38 FACTORS INFLUENCING SELECTION OF A HTR FOR A DEVELOPING COUNTRY*

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Abstract

Consumption of commercial energy and electricity in Bangladesh has to grow rapidly in order to attain socio-economic development of the country. Nuclear power is considered to be an appropriate proposition due to the inadequacy of indigenous primary energy resources. A technical, economic and financial feasibility study on a 300-500 MWe nuclear power plant is underway now. Responses from different suppliers in SMPR range were enumerated jointly by the Consultants and BAEC under the feasibility study. Criteria for selection of technology and the factor influencing the selection of Modular HTR for Bangladesh are described in the paper. Some indicative results of cost economic calculations are included to help form an idea about various limiting conditions, under which a SMPR with the selected technology could become competitive with the other conventional alternatives. Problems in decision making associated with the uncertainties in estimating plant and fuel cycle costs are enumerated. The implications of not having a reference plant vis-à-vis the advantageous safety features are described to show how these aspects can influence the selection of a new technology like HTR for a developing country.

Financing is identifiable as the major problem in implementing a nuclear power project in a developing country like Bangladesh. The entire scope of supplies and services may be broken down into components, so that the burden of financing could be shared by more than one exporting country. Some indicative ideas about the packaging of supplies and services are presented in the paper in order to identify different types of financing sources that could be explored for implementation of the project. Some salient features of the effect of joint-venture on the project financing and implementation are described in the paper.

1. INTRODUCTION

Per capita consumption of commercial energy and electricity in Bangladesh has to grow fast from its present low base, if the country has to attain a desired level of economic development. The present demand for electricity is largely suppressed by the shortage of generation. In fact, over the last few years the peak demand has been growing at a rate in the range of 10-20% per annum, which is explained by the partial improvement of the supply scenario through addition of a number of power plants to the national grid. According to the projections of different studies, the generation requirement of the country will have attained a level of 4000-7000 MWe by the turn of the century. For the mean value this implies that over the same period the per capita generation of electricity will increase to about 170 KWh as compared to the present generation of about 50 KWh.

The national grid of Bangladesh is divided geographically into two distinct zones and these are integrated by a East-West electrical Inter-connector. The known indigenous primary energy resource of the country, namely natural gas, is located entirely in the Eastern Zone, forcing the other zone to depend on gas-based electricity generation of the Eastern Zone. Moreover, the limited deposit of gas (estimated to be 11 trillion cft., only one-third of which is proven, the rest being probable and possible reserves) with its deversified uses in different sectors of economy, including fertilizer production and industries, is not sufficient to meet the entire future demand for power production. As such the country will have to depend on imported fuel to meet at least part of the demand for electricity generation (1). In this context nuclear power is considered an appropriate proposition for Bangladesh.

Need for introduction of nuclear power in Bangladesh was conceived as early as in 1961. A site at Rooppur in the Western Zone of the country was selected after duly considering the relevant criteria. Various feasibility studies since then reconfirmed techno-economic viability of nuclear power. The project could not, however, be implemented for different reasons and financing is easily identifiable as the main problem.

Analysis of projected growth rate of peak demand of electricity, consideration of committed addition and power plants and system reliability indicate that a nuclear power plant of size of about 300 MWe could be integrated to the national grid by the year 1996. A fresh study on technical, economic and financial feasibility of the nuclear project was initiated in 1987, which is now nearing completion. The IAEA Project Initiation Study on SMPR (2), which identified the potential designers of reactors that could meet the requirements of Bangladesh was of special relevance for selection of the technology. Information provided in the above IAEA Study and in the on going feasibility study are analysed in the following paragraphs to identify advantages and disadvantages of HTR, which could influence selection of a HTR for a developing country.

2. SELECTION OF TECHNOLOGY

Size of grid in most of the developing countries require that the selected technology should preferably be limited to reactors in the SMPR range. The immediate implication of this condition is that in contrast to the case of larger reactors the nuclear power project cannot be benefited from the experience in construction and operation of a reference plant. Proper reference may then be replaced by the concepts like use of proven concepts and components, results of experiments and rig tests, etc. Infrastructural situation in such countries has also bearing on the selection of technology.

* This paper was not presented at the meeting.

Above all safety of the chosen design is considered to be an important factor. While the extent of local scope in the first nuclear power project in a developing country cannot expected to be very extensive, the potentials, extent, opportunities and nature of possible technology transfer may also influence the selection. There could be a series of other criteria for choice of technology for a nuclear power project in a developing country, some of which are discussed in the following paragraphs.

2.1. Criteria for selection of technology

2.1.1. Design and Development Status

This criterion may consider factors like:

- difference between the proposed plant with any other operating plant of the same type
- development status of prototype, if any
- rig results and experimental basis
- incorporation of proven concepts and components
- status of development of the proposed design, which may influence time schedule for the project.

2.1.2. Vendor Experience

This criterion considers past experience of the Vendor in implementation of nuclear projects in developed and developing countries, performance with respect to project schedule, manufacturing capability, performance of the operating plants etc.

2.1.3. Licensing Status

Status of preparation, submission and clearance of a non-site specific design by the safety authority in the country of the Vendor may be considered as an important parameter for selection of technology. Availability of such a clearance could add to the confidence of the buyer in the proposed design, especially for those reactors for which there is no reference plant.

2.1.4. Safety

Special features to be considered under this criterion are the passive safety systems based on physical/chemical features of the design, which are expected to help cope with design basis accidents. Adequacy and reliability of such systems in contrast with commonly used safety systems (ECCS) need to be evaluated carefully in considering advantage of such a feature.

2.1.5. Plant Flexibility And Unit Size

This criterion addresses itself to the capability of the plant to meet specific requirements of the grid, like response to possible fluctuations in load, spinning reserve, system reliability, optimization of requirement and inventory of spares, etc.

2.1.6. Ease of Construction

Problems of infrastructural base in the buyer country that may affect the extent and type of works to be performed locally may be considered under this criterion. Designs that can utilize local expertise and experiment in performing on-site works may be considered more appropriate and cost efficient.

2.1.7. Technology Transfer

While the scope of local participation in the implementation of the first nuclear plant in a developing country can not be expected to be very high, the experience, intention, extent and mode of technology transfer by the Vendor may be considered to be an important factor in selection of technology.

2.1.8. Fuel Supply

Availability of fuel over the life-time of the plant is an important consideration. A guarantee on life time supply, diversified sources for the fuel cycle, cost of fuel, etc. factors may be covered by this particular criterion.

2.1.9. Special Materials

Requirement, sources of supply, make-up, polishing and cleaning, cost, convenience in operation and maintenance in case of reactors with special materials like heavy water and coolant gas have an influence on the choice of technology for the nuclear power plant in a developing country.

2.1.10 Operation and Maintenance

Points of special consideration under this criterion are mode of refueling, convenience in operation, maintainability, willingness of the Vendor to provide assistance and/or to be associated with the buyer in operation and maintenance for an extended period. Joint Venture arrangements with the supplier may be considered to be an additional advantage.

2.1.11 Waste Disposal and Decommissioning

Though this problem is common for any type of reactor, yet any special advantage proposed by a particular supplier also influence the process of selection of tehnology.

2.1.12 Cost Economics

This criterion considers the cost of implementation of the project, levelized generation cost and other financial and economic indicators, construction schedule and its effect on cost in the form of interest during construction, possible escalation, firmness of cost, etc.

2.1.13 Commercial Conditions

Attractiveness of commercial conditions, continuing association between the Vendor and the buyer, financial assistance, etc. factors may influence in selection of technology. Factors like type of contract for project implementation and possibilities of packaging of supply into independent components in order to distribute the burden of financing among different sources may also influence choice of technology.

3. EVALUATION OF REACTOR DESIGNS

The above criteria in general cover most of the important factors that may be considered in selecting a technology for a nuclear power plant project in a developing country. Relative importance of these factors will depend on the intention, requirements, time frame envisaged for implementation of the project, etc. factors relevant to the particular developing country. In numerical evaluation of the merit of proposed designs, therefore, relative weightage should be assigned to individual selection criterion depending on relevance of the criteria to the local conditions. The following weightage factors could be considered:

Design and Development Status	100
Vendor Experience	70
Licensing Status	90
Safety	180
Plant Flexibility	50
Unit Size	30
Ease of Construction	50
Technology Transfer	50
Fuel Cost	50
Special Materials	50
Operation and Maintenance	70
Waste and Spent Fuel Disposal	70
Cost Economics	90
Commercial Conditions	50
Total	1000

4. RELATIVE ADVANTAGES AND DISADVANTAGES OF HTR

Salient features of relative advantages and disadvantages of HTR over other types of reactors according to the above selection criteria are as follows.

4.1. Safety

The HTR designs available now or likely to be ready for export in foreseeable future have negative void coefficient. These designs are reported to incorporate passive safety systems based on physical and chemical features of the reactor, independant of systems like ECCS. It is envisaged that decay heat could be transferred to reactor vessel through radiation in the event of a design basis accident. In this case the maximum temperature is not expected to exceed certain safe level, thereby ensuring a margin to the melting point of uranium. This advantage is reported to be confirmed by rig tests and other experiments. Such calculations and results should be verified to ascertain the adequacy of the mode of heat transfer and effects, if any, on the structural materials in the event of a design basis accident. If such verification can confirm the claimed "inherent safety" of the design, then this particular advantage can be considered as a redeeming feature of HTR.

4.2. Fuel Supply

HTRs use coated particles in their fuel elements, which could be advantageous in retaining radioactivity within the fuel elements. Failure of such fuel is less likely due to the absence of separate cladding material. However, the sources of supply of fuel are limited and the fabrication appears to be complicated. On-load refueling is an advantage of HTRs with pebble bed fuel, but sampling and withdrawal of spent fuel elements are not easy operation. These factors have to be considered duly in the process of selection of technoloy.

4.3. Ease of Construction

Some of the HTRs in the SMPR range are modular in nature, which necessitates substantial shop fabrication. This ensures, better control over quality and project schedule. However, the scope of local work and transfer of technology could be reduced to a certain extent as compared with other reactors. Ways and means have to be found to improve upon this situation, probably through involvement of buyer's personnel in different phases like detailed designing, shop fabrication QA & QC programs etc. Potential buyers can also participate in international studies on development of HTR through the auspices of IAEA. This would not only ensure a proper mode of technology transfer, but also help incorporate requirements of developing countries in such designs.

4.4. Special Materials

HTRs use helium gas, which is inert, efficient as coolant, does not change phase and largely precludes possibilities of chemical interference with the properties of structural materials. Inventory and annual make-up requirements do not possibly justify the establishment of helium plant in the buyer country. Sources of supply on commercial basis are known to be diversified, which may be considered an advantage over the alternative like heavy water. Graphite in the reactor core acts as an additional heat sink. However, the accidental situation of ingress of water from steam generator into the core needs careful examination in the process of design evaluation. The alternate design consideration of placing the steam generator at a level lower than the core can reduce the possibility and quantity of ingress, nevertheless the possible consequences can not be ignored totally.

4.5. Waste disposal

The problem with reprocessing of spent fuel is more or less the same for any type of power reactor and the related technology have not been finalised conclusively. However, structural stability and probability of failure of pebbel bed fuel elements may be considered carefully on the basis of available statistics. In general such fuel elements are considered to be capable to retain structural integrity under varied operating conditions. On-site storage of fuel elements spent over the entire life of the plant need to be kept in view in case of a contingency of non-availability of reprocessing opportunities in future. For a HTR module with a total capacity of 300 MWe, the total space for on site storage of fuel over the life time of the plant is estimated to be about 2 hectares. Alternate arrangement like sending all the fuel elements to a third country, willing to accept them, would be advantageous if this could be arranged through bi-lateral of multi-lateral agreement with the support of the Vendor.

4.6. Reference Plant And Operating Experience

Inadequacy of operating experience and non existence of a proper reference plant for HTRs may be considered to be a disadvantge. This has to be traded off with its other advantages notably safety. Operating experience with existing HTRs, though small in number, can however be used as a basis for assuming acceptability of the concept in general and the relevant components in particular.

4.7. Time Schedule and Licensing

The design and development status of HTR appear to be more advanced than other types of reactors in the SMPR range. At least in the case of one particular Vendor, review of the non-site specific safety report is on the way of completion by the safety authority in its country. If such a clearance is accorded, then it would facilitate the process of review of Safety Analysis Report by the safety authority in the buyer's country. It is estimated that such a HTR can be considered for a developing country intending to integrate a nuclear power plant into its grid as early as in 1996.

Other advantages and disadvantages of HTR are more related to the particular Vendor to be selected for a developing country. On the basis of the criteria considered above, it can be assumed that a introductory nuclear power plant. Cost economics and factors and uncertainties that may influence the selection of technology are described in the subsequent paragraphs.

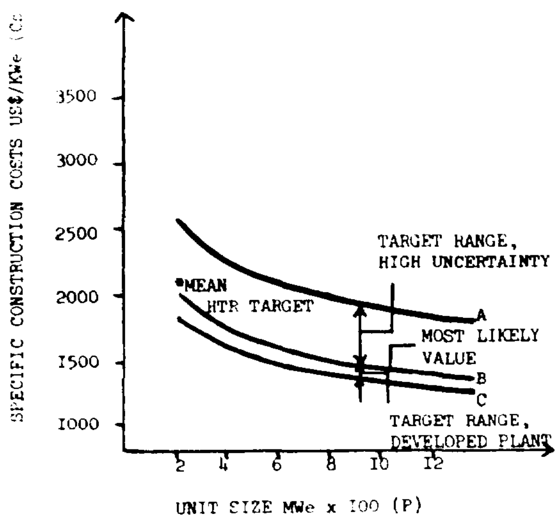
5. COST-ESTIMATES

"Experience with design, construction and implementation of modular HTRs is not significant. Therefore, it could be difficult for a Vendor to estimate the cost inspite of its wide experience with other types of reactors. The uncertainties in buyers countries usually tempt the Vendor in quoting an extremely high cost in order to cover all the risks associated with such uncertainties. Moreover, the size of the potential market is not clear, which could influence the supplier to include all its direct and indirect cost of R&D on the first buyer. For a LWR, for example, a factor associated with the economy of scale, may be useful in extrapolating the specific cost of more common larger plants. In the case of HTR, however, similar extrapolation is rendered difficult, because firstly, there is not sufficient experience of constructing such plants and secondly, cost of larger LWRs cannot be used as reference for extrapolation to the cost of HTRs due to the fact that latter design does not include any of the costly components of emergency core cooling system and the associated redundancies. Logically this should have a significant influence on the specific cost of HTRs. Moreover, many basic R&D programs have been financed by Governments of the developed countries. Also, in case of modular plant with 3-4 units serving a single turbine, the residual design cost is already expected to be shared by at least these 3-4 first units. In case of a larger plant order for 3-4 reactors are more difficult to obtain. It is believed that a supplier does not usually invest in design of a new concept unless it has preliminary indication about a number of prospective buyers, which means that the supplier should set a target to recover its extra R&D cost for development of a modular HTR from 9-16 units and the estimate for the plant should be prepared accordingly. It can, therefore, be assumed that the specific cost of a modular HTR should be at the lower and of the estimates of all SMPRs and close to larger LWRs being built presently. Shop fabrication, reduction of costs at site, reduction in soft-ware cost etc. factors also add to the above justification. An analysis of cost figures for different nuclear plants built in Europe (3) show that the specific cost of plants of size 1000 MWe lie within a range of $1200-1700/KW (fig.1.). Using a scaling factor of 0.2, the specific cost of a HTR could be 27% higher, which means that the specific cost of modular HTR should be in the range of $1520-2160/KWh. A mean value of the order of $1850/KWh could be considered as the realistic specific cost of a modular HTR. Efforts need to be made to construct a plant at this target specific cost.

The fuel cycle cost of HTRs, which is completely within the control of the supplier is also reported to be high. This is difficult to justify, because the average burn-up of HTR fuel is of the order of 3-4 times higher than the standard PWR fuel, yet the fuel cost per Kwh is about 40% higher for the HTR fuel. Such fuel is already in use for a number of years, so that the higher cost is also hardly justifiable. If the HTR has to compete with its alternative, then the fuel cost must be brought down at least to the level of PWR fuel.

6. COST ECONOMICS

Preliminary cost-economic calculations show that the levelized generation cost of a 320 MWe HTR module, built at a specific cost of $1850/Kw with fuel cost at 8 mills/Kwh at a discount rate of 10% is about 49 mills/Kwh. This is marginally cheaper that a coal-fired plant with Flue Gas Cleaning system and a coal price of $45/tonne, for which the generation cost is 52.12 mills/kwh, or a oil-fired plant at $15/barrel of crude, for which the generation cost is 53.44 mills/kwh or a gas-fired steam turbine at $2.90/1000 cft. of natural gas, for which generation cost is 54 mills/kwh. The interest rate assumed for these calculations is 6.5% with a repayment schedule of 15 years with a grace period of 5 years for contsruction (3). These preliminary figures show that even for the target specific cost of $1850/Kw, the nuclear plant with HTR looses the economic advantage over the conventional alternatives if the cost overrun exceeds 10% and fuel price reaches 10 mills/Kwh. Importance of these representative calculations is manifested in the fact that the decision of potential financiers and also the government could be influenced by the economic advantage of the nuclear option over its conventional alternative,



LEGEND:

1. Curves A, B, C are derived from analysis of historic costs, presented as targets for LWRs in Europe (1987)

   A. Target range, high uncertainty

   B. Most likely value (Cs $p^{-0.2}$)

   C. Target range, developed plant

2. * - Target HTR specific cost.

FIGURE 1 (3)

TARGET CONSTRUCTION COST OF HTR BASED ON LWR COST IN EUROPE

especially if the indigenous primary energy resources is underpriced or subsidized for power generation (as is done in Bangladesh, where natural gas is sold at US$ 80 cent per 1000 cft. for power generation).

7. FINANCING

Financing is the biggest hurdle in the way of implementation of a nuclear power project. A possible solution is to split the supplies into packages and to diversify sources of supply accordingly so that the burden of financing is showed by a number of suppliers' credit. An indicative splitting could be as follows:

Nuclear Island	40%
Turbine	20%
Electrical equipment	10%
Intake channel	4%
Commissioning, erection	6%
Civil works	20%
	100%

Assuming an expenditure curve covering six years (one year for designing and five years for construction) with six equal installments of payment, the yearly burden on any single financing source will be between 0.6% to 6.7% of total plant cost. For a specific cost of US$ 1850/KW this will mean that the yearly financial requirement for implementation of the project will be US$ 100 million to be shared tentatively according to the break-up shown above. It is felt that the item excepting the nuclear island and civil works could be covered to a great extent by suppliers' credits. Part of the cost of the nuclear island could be mobilized from the supplier's country and the rest of it could be raised through commercial loans. The local currency cost may be provided by the buyer country. In this context it will be very helpful if a Joint Venture Company is formed for the project with the local and expatriate partners with participation in equity. Such a scheme will help enhance credibility of the project and increase confidence of the financiers in its viability. The Government of the buyer's country may provide guarantee on repatriation of income of the equity share holders, debt servicing and all other payments in foreign currency.

8. INTERNATIONAL COOPERATION

HTR could be a technology useful to many developing countries provided its economic performance is proved to be better than its alternatives. Logically the specific cost should be lower than other SMPRs and there is no reason why such a plant could not be built at a specific cost stated earlier. However, the technology, especially with respect to safety and licensing has certain points that need further clarification. Issuance of a non-site specific license/design clearance in the manufacturer's country could add to the confidence in the buyer country. The codes, standards and guides applicable to HTRs are not as exhaustive as for LWRs, especially the PWRs. It is true, a few HTRs have been licensed and are operating in the developed countries and some codes, guides and standards could be in existence in those countries. These need to be compiled and new ones developed to ensure their completeness. IAEA could take a leading role in this connection, because this could be achieved only through international cooperation. International/collaborative studies may also be carried out on certain technical aspects like the applicability and adequacy of the passive safety systems in the event of a design basis accident, independent confirmation that in the worst case of such a situation the maximum fuel temperature will remain far below its melting point, temporary storage and final disposal of waste and spent fuel, possibly in collaboration with a third country willing to cooperate in this respect, effect on the core in case of water ingress from the steam generator, analysis of different cases of accidents, exchange of design information, standardization of fuel elements, etc. If such international collaboration can be materialized and produce positive results, then the HTR will have a good prospect in some of the developing countries. In parallel, the suppliers should realistically firm up their cost estimation and also the fuel cycle cost. International cooperation in solving the problem of financing is yet another area, which needs urgent attention.

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HIGH TEMPERATURE GAS COOLED REACTORS IN CHINA

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Abstract

China has plentiful energy resources, but it is unevenly distributed geographically. 60% of coal resources are concentrated in North China, 71% of hydro- power resources in the hardly accessible Southwest China, whereas the densely populated and highly industrialized 15 provinces/municipalities along the coast, yielding 73% of the gross national product, posses only 10% of national energy resources, which makes our railway system hard pressed. In fact, about 40% of the railway transport and 50% of the main waterway transport are committed to fuel. Yet the needs of energy in the coastal regions can not be met.

To develope nuclear power is a naturally expected approach to solving energy problems in China, particularly in the near term for the coastal regions, where the demand of electricity increases sharply and fuel transport from other regions is already tense.

Chinese nuclear circle is interested in MHTGR due to following reasons.

1. Small capacity of MHTGR is suitable for small power grid in certain areas.
2. Chinese manufactures are able to provide whole package of conventional island of MHTGR nuclear power plant.
3. multipurpose MHTGR is attractive for Chinese heavy industries.
4. MHTGR nuclear power plant can be built in suburbs due to inherent safety features.

Regarding the users' requirements in China, it can be summarised as:

1. Mature technologies and easy to get license from nuclear safety authority.
2. Emergency zone as small as possible, even unnecessary.