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U.S. REFERENCE PAPER ON NATIONAL DECISIONS ON BREEDER DEVELOPMENT AND DEPLOYMENT

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NATIONAL DECISIONS ON BREEDER DEVELOPMENT AND DEPLOYMENT

I. INTRODUCTION

A number of nations have embarked on breeder reactor research and development programs and some have plans to deploy breeders. Other nations will be considering these steps during the coming decades. This paper addresses the factors of concern in initial national decisions relating to the possibility of deployment of breeder reactor systems on the part of this latter group of states.

Whether breeders should be introduced in a particular nation's electric energy supply system, and the nature and timing of such a program, ought logically to depend on a number of factors: the nation's capability to achieve various degrees of breeder program implementation; the cost compared with feasible alternative means of generating electric power; the importance attached to energy independence and the degree to which a breeder program can help in the realization of that objective in the time scale of interest; and on other effects not captured in the usual economic analysis. A prior consideration, of course, is the rate of electrification needed to achieve desired economic growth and perceptions of the feasibility of meeting such needs with nuclear or nonnuclear technologies.

It is assumed that breeder deployment in any particular nation would at first supplement and perhaps later supplant a pre-existing converter reactor program, and perhaps fossil fuel power plants as well. The question of the comparative advantages of nuclear and nonnuclear strategies for achieving national energy objectives is beyond the scope of this paper.

Although also of great importance, the nonproliferation aspects of a breeder program decision are not discussed here; these are being addressed in other INFCE papers. We discuss below first a model for economic comparison of breeder and thermal reactors, and second some aspects of breeder deployment as they relate to the attainment of energy independence.

II. ECONOMIC COMPARISON OF BREEDER AND CONVERTER REACTORS

While there are a large number of variables that will enter into economic analysis of breeders versus nuclear alternatives, four are likely to be of first order concern to a nation comparing the breeder option with current generation or improved converter reactors:

1. The capital cost for the breeder, or more specifically, the differential in capital cost for the two kinds of plants. The capital charge component for breeder-generated electricity is likely to be greater than for converter reactors, principally because of the greater estimated cost of plants. In addition, there will be one-time transition costs associated with bringing breeder technology to maturity, including possible lower initial capacity factors than for mature LWRs.

2. Fuel cycle costs. Since breeders can be expected to use uranium much more efficiently than other reactors, their fuel cycle costs are expected to be substantially less than for LWRs, or other converter reactors, and are likely to depend mainly on reprocessing and fuel fabrication costs rather than on the costs or uranium. Since these latter costs are significant for converter reactors even at present uranium prices, the fuel cost disadvantage of converter reactors can be expected to be substantial and to increase as uranium costs increase, although this disadvantage would be mitigated by LWR fuel utilization efficiency improvements. The cost of enrichment will also have to be considered if it is required for the cycle against which the breeder is compared.

3. The research, development and demonstration (RD&D) costs of the breeder, or more precisely, the differential in RD&D costs for breeders and associated fuel cycles and those (if any) for converter reactors. A nation wishing to deploy breeders so as to maximize self-sufficiency will elect to develop the specialized indigenous manufacturing and fuel cycle capabilities needed beyond those existing in support of its converter reactor system. If such industrial development is undertaken, the country will have to incur RD&D costs the magnitude of which will be an important factor in the comparative economics of embarking on a breeder program as against alternative energy strategies.

4. The discount rate. A low rate will generally favor breeder deployment and a higher rate the less capital-intensive alternatives, especially if substantial research and development is anticipated for the breeder program.

For illustrative purposes, the table below suggests the relative impact of these factors on the comparative economics of LMFBRs and LWRs. The table shows the uranium costs that would make the choice between the two (together with associated fuel cycle capability or services) a matter of indifference on narrowly economic ground--that is, the uranium cost that would result in equal costs of produced electricity.

Indifference costs are shown for three ratios of breeder to LWR capital cost, the latter assumed to be $770/kW(e) and for two discount rates intended to indicate a range reflecting various assumptions about the cost of capital and other factors that may enter into the determination of an appropriate rate. All results are in contant 1978 dollars.

Table I

URANIUM INDIFFERENCE COSTS - \$/pound of U_3O_8
(No RD&D Breeder Costs; no taxes)

Discount Rate	FBR/LWR Capital Cost Ratio 1.25	1.50	1.75
4.5%	50	105	160
9.0%	65	130	200

Taking the middle estimate of capital cost differential, the table suggests that selection of breeders over LWRs on narrow economic grounds alone probably will be made in situations where a low discount rate applies only when it is anticipated that uranium prices will exceed around \$105 per pound U_3O_8 in the early part of the next century, the relevant period of interest. Where higher rates are appropriate a breeder decision would be made when uranium costs would be around \$130 or more per pound.

The figures in Table I assume no RD&D investment for the breeder program (or for the LWRs) and are therefore independent of the size and precise timing of the program at issue. However, if in an effort to achieve a degree of independence from foreign suppliers, or for other reasons, a nation wishes to do other than simply buy reactors and fuel cycle services, then RD&D costs will be incurred. *For illustrative purposes, in the following simplified example,* we assume a program that involves the addition of 1 GW(e) generating capacity per year during the period 2000-2030, with LWRs or FBRs, operation of them for 40 years, and then replacement with a new technology, unspecified. It is assumed that RD&D investment is incurred having a cost in 1978 dollars of two and ten billion dollars, spread evenly over fifteen years from 1985 to the year 2000.

Table II

Discount Rate	RD&D Cost	FBR/LWR Capital Cost Ratio 1.25	1.50	1.75
4.5%	None	50	105	160
	\$2 billion	90	140	200
	\$10 billion	235	290	340
9.0%	None	65	130	200
	\$2 billion	160	225	290
	\$10 billion	540	605	670

Table II suggests great sensitivity of the breeder decision to the discount rate if one assumes substantial RD&D. If this is required, a breeder program is probably economically attractive only at low discount rates, at least for countries that might deploy reactors at the rate assumed above.

III. ENERGY DEPENDENCE AND FAST BREEDERS

A. Assurance of Fuel Supply

Clearly, for some of the nations that have committed themselves to breeders, and for others that might, a major motivation will be a desire to reduce their dependence on other nations for energy supplies. A conventional nuclear power program (LWR or HWR) is itself often regarded as an important part of a strategy to enhance national energy security through diversification of energy sources and, in particular, reducing reliance on imported fossil fuels. A transition to breeder reactors represents a further step aimed at increased autonomy in nuclear fuel supply--i.e., at reducing the possibility that the nuclear program might be disrupted by a cut-off of uranium supplies, or a sharp escalation of their price, or that source nations might attach onerous conditions to sales.*

A breeder program at equilibrium or with only a moderate rate of growth can virtually eliminate dependence on other nations for fissionable materials. Enough plutonium could be produced so that the only fuel input necessary will be natural or depleted uranium, which will be required in such small quantities that fuel supply is unlikely to be a serious problem even for nations with virtually no indigenous resources.

In assessing the contribution of such a program to national energy independence, however, several factors must be considered. These include the potential for electrification of the national energy system, the timing and pace of breeder deployment, and the degree of technological and fuel cycle dependence that the breeder program may entail.

The scope for reducing energy dependence through breeder reactors is limited, of course, by the size of the nation's actual or potential

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*Supply assurance is considered here from the standpoint of an individual consumer nation rather than in terms of the global uranium resource base. The latter is of concern to the national energy planner primarily in terms of its impact on world prices. The price trend in turn helps determine the advisability and timing of a possible breeder decision, as illustrated by the analysis in the first part of this paper. It might be noted that breeder deployment by some nations could influence the long-term market outlook confronting others in a way that makes the breeder option less attractive. That is, an easing of a country's prospective uranium supply situation could occur as a result of breeder deployments elsewhere without its having to deploy breeders itself.

electrical energy needs and grid capacity relative to its total energy requirements, since at present it is primarily in the electrical sector that the possibility of substituting nuclear for imported nonnuclear fuel exists. Successful implementation of a breeder economy would not grant any country total energy independence, but would provide relative independence from external sources of fuel for electricity generation from large plants. For illustrative purposes, it may be noted that fuel for such plants currently accounts for between 5% and 15% of energy imports in the larger industrialized countries.

It should be emphasized that the realization of this goal is a long-term prospect for a country embarking on a breeder program. Even for nations whose breeder programs are well advanced, breeders will supply only a few percent of total energy demand during the early part of the next century.

Securing enough plutonium (or highly enriched uranium) for initial loading of breeders at the beginning of a program and during a period of rapid growth is a problem that will have to be considered by any nation contemplating deployment of breeders. The amounts of plutonium and/or highly enriched uranium required for initial fuel loadings wil be very substantial particularly if the breeders are of first generation technology, i.e., breeders with long doubling times. For example, assume a doubling time of twenty years and, as suggested earlier, a program involving adding 1 GW(e) of FBR capacity per year for 30 years. In order to get through the first 20 years of such a program, a total of about 40,000 kg of Pu (or an equivalent mix of Pu and highly enriched uranium) would have to have been provided from sources other than the breeders. This is equivalent to about 300 W(e) years of LWR output (or 10 million kg of separative work if highly enriched uranium is substituted for plutonium).

Thus, the realization of substantial benefits with respect to increased security of fuel supply may come only following a relatively long period of continued need for supply. In view of this, a nation contemplating initiating a breeder reactor program may wish to consider alternative measures that could reduce vulnerability to interruptions of fuel supply.

Stockpiling of uranium and/or separative work may be considered as an alternative to purchase of breeders as a hedge against interruption of supply, but the feasibility and economic attractiveness will depend on specific assumptions that require careful analysis.

Exploration for uranium and development of uranium production capability may be a more interesting option for many nations whose choice between reliance on breeders and converters depends largely on the issue of assurance of reliable fuel supply. This may be true even in the event that it is believed that indigenous uranium ore will be of low quality and that production costs will be high. This follows from a consideration of Table II.

Countries concerned about assurance of fuel supply that have any significant uranium potential might decide to undertake extensive exploration during the next decade or so while reserving until later decisions on investment in breeder infrastructure in view of the possiblity that exploration for uranium might demonstrate production prospects at costs that would make the more complex breeder option uneconomic during the early years of the next century.

Another approach to security of supply is the development of international fuel supply assurances such as those under discussion in INFCE Working Group 3. These could be particularly relevant for countries with small or medium sized programs.

B. Dependence on Technology and Services

The contribution of a breeder reactor program to national energy independence must be considered from the standpoint not only of fuel supply but also in terms of the technology and services associated with a breeder economy. To the extent that independence is a dominant objective, it follows that breeder deployment would be attempted with a minimum of reliance on outside support, which would lengthen the time before breeder deployment is started by demanding a higher level of domestic capability. In addition, complete nuclear autonomy requires eventual commitment to the entire fast breeder fuel cycle (reprocessing, fabrication, and waste managment) and in turn a commitment to a substantial number of such reactors.

For many countries contemplating a breeder option, this level of commitment is unlikely, at least initially, to be economically attractive or technically feasible. Therefore, in assessing the desirability of a breeder program, those nations will have to confront the prospect of continuing technological supply needs for a long period even if fuel import needs would be reduced at an earlier date.

The most realistic choice will normally be to depend initially on others, at least for nuclear steam supply systems (and perhaps for much of the entire plant) as well as for fuel cycle services. With time, and through licensing arrangements, it may be possible to increase the fraction of design, manufacturing, and construction that can be carried out indigenously. This path is likely to be attractive only for countries with substantial demand and industrial capability.

With respect to reprocessing, nations deploying breeders at a moderate rate may elect to rely on others to reprocess spent fuel from both their converter reactors and breeders, and possibly to fabricate new fuel as well. There may be an advantage to this choice, particularly as regards smaller programs, because of economics of scale. The capacity of what is likely to become the economically optimum size reprocessing plant will probably be around 1500 tons of heavy metal per year, sufficient to handle the spent fuel from about 30 to

50 1000 MW(e) breeder reactors, and therefore much larger than will be required in the case of many countries.* On the other hand, reliance on others for fuel cycle services introduces some risk of supply interruptions or delays (e.g., due to the need to transport spent fuel). This could lead to an increase in doubling times and hence defer the realization of appreciable fuel resource savings.

Whatever decision a nation takes with respect to reprocesing its breeder fuel, it will have a similar decision with respect to the disposal of radioactive waste from the breeder fuel cycle. If a nation is dependent on another for the disposal of its spent fuel or its reprocessing waste, that dependence may continue with respect to the waste from the breeder fuel cycle.

For most countries contemplating using breeders, a breeder program implies technological and fuel cycle dependence on others for many years. A nation contemplating such a program would have to make a judgment as to whether such dependence is preferable to reliance on converter reactors or fossil fuel power plants with their greater long-term dependence on others for fuel.

As a more modest goal, a buyer nation could aim to achieve independence of supplies as regards installed breeder generating units. This requires, of course, development of indigenous capabilities for maintenance and replacement of parts, and also for spent fuel reprocessing and fuel fabrication. Having such capabilities would not permit independent expansion of the number of plants, but would provide insulation against cut-off or drastic increases in cost of supplies and services by others. For at least some nations, it could lay the ground-work for complete breeder independence later.

As a final consideration, the relevance of industrial and manpower infrastructures to an independent breeder program should be addressed.** In the long term it may be possible to provide the necessary inputs to an independent or partially independent breeder program through investment in personnel training, the development of necessary manufacturing industry, etc. In the short and medium term a breeder program may be an unrealistic option for some nations because of shortages of particular skills or other necessary inputs, or it may compete with other programs for resources in critically short, and

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*Since the figures in Tables I, II, and III are derived based on the assumption of reprocessing in plants of optimum economic size, they may require upward adjustment if in fact reprocessing in plants appropriate to smaller grids is contemplated. The extent of economies of scale in reprocessing is not clear at this time. However, the cost of a small facility of around 300 tons capacity, could be equivalent to perhaps 1 mill/kWh greater, corresponding to an increase in the uranium break-even cost of about $20/pound.

**A useful discussion of the infrastructure problem in regard to nuclear programs generally is continued in Doc. Cochairmen/WG. 3/21, Evaluation and Definition Within the Scope of INFCE of the Specific Conditions in the Needs of the Developing Countries, prepared by the IAEA.

not easily expandable, supply. This is particularly true if the breeder system has not been preceeded by a substantial thermal reactor program.

For technology transfer to be successful, the recipient consumer nation must have the technological/industrial base to absorb the transfer and the indigenous technological ability to complete the transfer. Non-breeder nations may well be, at the deployment decision point in question, in the process of absorbing the conventional reactor technology from a supplier nation. Traditionally, consumer nations have elected to undertake some degree of domestic participation in the transfer of high technology principally from foreign exchange savings considerations. The experience of several nations in their attempts at domestic manufacture of conventional nuclear power plant components reveals that it required a heavy government participation and a large coordination effort to bring local industry on board the venture.

The manufacture of nuclear components requires adherence to high quality control standards and local industries may experience initial difficulties in meeting these standards. The costs of the units produced on a small scale were often higher than purchase prices in the international market. These considerations suggest that the first priority for each nation would be to build up and consolidate the industrial base to support its existing types of power generation facilities. It has to be recognized that the level of technology required for breeder deployment is considerably higher than that for conventional reactors and implies a new associated industrial base to support the technology.