiring the marshalling of almost the entire technical and industrial resources of the country. Such constraints do not usually affect projects in the industrialized countries to nearly the same extent. Additionally, nuclear power projects are inherently large and capital intensive, requiring significant amounts of available capital. With ready access to the capital market, the industrialized countries' ability to raise required finances is much better than that for the less industrialized ones. They can, therefore, be more selective about the sizes of the power plants they choose. With less access to capital and fewer financial resources, many less industrialized countries have to take much more account of capital cost when considering a major project, even if the long-term energy costs of more capital-intensive options are less. However, it is acknowledged that some electrical utilities (particularly smaller ones) in some industrialized countries are also extremely sensitive to front-end capital requirements and related capital risks.

6.4 REASONS FOR CONSIDERING SMALLER NUCLEAR REACTORS IN OECD COUNTRIES

Primarily as a result of uncertainties in electricity demand forecasts and the availability and cost of financing, an increasing number of utilities throughout the world are now placing orders for smaller electrical generating stations, and are demanding reduced construction schedules.

Some smaller countries, especially those of the developing world, see smaller units as necessary to initiate nuclear power programmes. The potential market for them is not, however, limited to such countries. There has been a growing recognition[2 to 5] by some utilities in OECD countries that SMPRs, and to a lesser extent MPRs, may have certain unique advantages and applications. A number of these advantages are listed in Sections 2.1.3 and 5.1. Some of them are controversial and may not be accepted by all parties. However, many of them may affect the perception of SMPRs held by utilities in OECD countries. It is useful to build on a few relevant points from these lists to assess the circumstances under which SMPRs and MPRs might be constructed. It is suggested that these could involve one or more of the following categories:

1. Areas with small grids	)	Areas compatible with
2. Remote and discontinuous areas	)	SMPR size ranges
3. Economic electricity supply	)	
4. Dedicated applications	)	Areas compatible with SMPRs,
5. Diversification	)	MPRs or larger units
6. Export sales considerations	)	

2. Scaling Factors of SMPR. Considerations for Comparative Evaluations of Small and Large Nuclear Power Plants, IAEA, Vienna, September 1984.
3. Small Reactor Assessment Programme - Phase I - Foreign Technology Survey, (Sener), report for Argonne National Laboratory, September 1982.
4. Report of the Argonne National Laboratory on Small Reactor Potential, 1982.
5. Analysis of the Potential for Small Reactors in the USA, C. Behrens, Congressional Research Service, Washington D.C., February 1983.

(a) Small Grids

As discussed in more detail in Section 6.5, a few OECD countries which do not as yet have nuclear power programmes have electrical systems which are too small, now and up to year 2000, to accommodate reactors of 700 MWe or larger size. Whereas some of these utilities may, a decade or two ago, have chosen to build a large nuclear plant anyway, they may now be more inclined to consider units in the SMPR or MPR ranges.

From the 1950s to early 1970s, electrical demand growth rates in the OECD regions were high and electricity demand increased rapidly. With high load growths, even relatively small grid systems had a demand increase that could utilized the output of new large generating units within only a few years. Large plants, because of the economies of scale and so the less expensive power they promised, were therefore frequently chosen to satisfy base load demand increases in OECD countries.

Since the 1970s, growth rates of electrical demand within the OECD region have become erratic and dropped to about 2.4 per cent per year, less than half of the rate of the early seventies. Smaller plants may now more closely match these lower growth projections. The addition of a number of smaller units can involve less risk than the sudden addition of one larger unit should growth projections prove low and unreliable.

Additionally, several OECD countries are federal states in which electrical distribution is the responsibility of a number of regional utilities whose grids sometimes have limited or no connections with their neighbours. Attention is therefore more appropriately directed towards the regions individually than the country as a whole. When considered on their own, many of these regions have electrical systems compatible with SMPRs or MPRs.

(b) Remote/Discontinuous Areas

Many OECD countries with large electrical systems have remote areas in them, or associated with them, that either are not connected to the national grid or which have such limited connections that they are more appropriately addressed alone. The state of Alaska in the US is an example. Other examples include a number of islands such as Puerto Rico, Hawaii and Crete. SMPRs or MPRs might serve as viable options for electrical supply in these areas.

(c) Economic Electricity Supply

The interest rates charged on borrowed capital in most of the OECD countries have more than doubled since the early 1970s. Interest rates after inflation now range up to 10 per cent and time-related charges often make up two-thirds of total capital costs in current dollars. Several vendors from OECD countries have indicated in their IAEA questionnaire responses (see Chapter 3) that shorter construction schedules will be possible for SMPRs. Such a reduction in construction schedule would reduce specific capital costs and would also reduce the period of financial risk for a purchasing country. Approximately $200/kWe may be attributed to the interest savings.

Even if shorter construction times for smaller units are not considered, smaller units can become competitive with larger units with lower specific capital costs. This comes from the fact that smaller units can approximate load growth better than larger units. It has been maintained[6,7]

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6. Economic Potential of Smaller-Sized Nuclear Plants in Today's Economy, C. Behrens, Congressional Research Service, 83-621 ENR, Library of Congress, Washington D.C., January 1984.
7. Economics of Small Reactors, C. Braun, EPRI, Trans. Am. Nucl. Society, 46, 563(1984).

that in the US a $200 to 400 kWe premium can be given to smaller units from a rate-payers point of view. In the US, where no nuclear plants have been ordered since 1978, most fossil plants ordered since 1979 have been under 650 MWe with many under 400 MWe.

Other recent papers[2,8,9] have also explored the potential that under certain circumstances, smaller nuclear power units might be desirable, and even economical, in electrical systems which could easily accomodate much larger units. Of these papers, one[8] has contended that the total carrying costs of a 3x400 MWe station may be equivalent to or lower than those for a 1200 MWe PWR, when the earlier displacement of costly fossil fuel use is considered. A Finnish study[2] showed carrying costs could be lower for 2x500 MWe vs 1x1000 MWe nuclear (and 2x500 MWe coal). Some of these circumstances were reviewed in the study mentioned above[6] and the argument can be summarized by:

> "...in times of slow growth, the large investment in a single [large nuclear plant] project can be both expensive and risky, especially when interest rates are high. In such circumstances the greater flexibility and lower front-end investment requirements of smaller units can compensate for a higher capital cost per kilowatt of capacity."

Cost comparisons and detailed economic analyses between multiple smaller units versus a comparable larger plant in the same locale will be required to determine the economic attractiveness of this concept and to show whether the flexibility benefits of a smaller plant will compensate for higher specific capital costs.

The relative economics of SMPRs of various types versus coal-fired units for electrical power generation were addressed in Chapter 4. Figure 6.1[10] shows further economic comparisons for an 800 MWth HTGR modular unit versus coal-fired units of similar size.

(d) Dedicated Applications

Many industries are very large consumers of electric power. Such industries are, of course, not limited to OECD countries but it is suggested they are more common and diversified in these countries than in other less industrialized ones.

Practically, there are four classes of industrial processes in which the use of electricity is either unique or essential and, given current economics, can be up to an order of magnitude more attractive than any alternative energy supply. These are:

- Electrolytic processes.
- Very high temperature processes where electricity is the only practical way of delivering the temperatures required.
- Processes needing very close control, where electricity is effectively the only practical way of ensuring that the process adheres to the very fine tolerances required.
- Processes which have a major component of mechanical drive.

8. Compact Nuclear Packages for Emerging Nations, J.I. Sweeny, General Electric Company. Presented at SMPR conference, Lima, March 1984.
9. The CNSS Plant Concept, Capital Cost and Multi-unit Station Economics, United Engineers and Constructors, ORNL/Sub 82/17455/4, UE&C-DOE-ORNL-830915, July 1984.
10. An Autarc Barge-mounted Energy Station with a Modular High Temperature Reactor. W. Steinwarz and H.D. Batschko. Paper presented at 2nd Technical Committee Meeting on SMPR Project Initiation Study, Vienna, March 1985.

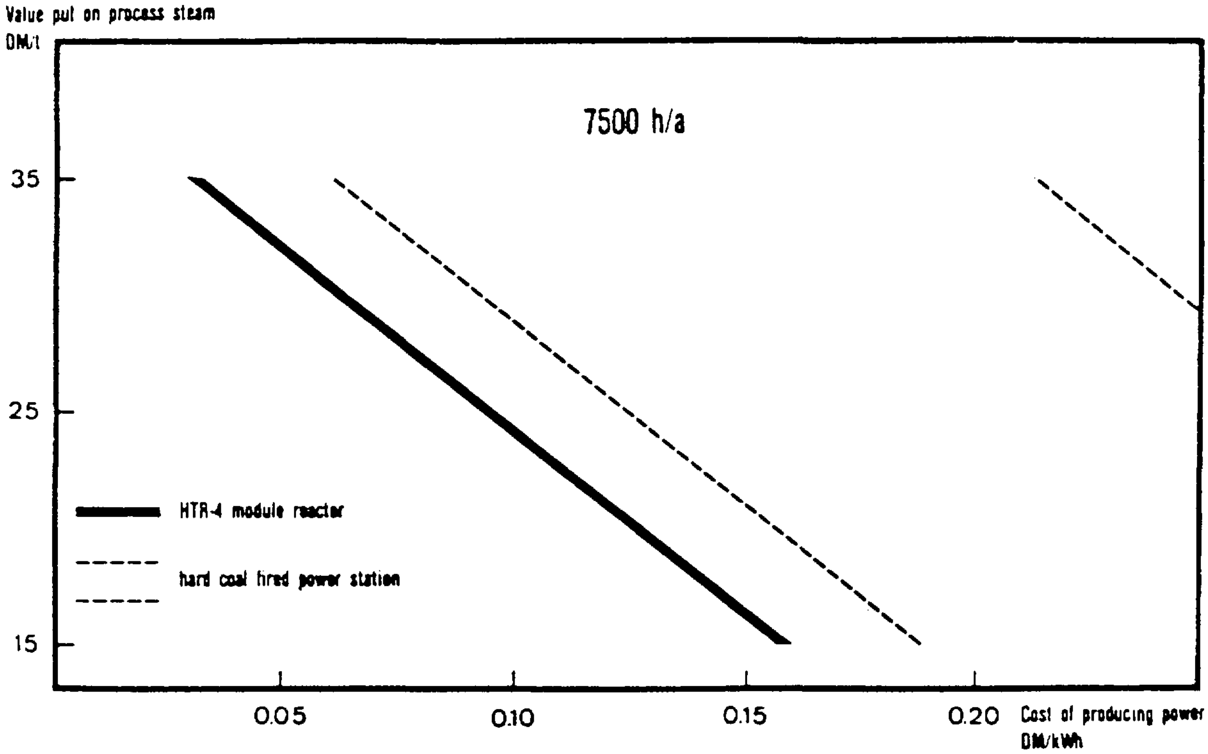

FIGURE 6.1

POWER COSTS OF MODULAR HTRs AND HARD COAL-FIRED POWER STATIONS

Table 6.5 Ranking of Industries According to Installed Capacity which would be Required at Efficient Scale*

Size (MWe)	Industry
Over 200	Aluminium, Uranium enrichment (diffusion)
100-200	Magnesium
50-100	Zinc, Sodium metal, Chlor-Alkali, Ferroalloys (Si), Steel
25-50	Copper, Nickel, Glass, Ferroalloys (Cr, Mn), Titanium
about 25	Lithium metal, Electroplating, Hydrogen, Peroxide, Abrasives Uranium enrichment (centrifuge), Industrial gases, Pulp and paper, Electrolytic H_2 production

* An efficient scale plant is one of an economic size which might be built using the latest technology.

Table 6.5 ranks various energy-intensive industries according to the electrical supply which they require.

The power requirements of some industries in these classes may be of a scale similar to the output of a smaller nuclear reactor, especially smaller SMPRs.

Some electrically-intensive industries may be located in regions inconvenient to the national electrical grids and/or may find it to their strategic advantage to control their own power supplies. The ownership and operation of hydroelectric facilities by American and Canadian aluminium companies is an example. The energy requirements for an industrial park can match the output of one or more smaller nuclear reactors located nearby, while a conveniently located hydroelectric project is rarely feasible.

Because such industries could not tolerate the loss of electrical supply during outages of a dedicated nuclear power plant, it is suggested that opportunities for dedicated supply will be more numerous in many OECD countries whose relatively large grids could easily accommodate electrical supply requirements during nuclear plant outages and the purchase of surplus power during industry shutdown. A good example of nuclear power supplying electricity to industry is the 4x915 MWe Tricastin station in France which supplies electricity to the Eurodif uranium enrichment plant as well as to the power grid.

The economics of dedicated electrical supply might be quite different from those for utility electricity distribution and would have to be examined on a case-by-case basis. Nevertheless, such industries may present smaller nuclear reactor opportunities, ones which could be implemented when new generation SMPRs are placed in operation by utilities.

(e) Diversification

Some SMPRs, and even MPRs, may be uniquely suited to opportunities in district heating, cooling, cogeneration and the supply of process heat for various industries[11,12] (e.g. for desalination, upgrading coal, splitting natural gas, the co-generation of process steam, etc.). While such opportunities can be found in countries throughout the world, they are likely to occur more often on a scale compatible with the output of a smaller nuclear reactor in the more highly industrialized countries.

Diversification is a complex subject beyond the scope of this evaluation. Should the costs of fossil fuels escalate, many new applications of nuclear energy could become cost effective. Diversification could also change the economics of smaller reactors since costs could be balanced against increased revenues from additional products rather than just against the alternative costs of electricity.

(f) Export Sales Considerations

Opportunities for export sales in the developing countries are being investigated by reactor vendors in some OECD countries. While several of the proposed SMPR designs are adaptations of existing larger units, others differ to greater degrees from existing designs, and some are of novel design. But

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11. Nuclear Process Heat Applications for the Modular HTR, W. Jäger et al, Interatom GmbH, Bergisch Gladbach, Federal Republic of Germany, Nuclear Engineering and Design, 78, 2 (1984) 137-145.
12. Modular High Temperature Reactor Power Plant Prospects for Capital Costs and Economy, I.A. Weisbrodt, KWU AG/Interatom GmbH, Federal Republic of Germany, Conference on Nuclear Power Plant Innovation for the 1990s, Massachusetts Institute of Technology Boston, US, December 1984.

whether of proven design or not, unlike the situation with many MPRs, most of the vendors from OECD countries do not have domestic SMPR reference plants to demonstrate their designs to potential customers*. Since some potential customers may feel that such a reference plant is essential, SMPR vendors may find it desirable, or even necessary, to construct a reference or demonstration SMPR in their home country. As it is usually not the vendor but the utility which will build and operate nuclear power plants, such reference plants might involve questions of national policy to provide encouragement for such plants.

It is not possible at present to accurately assess whether or not any domestic prototypes will be constructed. Questions will have to be answered such as whether an SMPR design is unique, and what trade-offs are necessary with respect to availability and risk sharing.

6.5 ASSESSMENT OF POTENTIAL MARKET FOR SMALLER NUCLEAR REACTORS IN OECD COUNTRIES

(a) Concrete Indications of Interest

The only OECD countries to submit buyer responses to the SMPR questionnaire were Finland and Turkey. In Finland's response, plans were outlined for 1000 to 1500 MWe of new capacity between 1991 and 1994. The response does not specifically address markets for SMPRs, but does note that competitive 500 to 600 MWe MPR units are being considered. Turkey is considering the purchase of its first nuclear power station. Although SMPRs are currently excluded, proposals involve units of 600 MWe and larger sizes. Although no other OECD countries responded to the questionnaire, literature sources indicate a potential in some of them. At least two surveys of utility opinions on smaller units have also been reported.

As shown in Figure 6.2, the US utilities polled in the first survey[13] expressed a relatively high interest for near term capacity additions in the ranges of 200 to 400 MWe and 400 to 700 MWe**.

In the second[14], a number of privately and publicly-owned US utilities were polled as to future plants, projections and other matters. Most favoured nuclear, but none were willing to purchase a nuclear power plant in today's environment. With regard to small versus large nuclear (and coal) plants, most

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* Chapter 3 provides information about the nuclear vendors in OECD countries who responded to the questionnaire. Of these, vendors in only three OECD countries (France, the FGR and the UK) can point to operating units (domestic or abroad) of about the same size as reference plants for their SMPR designs. This is a relatively small fraction. The situation is somewhat better with MPRs (see Table 6.3) where vendors in five OECD countries (Canada, Japan, Sweden, the UK and the US) could refer to operating units (domestic and/or abroad) of recent vintage. In addition, one further OECD country, Finland, has operating MPRs of Soviet design.

** This survey was carried out by the Gas Cooled Reactor Association (GCRA). It should be noted that it also indicated little utility interest for nuclear to serve the lower portions of the specified range.

13. The Future of HTGR, L.D. Mears, GCRA, presented at the April 1984 ANS meeting, Washington D.C.

14. Electric Utility Markets for New Electric Generating Plants. Interview Results and Questionnaires Responses. S.V. Jackson & C.A. Mangeng, Los Alamos, S4/84.2.

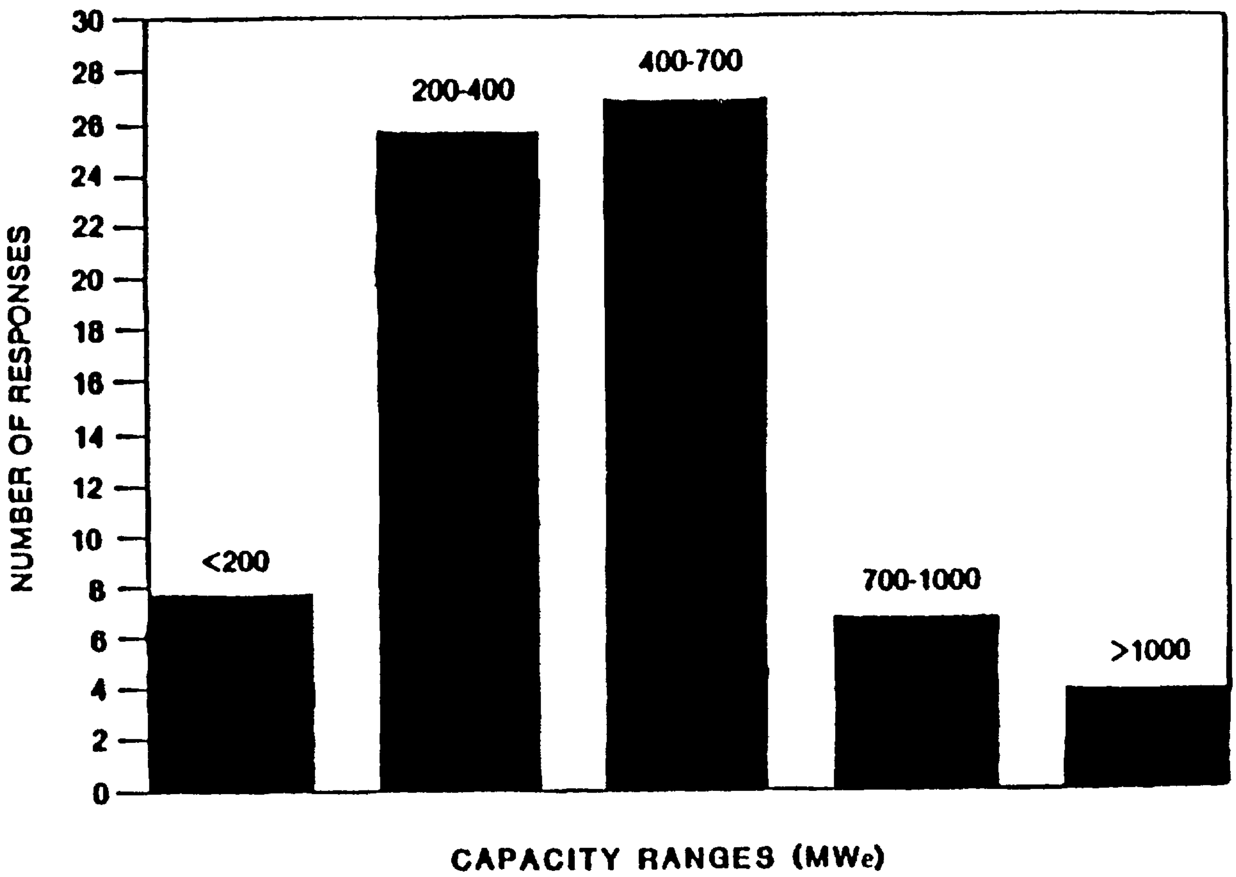

FIGURE 6.2

CAPACITY ADDITION PREFERENCE FROM GCRA SURVEY OF UTILITIES

felt some reduction in plant size would be desirable. The usual reasons for considering smaller plants (reviewed earlier in this report) were cited and there was considerable interest expressed in plants which would supply one to three years of projected load growth for a utility.

For the 33 electric utilities polled, two years of load growth ranges from 50 MWe (smaller utilities) to over 700 MWe (larger ones). The larger utilities were reported to favour plants providing somewhat more than two years' load growth, possibly putting their requirements above the SMPR and MPR ranges. But, as is noted later in this section, there is considerable interest in the US in the potential of multiple smaller units rather than a single larger one.

Two US nuclear vendors have each advanced LWR SMPR proposals and another group has proposed modular HTGRs. If current impediments to further nuclear station ordering in the US could be resolved, it is possible that a significant market for SMPRs and MPRs could develop there.

In the Federal Republic of Germany, the group "Arbeitgemeinschaft Hochtemperatur - Reactor", combines both high temperature reactor and small utility interests (but not exclusively) in a working party which seeks to assess smaller reactor competitiveness with large plants. There is also considerable interest in smaller power plant increments by some German utilities and the HTGR is seen as the only domestic design responsive to such a need.

In the United Kingdom, an active group involving representatives from industry, the government, the AEA and the banking world serves to formulate and develop UK thinking on the IAEA SMPR study. The Group also provides a focal point for consideration of the scope for export of SMPRs.

In the Netherlands, several thousand megawatts of electrical generating capacity has to be replaced. Dutch authorities have investigated scenarios in the past for building either 600 MWe units or 1000 MWe plants[15]. However, in January 1985 the government adopted a position, which included an expansion of nuclear energy with at least two power plants of between 900 and 1 300 MWe each.

In Canada, a proposal is being evaluated to construct a further 600 MWe unit in the province of New Brunswick and active investigations are under way on the potential of 300 MWe and 600 MWe units in other provinces for domestic and electricity trade requirements.

Portugal is also currently considering whether it should launch a nuclear power programme and there too initial indications are for units in the 600 MWe or greater range[15].

Thus there are strong indications that several OECD countries plan to launch or expand their nuclear programmes and some of the opportunities which may develop in them could involve SMPRs and MPRs, with real potential for the latter in Canada, Finland, Portugal, Turkey and the Netherlands.

(b) Analyses of Technical Market Potential

In the Subsections which follow, several ways of evaluating the SMPR and MPR potential in OECD countries are used. In Subsection (i), historical data on 200 to 400 MWe and 400 to 700 MWe thermal units are examined to obtain a perspective of what might be the maximum size of the markets available. In Subsection (ii), the ability of some OECD countries to "carry" (i.e., finance) a nuclear power unit, is evaluated. A standard grid-size evaluation is carried out in Subsection (iii), and in Subsection (iv) electrical load growth factors are addressed.

(i) Historic Analysis of Potential Market

The market for electricity generation is shared by fossil-fired (coal, oil, gas), nuclear, hydroelectric and other (geothermal, etc.) plants. In general, most readily accessible hydroelectric sites in the size ranges under discussion have already been developed in OECD countries, so in essence SMPRs and MPRs will have to compete for market share against fossil-fired plants, especially coal-fired ones of conventional and advanced designs.

Based on data[16] which may be incomplete but are nevertheless believed to be representative (see Table 6.6), 54 thermal electrical generating units (both for base and peak loads) in the 200 to 400 MWe size range entered service in the 1980 to 1984 period in OECD countries, while a further 59 are now under construction and due to enter service between 1985 and 1989. This number of units does not necessarily represent what the market for units in the 200 to 400 MWe size range will be in the future. Nevertheless, the numbers should be indicative and, if so, suggest a market of about 11 units per year in OECD countries. The comparative figures for the 400 to 700 MWe size range are 75 and 87 units respectively, for a total of 164 units over 10 years, or about 16 per year. As with the SMPR size range described above,

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15. The Future of Small Power Reactors: A European View. J. Fazekas, Motor Columbus, ANS Washington D.C. Conference, November 1984.
16. Kidder-Peabody and Company Incorporated (US). Industry analysis of Electric Power Construction Projects, Research Report, April 1984.

Table 6.6

Thermal Power Plant Additions in OECD Countries
(200 to 400 MWe)

	Historical Data 1980-1984	Units under Construction 1985-1989	Total
Coal-Fired	51	47	98
Oil-Fired	0	1	1
Nuclear	0	2	2
Other*	3	9	12
TOTAL	54	59	113
Average Number of Units per year			11

* Gas-fired, dual fuel, etc.

these MPR size range data represent only a gross estimate of the total size of the market for all types of thermal generating stations, fossil and nuclear.

The samples described above presumably also include some plants which are replacements for older units being shutdown. This portion of the market could decrease (but only on the short term) as there is considerable interest in some areas (e.g., the United States) in extending the lifetime of existing fossil-fired units (and nuclear ones in the United Kingdom) to defer the need for new construction. Of more impact on nuclear may be the growing perception of the highly deleterious effects of acid rain which is caused in part by coal-fired power stations. This could lead to measures which could lessen the economic competitiveness of coal-fired units and force a move to the only feasible large scale generating alternative, nuclear power.

It is not suggested that SMPRs and MPRs could capture all, or even significant proportions, of these markets for 200 to 400 MWe and 400 to 700 MWe plants, but the numbers do indicate that there has been a significant demand for these sizes of units in the recent past.

(ii) Financing of Nuclear Power Programmes

In addressing the market potential of SMPRs and MPRs in OECD countries which do not as yet possess ongoing nuclear power programmes, it is necessary to assess just when a country might first be able to initiate such a programme.

Morrison and Sims[17] carried out a series of evaluations in which they explored numerous criteria which they hoped would shed light on when a country might acquire its first nuclear power unit. They examined GNP, GNP per capita, the physical quality of life index, the level of industrial activity, absolute energy consumption, per capita energy consumption and electrical generating capacity. They concluded that of all of these indicators, a country's natural wealth as given by GNP seemed to be the best indicator of when it might be able to seriously consider its first nuclear power plant.

17. Nuclear Power in Developing Countries. A Search for Indicators, Morrison and Sims, Department of Energy Mines and Resources, Ottawa, August 1980.

From their evaluations, they concluded that this threshold was US $10 billion in GNP ($ of 1975) on the basis that repayment of principle and interest on investment in a nuclear station should not exceed 1% of GNP or about $100 million per annum. Furthermore, it is noted that this sum is equivalent to the yearly amount of repayment resulting from an investment of about $1 billion (a rough approximation of the cost in 1975 of a nuclear reactor) amortized over 30 years at 10 per cent interest rate. Since an SMPR is expected to cost about $ 1 billion today their guideline is still relevant.

In this type of calculations, one-tenth of GNP is referred to as "carrying capacity". The carrying capacity is, then, a measure of how many reactors (or other billion dollar financed projects) a country might reasonably afford based on its national wealth. The technique is applicable to industrialized as well as less industrialized countries, as shown in Table 6.7. For practical reasons GDP is used instead of GNP in this table.

The table suggest that all of the countries considered, with the exception of Iceland and Luxembourg, have large enough economies to be able to carry the financing costs of one or more nuclear reactors. If and when they might choose to do so is another matter.

Repeating these calculations with GNP estimates for future years would give slightly different values for "carrying capacity", as would considering the different investment costs required for different sized reactors.

Another approach suggests that a country should not place more than some percentage (perhaps 5 to 10 per cent) of its Gross Fixed Capital Formation (GFCF)* into one investment. This may be a valid criteria but, rather than evaluating the ability to repay a debt, it relates to national investment philosophy. It is more subjective and therefore has not been included in this analysis. However, based on 1984 OECD statistics, a criteria based on 10 per cent of GFCF would eliminate only two countries (Ireland and New Zealand) which would pass the "carrying capacity" test illustrated on Table 6.7.

(iii) Electrical Supply Growth Evaluations

For electrical generation, a commonly used rule-of-thumb is that no single generating unit should constitute more than 10 to 15 per cent of a system's total installed, interconnected capacity. This criterion is based on reliability, technical and economic considerations. Recent advances in planned load shedding schemes and in under-frequency relay technologies could, however, significantly change this restriction. Also, a higher value may be feasible where a grid is interconnected with other grids in adjacent areas. In practice, units of up to 20 per cent of installed capacity may be selected in some cases.

Table 6.8 compares current installed electrical capacity and that projected for year 2000, and evaluates market potential using the 10 per cent criterion.

Only one OECD country (Ireland) falls in the SMPR size range**. Two islands (Sardinia and Hokkaido) also fall in this range. Three OECD countries

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* The GFCF is the amount of purchases and own-account production of industries, producers and government services and producers of private non-profit services to households on additions of new and imported durable goods to their stocks of fixed assets, reduced by the proceeds of their net sales of similar second-hand and scrapped goods.

** The term "size range" as used here is only a convenience for grouping, and practically indicates only a minimum boundary. Clearly larger grids could also accommodate the smaller-sized reactors.

Table 6.7

The Carrying Capacities of OECD Countries Without Ongoing Nuclear Programmes

Country	GDP[(a)]	Carrying Capacity
Australia	149	15
Austria	79	8
Denmark	69	7
Greece	40	4
Iceland	3	0
Ireland	20	2
Luxembourg	4	0
Netherlands	166	17
New Zealand	25	3
Norway	60	6
Portugal	26	3
Turkey	65	7
Total		72

(a) 1983 Gross Domestic Product in billions (10^9) of constant 1980 US dollars[18].

(Portugal, Greece, New Zealand) fall in the MPR size range, along with one island (Puerto Rico).

There are a number of OECD countries and regions (states, provinces, territories and islands) which possess relatively independent electrical distribution systems which are now, or might be expected to become over the next few decades, large enough for consideration. In many cases these electrical systems are fully contiguous throughout the region while in others they are made up of a number of separate smaller grids and load centres. Some of these regions, even though they are not at the moment contiguous, are expected to become joined together in future and may be considered as such for these evaluations.

Australia, Canada, the Federal Republic of Germany and the United States are large federal states in which the distribution of electricity is the responsibility of one or more utilities in each province or state. Although strong interconnections often exist with the electrical systems of adjacent regions, in many cases they do not, and the electrical grids of some provinces and states need to be considered separately in evaluating their potential to add generating capacity of a certain size.

Australia does not as yet possess any nuclear power stations. In Australia, electrical distribution is the responsibility of utilities in six states and one territory. Only limited interconnections exist among most of them. Three Australian states (Western Australia, South Australia, and Queensland) fall in the SMPR range while one further one (Victoria) falls in the MPR size range.

Canada has three provinces which already have operating nuclear plants (Ontario, Quebec and New Brunswick) and which have grids which are extensively interconnected to adjacent provinces and American States. Of the other seven, only one (British Columbia) is large enough to accommodate a thermal

18. National Accounts, 1960-1983, OECD, Paris 1984.

Table 6.8

RECENT AND YEAR 2000 PROJECTIONS OF INSTALLED ELECTRICAL CAPACITY
IN AREAS OF THE OECD WITHOUT ONGOING NUCLEAR PROGRAMMES
10% SIZE CRITERION

	Recent(1)	GWe	Estimate for year 2000 (2)	GWe	
	Balearic Islands (Spain)	0.1(3)	Bermuda	0.2	
	Bermuda	0.1	Yukon	0.2	
	Crete (Greece)	0.1	Luxembourg	0.2(5)	
	Prince Edward Island (Can.)	0.1	Balearic Islands	0.3	
	Yukon (Can.)	0.1	Prince Edward Island	0.3	
	Corsica (France)	0.2(3)	Corsica	0.4	
	Luxembourg	0.2(4)	North West Territories	0.4	
	Northern Territory (Aust.)	0.2(3)	Crete	0.4	
	North West Territories (Can.)	0.2	Northern Territory	0.5	
	Bahamas (UK)	0.4	Bahamas	0.6	
	Iceland	0.9(4)	Okinawa	1.4	
	Okinawa (Japan)	0.9(3)	Oahu	2.0	
	Alaska (US)	1.3(3)	Iceland	2.2(5)	
	Oahu, Hawaii (US)	1.5	Alaska	2.6	SMPR
	Newfoundland (Can.)(6)	1.6(3)	Newfoundland	3.8	SIZE
	Tasmania (Aust.)	1.9	Western Australia	3.9	RANGE
	Western Australia	2.0(3)	Tasmania	3.9	
	Nova Scotia (Can.)	2.0	Ireland	4.1(5)	
SMPR	South Australia	2.1(3)	Sardinia	4.1	MPR
SIZE	Sardinia (Italy)	2.2(3)	South Australia	4.2	SIZE
RANGE	Saskatchewan (Can.)	2.4	Nova Scotia	4.8	RANGE
	Ireland	3.1(4)	Saskatchewan	5.6	
	Queensland (Aust.)	3.6(3)	Manitoba	6.7	
	Hokkaido (Japan)	3.7(3)	Queensland	7.2	
	Puerto Rico (US)	4.1	New Zealand	9.1(5)	
	Manitoba (Can.)	4.1	Denmark	9.4(5)	SMPRs
	Portugal	5.6(4)	Hokkaido	9.6	AND
MPR	Alberta (Can.)	6.2	Portugal	12.2(5)	MPRs
SIZE	Greece	6.4(4)	Victoria	13.0	NOT
RANGE	Victoria (Aust.)	6.5(3)	Netherlands	13.1(5)	EXCLU-
	New Zealand	6.6(4)	Puerto Rico	14.3	DED
	Turkey	7.7(4)	Alberta	15.5	
SMPRs	Denmark	7.9(4)	Greece	15.5(5)	
AND	British Columbia (Can.)	10.8	British Columbia	18.5	
MPRs	New South Wales (Aust.)	12.3(3)	Austria	19.9(5)	
NOT	Austria	13.0(4)	New South Wales	24.6	
EXCLU-	Netherlands	13.5(4)	Norway	29.0(5)	
DED	Norway	22.8(4)	Turkey	41.0(5)	

1. 1982 data unless otherwise noted.
2. Calculated using 1972-1982 growth in electrical capacity unless otherwise noted.
3. 1983 data.
4. 1984 data[1].
5. 1985 projections[1]
6. Newfoundland in this context refers to the island, not the province. The island's grid is not interconnected to the mainland part of the province.

generating unit above both the SMPR and MPR size ranges. Another two (Nova Scotia and Saskatchewan) are large enough to consider fossil-fired or nuclear plants in the SMPR size range. Two other Canadian provinces (Manitoba and Alberta) have electrical systems large enough to accommodate MPRs.

The US National Rural Electric Cooperative Association foresees[14] limited applications for small reactors in remote, rural segments of the US. However the state of Alaska was cited by the Association as a potential region. Alaska's current installed capacity of about 1300 MWe is divided among about 20 separate utilities. However, about 80 per cent of this total is located in the areas of the cities of Fairbanks and Anchorage and demand there is growing at above the US average. The US state of Hawaii has also been cited as a potential region. The island of Oahu is projected to have an installed capacity of 1500 MWe by 1990 and it could accommodate a 200 MWe unit at that time using a 15 per cent criterion.

The Association mentioned also a number of smaller islands outside the United States but within the OECD area as possible sites for small nuclear reactors. These include New Caledonia (France), Greenland (Denmark), the Virgin Islands (US/UK), the Canary Islands (Spain), St. Pierre and Miquelon (France), the Isle of Man (UK), the Channel Islands (UK), and Guam (US). Evaluation of the electrical generation capacity and projected electrical growth rates for these islands indicates, however, that they all are too small to practically consider even the smallest-sized SMPR in the foreseeable future.

Thus, there are eight regions which currently have electrical generation systems which theoretically could "accommodate" (i.e., fall in the size range of) a 200 to 400 MWe unit (either fossil-fired, hydraulic or nuclear). These are:

Australia	- Western Australia State	Ireland	
	South Australia State	Italy	- Sardinia*
	Queensland State*	Japan	- Hokkaido Island*
Canada	- Nova Scotia Province*		
	Saskatchewan Province*		

In addition, there are seven more areas that might now accommodate units in the 400 to 700 MWe range. These are:

Australia	- Victoria State	New Zealand
Canada	- Alberta Province*	Portugal*
	Manitoba Province*	United States - Puerto Rico
Greece*		

There is, of course, no reason why a region which is able to accommodate a 400 to 700 MWe size range unit could not consider a smaller SMPR size range unit instead. And even areas able to consider units above 700 MWe in size are not precluded from considering units in the SMPR or MPR ranges.

Given the projections for system growth by the year 2000 (Table 6.8), the 200-400 MWe range list shrinks to six, with five new regions (Oahu Island, Iceland, Alaska, Newfoundland and Tasmania) joining the list and seven others moving beyond it.

Thus, as far as electrical system size alone is concerned, there are a number of OECD regions which could reasonably consider generating facilities in the SMPR or MPR size ranges.

(iv) Electrical Load Growth Considerations

Another commonly used industry rule-of-thumb for assessing when additional capacity might be added to a generating system, is the anticipated growth rate over a fixed period. The purpose of this criterion is essentially to cover load growth during the construction period and uncertainties in growth projections during that time. Usually up to 5 years' growth are considered although, as noted earlier, one US survey[14] suggested 1 to 3

* Some interconnections do exist with these areas but an independent evaluation may still be more reasonable.

TABLE 6.9 TWO AND FIVE YEAR ELECTRICAL CAPACITY GROWTH

Country/State	Installed Capacity (GWe)	Electrical Capacity Growth Rate (2) (%)		Electrical Load Growth (MWe) Two-Year	Five-year	
Austria	13.0(4)	4.4		2650	6620	
Norway	22.8(4)	4.5		2180	5450	
Netherlands	13.5(4)	4.5		1840	4590	
Turkey	7.7(4)	9.2	SMPRs	1470	3670	
British Columbia	10.8(1)	5.2	AND MPRs	1240	3110	
New South Wales	12.3(3)	4.4	NOT	1180	2960	
Greece	6.4(4)	7.6	EXCLUDED	1060	2650	
Portugal	5.6(4)	7.1		830	2080	SMPRs
Puerto Rico	4.1(1)	8.1		780	1950	AND MPRs
Ireland	3.1(4)	8.1		750	1870	NOT
New Zealand	6.6(4)	5.2		750	1870	EXCLUDED
Alberta	6.2(1)	5.2		720	1790	
Victoria	6.5(3)	4.4		630	1570	
Hokkaido	3.7(3)	6.1	MPR	520	1290	
Manitoba	4.1(1)	5.2	SIZE	480	1200	
Denmark	7.9(4)	3.0	RANGE	430	1080	
New Brunswick	3.5(1)	5.2		400	1000	
Queensland	3.6(3)	4.4		350	870	
Sardinia	2.2(1)	8.0	SMPR	350	880	
Saskatchewan	2.4(1)	5.2	SIZE	270	680	
Nova Scotia	2.0(1)	5.2	RANGE	240	590	MPR
South Australia	2.1(3)	4.4		200	510	SIZE
Newfoundland	1.6(3)	5.2		190	480	RANGE
Western Australia	2.0(3)	4.4		190	470	
Tasmania	1.9(3)	4.4		180	450	
Hawaii	1.6(3)	4.7		160	400	SMPR
Alaska	1.3(3)	4.7		130	330	SIZE
Iceland	0.9(4)	5.0		80	210	RANGE
Luxembourg	0.2(4)	1.2		30	80	
Crete	0.1(3)	7.6		20	60	
Northern Territory	0.2(3)	4.4		20	60	
North West Territories	0.2(1)	5.2		20	50	
Prince Edward Island	0.1(1)	5.2		10	30	
Balearic Islands	0.1(3)	3.1		10	30	
Yukon	0.1(1)	5.2		10	30	

(1) 1982 data
(2) Average data for 1972-1982. Country data used for states/provinces where specific data not available
(3) 1983 data
(4) 1984 data[1]

years growth may be more appropriate for SMPRs. The growth allowance factor is evaluated in Table 6.9 for both two year and five year growth periods.

If two years' electrical growth rates are considered there are six regions (Canada's New Brunswick, Saskatchewan and Nova Scotia provinces along with Sardinia and Australia's Queensland and South Australian States) which have growths compatible with SMPRs. A further four (Denmark, Canada's Manitoba province, Australia's Victoria state and the Japanese island of Hokkaido) might be able to consider units in either the SMPR size range or the larger MPR (400 to 700 MWe) range units.

As also indicated in the table, there are only three regions in the OECD whose five year load growths are compatible with the addition of 200 to 400 MWe units and six with 400 to 700 MWe generating units. These are Iceland, and the US states Alaska and Hawaii; the Australian states of South Australia, Western Australia and Tasmania and the Canadian provinces of Nova Scotia, Saskatchewan and the island of Newfoundland. Electrical growth in a number of other areas is large enough to allow units larger than 700 MWe although smaller units are not precluded.

6.6 SUMMARY OF MARKET POTENTIAL FOR SMPRs AND MPRs

In summary, some expressions of interest in considering the purchase of nuclear power involving units in the SMPR and/or MPR ranges have been expressed by companies in Canada, Finland, Federal Republic of Germany, the Netherlands, Portugal, Turkey, and the United States. Five of these - Canada, Finland, the Netherlands, Portugal and Turkey, must be considered as good MPR candidates. The total market for 200 to 400 MWe sized thermal plants has averaged about 11 units per year in recent years in OECD countries, while for 400 to 700 MWe plants it has averaged about 16.

There is a significant market potential for these size ranges, though there is no assurance that nuclear plants will be able to penetrate that market in the future.

Based on meeting all three technical criteria of debt carrying ability, grid size and rate of capacity growth, the following regions in OECD countries could now, or by year 2000, accommodate generating capacity additions (either fossil, hydraulic or nuclear) in the SMPR and MPR size ranges.

Australia	- Queensland	Greece	
	South Australia	Iceland	
	Tasmania	Ireland	
	Victoria	Italy	- Sardinia
	Western Australia	Japan	- Hokkaido
Canada	- Alberta	New Zealand	
	Manitoba	Portugal	
	New Brunswick	United States	- Alaska
	Newfoundland		Oahu Island
	Nova Scotia		Puerto Rico

Again it must be stressed that the above list is based on technical evaluations only. This does not imply that these countries or regions are real potential markets. For example, Australia, Greece, Ireland and New Zealand have adopted electricity planning policies which exclude nuclear power. It seems unlikely that any reactor vendor would include these countries on a market survey "short list" at this time. Two other regions do not yet have large enough grids to practically take SMPRs (Newfoundland and

Alaska). Projected growth will have to be realized if these regions are to seriously consider SMPR sized units later this century. One of the remainder (Oahu Island, Hawaii) would have to be willing to allow one unit to cover more than two years projected growth to consider an SMPR sized unit.

On the other hand, some OECD countries or regions whose electrical systems are large enough to accommodate units of 700 MWe or greater may be interested in SMPRs or MPRs for economic or strategic reasons. However to date only the United States has shown much interest in this prospect. A small number of smaller units could possibly be built by vendor countries for demonstration or reference plant purposes though no such units are planned yet.

In conclusion, it appears that a number of OECD countries or regions offer potential markets for SMPRs or MPRs based on technical criteria. Detailed economic and other evaluations would have to be undertaken to determine whether these sized units would be practical options in any of these regions. Such studies are beyond the scope of this current study. A limited number of national studies (Canada, Finland, The Netherlands, Portugal and Turkey), all in the high end of the MPR size range (600 MWe or larger), are underway or being considered, but no significant national studies on SMPR sized units are known at this time.

LIST OF ABBREVIATIONS

AECL	Atomic Energy of Canada Limited
AEE	Atom Energo Export
BBC	Brown Boveri Corporation
B&W	Babcock & Wilcox Compagny
BWR	Boiling Water Reactor
CE	Combustion Engineering
GA	General Atomic
GCR	Gas Cooled Reactor
GDP	Gross Domestic Product
GE	General Electric
GFCF	Gross Fixed Capital Formation
GNP	Gross National Product
GCHWR	Gas-Cooled Heavy Water Reactor
HRB	Hochtemperatur Reaktorbau Gmbh
HTGR	High Temperature Gascooled Reactor
HWLWR	Heavy Water Moderated, Light Water Cooled Reactor
IAEA	International Atomic Energy Agency
IVO	Imatran Voima Oy
KWU	Kraftwerk Union AG
LMFBR	Liquid Metal Cooled Fast Breeder Reactor
LWR	Light Water Reactor
Magnox	Magnesium Oxide Reactor
MPR	Medium Sized Power Reactor
MWe	Megawatt Electrical 10^6 watts electrical
NEA	Nuclear Energy Agency
NNC	National Nuclear Corporation Limited
OECD	Organisation for Economic Co-operation and Development
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
SMPR	Small and Medium-Sized Power Reactor
SPR	Small Power Reactor

APPENDIX I

Safety Series – NUSS (Nuclear Safety Standards) Programme

<u>Governmental Organization</u>

Code of Practice

50-C-G	Governmental Organization for the Regulation of Nuclear Power Plants (1978)

Safety Guides

50-SG-G1	Qualifications and Training of Staff of the Regulatory Body for Nuclear Power Plants (1979)
50-SG-G2	Information to be Submitted in Support of Licensing Applications for Nuclear Power Plants (1979)
50-SG-G3	Conduct of Regulatory Review and Assessment during the Licensing Process for Nuclear Power Plants (1980)
50-SG-G4	Inspection and Enforcement by the Regulatory Body for Nuclear Power Plants (1980)
50-SG-G6	Preparedness of Public Authorities for Emergencies at Nuclear Power Plants (1982)
50-SG-G8	Licences for Nuclear Power Plants: Content, Format and Legal Considerations (1982)
50-SG-G9	Regulations and Guides for Nuclear Power Plants (1984)

<u>Operation</u>

Code of Practice

50-C-O	Safety in Nuclear Power Plant Operation, including Commissioning and Decommissioning (1978)

Safety Guides

50-SG-O1	Staffing of Nuclear Power Plants and the Recruitment, Training and Authorization of Operating Personnel (1979)
50-SG-O2	In-Service Inspection for Nuclear Power Plants (1980)
50-SG-O3	Operational Limits and Conditions for Nuclear Power Plants (1979)
50-SG-O4	Commissioning Procedures for Nuclear Power Plants (1980)
50-SG-O5	Radiation Protection during Operation of Nuclear Power Plants (1983)
50-SG-O6	Preparedness of the Operating Organization (Licensee) for Emergencies at Nuclear Power Plants (1982)
50-SG-O7	Maintenance of Nuclear Power Plants (1982)
50-SG-O8	Surveillance of Items Important to Safety in Nuclear Power Plants (1982)
50-SG-O9	Management of Nuclear Power Plants for Safe Operation (1984)
50-SG-O10	Safety Aspects of Core Management and Fuel Handling for Nuclear Power Plants
50-SG-O11	Operational Management of Radioactive Effluents and Wastes Arising in Nuclear Power Plants

Quality Assurance

Code of Practice

50-C-QA Quality Assurance for Safety in Nuclear Power Plants (1978)

Safety Guides

50-SG-QA1 Establishing the Quality Assurance Programme for a Nuclear Power Plant Project (1984)
50-SG-QA2 Quality Assurance Records System for Nuclear Power Plants (1979)
50-SG-QA3 Quality Assurance in the Procurement of Items and Services for Nuclear Power Plants (1979)
50-SG-QA4 Quality Assurance during Site Construction of Nuclear Power Plants (1981)
50-SG-QA5 Quality Assurance during Operation of Nuclear Power Plants (1981)
50-SG-QA6 Quality Assurance in the Design of Nuclear Power Plants (1981)
50-SG-QA7 Quality Assurance Organization for Nuclear Power Plants (1983)
50-SG-QA8 Quality Assurance in the Manufacture of Items for Nuclear Power Plants (1981)
50-SG-QA10 Quality Assurance Auditing for Nuclear Power Plants (1980)
50-SG-QA11 Quality Assurance in the Procurement, Design and Manufacture of Nuclear Fuel Assemblies (1983)

Technical Reports Series

Manpower Development for Nuclear Power. A Guidebook, Technical Reports Series No. 200, IAEA, Vienna (1980).

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

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

Expansion Planning for Electrical Generating Systems, A Guidebook, Technical Reports Series No. 241, IAEA, Vienna (1983).

Qualification of Nuclear Power Plant Operations Personnel, A Guidebook, Technical Reports Series 242, IAEA, Vienna (1984).

Economic Evaluation of Bids for Nuclear Power Plants, A Guidebook, Technical Reports Series No. 175, IAEA, Vienna (1976).

ANNEX I

Information on SMPR Concepts Contributed by Supplier Industries

Foreword

This annex shows the design summaries, drawings, basic data and suppliers provenness and readiness of the concepts given in the table hereunder. The concepts are classified in the alphabetical order of countries and alphabetical order of suppliers in each country (see table of contents). But to permit a better overview of the concepts the table hereunder gives a classification according to the type of NSSS

Type	Country	Supplier	Concept	Basic Data	Provenness & Readiness
BWR	Japan	Hitachi	BWR 500[1]	no	documented
		Toshiba	BWR 500[1]	no	documented
		Toshiba	BWR 200/ 300[1]	yes	documented
	USA	GE	Small BWR	yes	documented
PWR	France	FRAMATOME/ TECHNICATOME	NP 300	yes	documented
	Italy	ANSALDO/ NIRA	PWR 272	yes	documented
	Japan	Mitsubishi	PWR 300[1]	no	documented
	Sweden	ASEA/ATOM	PIUS 500	yes	documented
	UK	Rolls-Royce	PWR 300	yes	documented
	USA	Babcock & Wilcox	CNSS	yes	documented
			CNSG	yes	documented
	USSR	Atomenergo-export	VVER 440	yes	documented
PHWR	Canada	AECL	CANDU 300	yes	documented
	Germany, F.R.	KWU	PHWR 300	yes	documented
HWLWR	Italy	ANSALDO/ NIRA	CIRENE 300	yes	documented
GCR	UK	GEC	MAGNOX[1]	no	under review
		NNC	MAGNOX 300	yes	documented
HTGR	Germany, F.R.	HRB	HTR 100-300-500	yes	documented
		INTERATOM	HTR Module	yes	documented
	USA	GE	HTGR[1]	no	under review
LMR[2]	USA	GE	MRP[1]	no	under review

1. No summary description
2. Liquid Metal Reactor

A.I.1 The CANDU 300

A.I.1.1 Design Summary

The CANDU nuclear power system has evolved over a 40-year period, and has accumulated over 105 reactor-years of operating experience. Standardization and modularization has always been a key thrust of CANDU designs.

As a member of the CANDU family, the CANDU 300 design closely follows that of the larger CANDU 600 and CANDU 950 nuclear power plants and is is illustrated in Figure A; key CANDU features include a pressure tube reactor, heavy water (D_2O) moderator, natural uranium fuel, and on-power refuelling.

The CANDU 300 utilizes the standard CANDU lattice design and fuel channel arrangement, with 208 fuel channels. The fuel channels are contained within an atmospheric pressure tank (known as the calandria), which is filled with low-temperature heavy-water moderator. Each channel contains 12 standard CANDU 37 element natural uranium fuel bundles. The heat transport system is a pressurized high temperature system which circulates heavy water through the fuel channels and transports the heat of fission from the fuel to the steam generators, to produce steam.

All control and shutdown devices, and in-core instrumentation are located within tubes perpendicular to the fuel channels and function within the low temperature and low pressure environment of the moderator. All CANDU reactors have two completely independent reactor shutdown systems of different designs, each capable of shutting down the reactor; these safety systems are in addition to the reactor regulation system.

The CANDU 300 has redundant digital computer control systems, and utilizes central and local processors and remote multiplexing. Systems controlled by the digital computers include: reactor regulation, power output regulation, steam pressure control, steam generator level control, moderator temperature control, heat transport system pressure and inventory control, fuelling machine control, and many other control functions. The CANDU 300 control room makes extensive use of computer generated colour graphic displays similar to those installed in existing CANDU 600 stations.

All system concepts and system operating conditions in the CANDU 300 are virtually the same as those on the larger CANDU units, and all key components (steam generators, heat transport pumps, pressure tubes, fuelling machine, and reactivity control devices, for example, are identical to those now in service on operating CANDU 600 stations.

The emphasis of the CANDU 300 design effort has been to reduce construction time and cost. This is aided by a station layout which provides 360 degree construction and maintenance access to the five principle buildings (Figure B), thereby permitting optimized construction sequence and methods. Modularized shop fabricated systems are also extensively used.

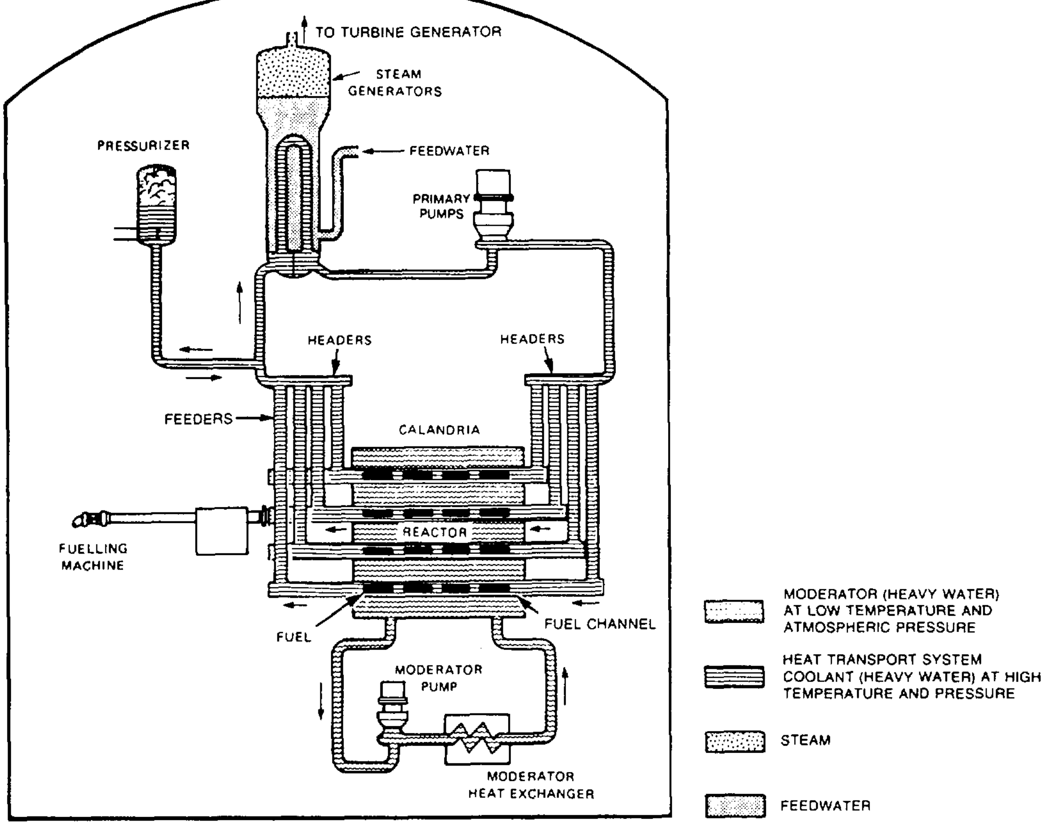


FIGURE A: NUCLEAR STEAM SUPPLY SYSTEM

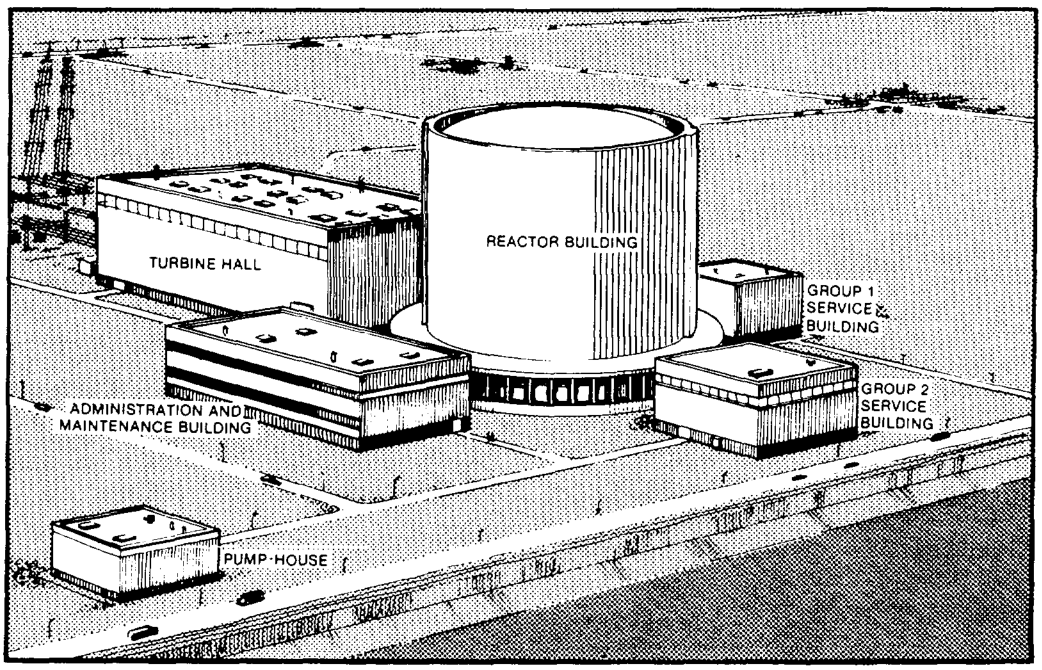


FIGURE B: STATION LAYOUT

A.I.1.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: AECL			
Reactor Type: PHWR			
Design Name:		CANDU-300	CANDU 600
Core Power (MW(th))		1032	2047
Net Output (MW(e))		320	638
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	0.1	0.1
	Length (m)	6	6
No. of Fuel Channels/Assemblies*		208	380
Moderator:	medium	D_2O	D_2O
	pressure (MPa)	0.1	0.1
	temp. (°C)	77	71
Primary System:	medium	D_2O	D_2O
	pressure (MPa)	10	10
	temp. (°C)	310	309
	loops	1	2
	steam generators	2	4
	pumps	2	4
Fuel:	enrichment (%)	0	0
	assembly length (m)	0.5	0.5
	assembly width/ diam.(m)	0.1	0.1
	No. of bundles/fuel channel	12	12
	No. of fuel elements (rods)/assembly	37	37
	mass of fuel in core(t)	46	85.8
Refuelling:	ON/OFF-LOAD	ON	ON
Secondary System:	pressure (MPa)	4.7	4.7
	temp. (°C)	260	260

* underline relevant one

A.I.1.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: AECL (Canada)

CONCEPT: CANDU 300; 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: Pt. Lepreau, 600 MW(e) CANDU

PROTOTYPE PLANT: Not Applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

CANDU type plants have accumulated 105 reactor years of experience with average load factor of 80% (PHWR in Canada only) untill the end of 1983. Pt. Lepreau was connected to grid on 1982-09 (2.2 reactor years). Cumulative load factor for Pt. Lepreau until the end of 1983 is 84.6%.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design in progress

STATUS OF REGULATORY REVIEW:

Not yet licensed. The reference plant is licensed in Canada and operating. The design and philosophy of CANDU 300 process and safety systems follow the same principles as those of the reference plant.

A.I.2 The NP 300, a Compact 300 MW(e) Nuclear Power Plant (FRANCE)

A.I.2.1 Design Summary

The NP 300 embodies a pressurized water reactor (PWR) in a compact NSSS design, enclosed in a small egg-shaped containment. This compact NSSS design is based on the extensive experience of TECHNICATOME in this area, with 13 PWR in operation or in construction and namely 9 years of operation of a prototype unit (CAP) at Cadarache in France.

The technology of the main components is based on that of the 3-loop, 900 MW(e) series and the 4-loop, 1300/1500 MW(e) series, a total of 63 units having been built or ordered. The operating experience of these FRAMATOME reactors amounts to a total of 135 reactor-years. Added to this experience is that of Chooz A1, a 300 MW(e) Franco-Belgian unit with over 16 years of successful operation.

Following are some of the main design characteristics of the NP 300:

- the core design allows extended fuel cycles with reloading only every two years. The fuel assemblies (except for their length) are identical to the standard fuel assemblies used in other FRAMATOME PWRs and thus benefit from vast experience (2 000 000 fuel rods; 87 cycles completed or in progress as of June 1984).

- the plant can be operated in load follow mode, as the one-line French units.

- the compact design of the reactor coolant system results in short connections between the reactor vessel and the two steam generators; the reactor coolant pumps with canned motors are integrated into the steam generator channel head. This gives two basic advantages:

  1) reduction of the size of LOCA break to that of small piping connected to the reactor coolant system,

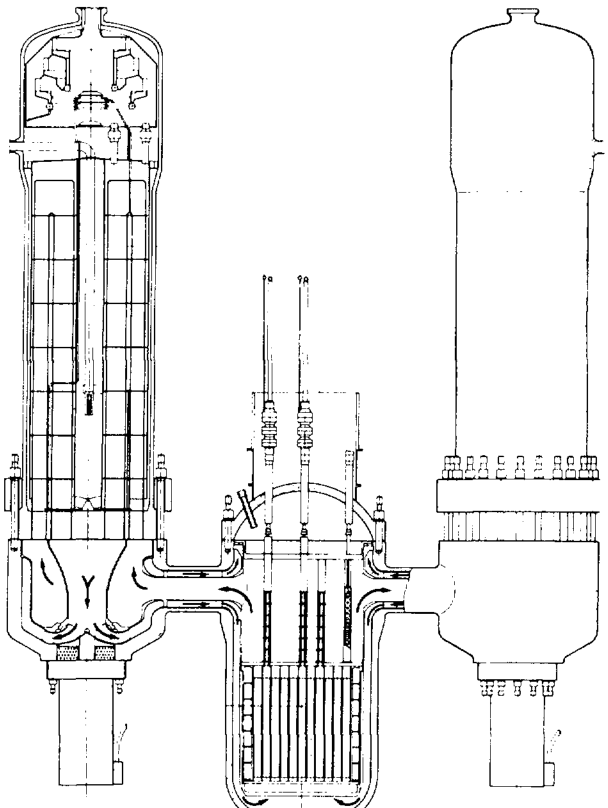
  2) reduction of the containment size

- the reactor vessel, reactor internals, steam generators, control rod drive mechanisms, etc. use proven technology and design upgrading resulting from the manufacturing and operating experience of large PWR units

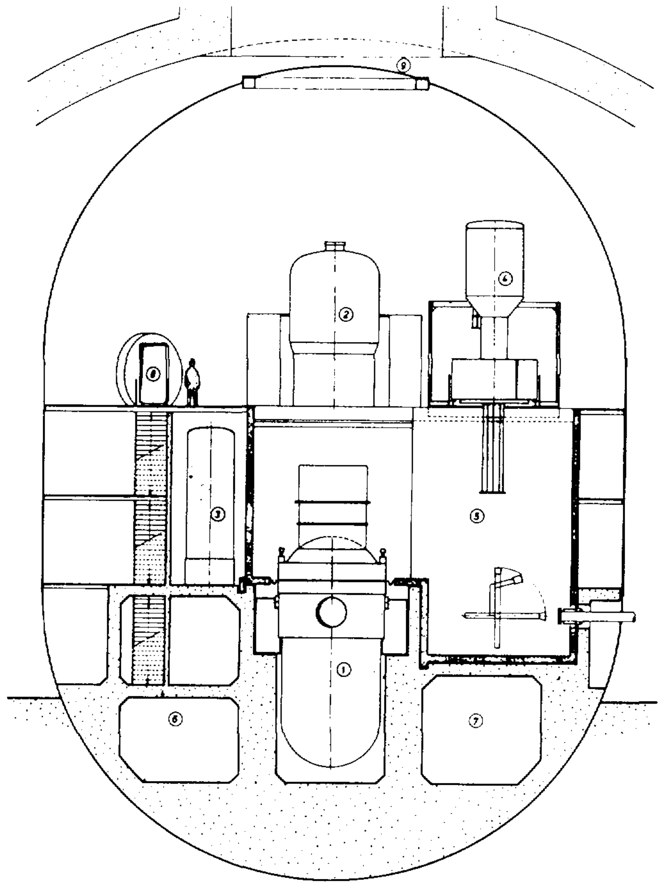
- the egg-shaped metallic containment, the fuel storage pool and all the safety nuclear auxiliaries are protected against external hazards by a semi-circular concrete tunnel

- shop fabrication and modular systems design are widely implemented, so that the overall construction time is reduced to five and one-half years.

The NP 300 has been designed under the same criteria as those applied for high-power French Nuclear Power Plants.

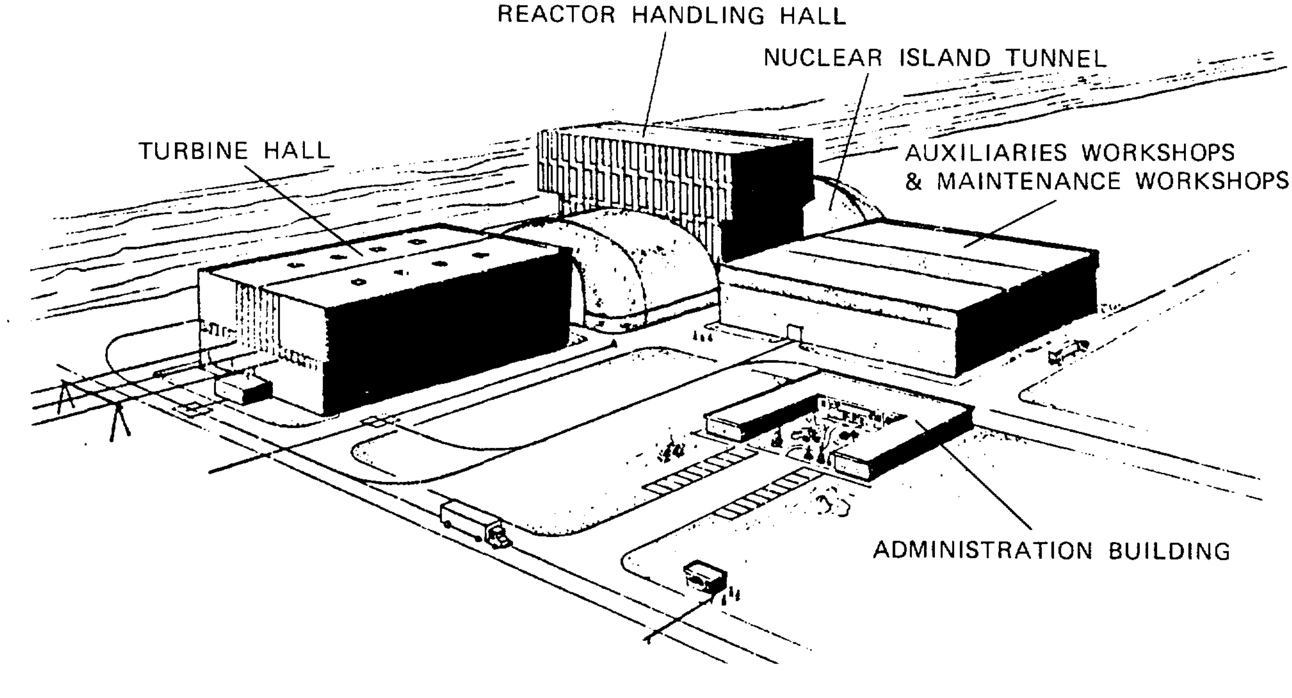


PRIMARY EQUIPMENT



ARRANGEMENT OF THE CONTAINMENT VESSEL

1 - Reactor vessel
2 - Steam generator
3 - Pressurizer
4 - Fuel loading machine
5 - Transfert fuel pool
6 - Residual heat removal pumps room
7 - Primary pumps handling room
8 - Personnel air lock
9 - Equipment hatch



A.I.2.2 BASIC DATA

SUPPLIER:	FRAMATOME TECHNICATOME	Proposed Plant	Reference Plant
Reactor Type: PWR			
Design Name:		NP 300	None
Core Power (MW(th))		950	
Net Output (MW(e))		300	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	3.350	
	Length (m)	8.990	
No. of Fuel Channels/Assemblies*		97	
Moderator:	medium	H_2O	
	pressure (MPa)	15.5	
	temp. (°C)	312/278	
Primary System:	medium	H_2O	
	pressure (MPa)	15.5	
	temp. (°C)	312/278	
	loops	2	
	steam generators	2	
	pumps	2	
Fuel:	enrichment (%)	4%	
	assembly length (m)	2.43 (active length)	
	assembly width/ diam.(m)	0.214	
	No. of fuel elements (rods)/assembly	289	
	mass of fuel in core(t)	29.5	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	5.3	
	temp. (°C)	293	

* underline relevant one

A.I.2.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: FRAMATOME (France)

CONCEPT: NP 300, PWR (CAS) 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: None

PROTOTYPE PLANT: CAP 140 MW(th) at Cadarache Research Centre

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

NP 300 is a PWR of the French "CAS" type with 9 years of reactor operating experience on the prototype at Cadarache Research Centre.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Two years to submit an offer

STATUS OF DESIGN DEVELOPMENT: General design is defined. Detail design studies in progress.

STATUS OF REGULATORY REVIEW:

Not yet licensed. Reactor is under design review.

A.I.3 BBC/HRB High-Temperature Reactor

A.I.3.1 Design Summary

The BBC/HRB group has been engaged in the design, construction and commissioning of high-temperature reactors (HTR) with spherical fuel elements for more than 25 years. The first German HTR project was the AVR experimental pebble bed reactor in Jülich, designed for a power output of 15 MWe. This experimental reactor has been in operation for more than 17 years. The second HTR in Germany, the THTR-300, located at Uentrop/Schmehausen, has been based on this experience and will go into commercial operation in 1985.

In a pebble-bed reactor the nuclear heat source consists of a loose bed of spherical graphite fuel elements. The fuel elements are continuously added during operation and discharged from the reactor after having passed through the reactor core. The THTR fuel elements are of the size of tennis balls. They contain high or low enriched uranium inside coated particles. Because of the multiple coating and the additional retaining properties of the graphite matrix and shell, hardly any radioactive contamination is released to the coolant gas.

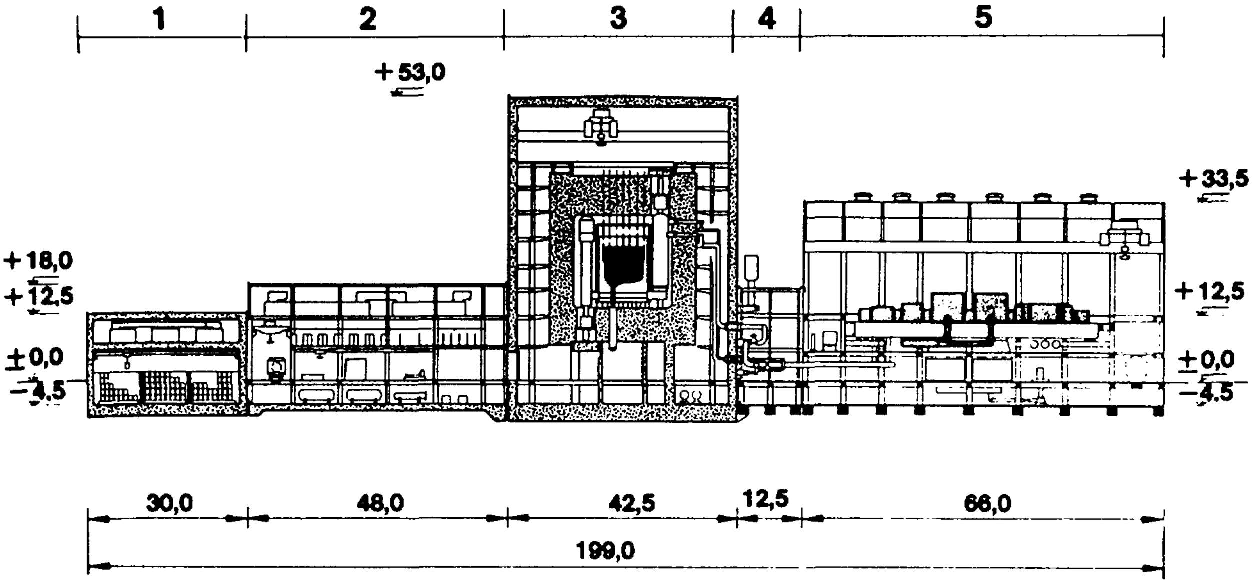
Following are some of the characteristics of the HTR which have already been verified during the operation of the AVR.

- High inherent safety, experimentally verified by simulating serious accidents.
- Possibility of achieving high gas temperatures up to 950°C (normally 750°C) in continuous operation. The AVR has been operated for five years in this condition.
- Low radiation exposure to operating and maintenance personnel.
- High plant efficiency (39 to 40%) and hence lower thermal discharges.

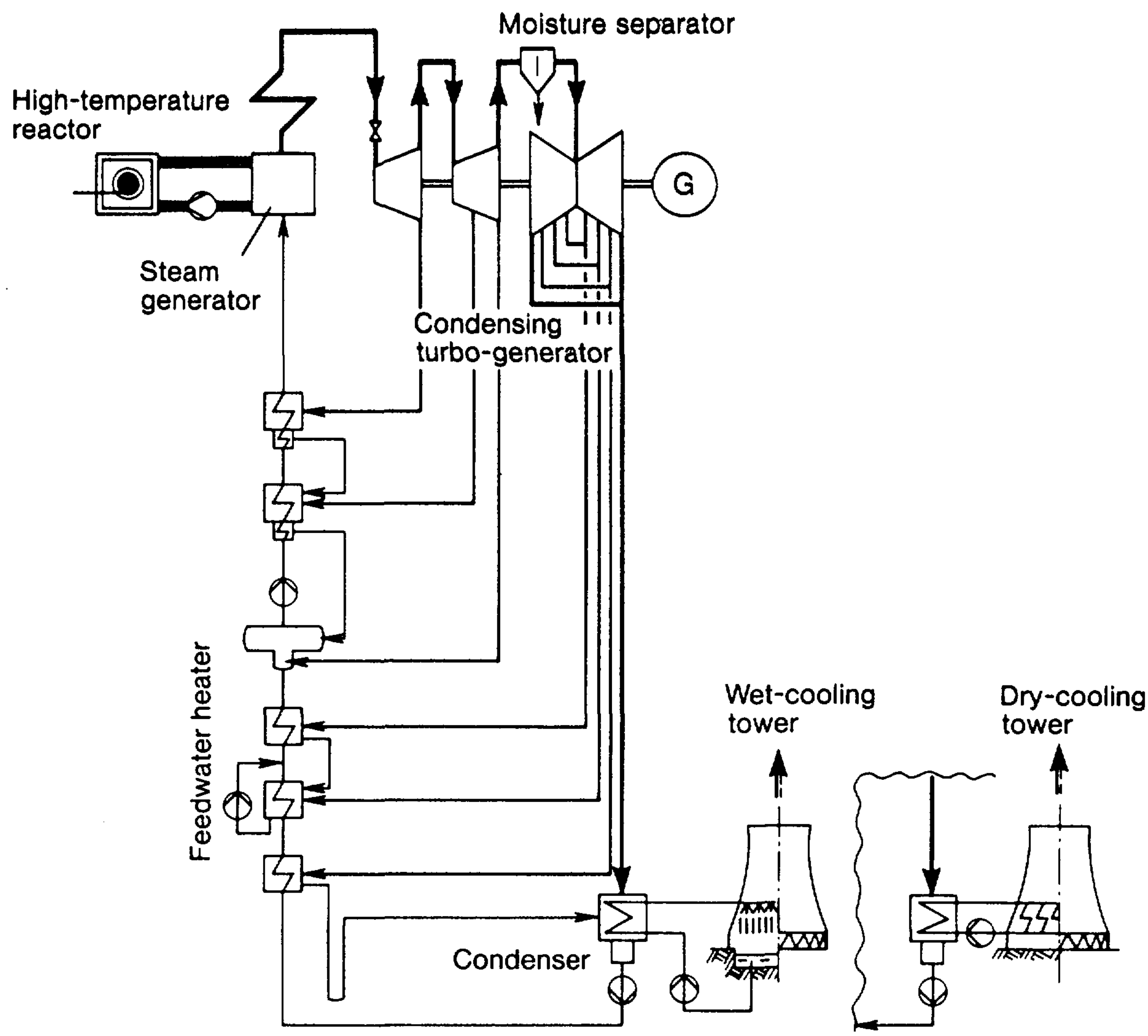
Some of the safety aspects of the HTR are:

- The low power density and high heat capacity of the core result in slow transient responses of the reactor in the case of an accident. This makes the HTR insensitive e.g. to a loss of coolant accident.
- Owing to the use of ceramic materials for the core a melt-down of core and subsequent release of radioactive materials is excluded.
- The negative temperature coefficient of reactivity causes a decrease of neutron production in the reactor with increasing temperatures. It thus guarantees an inherent safety mechanism in the system.

BBC/HRB offer the standardized power plants HTR-100, HTR-300 and HTR-500 equipped with High-Temperature Reactors of 100, 300 and 500 MW of electrical power for a number of applications in the electrical and overall thermal energy markets. All HTRs can also be supplied as twin plants.



1 Spent fuel building
2 Reactor auxiliary building
3 Reactor building
4 Valves building
5 Turbine hall



A.I.3.2 BASIC DATA

SUPPLIER: BBC/HRB		Proposed Plant	Reference Plant
Reactor Type: HTGR			
Design Name:		HTR 100	None
Core Power (MW(th))		256	
Net Output (MW(e))		100	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	6.1	
	Length (m)	29.8	
No. of Fuel Channels/Assemblies*		not applicable	
Moderator:	medium	graphite	
	pressure (MPa)	not applicable	
	temp. (°C)	670	
Primary System:	medium	Helium	
	pressure (MPa)	7.0	
	temp. (°C)	700	
	loops	3	
	steam generators	3	
	circulators	3	
Fuel:	enrichment (%)	6-9	
	fuel element diameter (m)	0.06	
	assembly width/ diam. (m)	not applicable	
	No. of fuel elements (rods)/assembly	not applicable	
	mass of fuel in core(t)	1.2	
Refuelling:	ON/OFF-LOAD	ON	
Secondary System:	pressure (MPa)	19	
	temp. (°C)	530	

* underline relevant one

A.I.3.2 (cont.) BASIC DATA

SUPPLIER: BBC/HRB		Proposed Plant	Reference Plant
Reactor Type: HTGR			
Design Name:		HTR 300	THTR 300 Hamm Uentrop
Core Power (MW(th))		760	750
Net Output (MW(e))		300	300
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	23.0	15.9
	Length (m)	27.2	15.3
No. of Fuel Channels/Assemblies*		not applicable	
Moderator:	medium	graphite	graphite
	pressure (MPa)	not applicable	
	temp. (°C)	670	?
Primary System:	medium	helium	helium
	pressure (MPa)	5.5	3.9
	temp. (°C)	700	750
	loops	6	6
	steam generators	6	6
	circulators	6	6
Fuel:	enrichment (%)	5-9	?
	fuel element diameter (m)	0.06	0.06
	assembly width/ diam.(m)	not applicable	
	No. of fuel elements (rods)/assembly	not applicable	
	mass of fuel in core(t)	3.5	?
Refuelling:	ON/OFF-LOAD	ON	ON
Secondary System:	pressure (MPa)	19	17.75
	temp. (°C)	530	530

* underline relevant one

A.I.3.2 (cont.) BASIC DATA

SUPPLIER: BBC/HRB		Proposed Plant	Reference Plant
Reactor Type: HTGR			
Design Name:		HTR 500	THTR 300 Hamm Uentrop
Core Power (MW(th))		1264	750
Net Output (MW(e))		500	300
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	25.0	15.9
	Length (m)	31.0	15.3
No. of Fuel Channels/ Assemblies*		not applicable	
Moderator:	medium	graphite	graphite
	pressure (MPa)	not applicable	
	temp. (°C)	670	?
Primary System:	medium	helium	helium
	pressure (MPa)	5.5	3.9
	temp. (°C)	700	750
	loops	8	6
	steam generators	8	6
	circulators	8	6
Fuel:	enrichment (%)	5-9	?
	fuel element diameter (m)	0.06	0.06
	assembly width/ diam.(m)	not applicable	
	No. of fuel elements (rods)/assembly	not applicable	
	mass of fuel in core(t)	5.9	?
Refuelling:	ON/OFF-LOAD	ON	ON
Secondary System:	pressure (MPa)	19	17.75
	temp. (°C)	530	530

* underline relevant one

A.I.3.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: BBC/HRB (F. R. Germany)

CONCEPT: HTR 100; 100 MW(e)

A. PROVENNESS

REFERENCE PLANT: None

PROTOTYPE PLANT: AVR Jülich; 15 MW(e)

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The HTR has accumulated 17 reactor years of experience on an experimental reactor (AVR Jülich) with an average load factor of 64.0% until the end of 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design complete

STATUS OF REGULATORY REVIEW:

Status not mentioned.

A.I.3.3 (cont.) PROVENNESS AND SUPPLIER'S READINESS

VENDOR: BBC/HRB (F. R. Germany)

CONCEPT: HTR 300; 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: THTR 300; 300 MW(e)

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The HTR has accumulated 17 reactor years of experience on an experimental reactor (AVR Jülich) with an average load factor of 64.0%. The THTR 300 (reference plant) is under commissioning and is expected to be in commercial operation in 1985.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design complete

STATUS OF REGULATORY REVIEW:

Status not mentioned.

A.I.3.3 (cont.) PROVENNESS AND SUPPLIER'S READINESS

VENDOR: BBC/HRB (F. R. Germany)

CONCEPT: HTR 500; 500 MW(e)

A. PROVENNESS

REFERENCE PLANT: THTR 300; 300 MW(e)

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The HTR has accumulated 17 reactor years of experience on an experimental reactor (AVR Jülich) with an average load factor of 64.0% until the end of 1983. The THTR 300 (reference plant) is under commissioning and is expected to be in commercial operation in 1985.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design complete

STATUS OF REGULATORY REVIEW:

Not yet licensed. An SAR is planned for the end of 1986.

A.I.4 INTERATOM HTR-Module-80

A.I.4.1 Design Summary

The HTR-Module-concept is based on the idea of combining small standardized units to form plants of a wide range of thermal ratings. The reactor follows basically the German line of HTR development and uses the well-known "pebble-bed" reactor of AVR-Jülich as reference plant.

A module has a power rating of 170 MW(th) at 950°C helium outlet temperature for process heat applications, while for electricity production or coproduction of electricity and process steam or district heating a rating of 200 MW(th) at an exit temperature of 700 °C is achieved. For reasons of economics and demand, plant sizes of 8 units appear to be an upper limit. Additionally the modular HTR as a small and inherent safe reactor system fullfil the criterion for the design of an autarc barge-mounted energy station in an optimum way.

Core and core internals of the HTR-Module are placed in a ferritic pressure vessel, the steam generator or - for advanced applications - an intermediate He/He-heat exchanger or a steam reformer unit is housed in a separate one.

Reactor and steam generator are connected by a coaxial duct which is enclosed in a pressure shell. Cold helium under high pressure flows in the outer annulus, so the pressure vessel is never subjected to any impermissible temperature loads. The "two vessel side-by-side" arrangement has advantages with regard to accessibility, adaptability, repairability, easy maintenance and low radiation dose during routine operation inspection and replacement of components, which is easily achievable.

The helium coolant flows downwards through the core. On-load refuelling is obligatory. The fuel pebbles are passing the core 15 times. Due to the limited core diameter no metallic structure is required to support the top graphite reflector, and the control/ absorber units can be installed within the radial reflector, acting by gravity. Each module can be operated and maintained separately. The modular HTR is designed for a low enriched Uran-fuel cycle and burn-up of up to 80 GWd/t can be achieved.

Some other important design and safety aspects of the HTR-module are:

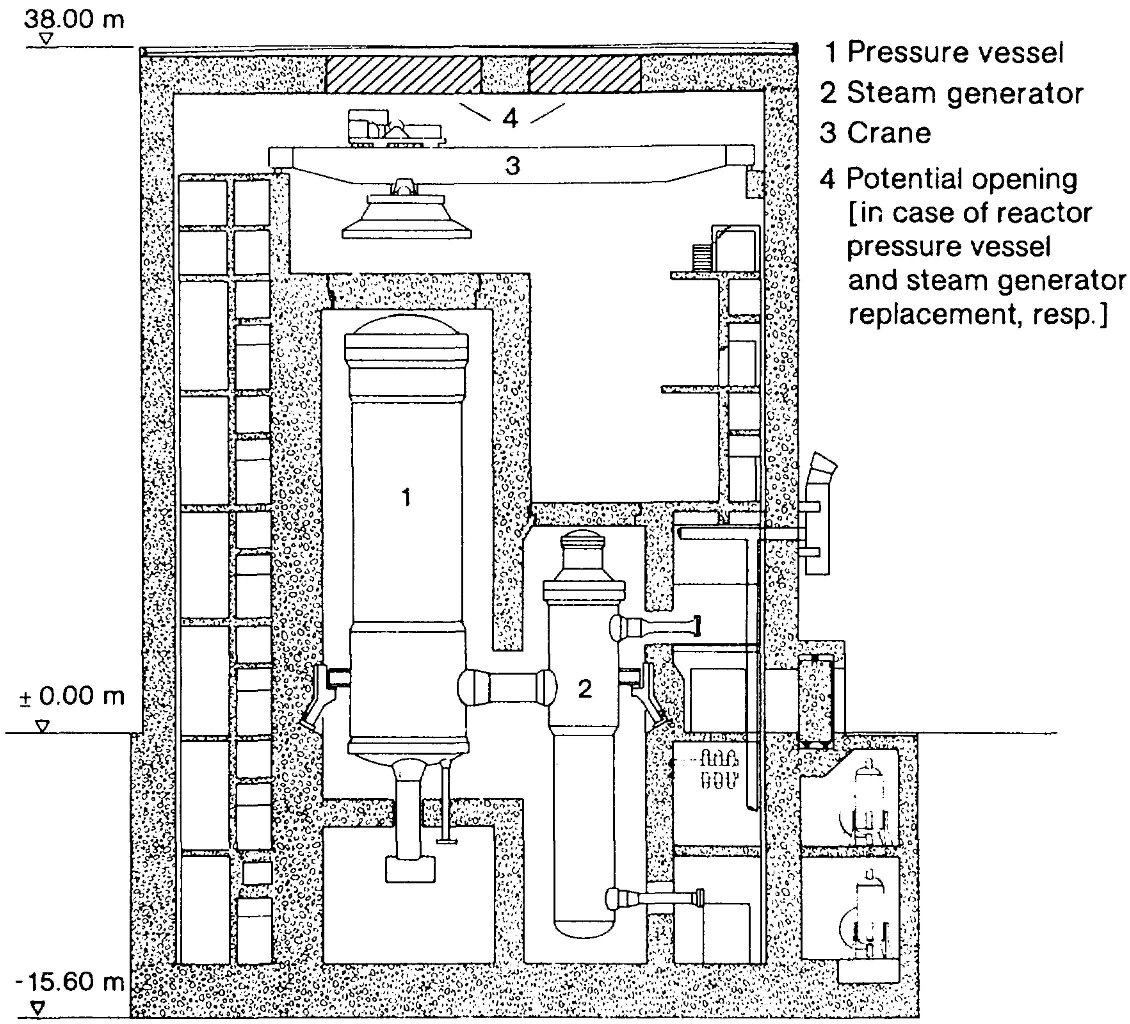
- Engineered safeguards and other safety measures must not be provided to prevent malfunctions and to confine the consequences of inadvertent operations or failures and external events to the containment. The reactor can be built near industrial and urban sites.

- Due to the 3 m core diameter and the low power density of 3 MW/m^3 no decay heat removal system is needed. The maximum fuel pebble temperature does not exceed about 1600 °C even under postulated severe accident conditions.

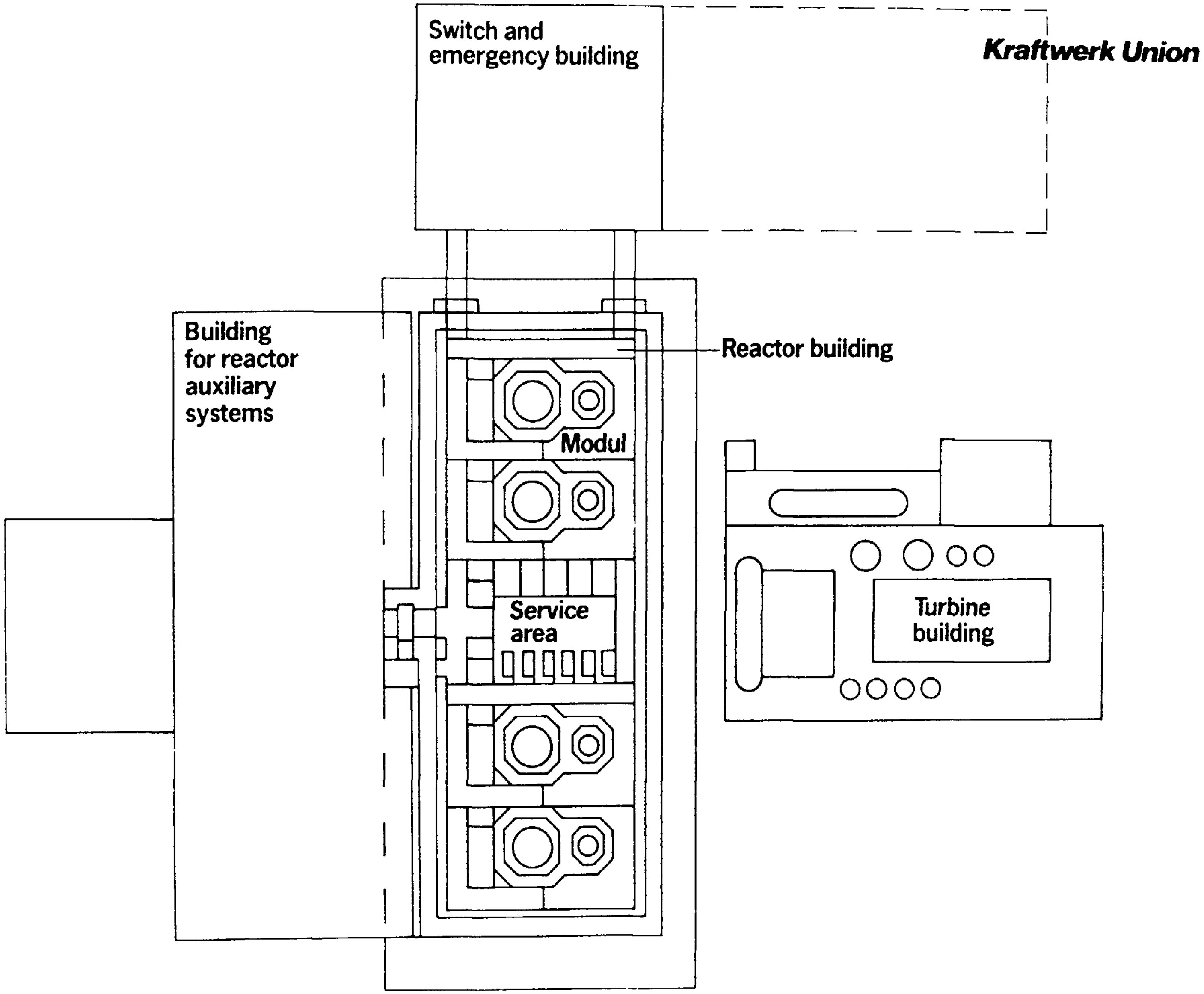
- In case of failure of the main heat removal system decay heat removal is achievable by conduction and radiation via radial reflector and pressure vessel to surface coolers installed around the pressure vessel. These surface coolers limits the temperatures of the pressure vessel and the concrete structure.

- Reactivity excursions are limited by utilization of the negative temperature coefficient.

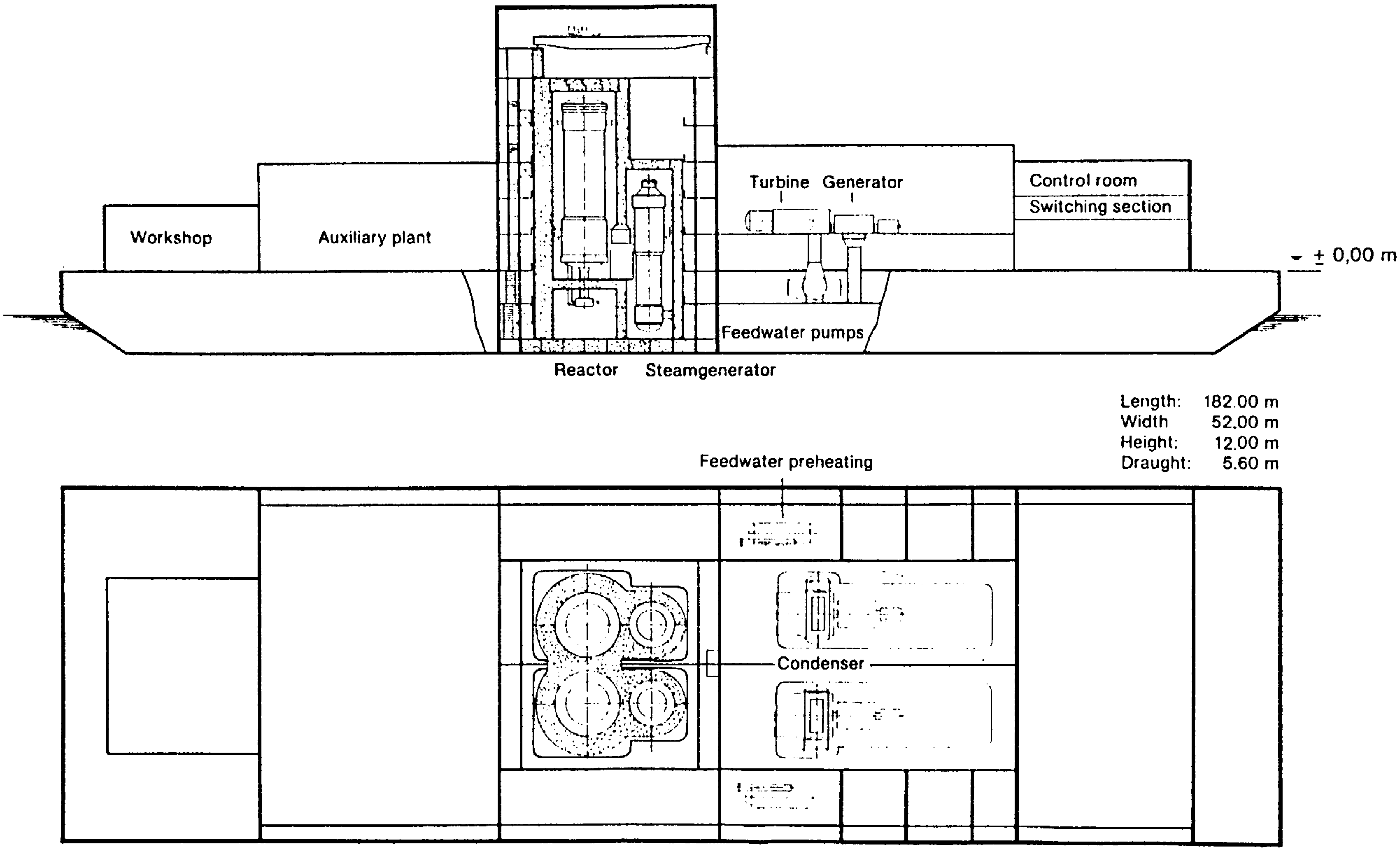
- In limiting the accident temperatures within the fuel below 1600 °C (see above) only a negligible release of fission products occur. So the radiation doses in the environment of the reactor lie significantly under the low accident dose limits specified by the German Radiation Protection Ordinance. There is no need for a gas tight reactor building, no filter system has to be provided for retention of radioactivity, unfiltered ground release is permissible during all accidents, should they happen.



Cross section of the Modular HTR reactor building [as per 1/85]



General Plan of the HTR-4-Module



Overall view - HTR-2- Module on barge [as per 12/84]

A.I.4.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: INTERATOM			
Reactor Type: HTGR			
Design Name:		HTR Module	None
Core Power (MW(th))		200	
Net Output (MW(e))		80	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	5.9	
	Length (m)	25	
No. of Fuel Channels/Assemblies*		not applicable	
Moderator:	medium	graphite	
	pressure (MPa)	-	
	temp. (°C)	-	
Primary System:	medium	helium	
	pressure (MPa)	0.6	
	temp. (°C)	700	
	loops	1	
	steam generators	1	
	pumps	1	
Fuel:	enrichment (%)	7.8	
	assembly length (m)	-	
	pebble diam.(m)	0.06	
	No. of fuel pebbles	360 000	
	mass of fuel in core(t)	0.2	
Refuelling:	ON/OFF-LOAD	ON	
Secondary System:	pressure (MPa)	19	
	temp. (°C)	530	

* underline relevant one

A.I.4.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: INTERATOM (F. R. Germany)

CONCEPT: HTR 80; 80 MW(e) (Module unit grouped in the range of two to eight units)

A. PROVENNESS

REFERENCE PLANT: Not applicable

PROTOTYPE PLANT:
1. AVR Juelich; 15 MW(e) experimental reactor
2. THTR 300 for some components

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The HTR line started with the experimental reactor, AVR in Jülich, which is successfully in operation for 17 years with an average load factor of 64%. A larger plant, THTR-300 is in commissioning and is expected to go into commercial operation 1985. The technology for both plant designed and built by BBC/HRB, is available to Interatom via a license agreement.

The INTERATOM design of modular HTR also benefits from KWU's extensive experience in the construction of LWR's. The pressure vessels used for HTR-modules e.g. are fabricated from ferritic steel like the pressure vessels for KWU's LWR. INTERATOM itself has constructed SMPR's like an integrated pressurized water reactor (38 MWth, equal to 10000 shaft horse power) for the nuclear powered ship "Otto Hahn". KNK-II a sodium cooled fast reactor (20 MW(e)), in operation at the Kernforschungszentrum Karlsruhe (FRG) and the sodium cooled fast breeder reactor SNR-300 (300 MW(e)), still under commissioning, going to full power operation at Kalkar (FRG) in 1986.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Conceptual design complete

STATUS OF REGULATORY REVIEW:

Not yet licensed. SAR will be available at the end of 1986.

A.I.5 The KWU PHWR-300

A.I.5.1 Design Summary

The PHWR 300 of KWU is a pressurized heavy water reactor of the pressure vessel type with the following main characteristics:

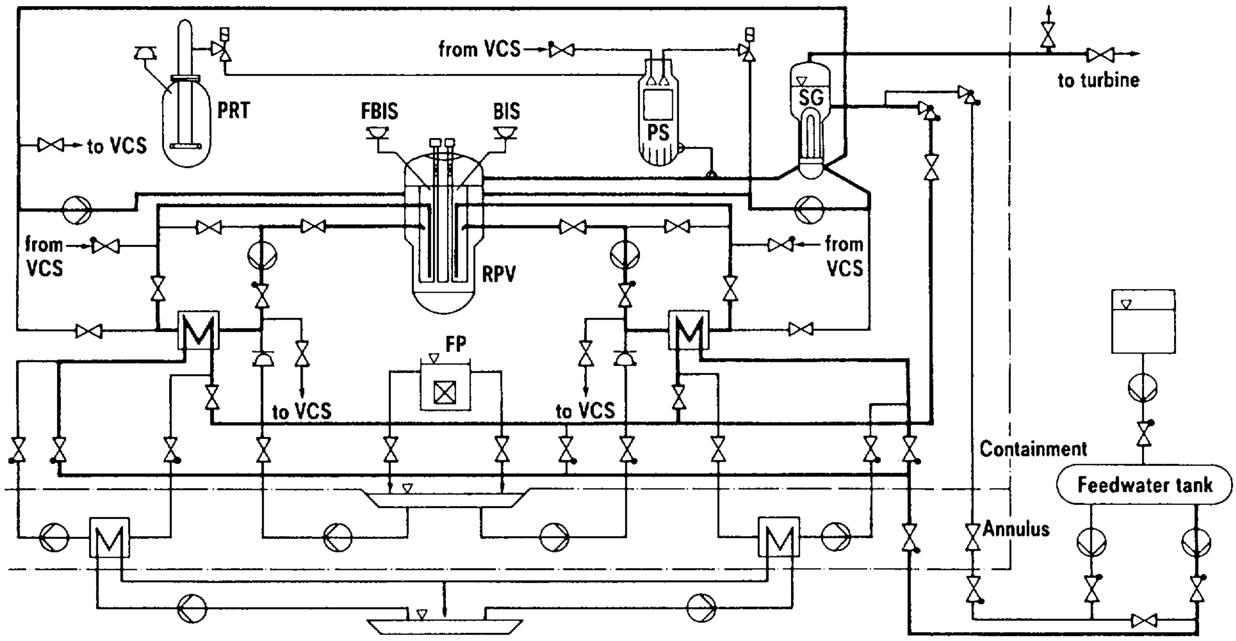
- Use of light water reactor technology, especially of KWU's PWR technology, to the maximum extent
- Use of well-proven special heavy-water equipment and systems from the heavy-water reactor power plants MZFR (multi-purpose-research reactor, Karlsruhe, FRG, 58 MW) and Atucha I (Argentina, 367 MW(e)).

The plant is designed for on-load refuelling. The fuel is natural uranium. However, there are several options for alternative fuel cycles which improve the economy of the plant, e.g. slightly enriched uranium up to 1.2% enrichment, recycling of plutonium in the form of spiked-fuel elements or homogeneous mixed oxide fuel, tandem operation together with light water reactors etc.).

The reference plant is Atucha I (CNAI) which has achieved an availability of 83% over 10 years of commercial operation. The main design features are briefly summarized in the following:

- Special emphasis in the design approach to make the plant more suitable for weaker grids and to decrease the specific installation cost to a value at which this size of nuclear power plant can compete economically with other energy sources.
- The main coolant system (see Fig. 1) has only one coolant loop with one steam generator and two main coolant pumps instead of two loops used in CNAI.
- In place of two separate spent fuel pit buildings used in CNAI for intermediate storage of spent fuel, a single storage pit is provided inside the containment (Fig. 2). Due to a compact storage system, the capacity is enough for 40 years of operation. This concept allows development of the final spent fuel disposal strategy in parallel with commercial plant operation.
- In the CNAI design, the maximum credible accident is assumed to be a double-ended pipe rupture. Advanced design concepts used for PHWR 300 emphasize the high quality and reliability of piping systems, so that double-ended pipe ruptures are most unlikely to happen and therefore do not have to be considered in the design of safety-related systems. This philosophy leads to greater safety because, with less required piping supports and restraints, access to the systems for maintenance and inservice inspection is improved considerably, thus decreasing the occupational radiation dose for the personnel.
- Hydraulically driven control rods. A newly developed control rod concept allows better control of power distribution over the core, thus achieving high load flexibility for the plant. Together with the design of emergency power equipment for a self-powered start-up independently of an external grid, the PHWR-300 is well suited for weak grids even with low capacity.
- Layout (see Fig. 3). The layout considers good accessibility to the several buildings for construction in order to achieve short construction periods, resulting in low interests during construction time.

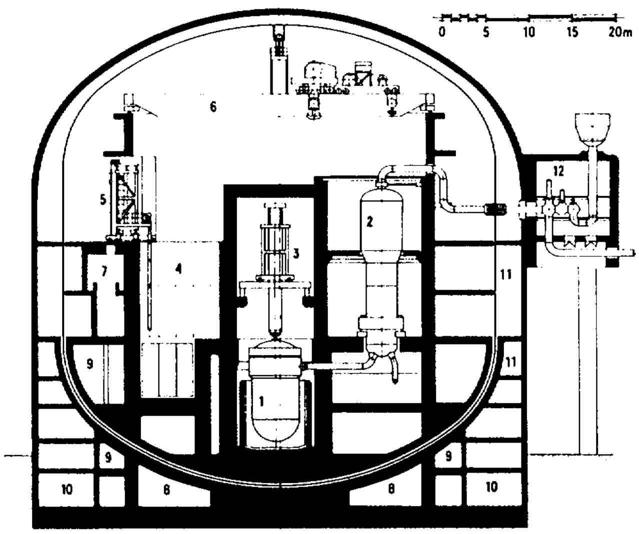
The safety concept, in principle, is derived from the PWR technology, considering the special features of heavy water reactors. The high safety level is documented by a preliminary risk study.



RPV Reactor pressure vessel
PS Pressurizer
SG Steam generator
PRT Pressurizer relief tank
FP Fuel pool
VCS Volume control system
FBIS Fast boron injection system

Primary System and Safety Related Systems
Normal Operation

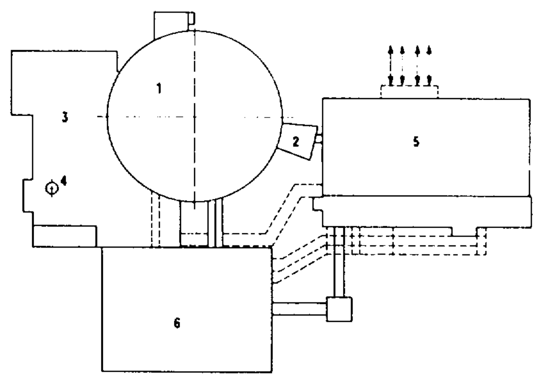
Fig. 1



1 Reactor pressure vessel
2 Steam generator
3 Refueling machine
4 Spent fuel pool
5 Manipulating bridge
6 Reactor building crane
7 New fuel store
8 Safety injection pump
9 Pipe duct
10 Residual heat removal pump
11 Cable spreading room
12 Main steam valve compartment

Reactor Building
Cross-Section

Fig. 2



1 Reactor building
2 Main steam valve compartment
3 Reactor auxiliary building
4 Vent stack
5 Turbine building
6 Switchgear and emergency supply building

Arrangement of
Main Buildings

Fig. 3

A.I.5.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: KWU			
Reactor Type: PHWR			
Design Name:		PHWR 300	ATUCHA I
Core Power (MW(th))		875	1179
Net Output (MW(e))		275	367
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	5	5.4
	Length (m)	12	12
No. of Fuel Channels/Assemblies*		189	253
Moderator:	medium	D_2O	D_2O
	pressure (MPa)	11.5	11.5
	temp. (°C) average	162	185
Primary System:	medium	D_2O	D_2O
	pressure (MPa)	11.5	11.5
	temp. (°C) outlet	313	296
	loops	1	2
	steam generators	1	2
	pumps	2	2
Fuel:	enrichment (%)	natural	natural
	assembly length (m)	5.3	5.3
	assembly width/ diam.(m)	0.108	0.108
	No. of fuel (rods)/assembly	37	37
	mass of fuel in core(t)	35.8	38.6
Refuelling:	ON/OFF-LOAD	ON	ON
Secondary System:	pressure (MPa)	5.6	4.4
	temp. (°C)	270	255

* underline relevant one

A.I.5.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: KWU (F. R. Germany)

CONCEPT: PHWR 300; 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: ATUCHA-I, 357 MW(e)

PROTOTYPE PLANT: Not Applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

KWU PHWR plants have accumulated 30 reactor years of experience. MZFR (PHWR) has accumulated load factor of 62.6% until the end of 1983. ATUCHA-I is connected to the grid since 1974-06. It has accumulated 9 years of reactor years with a cumulative load factor of 78.4% until the end of 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design almost complete

STATUS OF REGULATORY REVIEW:

Not yet licensed. Reference plant licensed and operating. A SAR will be available only on request of an interested client.

A.I.6 ANSALDO-NIRA PWR-300

A.I.6.1 Design Summary

The 300 MW(e) pressurized water reactor of ANSALDO-NIRA is based on WESTINGHOUSE design and uses the "Enrico Fermi" nuclear power plant sited at Trino Vercelese in Italy as reference plant.

The Trino plant of 272 MW(e) started (first criticality) in June 1964. From June 1979 to April 1984 the plant was shut down in order to implement an extensive upgrading of the safety related systems, both fluid and electrical. The plant safety was assessed against the recent acceptance criteria and post-TMI requirements. The plant restarted in April 1984 and now (time of the IAEA questionnaire answer) is operating at full power with a reactor availability factor, within the eight cycles, of 99.9 percent.

For a 300 MW(e) power plant ANSALDO can provide a large share of supply as reactor assembly, power channel, fuel handling machine, reactor vessel, steam generators, turbine/generator group.

A.I.6.2 BASIC DATA

SUPPLIER: ANSALDO-NIRA		Proposed Plant	Reference Plant
Reactor Type: PWR			
Design Name:		272 MW(e)	TRINO VERCELESE
Core Power (MW(th))		870	870
Net Output (MW(e))		272	272
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	3.200	3.200
	Length (m)	11.300	11.300
No. of Fuel Channels/Assemblies*		112	112
Moderator:	medium	H_2O	H_2O
	pressure (MPa)	14.1	14.1
	temp. (^oC)	289	289
Primary System:	medium	H_2O	H_2O
	pressure (MPa)	14.1	14.1
	temp. (^oC)	289	289
	loops	4	4
	steam generators	4	4
	pumps	4	4

* underline relevant one

Fuel:	enrichment (%)	4.47	4.47
	assembly length (m)	2.640	2.640
	assembly width/ diam.(m)	0.2	0.2
	No. of fuel elements (rods)/assembly	208	208
	mass of fuel in core(t)	34.5	34.5
Refuelling:	ON/OFF-LOAD	OFF	OFF
Secondary System:	pressure (MPa)	3.25	3.25
	temp. (^{o}C)	237	237

A.I.6.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: ANSALDO - NIRA (Italy)

CONCEPT: PWR 300 (based on Westinghouse design); 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: Trino Vercelles; 272 MW(e)

PROTOTYPE PLANT: Not Applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The vendor has accumulated 19.0 reactor years of experience with a cumulative load factor of 48.0% until the end of 1983. All of their operating years of experience is on the reference plant.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Design complete

STATUS OF REGULATORY REVIEW:

Proposed plant not yet licensed. Reference plant licensed. FSAR for reference plant has been re-issued.

A.I.7 ANSALDO-NIRA - CIRENE 300 MW(e) Plant Description

A.I.7.1 Design Summary

CIRENE is a pressure tube heavy water reactor cooled by boiling light water. A 40 MW(e) demonstration plant is under construction at the Latina site. The completion of the plant is scheduled for 1985. The realization of the Latina plant is carried out jointly by ENEA (the National Commission for Nuclear and Alternative Energy Sources) and ENEL (the National Electricity Generating Board); NIRA is the main contractor for the nuclear island.

CIRENE Latina is a reactor concept which has been developed entirely in Italy and which is based on the following main features:

- reactor configuration: pressure tube;
- reactor moderator: heavy water at low pressure and temperature
- reactor fuel: natural and slightly enriched (1.15%) UO_2 in the form of 18 rod bundles;
- steam cycle: direct to turbine generator.

The short description of the CIRENE 300 MW(e) NPP is as follows:

The cylindrical stainless steel calandria of CIRENE contains the heavy water moderator/reflector, the reactivity control mechanism and 280 vertical fuel channel assemblies. The calandria is housed in a steel lined concrete vault filled with light water (for thermal shield).

Short fuel elements (50 cm long) are used, minimizing neutron flux distorsion problems and leading to assemblies light in weight and easy to handle. The assemblies are very similar to current CANDU-PHWR fuel elements; these are made of 36 rods.

Slightly subcooled water enters the reactor from the bottom; about 28% of the coolant is evaporated along the core length. From the top of the core the steam-water mixture flows to the steam drums where steam and water are separated. The water is pumped to the reactor inlet and the steam is sent directly to the turbine.

Feedwater is returned from the turbine system to the steam drum. The heat transport system consists of two functionally separated loops each one cooling half of the core. Each loop contains one steam drum and two circulating pumps.

Fuel is loaded into and out of the reactor on power, thus maintaining reactivity and power distribution and allowing a higher load factor.

The plant is provided with two independent shut down systems: the moderator dump and the liquid rods. Other safety systems are the containment and the emergency core cooling system.

Feasibility studies have been carried out to evaluate to feed a CIRENE type reactor with slightly enriched uranium (1.1%) and also on the use of CIRENE reactor for dual purpose plants - (desalination and electricity).

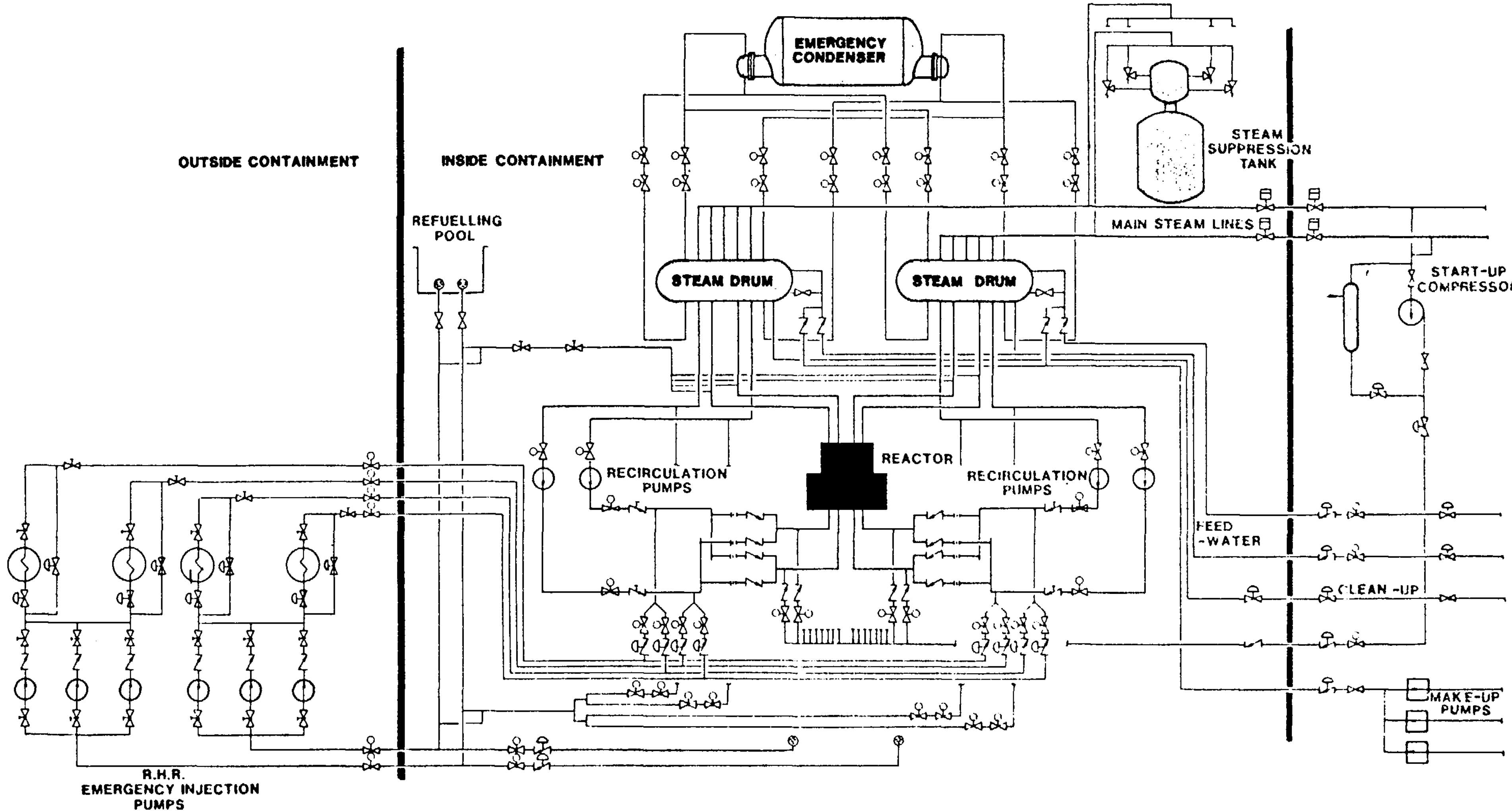


FIG. 1
300 MWe CIRENE NUCLEAR POWER PLANT
PRIMARY AND EMERGENCY
COOLANT SYSTEM FLOWSHEET

A.I.7.2 BASIC DATA

SUPPLIER: ANSALDO-NIRA		Proposed Plant	Reference Plant
Reactor Type: HWLWR			
Design Name:		CIRENE 300	CIRENE Latina
Core Power (MW(th))		1000	120
Net Output (MW(e))		300	40
Cycle:	Direct/Indirect	Direct	Direct
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	0.106	0.106
	Length (m)	0.400	4
No. of Fuel Channels/Assemblies*		280	60
Moderator:	medium	D_2O	D_2O
	pressure (MPa)	atmosph.	atmosph.
	temp. (°C)	60	60
Primary System:	medium	H_2O	H_2O
	pressure (MPa)	4.4	4.3
	temp. (°C)	258	255
	loops	2	1
	steam generators	-	-
	pumps	4	4
Fuel:	enrichment (%)	natural	1/1.15
	assembly length (m)	0.50	0.50
	assembly width/diam.(m)	0.105	0.105
	No. of fuel elements (rods)/assembly	36+1	18+1
	mass of fuel in core(t)	43	10.1
Refuelling:	ON/OFF-LOAD	ON	ON/OFF
Secondary System:	pressure (MPa)	4.4	4.3
	temp. (°C)	258	255

* underline relevant one

A.I.7.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: ANSALDO - NIRA (Italy)

CONCEPT: CIRENE - HWR - 300; 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: Refer to prototype plant

PROTOTYPE PLANT: CIRENE Latina Plant; 40 MW(e)

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

CIRENE Latina Plant is still under construction (60% complete) and plant commissioning will start early 1986.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Conceptual design stage completed

STATUS OF REGULATORY REVIEW:

Not yet licensed. FSAR for CIRENE Latina Plant will be completed by summer 1985.

A.I.8 Hitachi BWR 500

A.I.8.1 Design Summary: not provided

A.I.8.2 Basic Data: not provided

A.I.8.3 (see next page)

A.I.8.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Hitachi (Japan)

CONCEPT: BWR 500; 500 MW(e) (under G.E. license)

A. PROVENNESS

REFERENCE PLANT: Shimane Unit #1; 460 MW(e)

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

Hitachi has accumulated 14 reactor operating years of experience on BWR type reactors with an average load factor of 68.4% until 1983. Shimane I is in commercial operation since 1974-3 with cumulative load factor of 66.5% until 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Conceptual design complete

STATUS OF REGULATORY REVIEW: Not mentioned

A.I.9 Mitsubishi - PWR 300

A.I.9.1 Design Summary: not provided

A.I.9.2 Basic Data: not provided

A.I.9.3 (see next page)

A.I.9.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Mitsubishi (Japan)

CONCEPT: PWR (under Westinghouse design). Output of the proposed plant is not mentioned.

A. PROVENNESS

REFERENCE PLANT: MIHAMA #1; 340 MW(e)

PROTOTYPE PLANT:

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

Mitsubishi has accumulated 45 reactor years of experience on PWR type plants with a cumulative load factor of 65% until 1983. MIHAMA #1 is in commercial operation since 1970-11 with a cumulative load factor of 23.0% until 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately with Japanese specifications

STATUS OF DESIGN DEVELOPMENT: Elementary design stage. Answer to Q 2.6 is , "can be designable and constructed with Japanese specification."

STATUS OF REGULATORY REVIEW:

Not yet licensed. The regulatory body has not yet reviewed the elementary design.

A.I.10 Toshiba BWR 500

A.I.10.1 Design Summary: not provided

A.I.10.2 Basic Data: not provided

A.I.10.3 (see next page)

A.I.10.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Toshiba (Japan)

CONCEPT: BWR 500 (under G.E. license)

A. PROVENNESS

REFERENCE PLANT: 1. HAMAOKA I (R), 540 MW(e)
2. ONAGAWA I (R), 524 MW(e)

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

Toshiba has accumulated 25 reactor years of experience on BWR type plants with an average load factor of 60.9% until 1983. HAMAOKA I and ONAGAWA I are in commercial operation since 1974-08 and 1983-11 respectively. The cumulative load factor of HAMAOKA I is 53.4% until 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT:

Design is complete (based on Japanese specifications)

STATUS OF REGULATORY REVIEW:

Not yet licensed. The reference plants are licensed and operating.

A.I.11 Toshiba BWR 200/300

A.I.11.1 Design Summary: not provided

A.I.11.2 Basic Data: see next page

A.I.11.3 see next page

A.I.11.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: TOSHIBA			
Reactor Type: BWR			
Design Name:		BWR 200/300	Not mentioned
Core Power (MW(e))		700	
Net Output (MW(e))		200	
Cycle:	Direct/Indirect	Direct	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	4.7	
	Length (m)	20	
No. of Fuel Channels/Assemblies*		368	
Moderator:	medium	H_2O	
	pressure (MPa)	7	
	temp. (°C)	286	
Primary System:	medium	H_2O	
	pressure (MPa)	7	
	temp. (°C)	286	
	loops	n.a.	
	steam generators	n.a.	
	pumps	natural circulation	
Fuel:	enrichment (%)	3	
	assembly length (m)	3	
	assembly width/diam.(m)	-	
	No. of fuel elements (rods)/assembly	64	
	mass of fuel in core(t)	52	

* underline relevant one

Refuelling:	ON/OFF-LOAD	OFF
Secondary System:	pressure (MPa)	7
	temp. (^oC)	286

A.I.11.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Toshiba (Japan)

CONCEPT: BWR 200/300.

A. PROVENNESS

REFERENCE PLANT: Not Mentioned

PROTOTYPE PLANT: Not Mentioned

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

Toshiba has accumulated 25 reactor years of experience on BWR type plants with an average load factor of 60.9% until 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: No date mentioned

STATUS OF DESIGN DEVELOPMENT: Conceptual design stage

STATUS OF REGULATORY REVIEW:

Not yet licensed.

A.I.12 ASEA-ATOM - The SECURE P (PIUS) Design Summary

A.I.12.1 Design Summary

The SECURE reactor is basically a pool type PWR. The entire primary circuit, including the steam generator, is located inside a massive, leakproof, practically indestructible pressure vessel that contains a large pool of borated water.

This pool is kept cold and acts as the emergency core cooling water. It is kept separated from the primary circuit coolant - which has a low boric acid content - that moderates the fission reaction. The reaction is controlled by the concentration of boron in the primary circuit coolant.

The pressure vessel is a 65 m high concrete structure, prestressed with steel tendons and containing an embedded steel membrane. Inside the cavity is a stainless steel liner.

As designed, no conceivable event short of a direct hit by a nuclear weapon could penetrate both steel membranes and the concrete wall of the vessel to cause a leak that might uncover the core. Also, access to the core and the pool of water is from above, and there are no fittings in the walls of the vessel from which a large leak could erupt. The vessel is capped with a cover that transfers internal pressure to the overlying concrete and steel tendons that form a yoke. The cap is slid out to gain access to the pool and the core.

During normal operation the reactor core coolant outlet temperature is kept constant at 290^{o}C, the inlet temperature varies with the power level (260^{o}C at full power). The primary circuit coolant and the pool water are in direct contact below the core inlet plenum and at the top of the riser. The heated water from the core will rise up through the riser since its density is lower than the pool water density (the chimney effect), and the flow rate is determined by the temperature differences. By controlling the speed of the recirculation pump its flow is adjusted to the flow rate up through the riser to maintain the lower hot/cold interface at a constant position - no pool water will enter the primary circuit.

So, during normal operation the pump work accomplishes a balance between the heated primary circuit water column and the cold borated pool water column. In the event of major disturbances, e.g. loss of the recirculation pump function, the balancing force disappears and the cold water column "pushes" borated pool water into the core, and the fission reaction is stopped. With the reaction stopped, the borated pool of water is sufficiently large to remove the decay heat through natural convective currents and evaporation, and yet keep the core covered for about a week.

Apart from this automatic shutdown function which is an "ultimate safety" feature, there is a conventional protection system which initiates scram when operation limits are exceeded. Such scrams are performed by means of a scram valve, letting pool water in to the recirculation pump suction side. In addition, the reactor can be shut down by boron injection via the normal control system.

The steam generator is of once-through type with steam generation inside the tubes, and the steam generator penetrations, as well as other penetrations, are located in the upper part of the pressure vessel.

The control systems are based on redundant digital computers, utilizing central and local processors and remote multiplexing. Control room presentations take place via computer generated colour graphic displays.

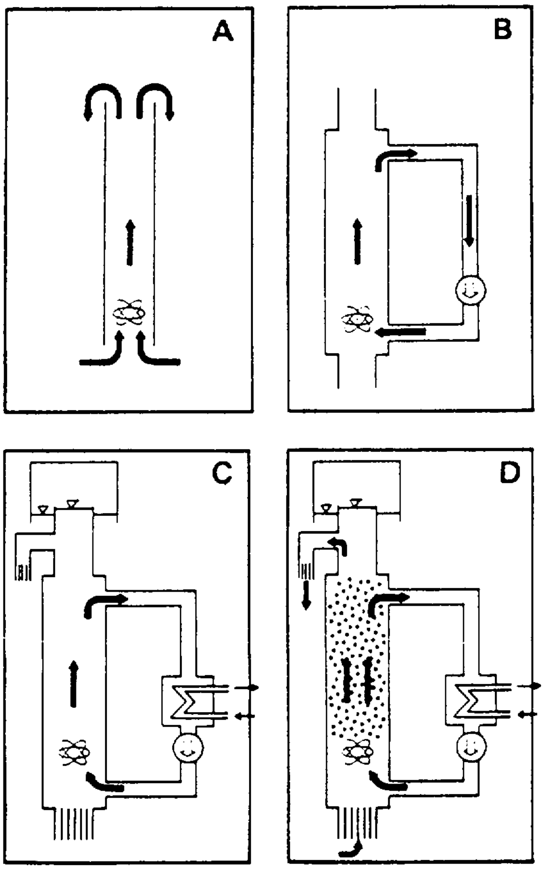
The recent design concept is based on a modular nuclear steam supply system - each module has a reactor core, steam generator and recirculation pump, with individual ancillary systems. The core thermal power of each module is 670 MW, corresponding to about 200 MW(e), and power plants of (200) - 400 - 600 - (800) MW(e) can be accomplished by using 1-4 modules in a common pressure vessel.

The modules will be standardized units, well adapted for shop fabrication in series. The concrete pressure vessel is constructed at site, of course, but the construction of the huge vessel is not considered to be any great problem, according to Swedish constructing companies. A total construction period of about 4.5 years can be achieved by optimized construction sequence and methods.

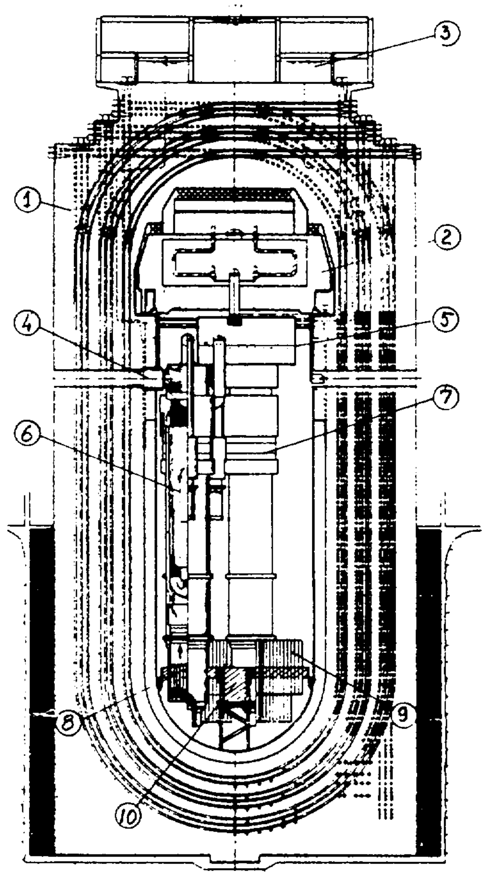
All systems that are important to safeguard plant safety, are protected by the concrete vessel. The rest of the plant can be built as a conventional fossil-fired plant.

PIUS – SECURE P

The operating principles of the
PIUS primary system

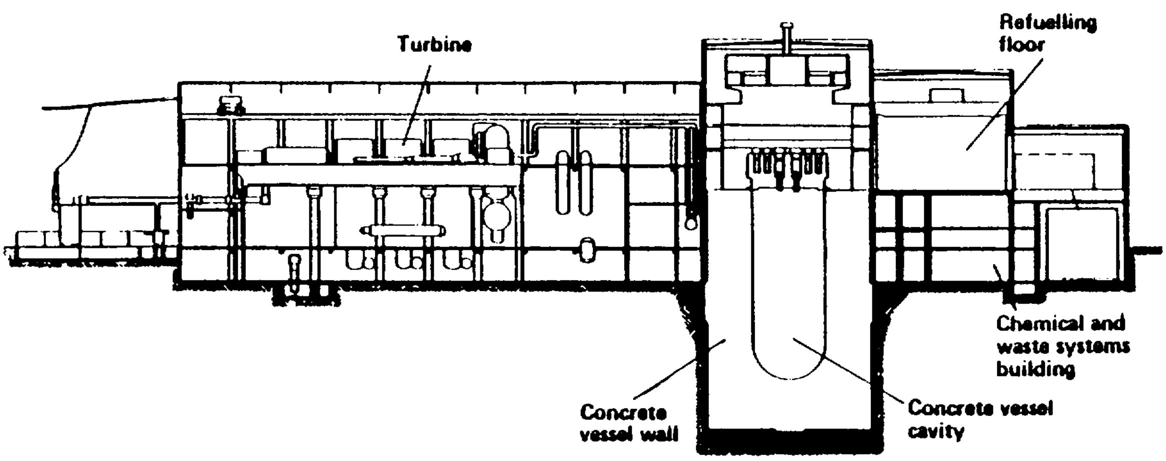


OVERALL ARRANGEMENT IN CONCRETE VESSEL



1	Reactor vessel	6	Reactor module 1
2	Reactor vessel cover	7	Reactor module 2
3	Water pools	8	Reactor core
4	Steam lines penetrations	9	Spent fuel racks
5	Pressurizer	10	Rotatable platform

Vertical section through single unit
500 MW(e) plant



A.I.12.2 BASIC DATA

SUPPLIER: ASEA-ATOM		Proposed Plant	Reference Plant
Reactor Type: PWR			
Design Name:		PIUS	None
Core Power (MW(th))		670	
Net Output (MW(e))		200	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	13.4	
	Length (m)	36	
No. of Fuel Channels/Assemblies*		89	
Moderator:	medium	H_2O	
	pressure (MPa)	9.0	
	temp. (^oC)	260-290	
Primary System:	medium	H_2O	
	pressure (MPa)	9.0	
	temp. (^oC)	260-290	
	loops	1	
	steam generators	1	
	pumps	1	
Fuel:	enrichment (%)	3.15	
	assembly length (m)	1.97	
	assembly width/diam.(m)	0.24 x 0.24	
	No. of fuel elements (rods)/assembly	232	
	mass of fuel in core(t)	31.3	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	4.0	
	temp. (^oC)	250	

* underline relevant one

A.I.12.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: ASEA-ATOM (Sweden)

CONCEPT: SECURE P (PIUS), (200) - 400 - 600 - (800) MW(e)

A. PROVENNESS

REFERENCE PLANT: The reactor concept is new, and there is no reference plant yet. Develop programs under way are related to the thermal-hydraulic functions, the hot/cold interface functions, the wet thermal insulation and the Once-Through Steam Generator design. References to plants in operation are valid for other systems and components, however.

PROTOTYPE PLANT: Some sort of prototype plant will be built at the end of this decade for integral testing and verification, probably as full scale module.

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT: Too early to be stated.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Scheduled for beginning of 1990s.

STATUS OF DESIGN DEVELOPMENT: Consolidation of conceptual design.

STATUS OF REGULATORY REVIEW: The concept is not yet licensed. Formal interactions with the USNRC have been initiated and design review meetings with the NRC Advanced Reactor Group commenced in 1984. The Draft Licensing Plan involves submittal of a PSID (Preliminary Safety Information Document) at the end of 1985 and proposes an NRC FDA (Final Design Approval) in 1992.

A.I.13 GEC Magnox, UK

p.m. no design summary, basic data, provenness and readiness provided

A.I.14 300 MW(e) MAGNOX Generating Units

A.I.14.1 Design Summary

The 300 MW(e) plant, proposed by the National Nuclear Corp. (NNC), UK, incorporates a natural uranium magnox reactor. The design is based upon that used for two magnox reactors at the Oldbury Station which have given continuous satisfactory service to the CEGB since they were commissioned in 1967. During 1980-81 the station achieved a load factor of 90.2% and the availability is now 90%.

With the Magnox reactor, the spent fuel leaving the reactor is of low value and there is no need for re-processing. On-site fuel storage is also cheap. A substantial fraction of local supply and manufacture in the construction can be foreseen, as the reactor incorporates no strategic materials and does not call for particularly sophisticated engineering techniques either at the manufacturer's works or on the site.

The plant is designed for on-load refuelling. Increasing the aluminium concentration in the uranium fuel rod to reduce the rate of swelling has permitted longer irradiation. An average discharge burnup of 5300 MWd/t without any limit on residence time in the reactor core is now achieved.

One significant feature of the reference plant which has now been proposed to be changed is the replacement of mild steel with 9% Cr. steel for the superheater and re-heater tubes and boiler casings. This will enable the operating temperature to be raised from 365°C to 400°C, resulting in an increase in unit electrical output from 208 MW to 300 MW.

The reactor has a pre-stressed concrete pressure vessel and several attractive safety features as well as other features to facilitate easier and quicker maintenance:

- The arrangement of the reactor core, boilers and gas circulators entirely within the pre-stressed concrete vessel ensures a high integrity boundary for the primary coolant flow.

- The graphite moderator helps to limit overheating during low coolant flow.

- There is no risk of explosive evaporation of the coolant or exothermic fuel clad/coolant interaction.

- Reactivity changes during refuelling and power changes are low.

- Low radioactivity of the coolant circuit shortens routine maintenance procedures.

- Internal shields allow access for visual inspection of much of the reactor, boiler and gas circulator structures.

On the basis of reference plant's experience, the estimated construction time for the first 300 MW(e) plant is five years. Training on the reference plant will be arranged by NNC for the operating staff of the buyer country.

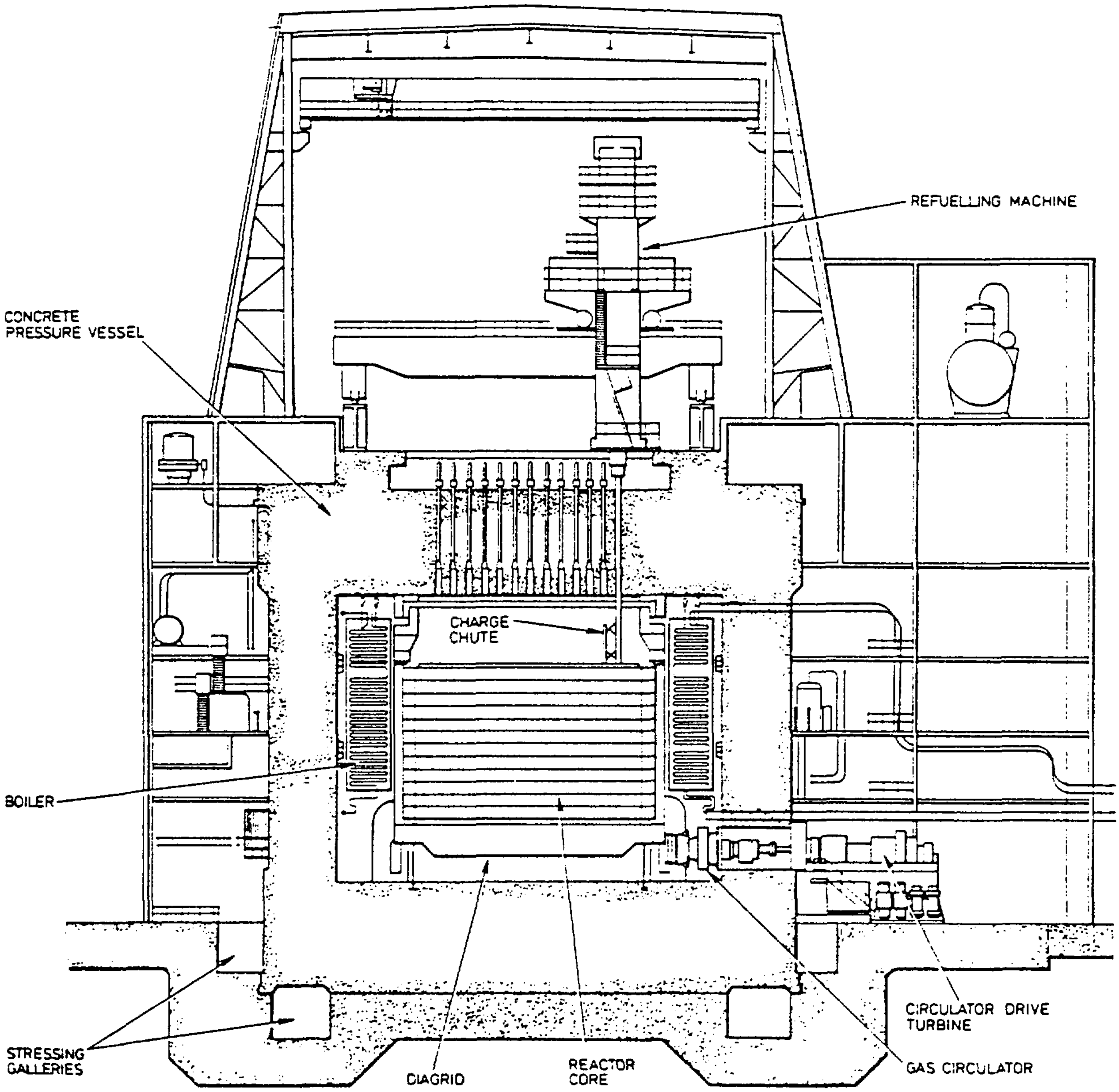


FIG. 1 REACTOR CROSS-SECTION

A.I.14.2 BASIC DATA

SUPPLIER: NNC		Proposed Plant	Reference Plant
Reactor Type: GCR			
Design Name:		MAGNOX 300	OLDBURY
Core Power (MW(th))		925	892
Net Output (MW(e))		300	300
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	24	23.5
	Length (m)	18.3	18.3
No. of Fuel Channels/Assemblies*		3308	3308
Moderator:	medium	graphite	graphite
	pressure (MPa)	-	-
	temp. (^{o}C)	-	-
Primary System:	medium	CO_2	CO_2
	pressure (MPa)	2.75	2.51
	temp. (^{o}C)	400	412
	loops	4	4
	steam generators	4	4
	pumps	4	4
Fuel:	enrichment (%)	natural	natural
	assembly length (m)	1	1
	assembly width/diam.(m)	0.028	0.028
	No. of fuel elements (rods)/channel	8	8
	mass of fuel in core(t)	293	293
Refuelling:	ON/OFF-LOAD	ON	ON
Secondary System:	pressure (MPa)	HP 8 LP 4	9.75 ?
	temp. (^{o}C)	HP 395 LP 390	393 ?

* underline relevant one

A.I.14.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: NNC (United Kingdom)

CONCEPT: MAGNOX 300, 300 MW(e)

A. PROVENNESS

REFERENCE PLANT: Oldbury on Seven, twin units of 300 MW(e) each

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

The MAGNOX plants have accumulated 432 reactor years of experience with an average load factor of 67.4% until the end of 1983. Oldbury on Seven (twin units) is connected to the grid since 1967-11 (combined 33 years). Cumulative load factor to the end of 1983 is 78.3%.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: More than conceptual stage

STATUS OF REGULATORY REVIEW:

Not yet licensed. Reference plant licensed and operating. In the U.K., regulatory review is only carried out for specific design for specific sites.

A.I.15 The Rolls-Royce 300 MW(e) Prefabricated Nuclear Plant

A.I.15.1 Design Summary

The Rolls-Royce prefabricated nuclear plant is a 300 MW power station mounted on two barges. The nuclear island is contained on one barge and the conventional plant on the other. Essentially the nuclear island consists of a compact 4-loop PWR using standard components and designed to meet UK safety criteria with appropriate equipment redundancy and diversity (Fig. 1). The reactor has been designed to take full advantage of PWR safety improvements since the Three Mile Island incident in 1979. Basic data are given in Table 1.

Reactor shutdown and engineered safety systems are initiated by two diverse reactor protecton systems with the safety systems arranged in four trains.

The reactor vessel design utilises the concept of ring forgings to minimise the number of welds required in manufacture, as is proposed for the Sizewell B PWR.

All major components including the steam generators are of a type that have proved to be highly reliable in service. Great care has been taken in the design to minimise the radiation dose to the operators during maintenance and in-service inspection.

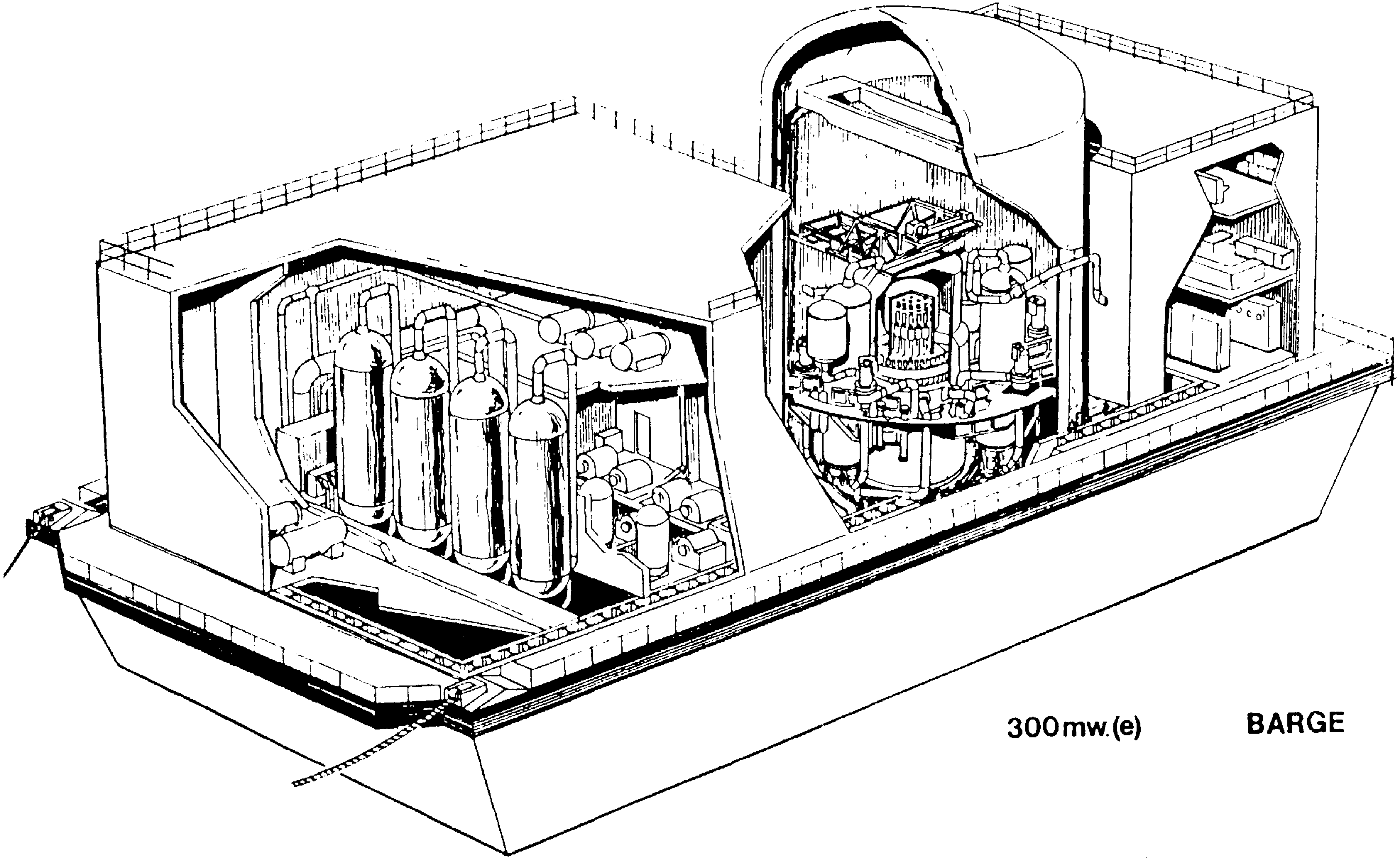
The reactor core consists of standard PWR rod bundle fuel as used in larger reactors.

The main concept of the plant is that it is prefabricated on the barges and shipped to the site. This reduces the work to be carried out at site to a minimum and permits the reduction in overall construction time. By mounting the plant on two barges the buyer has the option of building the conventional plant at a shipyard of his own choice, provided the plant meets the overall interface requirements specified by Rolls-Royce.

During installation the barges are taken to the site, which includes a large prepared dry dock or lagoon. After docking, the lagoon is emptied and the barges settle on prepared aseismic mountings. The installation is completed by connecting the steam supply from the nuclear barge to the conventional barge, connecting the previously prepared cooling water and main feedwater supplied to the barges, and making the main electrical connections to the customer's distribution systems. Core loading and final system testing then take place in the normal way.

Partial core refuelling takes place annually, and the nuclear barge contains the refuelling facilities and fuel storage pond. Any major maintenance is also scheduled for the annual shutdown.

The Rolls-Royce barge-mounted prefabricated plant, based on standard components and utilizing the long experience of Rolls-Royce in PWR engineering, provides the buyer with advantages in quality and scheduling of prefabrication, minimized site work and a degree of flexibility in final decommissioning of the plant.


300mw.(e)
BARGE

A.I.15.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: ROLLS-ROYCE			
Reactor Type: PWR			
Design Name:		Prefabricated 300 MW(e)	Not mentioned
Core Power (MW(th))		1025	
Net Output (MW(e))		300	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	3.5	
	Length (m)	9.2	
No. of Fuel Channels/Assemblies*		89	
Moderator:	medium	H_2O	
	pressure (MPa)	15.5	
	temp. (°C)	300	
Primary System:	medium	H_2O	
	pressure (MPa)	15.5	
	temp. (°C)	300	
	loops	4	
	steam generators	4	
	pumps	4	
Fuel:	enrichment (%)	3.3	
	assembly length (m)	3	
	assembly width/diam.(m)	0.215	
	No. of fuel elements (rods)/assembly	264	
	mass of fuel in core(t)	30	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	5.5	
	temp. (°C)	270	

* underline relevant one

A.I.15.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Rolls Royce (United Kingdom)

CONCEPT: Pre-fabricated barge mounted 300 MW(e) PWR

A. PROVENNESS

REFERENCE PLANT: Not mentioned

PROTOTYPE PLANT: Not mentioned

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

B. SUPPLIER'S READINESS

WHEN READY TO BID: Immediately

STATUS OF DESIGN DEVELOPMENT: Detail design level

STATUS OF REGULATORY REVIEW:

Not yet licensed. The design is under review in order to take into account the development in U.K. safety requirements since the initial design date of 1980.

A.I.16 B & W CNSG Plant Description

A.I.16.1 Design Summary

The Consolidated Nuclear Steam Generator (CNSG) is a small, integral design pressurized-water reactor developed by B&W from commercial nuclear ship propulsion designs. Table 1 lists major design parameters of the CNSG. In the CNSG (Figure 1), the core and steam generators are located inside the reactor vessel; the only external portion of the primary system is an electrically heated pressurizer and interconnecting piping. The reactor coolant system is integrated into the reactor vessel, twelve modular, once-through steam generators located in the vessel, four wet-rotor reactor coolant pumps mounted on the vessel in an annulus above and radially outside the core. The reactor coolant pumps are mounted on the reactor vessel head above the steam generators with their impellers and diffusers in the steam generator annulus. The reactor coolant is directed down through the steam generator tubes. The steam is generated on the shell side of the steam generator. The coolant continues down through the annulus below the steam generator to the bottom of the reactor vessel where it is turned upward through the core.

The CNSG has the following major features:

- Modular components to improve plant availability (i.e. 4 reactor coolant pumps, 12 steam generators, etc.)

- Elimination of large reactor coolant piping, reducing the number of supports and restraints, and reducing the impact of a LOCA. This permits the use of simplified safety systems and a smaller, less expensive containment.

- Wet-rotor reactor coolant pumps to eliminate the systems and maintenance associated with pump seals and lube oil systems.

- Compact plant arrangement permitting the entire plant to be mounted on a single barge.

- Shop fabrication of the entire plant if barge mounted, or all major components if land based (Figure 2).

- The 91 MW(e) capacity can fit into developing utility grids more easily minimizing the impact of a single plant outage.

- Proven fuel design.

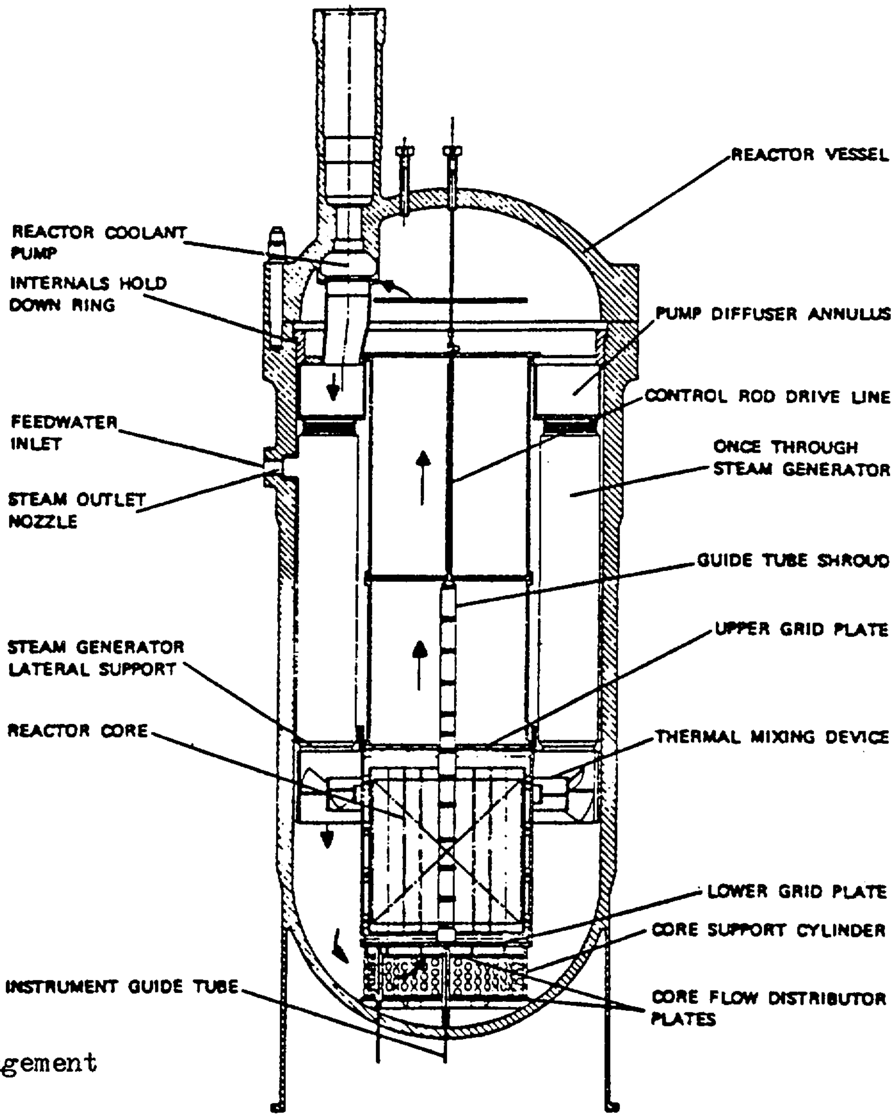


Figure 1. CNSG Arrangement

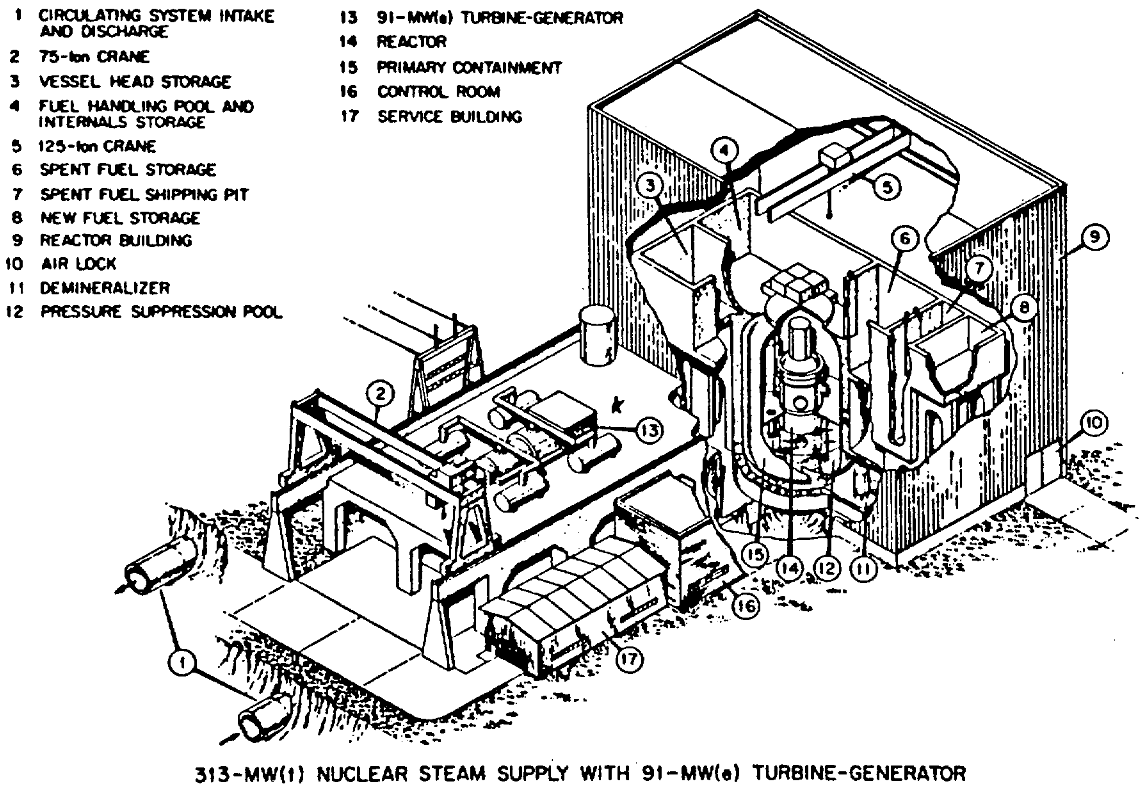


Figure 2. Land Based CNSG

A.I.16.2 BASIC DATA

SUPPLIER: BABCOCK & WILCOX		Proposed Plant	Reference Plant
Reactor Type: PWR			
Design Name:		CNSG	Not mentioned
Core Power (MW(th))		313	
Net Output (MW(e))		91	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	3.99	
	Length (m)	14.22	
No. of Fuel Channels/Assemblies*		57	
Moderator:	medium	H_2O	
	pressure (MPa)	15.8	
	temp. (°C)	318	
Primary System:	medium	H_2O	
	pressure (MPa)	15.8	
	temp. (°C)	318	
	loops	integrated	
	steam generators	12	
	pumps	4	
Fuel:	enrichment (%)	2-4	
	assembly length (m)	3.60	
	assembly width/diam.(m)	0.218	
	No. of fuel elements (rods)/assembly	264	
	mass of fuel in core(t)	11.94	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	4.8	
	temp. (°C)	281	

* underline relevant one

A.I.16.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: B & W (U.S.A.)

CONCEPT: Integral PWR CNSG

A. PROVENNESS

REFERENCE PLANT: Not mentioned

PROTOTYPE PLANT: Not mentioned

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

B & W has accumulated 65 reactor operating years of experience on PWR type plants in U.S.A. The cumulative load factor until 1983 is 55.0%.

B. SUPPLIER'S READINESS

WHEN READY TO BID: About ten (10) years

STATUS OF DESIGN DEVELOPMENT: Conceptual design stage

STATUS OF REGULATORY REVIEW:

Not yet licensed; neither is regulatory review planned.

A.I.17 B & W CNSS Plant Description

A.I.17.1 Design Summary

The 1255 MW(th)/400 MW(e) Consolidated Nuclear Steam System (CNSS) is an integral pressurized-water reactor (PWR) with the reactor core and steam generators located within the reactor pressure vessel (see Figure 1). Reactor coolant system pressure is controlled via an electrically heated pressurizer connected to the reactor vessel through four surge lines.

The CNSS integral reactor vessel is slightly larger than the vessel used for a large central station (1200 to 1300 MWe) PWR of current design. The CNSS has eight glandless, wet-rotor pumps mounted in the integral pump casings in the reactor vessel head. Ten straight-tube-and-shell steam generator modules are located in the annular region below the coolant pump discharge and above and exterior to the reactor core. Each module, with its own concentric nozzle for feedwater inlet and steam outlet, is bolted into an opening in the reactor vessel wall.

Because of its small size, the reactor containment structure is located within a reactor service building. The general layout of systems and equipment within the reactor service building is as shown in Figures 1,2, and 3 with critical reactor auxiliary equipment placed near the reactor. Radwaste systems and equipment are situated at one end of the reactor service building away from the reactor. Large, heavy equipment is placed on the bottom floor elevation, while lighter equipment is located on the upper elevations. The system layouts are based on past experience with central station plants.

The plant arrangement provides for surrounding the reactor vessel with the containment, the biological shiled, and the service (auxiliary) building. The additional protection provided by these multiple barriers prevents radioactivity from leaking directly to the atmosphere.

Specific Features of the CNSS

- Modular components to improve plant availability (8 reactor coolant pumps, 10 steam generators, etc.)

- Elimination of large reactor coolant piping, reducing the number of supports and restraints and reducing impact of a LOCA. This permits the use of simplified safety systems and a smaller, less expensive containment.

- Wet-rotor reactor coolant pumps are used to eliminate maintenance associated with pump seals and lube oil systems.

- Shop fabrication of major components including the reactor coolant system.

- Proven fuel design.

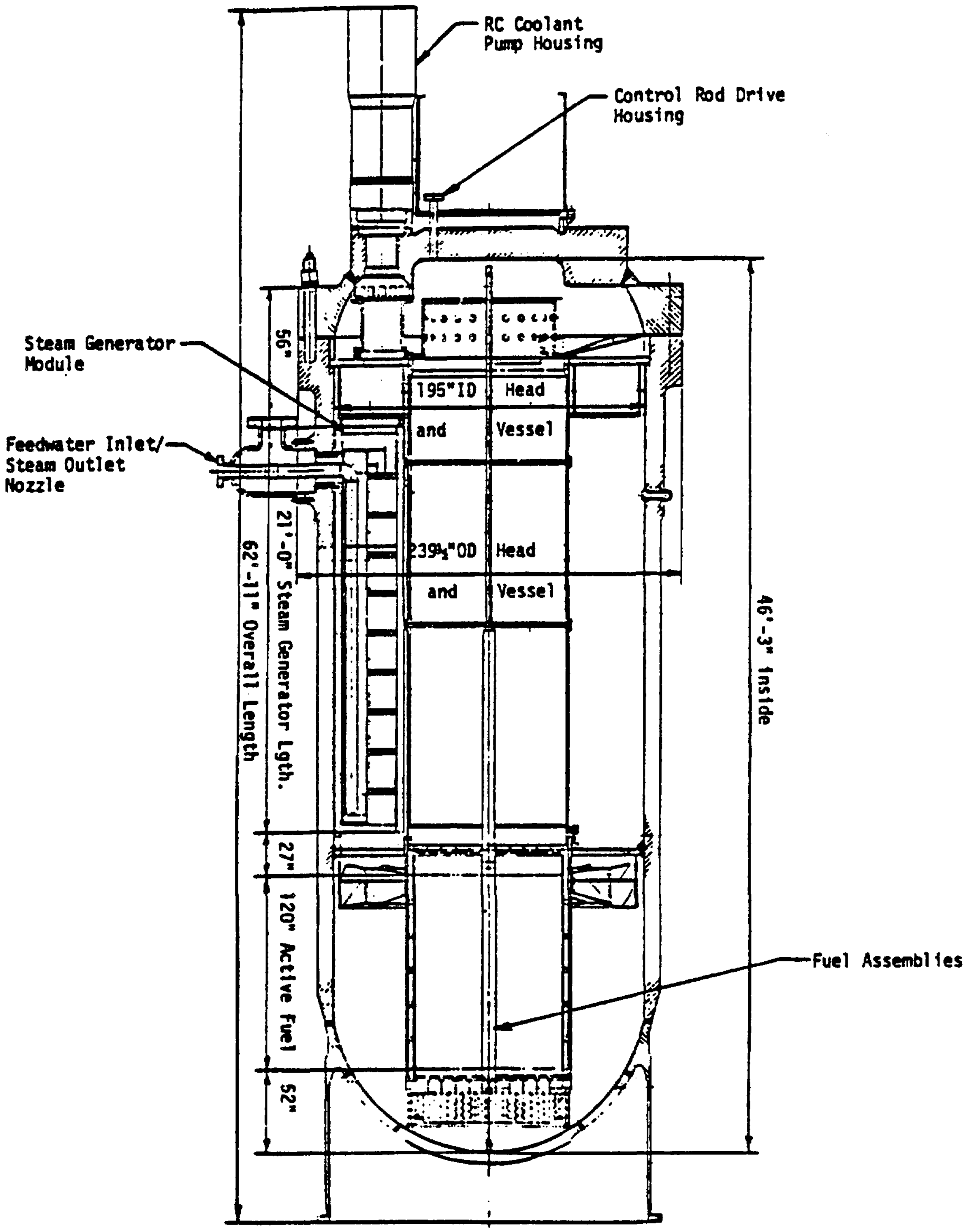


Figure 1. CNSS Reactor Vessel, Longitudinal Section

A.I.17.2 BASIC DATA

SUPPLIER: BABCOCK & WILCOX

Reactor Type: PWR

		Proposed Plant	Reference Plant
Design Name:		CNSS	Not mentioned
Core Power (MW(th))		1255	
Net Output (MW(e))		400	
Cycle:	Direct/Indirect	Indirect	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	4.953	
	Length (m)	14.10	
No. of Fuel Channels/Assemblies*		89	
Moderator:	medium	H_2O	
	pressure (MPa)	15.8	
	temp. (^oC)	313	
Primary System:	medium	H_2O	
	pressure (MPa)	15.8	
	temp. (^oC)	313	
	loops	integrated	
	steam generators	10	
	pumps	8	
Fuel:	enrichment (%)	2-4	
	assembly length (m)	3.60	
	assembly width/diam.(m)	0.218	
	No. of fuel elements (rods)/assembly	264	
	mass of fuel in core(t)	34.06	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	6.45	
	temp. (^oC)	300	

* underline relevant one

A.I.17.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: B & W (U.S.A.)

CONCEPT: Integral PWR CNSS

A. PROVENNESS

REFERENCE PLANT: Not mentioned

PROTOTYPE PLANT: Not mentioned

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

B & W has accumulated 65 reactor operating years of experience on PWR type plants in U.S.A. The cumulative load factor is 55.0%.

B. SUPPLIER'S READINESS

WHEN READY TO BID: About ten years

STATUS OF DESIGN DEVELOPMENT: Conceptual design stage

STATUS OF REGULATORY REVIEW:

Not yet licensed; neither is regulatory review planned.

A.I.18 Future Small BWR (G.E.)

A.I.18.1 Design Summary

A small Boiling Water Reactor (BWR) design concept has been developed at GE which maximizes the use of BWR design, technology and operating experience. Modest innovations are included to simplify the performance of safety functions. These, as well as other system simplifications, and a reduced power rating less than 600 MW(e) can reduce total costs and speed construction.

This small BWR concept (Figure 1) uses an isolation condenser to improve transient response. Gravity-driven control rods and gravity-driven borated water injection are used to simplify and provide diversity to the shutdown function. Core cooling and decay heat removal are provided by depressurizing the reactor to an elevated suppression pool. The drywell and pool gas spaces are inert.

Steam is produced in the reactor vessel in a manner similar to that of current BWRs. The forced recirculation system of large BWRs is replaced with natural circulation. The steam-water mixture exiting the core is directed to separators and dryers which are positioned above and around the core periphery to allow entry of control rod drives to the top of the core. Control rod drives are mounted on the top head to reduce vessel and building size, to simplify the shutdown system, and to minimize penetrations below the core.

Reactor pressure is normally controlled with turbine throttle and bypass valves. When the reactor vessel is isolated from the turbine condenser, an isolation condenser controls pressure. This device was selected because of its simplicity and because it provides high-pressure reactor water inventory control. A failure of the isolation condenser to control reactor pressure, is not expected during the plant live. If such a failure occurs, safety and depressurization valves provide a backup depressurization to the suppression pool which is positioned above the reactor vessel. When the reactor pressure is sufficiently low, check valves open in the suppression pool-to-vessel fill lines and water flows by gravity into the reactor vessel to keep the core covered. The response to a loss-of-coolant accident and transient with failure to scram is similar.

The suppression pool contains borated water to provide a diverse backup to the gravity-driven control rods. Core cooling and decay heat removal is assured, with water returned to the reactor vessel and steam produced by decay heat vented to the suppression pool. The containment overpressure relief periodically opens to vent steam from the suppression pool. There is a three-day supply of water available to accept decay heat. No operator action is required during this time. For longer periods the suppression pool is manually refilled. Emergency diesel generators and core cooling pumps are not required.

A severe accident is extremely unlikely. However, the ability to retain fission products in the suppression pool is an impotant feature which provides for a mitigation of severe accidents. This feature is retained.

Use of simple safety devices, activated by stored energy and use of inherent processes such as natural circulation and gravity-fed water delivery to the core, could reduce costs through modularization and system elimination. The licensing process could be simplified. The safety features of this small BWR concept are consistent with the long-term BWR evolution of improved safety (two examples of which are the introduction of core spray systems and pressure suppression containment). Some developments (top mounted control rod drives, gravity drain core cooling) would be needed, but it is substantially less than that needed for concepts which depend more drastically from current technology. This approach increases the chances that the new product would perform without major new issues being discovered.

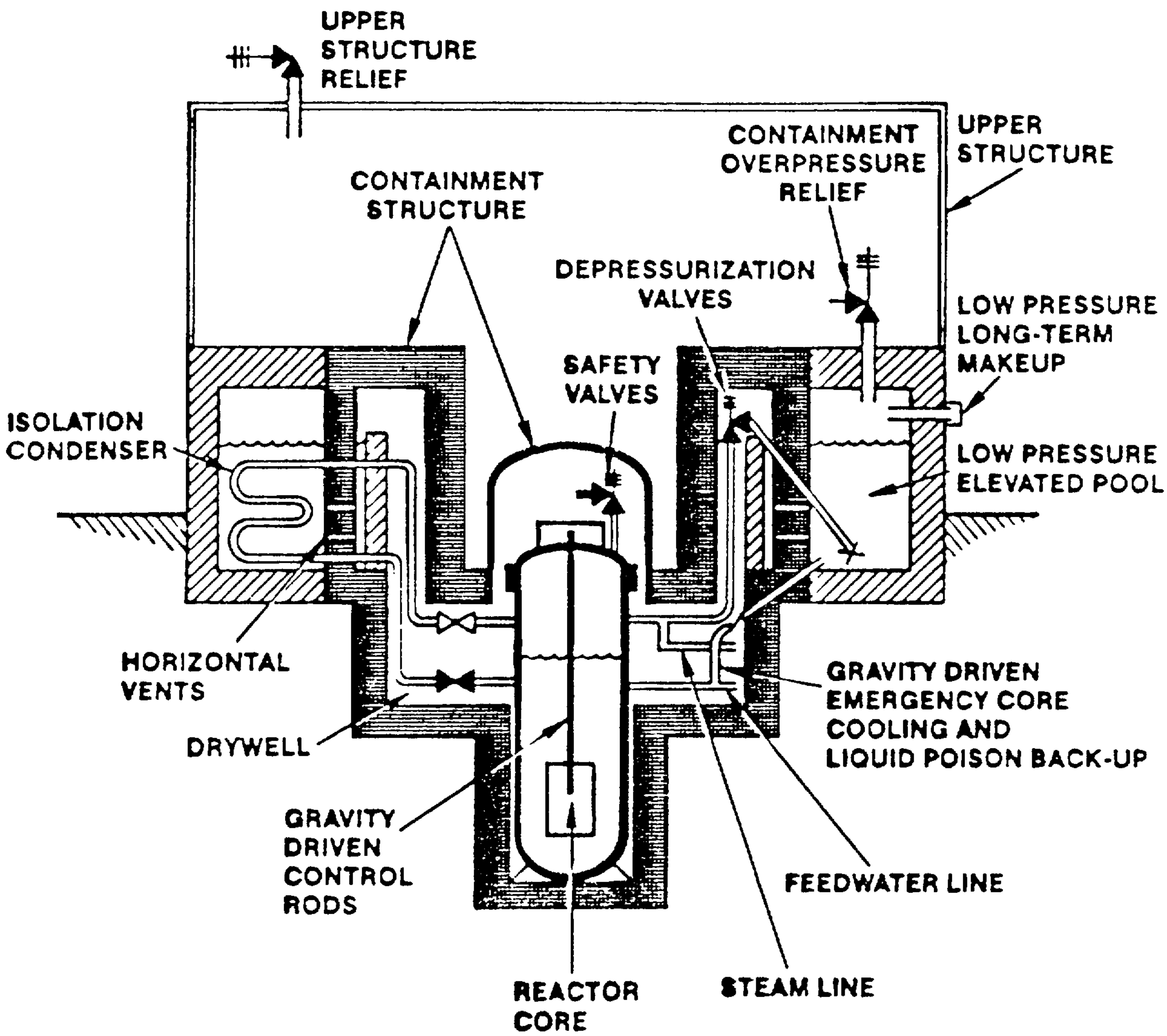


Figure 1. A Small BWR Concept

A.I.18.2 BASIC DATA

		Proposed Plant	Reference Plant
SUPPLIER: GENERAL ELECTRIC			
Reactor Type: BWR			
Design Name:		Small BWR	Not mentioned
Core Power (MW(th))		890	
Net Output (MW(e))		300	
Cycle:	Direct/Indirect	Direct	
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	7	
	Length (m)	14	
No. of Fuel Channels/Assemblies*			
Moderator:	medium	H_2O	
	pressure (MPa)	7.17	
	temp. (°C)	287	
Primary System:	medium	not applicable	
	pressure (MPa)	not applicable	
	temp. (°C)	not applicable	
	loops	not applicable	
	steam generators	not applicable	
	pumps	not applicable	
Fuel:	enrichment (%)	not yet determined	
	assembly length (m)	not yet determined	
	assembly width/diam.(m)	not yet determined	
	No. of fuel elements (rods)/assembly	not yet determined	
	mass of fuel in core(t)	not yet determined	
Refuelling:	ON/OFF-LOAD	OFF	
Secondary System:	pressure (MPa)	7.17	
	temp. (°C)	287	

* underline relevant one

A.I.18.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: G.E. (U.S.A.)

CONCEPT: Small BWR (300 MW(e) most likely size)

A. PROVENNESS

REFERENCE PLANT: Not mentioned. A number of BWR in operation.

PROTOTYPE PLANT: Not applicable

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT:

G.E. has accumulated 211 reactor operating years of experience on BWR type plants in the U.S.A. The cumulative load factor is 59.4% until 1983.

B. SUPPLIER'S READINESS

WHEN READY TO BID: Four years

STATUS OF DESIGN DEVELOPMENT: Conceptual design is being prepared.

STATUS OF REGULATORY REVIEW:

Not yet licensed. SAR is also not yet available.

A.I.19 G.E. HTGR

A.I.19.1 Design Summary

This system employs a compact steam generation system and a conventional steam turbine power generation system for electricity production. Each module of the General Electric Modular concept is designed to produce about 95 MW(e). Modules can be added at a site to meet larger power demand levels. The design is currently in the concept stage and would not be ready for commercialization until a prototype has been demonstrated possibly within 8 to 10 years.

A.I.19.2 Basic Data: not ready

A.I.19.3 Provenness and readiness: not ready.

A.I.20 G.E. MRP

A.I.20.1 Design Summary

General Electric is currently developing a small liquid metal reactor called the Modular Reactor Plant (MRP). The concept employs a compact nuclear heat supply assembly, an intermediate liquid metal system for steam generation, and a conventional steam turbine power generation system for electricity production. Each module is designed to produce about 110 MW(e). Modules can be added at a site to meet larger power demand levels. The design is currently in the concept stage and would not be ready or commercialization until a prototype has been demonstrated, possibly within 8 to 10 years.

A.I.20.2 Basic Data: not ready

A.I.20.3 Provenness and readiness: not ready.

A.I.21 The VVER-440 PWR

A.I.21.1 Design Summary

The VVER-440 PWR, for a 440 MW(e) gross nuclear power station, started from a smaller prototype and was first realized in its present size with the third Novo-Voronezh unit which started operation in 1971. Since then 30 units of this type have been successfully built and operated in the USSR and in other countries; several more are under construction. This Novo-Voronezh type has been developed to meet current international safety standards; the most recent plant to go on line in the USSR is the Kola nuclear power station (4 units) (Fig. 1). The VVER-440 concept provides several options which can be suited to various conditions ranging from hot deserts or those of the arctic tundra to optimal conditions for a power plant in a moderate climate. The sound and reliable design of the plants is confirmed by the excellent operational records of nuclear power plants of this type.

The main objective in developing the VVER-440 reactor series was to produce a safe, reliable and clean concept at reasonable cost while also satisfying maintenance and operation requirements. The primary circuit comprises a nuclear steam generating unit including the reactor, six horizontal steam generators, six main circulation loops with reactor coolant pumps, a pressurizer and primary system isolation valves. This provides reliable cooling also in a case of a rupture in the primary loop or feedwater lines. Transients in the primary circuit will also be slower than in most nuclear steam supply systems, owing to a large water inventory in the horizontal steam generators.

The design approach is conservative; all components are laid out with ample margins, and as a rule only components well proved in practice are used:

- The containment can be built in the following versions:
  - double containment, full-pressure type
  - single containment, full-pressure type
  - single or double containment with pressure suppression (as in the case of the Loviisa plant in Finland).

- The reactor pressure vessel houses the reactor core. The nozzles for the reactor coolant loops are located on two levels, with a lower row for the loops' cold legs and a higher row for hot legs. Additionally there are four special nozzles for the accumulators of the emergency core cooling system.

- The reactor core consists of fuel assemblies of which 312 are stationary and 37 moving control assemblies. Each fuel assembly comprises a bundle of 126 fuel rods in a triangular lattice, a hexagonal shroud tube and upper and lower end pieces. The control assemblies comprise an absorbing part and a fuel follower almost identical to the stationary assemblies. The absorbers and followers are coupled to each other and to the drives by connecting rods. The thermal loading of the reactor core is low, ensuring integrity as well as reliable fuel performance.

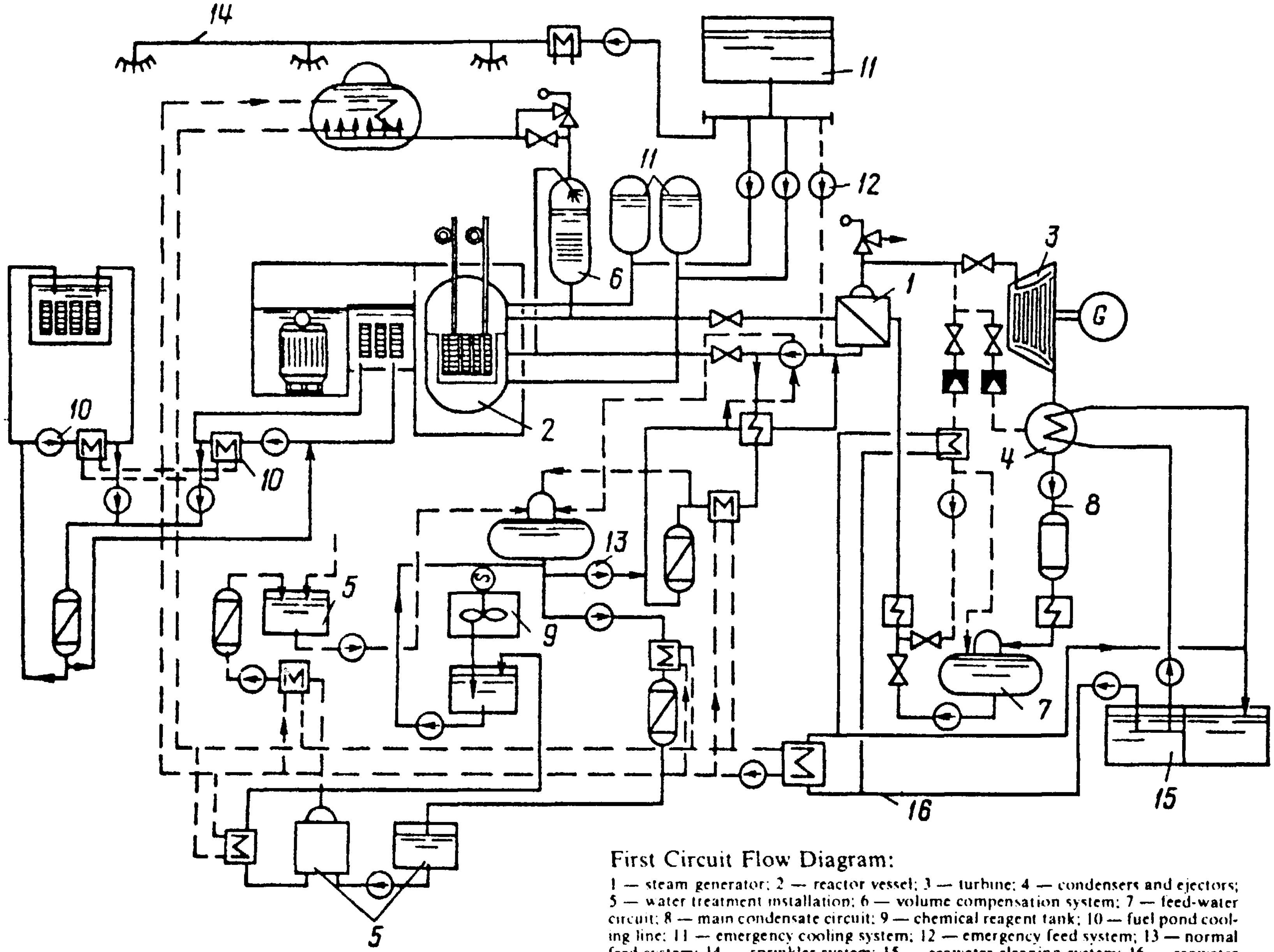
- VVER-440 fuel is characterized by its:
  - conservative rating (linear power max. 325 W/cm, burnup 28.6 MWd/kgU)
  - long experience gained with various research and commercial reactors
  - extensive use of materials internationally recognized as the best possible, especially zirconium-niobium alloys in fuel cladding tubes.

- All safety systems in the VVER-440 concept are divided into three, or in certain sections four, separate and independent redundant subsystems, each of which meets the requirements caused by loss-of-coolant accidents or other disturbances. The various circuits of the redundancy subsystems are located in physically separate areas and supplied with electrical power from separate diesel-backed sources. This separation principle provides reliable protection against external and internal influences, such as earthquakes, airplane crashes, explosions, flooding and fire, etc.

- Several types of automation and control systems have been used and all have performed successfully. Thus the VVER-440 is fully developed to be fitted with state-of-the-art instrumentation, automation and control system technology covering several operating modes. This includes advanced control room layouts featuring process computers and colour CRT-displays for monitoring and control duties.

- The steam generators of VVER-440 NPS are of horizontal design. This steam generator type is not susceptible to the corrosion problems which plague other pressurized water reactor types. The flow dynamics of the secondary circuit water provide the advantage of slower changes in the water level of the steam generator. Maintenance space is also easier to accommodate at the reactor building main level. This means better availability and maintainability of the NPP main equipment.

- The question of one or two turbines is one of investment costs, but it is also a question of availability. The VVER-440 NPP can be equipped either with two turbines of the K-220-44 type or with one turbine of the K-500-44 type (or similarly suitable ones). These turbines are basically condensing turbines, but they can be modified for multipurpose (cogeneration) use.



First Circuit Flow Diagram:

1 — steam generator; 2 — reactor vessel; 3 — turbine; 4 — condensers and ejectors; 5 — water treatment installation; 6 — volume compensation system; 7 — feed-water circuit; 8 — main condensate circuit; 9 — chemical reagent tank; 10 — fuel pond cooling line; 11 — emergency cooling system; 12 — emergency feed system; 13 — normal feed system; 14 — sprinkler system; 15 — seawater cleaning system; 16 — seawater intermediate circuit

A.I.21.2 BASIC DATA

SUPPLIER: ATOMENERGOEXPORT

Reactor Type: PWR

		Proposed Plant	Reference Plant
Design Name:		VVER-440	KOLA
Core Power (MW(th))		1375	?
Net Output (MW(e))		420	?
Cycle:	Direct/Indirect	Indirect	Indirect
Pressure Vessel/ Pressure Tube*:	Inside diam. (m)	3.542	4.3
	Length (m)	?	11.8
No. of Fuel Channels/Assemblies*		349	312
Moderator:	medium	H_2O	H_2O
	pressure (MPa)	12.3	?
	temp. (°C)	296	295
Primary System:	medium	H_2O	H_2O
	pressure (MPa)	12.3	?
	temp. (°C)	296	295
	loops	6	6
	steam generators	6	6
	pumps	6	6
Fuel:	enrichment (%)	3.6-2.4	3.6
	assembly length (m)	242	2.5
	assembly width/diam.(m)	?	0.114 triangular lattice
	No. of fuel elements (rods)/assembly	126	126
	mass of fuel in core (t)	4.2	?
Refuelling:	ON/OFF-LOAD	OFF	OFF
Secondary System:	pressure (MPa)	4.4	?
	temp. (°C)	256	?

* underline relevant one

A.I.21.3 PROVENNESS AND SUPPLIER'S READINESS

VENDOR: Atomenergoexport (USSR)

CONCEPT: Standard 440 MW(e) PWR, "VVER"

A. PROVENNESS

REFERENCE PLANT: No particular one mentioned. A large number of this type already built and under construction. Most recent plant commissioned (1983) in USSR is the KOLA plant.

PROTOTYPE PLANT: Smaller Novovoronesh unit.

DATA FOR AND OPERATING EXPERIENCE WITH REFERENCE/PROTOTYPE PLANT: 30 units with 182 reactor operating years.

B. SUPPLIER'S READINESS

WHEN READY TO BID: immediately.

STATUS OF DESIGN DEVELOPMENT: Standard product and all specifications available.

STATUS OF REGULATORY REVIEW: Recently licensed in USSR and several other countries.

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