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Informal Report

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An Economic Analysis of Nuclear Power Reactor Dissemination to Less Developed Nations with Implications for Nuclear Proliferation

University of California

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An Economic Analysis of Nuclear Power Reactor Dissemination to Less Developed Nations with Implications for Nuclear Proliferation

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by

Robert L. Gustavson and Joseph S. Howard II

ABSTRACT

We have applied an economic model to the transfer of nuclear-power reactors from industrialized nations to the less developed nations. The model includes demand and supply factors and predicts the success of U.S. nonproliferation positions and policies.

We conclude that economic forces dominate the transfer of power reactors to less developed nations. Our study shows that attempts to either restrict or promote the spread of nuclear-power technology by ignoring natural economic incentives would have only limited effect. If U.S. policy is too restrictive, less developed nations will seek other suppliers and thereby lower U.S. influence substantially. Allowing less developed nations to develop nuclear-power technology as dictated by economic forces will result in a modest rate of transfer that should comply with nuclear-proliferation objectives.

I. SUMMARY AND CONCLUSIONS

A. Summary

The Organization for Economic Cooperation and Development (OECD) and the International Atomic Energy Agency (IAEA) previously predicted a large and rapid transfer of nuclear-power plants to lesser developed countries (LDCs). The prediction was based upon a critical shortage of energy in LDCs and few alternative energy souces, along with a strong desire by nuclear powers to export reactors to establish markets and gain production economies of scale. Present deferrals and cancellations of power plant sales to LDCs is indicative of the difficulty of LDCs to assimilate this technology and of venders to have continued motivation to pursue sales.

We found that economic considerations will dominate nuclear-reactor trade between the supplying industrialized nations and the demanding less developed countries. Our major findings are described in Fig. I-1.

B. Approach

One can analyze the transfer of nuclear-power reactors and the possibility of resulting weapon proliferation from a technical, political, or economic viewpoint. We focus on the economic viewpoint. The competitive model explains and predicts the behavior of those who demand and those who supply nuclear power reactors. LDCs face a series of critical choices forced by their scarce energy resources--a situation portraying the essence of economics. We use macro- and microeconomic conceptual frameworks as the basic analytical tool for our study.

Our evaluation of economic incentives, nuclear-power-reactor status, and reactor experience provides insights into anticipated expansion of nuclear electric power by LDCs. Nuclear nonproliferation objectives formulated internationally and incorporated into bilateral agreements reflect a desire to promote the dissemination of nuclear power reactors while minimizing the risk of nuclear proliferation. Our review indicates that nonproliferation agreements have not inhibited economic incentives.

C. Demand for Nuclear Reactors

LDC demands for nuclear reactors reflect strong economic incentives to increase energy availability because it is essential to economic development. We show this demand to be strong, as alternative domestic electrical energy sources are exceptionally scarce in LDCs.

We define lesser developed nations as countries with per capita gross domestic product below $2000 in 1974, plus Saudia Arabia, Venezuela, Greece, Libya, Puerto Rico, Singapore, and Gabon. Though these countries exceed the minimum per capita income, they have not established a mature industrial base.

A good part of the electrical energy of most LDCs comes from oil-fired generators using imported oil. For these countries, higher oil prices have

- Competitive model illustrates the importance of economic incentives.
- LDC demand for nuclear reactors reflects strong economic incentives.
- Rising supply costs inhibit spread of nuclear reactors.
- Nonproliferation legislation and safeguards promote international interests most effectively when they parallel economic motivations within the framework. of the competitive model.

Fig. I-1.
Economic considerations will dominate nuclear-reactor trade with LDCs.

magnified balance-of-payments problems, forced electric-power conservation, and reduced expectations for economic development. Even oil-rich LDCs have used huge oil revenues to acquire western reactor technology and enhance economic development. The largest expansion of reactor technology has been in the largest LDC with substantial proven reserves of oil. The oil embargo and subsequent price increases have thus provided a clear signal to LDCs, both with and without oil, that they must develop alternatives to this dominant source of energy. As finite fossil-fuel energy sources become increasingly scarce, LDCs must find other energy sources, including nuclear, if economic development is to continue. This phenomenon reflects both decreased supply and increased demand.

D. Supply of Nuclear Reactors

On the other hand, rising nuclear reactor supply costs have inhibited their spread and resulted in fewer transfers than projected demand alone would have indicated. Although demand for nuclear power reactors indicates that substantial technology transfer to LDCs will continue, substantial economic forces will tend to limit this demand, particularly for other than the largest LDCs. Several factors have caused the rise in supply costs.

The desire to establish nuclear-reactor markets that would justify increased production capacity and consequent economies of scale initially motivated suppliers to follow aggressive commercialization policies. Loss-lead sales tactics based on highly subsidized contracts were used to establish markets. Poor site selection in terms of construction and operating costs, inadequate infrastructure,* inflation, currency devaluation, rising capital costs, contract deferrals over safety and environmental issues, and rising interest costs all serve to magnify losses on initial reactor contracts. The effects have been sufficient to cause contract renegotiations and subsequent contracts with far less generous terms. Furthermore, LDCs have not limited their reactor purchases to one supplier, but have sought various suppliers and fuel cycles. Failure to establish markets and the financial reversals on loss-lead contracts have led to present contracts that more accurately reflect average total production cost.

Fuel-cycle and vendor selection seem to have been significantly influenced by financing terms. LDCs initially received very favorable financing terms from supplying-nation export-import banks. These banks supported LDC exports to help establish markets that would promote LDC employment, development of advanced technology, and improved balance-of-payments. However, inflation and currency devaluations have made lending terms much less favorable; and other domestic industries are competing for the limited EX-IM Bank financing support. As a result, reactor contracts have had to be negotiated with private financing at higher interest rates.

Because industrial nations and the most industrialized LDCs require large, efficient nuclear reactors, resulting production models are generally inappropriate for all but the largest LDCs. Most LDCs cannot obtain capital, provide infrastructure, establish distribution systems, or absorb enough power-generating capacity in their small grids to justify the use of larger reactors. The level of industrialization in small countries is often insufficient to

*Infrastructure is composed of important services and facilities which LDCs rely upon, and which would be costly for each firm to provide individually. It may include water supply waste treatment facilities, transportation, educational research and engineering, financial and banking institutions, as well as management and public relations consultants.

permit nuclear-reactor operation at load capacities that make them competitive with fossil fuel and hydroelectric plants. The lack of technology and experience to handle nuclear plants will continue to impede reactor dissemination. Indeed, any skilled manpower taken from the limited total of trained workers would be subtracted from other sectors of the economy. Higher costs, recession, safety issues, environmental considerations, uncertainty of enriched-uranium supply, and financing have caused contract cancellations and deferrals.

E. Legislation and Safeguards

Finally our model indicates that nonproliferation legislation and safeguards promote international interests most effectively when they parallel economic motivations.

When initial U.S. efforts to keep nuclear technology from spreading proved futile, we reversed our policy to one of widespread dissemination of nuclear reactors. This Eisenhower "Atoms for Peace" policy was subsequently complemented by the International Atomic Energy Agency (IAEA) agreements to verify that nuclear-technology spread would be for peaceful purposes only. The IAEA has provided a forum for discussing concerns about nuclear-reactor development, and for promoting nonproliferation agreements. National commercialization interests initially appeared to dominate, as bilateral agreements included technology transfer that caused nuclear-proliferation concerns. Violations of international agreements, however, have brought censure by IAEA members and helped bring about more explicit and restrictive bilateral agreements of cooperation. Also, a suppliers group was established to set common guidelines and stimulate cooperation in supplying reactors while minimizing proliferation risks.

Large initial Organization for Economic Cooperation and Development (OECD) and IAEA estimates of demand for peaceful nuclear technology caused substantial proliferation concern. Although most industrialized nations have nuclear-power reactors, only five LDCs have operational reactors. Those LDCs are the largest and most industrialized, with established means of acquiring capital to construct reactors and with relatively large electric-power grids through which to serve commercial markets. Seventeen additional LDCs have plans to construct nuclear power reactors. While a modest increase in light-water reactors (LWRs) may be anticipated, we believe that concentration of this expansion in a few large LDCs will minimize the problem of nuclear proliferation.

F. Conclusions

Economics has dominanted the spread of nuclear reactors to LDCs. Attempts to make the spread of LWR technology deviate from what economic incentives would dictate seem to have had very little effect. Safeguarding legislation has not impeded the spread. If we allow LDCs to develop LWR technology as dictated by economic interests, the resulting modest rate of spread will not subvert nuclear-proliferation objectives.

We feel that future U.S. nonproliferation objectives must explicitly consider LDC economic motivations. Though rising supply costs have resulted in nuclear-power reactors spreading much less than initially predicted, U.S. policies must recognize LDC demand motivations. If U.S. policy becomes overly restrictive, LDCs will turn to other suppliers and thereby lower our influence substantially.

II. INTRODUCTION AND COMPETITIVE MODEL

A. Introduction

Since World War II, electric-power demand has generally expanded quite rapidly mostly to satisfy population and economic growth. At the same time predictions of dwindling fossil-fuel reserves and hydroelectric potential made some feel that nuclear power could be a panacea for the world energy problems. Initial estimates of a vastly increasing number of nuclear-power reactors throughout the world raised strong fears about nuclear proliferation. Nuclear proliferation means the spread of nuclear-weapons capability to additional nations. The nonproliferation treaty (NPT) was a response to fears that the acquisition of nuclear reactors under the "Atoms for Peace" policy had resulted in an accumulation of technology and experience that might be applied to nuclear weapons.

We argue that nations desiring nuclear weapons can obtain them more quickly and cheaply by a direct effort. The link between nuclear power technology and a nuclear-weapon capability is weak. However, U.S. policy has reflected a desire to minimize the possibility of disseminating nuclear-weapon technology. Our study focuses on the implications of LDC supply and demand considerations with regard to nuclear power technology. While problems regarding enriched-uranium supplies, safeguards, and spent-fuel management remain crucial issues they are beyond the scope of our paper.

Economics seems to have had a significant influence in spreading nuclear technology to nearly all the industrialized nations and remains a key determinant in spreading peaceful nuclear technology to LDCs. Additional forms of energy will be required to supplement energy from finite fossil-fuel and hydroelectric sources and to meet demands of growing populations, rising standards of living, and developing LDC economies. The present energy transition may be one of the most critical economic problems since the start of the industrial age. Industrialization required 200 years to reach present levels, but, if demands for further industrialization are to be met, additional energy sources will be required.

We evaluate economic incentives, nuclear-reactor status, and reactor experience to provide insights into anticipated expansion of nuclear-electrical power by LDCs. The U.S. and the U.S.S.R. installed the first nuclear-power reactors in 1954. Since then, 20 additional nations have produced electric power from operational nuclear reactors. The major industrialized nations have constructed nuclear reactors to supplement electric power from alternative sources. The future spread of nuclear power in the noncommunist world will therefore be primarily among LDCs. As LDCs have attempted to obtain nuclear power to supplement present electric-power generation, however, the transfer of technology has been much more difficult than either the supplying or demanding nations initially anticipated.

B. Competitive Model

Economics provides one of the perspectives from which we may examine the motivations for dissemination of nuclear-reactor technology. Energy is scarce and, therefore, an economic good. We can reasonably assume that industrialized nations will maintain their high-energy economies and that LDCs will try to increase their energy supply to enhance economic development. Most LDCs now face or anticipate constraining energy shortages and there is no technological fix to remove the critical constraint of energy on growth and development in the next 25 years.

The competitive-market model integrates the actions of supplier and demander nations and characterizes the behavior of free-world enterprise. The owners of scarce resources seek markets where the prices for their products are the highest. Demanders look for scarce resources at the least possible price. The demand-supply interaction establishes a total price that signals suppliers what to produce, how to produce it, and how much to produce; it signals demanders as to possible alternatives. Competitive self-serving actions see that market demands are met subject to resource availability. The market process allows estimates of how well the economic system can substitute one resource for another. The competitive model lets the economist observe and analyze supply-demand behavior and thereby provides a powerful predictive tool; it provides a reasonable basis for estimating how nations will allocate their scarce resources.

The LDC demand for nuclear power reactors is an inverse function of total price and quantity in gigawatts. In Fig. II-1, D_o shows this relationship. The demand curve D_o is shaped by the law of demand--countries will purchase more reactors at a low price than they will at a high price. The location of D_o is determined, however, by other, nonprice determinants. These include the wealth or income of the LDC; the prices of alternative energy sources; expectations as to future prices and incomes; the electrical requirements for the LDC as a whole; and "other preferences." These preferences could include safety and environmental concerns, energy independence, etc.

We show an increase in demand by shifting the demand schedule from D_o to D_1, reflecting increases due to nonprice determinants. For example, if oil prices rise substantially, LDC demand for nuclear power would increase because oil and nuclear power are substitute or competing goods. Likewise, we use D_2 to illustrate a decrease in demand due to nonprice determinants. If LDC electrical requirements fall because of, say, lower economic growth, the demand for nuclear reactors would decrease. Conversely, the supply (S_1) of nuclear-power reactors from industrialized nations follows a direct relationship between total price and quantity (gigawatts) supplied, as we illustrate in Fig. II-2.

The shape of the curve reflects the law of supply, where producers will make and offer for sale more reactors at a high price than they will at a low price. The position of the curve depends on several determinants: capital and other resource costs; infrastructure costs to support nuclear power, reactor size and economies of scale, electrical load factors, and externalities such as proliferation concerns.

We show our increase in supply by shifting the curve from S_o to S_1. If nuclear-power-plant load factors increase, for example, the electrical capacity in the LDC increases though price remains at P. On the other hand, we illustrate

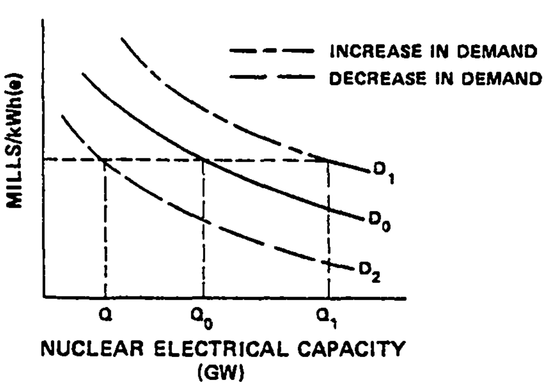

Fig. II-1.
Competitive model explains and predicts demand behavior.

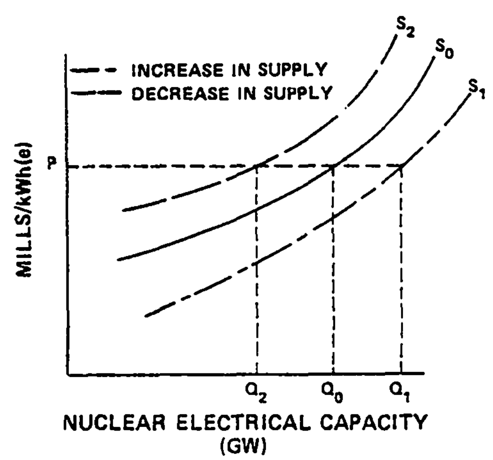

Fig. II-2.
Competitive model explains and predicts supply behavior.

a decrease in supply by shifting our curve from S_o to S_2. An example might be increases in reactor capital costs by the industrialized supply nations.

We can easily show market equilibrium by bringing our demand and supply curves together in Fig. II-3. Equilibrium or "balanced prices and quantities" occur at price P_o and quantity Q_o. Competition among power-reactor buyers (LDCs) and sellers (industralized nations) will clear the market of surpluses or shortages. At price P_1 a surplus exists--quantity supplied (Q_1) exceeds quantity demanded (Q_2). The competing industralized nations will bid reactor prices down to rid themselves of their surplus until market equilibrium is restored.

III. DEMAND MOTIVATIONS

A. Introduction

Figure III-1 describes some of the motivations that underlie LDC demand for nuclear reactors. Unlike the industralized nations, the LDCs have low per-capita incomes and to a large extent depend upon noncommercial forms of energy that allow no room for energy conservation.

B. Economic Development and Energy Consumption

In the early stages of economic development, LDCs support agrarian economies on noncommercial forms of energy such as cow dung, straw, and wood. With the transition to an industrial state and extensive manufacturing, the developing economies substantially increase their commercial forms of energy. We examined the results of several studies on the relationship between increases in gross domestic product (GDP) and energy consumption. These studies indicated that increases in GDP result in even larger increases in energy consumption. A Pan Heuristic study indicates that 87% of variation in GDP could be explained by variation in energy consumption.[1] Another study suggests that increasing GDP by 10% will increase energy demand by 13 to 16%.[2]

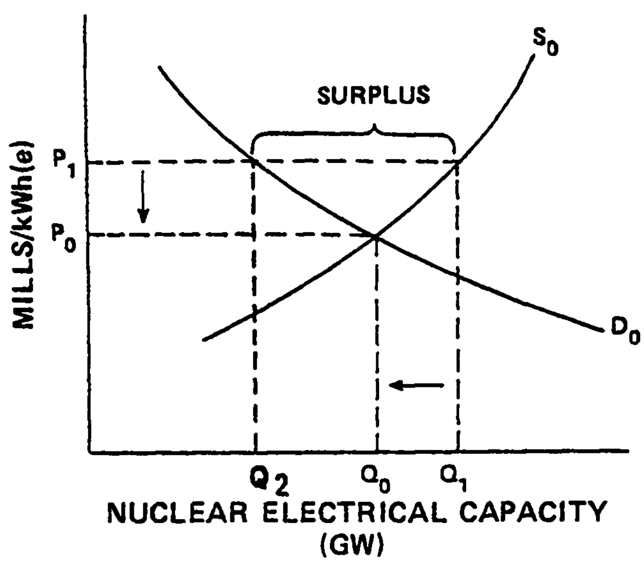

Fig. II-3.
Competition is a powerful force that clears the market of surpluses (or shortages).

- Economic development requires substantially increased energy consumption.
- Historical evidence indicates growth in electrical requirements of LDCs.
- Availability of economically competitive domestic energy sources in the LDCs is extremely limited.
- Strong desires for energy independence motivate LDCs to diversify energy sources.

Fig. III-1.
LDC demand for nuclear reactors reflects strong economic incentives.

We estimated that the developing countries increased their demand for electrical energy by over 250% between 1961 and 1971. Although this increase occurred while the price of electric energy was falling, it still represents a large increase in energy consumption. In 1971, however, 16 of the LDCs consumed 3/4 of the LDC total. Six (India, Brazil, Mexico, Argentina, South Korea, and Taiwan) accounted for over half of the total LDC electrical consumption. Though LDCs accounted for less than 10% of current world energy consumption in 1975, their rate of growth was much higher than that of industrialized nations. We believe that LDC consumption may reach 20% of the world total by the year 2000.

To meet these electrical requirements for economic growth, some LDCs turned to nuclear power. Table III-1 shows the LDCs with operational or planned reactors. Though only five noncommunist LDCs have operational nuclear-power reactors, four other LDCs are constructing reactors and an additional thirteen are planning for reactors. Our table, however, shows that only the richest LDCs can implement their demand motivations for reactors. Low income, insufficient wealth, and high population growth rates restrict the poorer LDCs.

C. Domestic Energy Alternatives

The alternatives to nuclear power substantially influence LDCs to promote nuclear technology. We found that LDCs generally have hydroelectric potential but have harnessed only a small fraction of it. This indigenous energy source has a low price at the generator and also avoids balance-of-payments problems. Unfortunately, it is very unevenly distributed and requires huge capital outlays for both dams and long-distance distribution networks. Seasonal water fluctuations, irrigation priorities, and siltation problems from flooding also inhibit hydroelectric-power generation. Although hydroelectric power will continue to be an important energy source, it will provide only a small fraction of LDC requirements by the year 2000 even with extensive expansion.

LDCs have almost no coal supplies, as about 97% of known reserves are in the northern hemisphere. Because transportation costs are a major part of total coal cost, coal becomes a very expensive source of electric energy for the LDCs.

TABLE III-1

LDC DEMAND FOR NUCLEAR-POWER REACTORS CORRELATES WITH GDP.[3]

COUNTRY*	1974 GDP (Millions of U.S. $)	GDP Increase, 1965-1973 (%)	Per-Capita 1974 GDP (U.S. $)	1974 Population (Millions)	Population Increase, 1965-1973 (%)
Brazil (c)	84,873	9.0	768	103.4	2.9
India (o)	80,051	3.5	137	586.3	2.2
Mexico (c)	65,032	6.5	1119	58.1	3.5
Argentina (o)	48,948	4.5	1954	25.0	1.5
Iran (c)	48,423	11.3	1507	32.1	3.2
Venezuela	29,568	4.5	2542	11.6	3.6
Turkey (p)	28,977	6.6	757	38.3	2.4
Saudia Arabia (p)	28,441	12.7	3267	8.7	1.7
Greece (p)	19,173	8.0	2140	9.0	.5
Indonesia (p)	17,379	6.8	264	132.6	2.1
South Korea (o)	16,862	10.9	504	34.7	1.9
Philippines (c)	14,728	5.8	355	41.3	3.0
Nigeria	13,887 ('73)	--	223 ('73)	61.3	2.7
Twaiwan (o)	13,802	10.5	709	15.5	2.6
Thailand (p)	13,252	7.4	323	40.8	3.0
Columbia (p)	12,453	6.1	520	22.9	3.2
Libya	12,284	10.5	5236	2.4	3.7
Algeria	11,561	7.0	710	16.3	3.4
Egypt (p)	9,450	3.3	264	36.4	2.5
Pakistan (o)	9,006	5.3	128	68.2	3.3
Puerto Rico	8,135	--	2685	3.0	2.6
Bangladesh (p)	7,940	0.4	100	75.0	2.8
Chile (p)	7,497	3.3	720	10.1	2.0
Peru	7,268	4.7	473	15.2	2.9
Malaysia	6,813	5.8	602 ('73)	11.7	2.8
Hong Kong (p)	6,655	7.4	1566	4.3	1.9
Morocco	6,119	4.9	362	16.9	--
Iraq (p)	5,327	5.9	483	10.8	3.3
Singapore (p)	5,160	12.7	2324	2.2	1.8
Syria (p)	3,994	6.6	561	7.1	3.3
Ethiopia	3,678	4.2	98 ('70)	27.2	2.6
Uruguay	3,668	1.4	1210	3.1	1.2
Ecuador	3,660	6.0	562	7.0	--
Tunisia	3,533	7.7	626	5.6	2.4
Zaire	3,533	5.8	146	24.2	2.8
S. Rodesia	3,386	6.6	555	6.1	3.5
Sri Lanka	3,210	4.2	235	13.7	2.2
Guatemala	3,161	6.1	555	5.9	--
Ivory Coast	3,073	7.4	644	4.8	2.5
Burma	3,057	7.2	101	29.7	2.5
Kenya	2,865	7.1	222	12.9	3.6
Zambia	2,804	2.1	590	4.8	3.2
Jamaica	2,469	6.1	1235	2.0	1.7
Dom. Republic	2,342	8.4	529	4.6	3.0

TABLE III-1 Continued

COUNTRY*	1974 GDP (Millions of U.S. $)	GDP Increase, 1965-1973 (%)	Per-Capita 1974 GDP (U.S. $)	1974 Population (Millions)	Population Increase, 1965-1973 (%)
Tanzania	2,219	5.3	155	14.8	2.9
Ghana	2,155	3.5	237	9.6	2.6
Mozambique	1,872 ('70)	6.6	228	9.0	2.3
Cameroon	1,868 ('73)	6.7	303 ('73)	6.3	1.9
Bolivia	1,866	4.9	341	5.5	2.7
Sudan	1,832	2.1	117	15.3	2.5
Trinidad	1,764	3.8	1649	1.1	--
Panama	1.740	7.6	1068	1.6	3.1
Costa Rica	1,656	6.8	862	1.9	2.6
Angola	1,645	2.4	297	5.8 ('72)	1.3
El Salvador	1,576	4.6	405	3.9	--
Gabon	1,545	8.6	2972	.5	1.0
Lebanon	1,488 ('70)	6.2	603	2.8	3.0
Nicaragua	1,483	4.5	712	2.1	3.3
Paraguay	1,333	5.1	519	2.6	2.8
Uganda	1,323	4.0	135	11.2	3.3
Nepal	1,243	1.9	101	12.3	2.3
Senegal	1,163	1.0	294	4.0	--
Jordan	1,065	0.8	407	2.6	3.3

Note: Table excludes LDCs with GDP below 1000.

*(o) = operational power reactors
(c) = power reactors under construction
(p) = power reactors planned

Imported coal exacerbates LDC balance-of-payments problems. LDCs accounted for only 5% of world coal consumption in 1975.

Oil and gas account for 75% of present world energy consumption. Oil discovery has been a dominant influence in the development of industrialized nations. It has been a particularly attractive energy source because of its low cost and easy transport and storage. The 1973 oil embargo was a vivid reminder that the supply of fossil fuels is finite and that increasing world energy demands hasten the day when alternatives to oil must be available.

Present estimates place 87% of the world's oil in the Eastern Hemisphere, and somewhere between 55 and 67% of the total world oil reserve is held by Middle East countries. While a few LDCs hold most of the world's oil reserves, most LDCs must import oil to meet energy requirements. Cheap oil had been the hope of most LDCs for promoting economic development. The 1973 oil embargo raised doubts about furthering our dependence on oil and raised fears of disruptive economic consequences stemming from our need for imported oil. The subsequent nearly fivefold increase in oil prices brought huge revenues to oil-producing countries but adversely affected oil-importing LDCs. The oil price increases took so much capital from oil-importing LDCs that economic development was restricted, as we found reflected in reduced energy consumption in many

LDCs. Because most LDCs must import oil, the shortage of foreign exchange makes the wisdom of depending on oil as the primary source of energy very questionable.

On the other hand, we see higher oil prices as an extremely important source of foreign exchange for the oil-rich exporting LDCs. Foreign exchange allows acquisition of advanced technology, which substantially enhances economic growth. Foreign oil sales combined with increased domestic oil consumption, concomitant with economic growth, can eventually deplete finite oil reserves. We believe increased industrialization must ultimately be supported by alternative sources of electrical energy. Iran is an excellent example of an oil-rich nation that initiated plans to use a part of its huge oil revenues to promote development of alternative energy sources. Mexico has stated an official government position to use its vast oil reserves to develop nuclear power and has nuclear power plants under construction. Although Taiwan has recently made substantial oil discoveries on its north and west banks, their nuclear power program continues among the world leaders. Thus oil-rich nations appear to be the LDCs most likely to develop the nuclear alternative. Their rapidly expanding GDP, expanding electrical grids, increasing markets for commercial energy consumption, and sizable oil revenue establish an economic feasibility for nuclear power plants.

We summarize that oil price increases appear to provide economic incentives for both oil-rich and oil-poor LDCs to pursue the nuclear alternative.

Major technological breakthroughs will be required to make solar energy, geothermal, and nuclear fusion commercially feasible. Most studies indicate that it is unreasonable to anticipate significant contributions from these sources before the year 2000. Fossil fuels, hydroelectric power, nuclear energy, and solar and geothermal forms of energy should not be viewed as competing forms of energy, but rather as complementary forms.

D. Energy Independence

We believe that nations desiring energy independence and economic security may become strong demanders of nuclear energy, especially when domestic fossil-fuel and hydroelectric-energy sources are inadequate. By diversifying its energy sources, a country becomes more energy-independent, promotes its economic growth, and minimizes destabilizing external influences. For example, inflated oil prices after the 1973 oil embargo affected most LDC economies adversely. With 70% of its cost in the initial investment, nuclear energy is relatively insensitive to fuel price increases as compared with other energy sources.

The desire for energy independence is important for LDCs that have operational reactors as well as for those planning and constructing reactors. The selection of CANDU reactors was in part influenced by the desire for energy independence. Most countries have natural uranium, the fuel required for CANDU reactors. These reactors promote sustained economic growth, by providing an independent source of energy free from foreign embargoes and inflated fuel prices. We also see the desire for energy independence as a basic argument by countries desiring to develop fuel enrichment, fabrication, heavy-water production, and, ultimately, fast-breeder reactors.

E. Demand Applications of Competitive Model

Our competitive model can graphically display the demand motivations we discussed above. We will analyze the effects of five nonprice determinants on the demand curves for nuclear-power reactors.

In our Fig. III-2, we assume that D_0 gives the starting demand by LDCs for nuclear-power reactors.

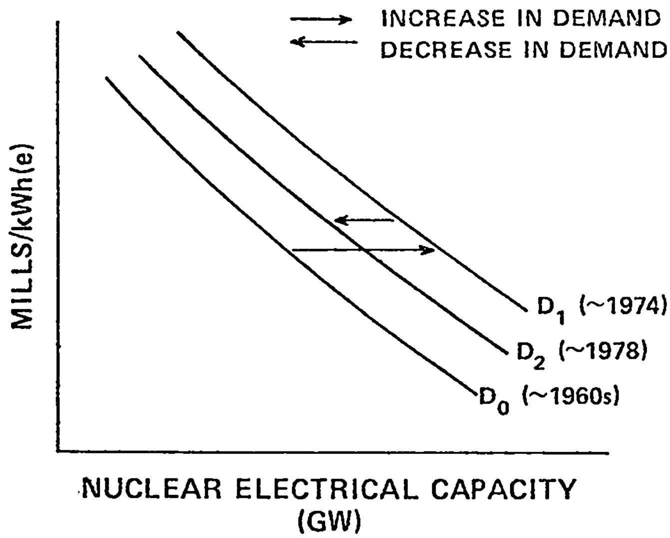

Fig. III-2
Demand motivations have led to an increase in demand for nuclear reactors.

By the early 1970s, optimistic estimates indicated that the LDCs would be creating a strong demand for nuclear power, as shown by the shift from D_o to D_1.

One determinant was the higher price and lower availability of alternative electric-energy sources. As the prices of alternative sources have risen, particularly because of the oil cartel, the demand for nuclear power has risen. Demand is further heightened by expectations of future oil price increases and by LDC preferences to achieve energy independence through nuclear power. Thus, the shift from D_o to D_1. Furthermore, some analysts would maintain that the externality of nuclear weapons (that is, obtaining a nuclear power plant can be a significant way to obtain nuclear material for weapons) would cause demand to increase. We show later that this route is an expensive one and, hence, a weak link when given the many other routes to nuclear weapons.

On the other hand, the oil cartel has significantly lowered the wealth and income of the oil-importing LDCs. This income effect may have substantially or completely reversed the substitution effect of using nuclear power instead of oil to generate electricity. We show this decrease in demand by moving from D_1 to D_2.

Because LDCs depend on oil for 75% of their commercial energy supply, the increased oil prices have affected their economies sharply. LDCs that depend on oil imports have been faced with larger balance-of-payments deficits and absorption of funds that could have been used to purchase western technology and expand production capacity. Higher oil prices have also contributed to a severe and extended recession among LDCs during the mid-1970's. Forced reductions in energy consumption have contributed to slower economic growth.

In summary, Fig. III-2 shows that the conflicting demand motivations have probably led to an overall increase in demand for nuclear reactors, as shown by the modest increment from D_o to D_1 and finally back to D_2. We show, however, that this increase in demand is less than that earlier predicted because of the loss of income to the oil-exporting LDCs. Furthermore, the supply constraints we discuss below have affected the trade in nuclear power reactors.

IV. SUPPLY CONSTRAINTS

A. Introduction

In 1978, the International Atomic Energy Agency (IAEA) lowered its estimate of total LDC nuclear-power reactors to 50% of its 1974 estimate. Furthermore, the Organization for Economic Cooperation and Development (OECD) recently reduced its world estimates of nuclear-power-reactor capacity in 1985 from a range of 479 to 530 GWe to a range of 277 to 368 GWe and, for the year 2000, from a range of 2005 to 2480 GWe to a range of 1000 to 1890 GWe. Iran's order for nuclear reactors in mid-1978 was the first order by an LDC in 18 months.

Our previous section showed that LDC demand motivations are still strong, though not as strong as in the era before the oil cartel. We now demonstrate in our competitive model that decreases in supply due to rising costs and due to nonprice determinants have shifted market equilibrium to a lower level. Our Fig. IV-1 summarizes these factors.

B. Infrastructure

We found infrastructure a dominant influence on the success of nuclear-energy programs in LDCs with operational nuclear reactors and a strong factor in the desirability of nuclear-energy programs in LDCs planning and constructing nuclear reactors.

LDCs acquiring their first reactor incur the auxiliary costs of transport systems, harbors, housing, and personnel training. Establishing electric-power distribution grids can cost more than construction of the nuclear-power reactors themselves.

Nuclear power is unique in its greater dependence on human resources instead of natural resources. We found that LDCs with nuclear-power reactors

- Inadequate infrastructure requires substantial investment.
- Reactor capital costs have risen substantially.
- Small reactors involve poor economies of scale.
- Suppliers have discontinued loss-lead policies.
- Operation and maintenance (O&M) load factors have been relatively low.
- Externalities or spillover benefits have been lower than expected.

Fig. IV-1
Rising supply costs have inhibited spread of nuclear reactors.

invariably required highly qualified manpower. The most successful LDC nuclear programs were those whose planning called for prior operational experience with research reactors. Argentina's experience with research programs has resulted in substantial technological and manpower expertise. India's emphasis on training is a distinctive characteristic of its program, which graduated over 3000 engineers and scientists in nuclear design and research-reactor operations and which included a separate school at Rajasthan for nuclear power reactors. We found that programs (especially "turnkey" programs) that had not provided extensive manpower training experienced greater delays and larger cost overruns in construction and initial operation of power reactors.

Our review of LDC operating experience with nuclear power reactors reveals that external distribution, insufficiently trained personnel, inadequate development of industrial and engineering infrastructure, and deficient equipment support have major adverse effects on program success.[4] While the IAEA provides information and guidance, it has neither the authority nor the ability to establish and supervise minimum training and operational levels of capability. The inadequacy of LDC infrastructure during nuclear-reactor construction and operation has been particularly perplexing and has contributed to low load factors and much higher electrical costs than anticipated. E. I. Goodman found that reactor outages have more often been due to failure of infrastructure rather than failure of the reactor itself.[5] Dr. D. B. Nag Chaudhuri made this same observation in his study of India's experience with nuclear-power reactors.[6] He found that infrastructure significantly affects reactor operation. Nuclear power was initially twice as costly in India as electric power from coal. By 1978, after several years of experience, nuclear power was slightly more than twice as expensive. Dr. Chaudhuri concluded that infrastructure failures were significant elements in low load factors, which contributed to the inability of nuclear power to remain competitive with coal.

Figure IV-2 illustrates the effects of the above factors. Our competitive model demonstrates that inadequate infrastructure equates to a decrease in supply from S_o to S_1, and equilibrium occurs at lower quantities and higher prices. We see this as one reason why LDC demand for nuclear-power reactors is lower than previously estimated.

C. Reactor Capital Costs

Over the past decade, we estimate that the capital cost of a 1000-MWe nuclear reactor has increased from a range of 200 to $300 million to about $1 billion. For example, Iran purchased four reactors from France for about $4 billion in 1978.[7] Though this appears to reflect an average world market price for a 1000-MWe reactor, we find it very difficult to generalize estimates of capital costs because of the variability of industrial and labor infrastructure, site conditions, scope of supply, type of contract, and financing terms. We think it is clear, however, that capital costs have increased substantially and contributed to reduced trade in power reactors for LDCs. We again show these effects graphically in Fig. IV-3.

Because the costs for constructing new reactors have risen dramatically in the last decade, reactor suppliers can offer a given electrical capacity only at higher prices. The overall effect is to move equilibrium to a point representing higher prices (P_1) and lower quantities (Q_1).

Among the most important factors in rising capital costs have been environmental and safety concerns that delay the construction and operation of nuclear reactors. Regulations have approximately doubled the capital and manpower costs associated with concrete, steel pipes, and cables. These elements alone have doubled the cost of nuclear reactors.[8] Because licensing requirements apply at

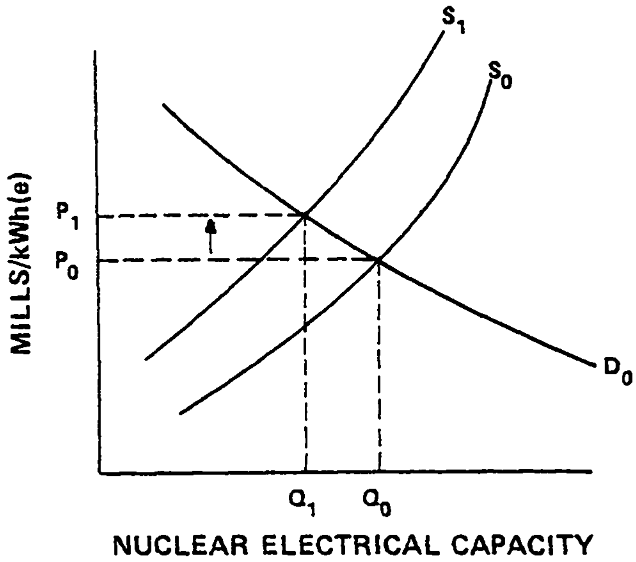

Fig. IV-2.
Insufficient infrastructure has contributed to higher electrical costs.

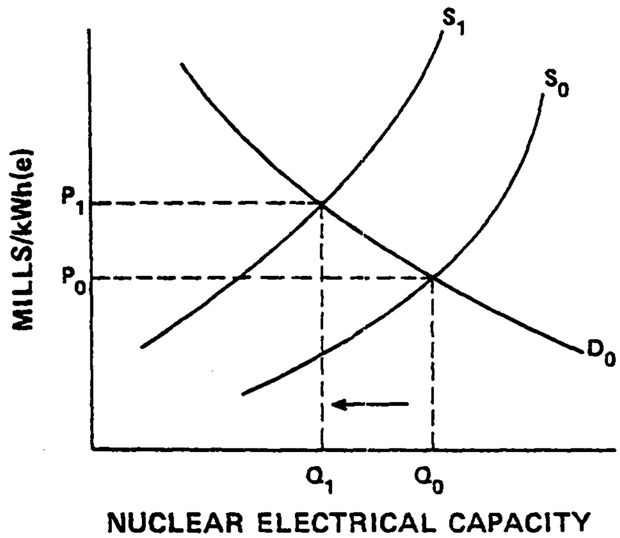

Fig. IV-3.
Rising reactor capital costs have lowered supply of nuclear reactors.

the point of reactor production, LDCs can not avoid cost increases. The IAEA suggests that capital-cost increases resulting from environmental and safety protection requirements may have peaked. If so, a reduction of licensing procedures for standardized units may permit nuclear stations to achieve the savings inherent in the up-to-now elusive learning curve.[9]

As environmental and safety concerns slowed reactor construction and as infrastructure inadequacies delayed construction and operation, we found that the LDCs also incurred substantially higher financing costs. Higher interest rates and capital costs have both contributed substantially to large cost increases for nuclear reactors. The result has been further uncertainty and delay for LDCs pursuing the nuclear option. Unavailability of capital while capital costs for nuclear reactors have been rising rapidly has been a major deterrent to reactor acquisition. We also found that, as capital costs increased, the LDCs found it more difficult to obtain the necessary foreign exchange.

D. Reactor Size

Nuclear-reactor size strongly affects electricity costs and, therefore, nuclear power competitiveness. IAEA estimates indicate that, even without adding first-of-a-kind costs, 600-MWe nuclear-power plants are not competitive with oil-fired plants at 1977 costs. We saw that the primary fixed costs associated with reactor capital costs depended largely on reactor size. As nuclear-power technology has progressed, the production size of nuclear reactors has increased to take advantage of economies of scale. Figure IV-4 shows that, as nuclear-reactor size increases from 600 to 900 MWe, nuclear energy gains a competitive edge.[10] E. I. Goodman has also confirmed the economic disadvantage of nuclear-power plants of 600 MWe or less capacity.[11] Current production-model capacities are at least 600 MWe and are generally 800 MWe.

We found that the large size of current nuclear-reactor production models poses a number of problems for LDCs. The limited market for electricity in all

	LWR 600 MWe	LWR 900 MWe	Oil-Fired Plants 600 MWe	Oil-Fired Plants 900 MWe
Plant Investment ($/kW)[1]	1150	910	540	510
Generation Costs (mills/kWh)[1]				
Capital[2]	24.2	19.2	11.2	10.8
Fuel	7.0	6.8	18.3[3]	18.3[3]
O + M	2.2	2.0	1.4	1.2
Total	33.4	28.0	31.1	30.3

[1]All costs are in constant U.S. mid-1977 dollars.
[2]65 percent plant factor, 12 percent annual charge.
[3]Based on high sulphur fuel oil at $11/barrel.

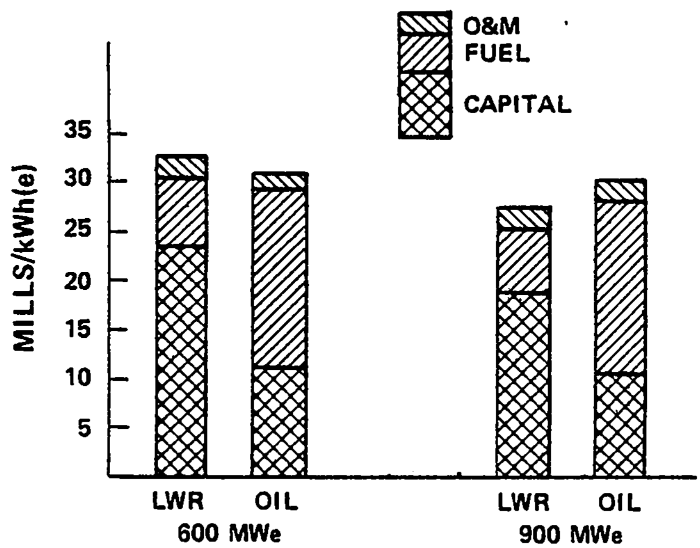

Fig. IV-4.
Reactor size directly influences its competitiveness.

but the largest LDCs contributes to low load factors for large reactors and reduces the competitiveness of nuclear power. Operational experience in LDCs indicates that nuclear reactors have significant outages for maintenance and refueling. While a reactor is down, an alternate source of energy must be available. We therefore believe it is unwise to have one unit of electric-energy generation provide over 15% of total generation. For example, if an 800-MWe nuclear reactor is part of a system, the total capacity for the LDC should be about 5000 MWe, which is much more than most LDCs consume in their entire country.

Large-capacity reactors have high capital costs and require a very expensive grid to support an extensive market. Only the largest LDCs have the capital and markets to warrant use of present production models. The IAEA has recommended the development of small reactors (400 MWe or less) to meet the needs of selected American markets and the smaller grids of LDCs. A proposal at an advisory group meeting in Athens in 1977 favored making small reactors more competitive by standardizing the design and producing a series of units. The Babcock and Wilcox Corporation has developed expertise with small reactors for merchant ships and is aggressively pursuing development of 400-MWe reactors. They argue that large reactors have not achieved desired economies of scale, their construction costs have increased rapidly, and smaller reactors could become operational two to three years sooner than larger ones, with considerable initial capital savings.[12] But in December 1978, Babcock and Wilcox indefinitely suspended small nuclear reactor development based upon "abounding uncertainties over nuclear power expansion in view of estimates of 10 years required to commercialize the CNSS concept."[13] We also found that a French firm is developing a 125-MWe, completely shop-fabricated reactor and has a prototype in operation at the Cadarache Centre in France. These reactors must obviously meet national safety standards.

The most serious problem with small-reactor development is a very limited market, generally in the smaller LDCs. Small reactors have not yet demonstrated that they are competitive with larger reactors or with coal (see Fig. IV-4). Finally, most LDC reactors are purchased by the largest LDCs, who still favor larger and more efficient reactors.[14]

E. Financing and Loss-Lead Policies

Most LDCs have access to nuclear technology and fuel only through imports from a still-small number of supplier nations. The primary suppliers of nuclear power reactors at present are the U.S., USSR, U.K., France, West Germany, Canada, Sweden, and Japan. Italy and India have expressed strong desires to become nuclear suppliers. Brazil and South Korea have offered limited supply assistance to other LDCs. When the nuclear-supplier group met in January 1978, 15 nations attended to establish guidelines for nuclear-technology transfer. We believe that supplying nations have a dominant influence on the dissemination of nuclear power technology to LDCs.

Since the drafting of the NPT (Nonproliferation Treaty), a major source of concern has been the degree to which commercial nuclear-industry interests would erode the treaty. The fact that domestic markets do not totally absorb the production capacity of private nuclear-reactor producers magnifies the competition among these producers. For example, a 1977 U.S. government estimate indicated U.S. companies could produce four times the then-current domestic requirement. Private firms have found that substantial economies of scale attend the mass production of nuclear reactors, and we found that suppliers of nuclear power reactors have consequently pursued aggressive marketing policies to establish export markets. The desire was for export markets to provide an outlet to absorb excess capacity. Marginal pricing was practiced to obtain markets to gain some return on high R&D costs while producing at optimum levels. Generous financing provisions helped in obtaining contracts. Low-priced preferential access to nuclear fuels was also considered essential to establish markets.[15] These policies, which have been referred to as "loss-lead," have provided reactor systems to LDCs under highly subsidized terms.

Since the negotiation of initial contracts, nuclear-reactor suppliers have undergone substantial increases in production costs, as discussed earlier. Regulations requiring safety and environmental modifications on nuclear reactors must be observed for both export and domestic production. Lack of geological expertise has resulted in poor site selection. While the sites selected by LDCs have not resulted in major safety problems, they have contributed to construction delays and expensive modifications. Infrastructure inadequacies have contributed to delays in attaining reactor operational status and to unanticipated high maintenance costs. High inflation rates in LDCs and subsequent currency devaluations have necessitated renegotiations of initial contracts because of financial hardships on both supplying and demanding nations. It is widely accepted that German, U.S., and Canadian vendors of nuclear power reactors have incurred substantial losses while attempting to establish nuclear-power-reactor markets.[16] Most suppliers no longer extend fixed-price "loss-lead" offers because of the substantial losses on initial reactor sales.[17]

Other factors have also altered supplier attitudes toward "loss-lead" policies in reactor sales. After initially purchasing nuclear technology from one country, India, Argentina, and Taiwan purchased additional nuclear technology from other countries, thereby bringing the wisdom of "loss-lead" policies into question. South Korea and Mexico also appear to be diversifying their nuclear fuel cycle and their nuclear suppliers.

We believe another factor of substantial importance has been the increase in oil prices. Higher prices allowed reactor suppliers to discontinue unsuccessful "loss-lead" policies and negotiate reactor sales contracts that reflect market costs, while still remaining competitive with alternative energy sources such as the oil-fired plants.

F. Operation and Maintenance

Operation and maintenance costs plus fuel costs for a 900-MWe reactor account for about 30% of total nuclear power costs when reactors are operating at or near their designed load capacity. We found that reactor utilization rate significantly affects nuclear-energy cost. If the utilization rate drops to 60% or less, other forms of energy generally become more efficient.[18]

Argentina achieved an excellent load factor of 85.9% in 1976, but India's load factors have ranged only from 30 to 60%. The other LDCs with operational nuclear-power reactors have had load factors around 30%. Operational experience in LDCs shows that nuclear-energy competitiveness has been hampered by the inability to maintain reactors in operable condition.

G. Uranium Supply

Authoritative estimates of assured and probable uranium reserves (U_3O_8 at or below $30/lb) are 5.4 million tons,[19] more than twice the requirement associated with 1000 GWe of installed capacity in the year 2000.[20] The OECD released an estimate in February 1978 reducing by 42% its earlier estimate of installed nuclear power capacity in 1985. The same report raised by 48% the OECD estimate of world reserves of low cost uranium.[21]

Fuel costs for nuclear power are surprisingly small. Uranium accounts for only 5 to 10% of the cost of electricity at the power plant. In 1970, the cost of uranium was about $6/lb. By 1978, uranium under contract was averaging about $20/lb, though spot orders had reached 40 to $43/lb. The effect was to raise the overall cost of electricity by about 20%. Nuclear-fuel costs would have to change by 50% to have the same effect as a 20% change in the capacity factor or the capital costs. We conclude that higher uranium costs have not significantly affected nuclear-reactor sales.

H. Externalities

While the dominant factor in LDC acquisition of nuclear-power reactors is to satisfy demand for electricity, highly desirable spillover benefits or externalities have also been anticipated. The effect of these externalities would be to lower the real costs of nuclear electric energy and cause the supply curve to shift right, and result in equilibrium at a lower price and a higher capacity.

We think that many countries have expected progress to follow quickly after acquiring modern, energy-intensive technologies; but experience with nuclear-reactor acquisition has introduced a note of caution. "Turnkey" projects depend on foreigners for construction, technology, and initial operation. "Dualism" often exists, with an isolated modern sector benefiting a narrow spectrum of people in the midst of a large traditional economy. An expectation that large-scale desalination of sea water would provide a major externality has diminished as the economies of desalination with nuclear power have failed to materialize.[22] Indeed, nuclear power could prove a negative externality to LDCs by absorbing economic and manpower resources vital to other sectors of the economy.

V. PROLIFERATION POLICIES

A. Introduction

We summarize our paper by combining the demand and supply curves to explain historical price-quantity relationships. Our competitive model then predicts future equilibrium relationships. We discuss ways that future LDC imports of nuclear technology might affect weapon proliferation and find a weak linkage. We conclude in Fig. V-1 that future U.S. nonproliferation policies must incorporate economic considerations to be effective.

B. Policies before Mid-1970's

The export of nuclear technology, materials, and facilities could bring substantial economic advantages to supplying nations. Some experts have estimated that nuclear-reactor sales may exceed the value of aircraft-industry sales. Anticipated benefits in foreign policy, commercial development, national security, gross domestic product, employment, and balance-of-payments have influenced

- Atoms-for-peace program worked during era of strong LDC demand and low supply costs.
- Nonproliferation treaties and safeguards are acceptable during present period of high supply costs.
- Link between power-reactor trade and nuclear-weapon proliferation is indirect and weak.
- Overly restrictive U.S. positions will cause LDCs to seek alternative suppliers if economic benefits are high.

Fig. V-1
Nonproliferation legislation and safeguards promote international interests most effectively when they parallel economic motivations within the framework of the competitive model.

governments to promote policies of assistance to their private nuclear suppliers. These policies have included access to restricted information, provision of materials and services, preferential treatment for international markets, easing of intergovernmental regulatory procedures, and low-interest financing.

The Baruch Plan, however, attempted to "outlaw" atomic energy in all forms in the early days. This U.S. attempt to restrict nuclear-technology export was rejected by the U.S.S.R. America's restrictive policy did not stop the U.S.S.R. and U.K. from developing atomic weapons. President Eisenhower rejected the U.S. restrictive atomic-energy policy and established "Atoms-for-Peace," which promoted the dissemination of nuclear technology for peaceful purposes.

An attempt to control the spread of nuclear technology by international agreement was initiated in 1957 with establishment of the IAEA. The IAEA established a safeguards system that required nations to file regular detailed reports on their civilian nuclear activities. It further provided that an international inspector would visit nuclear facilities to verify these reports and ensure that no materials had been diverted from civilian to military purposes. The IAEA was to complement "Atoms-for-Peace" by providing safeguards for identifying any nuclear technology transferred for peaceful energy production but diverted to military purposes. Although the safeguarding role has expanded considerably, the IAEA safeguard system is limited by not including physical security as a safeguard function. It also lacks authority to prescribe minimum standards for the national systems of material accounting and management, which it must depend upon heavily in carrying out its function.

The Nonproliferation Treaty (NPT) signed in 1968 and effective in 1970 reflected international desire to limit the spread of nuclear weapons. Before the NPT, only imported nuclear technology was subject to safeguards; domestically produced facilities thus remained outside the safeguards. Ninety-eight nations that signed the treaty agreed not to develop or aid the development of nuclear weapons in nonnuclear weapon states and to put all nuclear facilities under safeguards. Initially, the IAEA and NPT appeared to be effective in limiting horizontal proliferation. The Indian explosion of a "peaceful" nuclear device in 1974 and the oil embargo with its subsequent near-fivefold increase in oil prices created widespread insecurity and brought into question the success of national and international attempts to mitigate nuclear proliferation.

These above policies were not so restrictive as to impinge upon the economic motivations of both the suppliers and the LDC demanders of nuclear energy. As we show on Fig. V-2, the "Atoms for Peace" era was a period of increasing demand motivations and falling supply costs. Prices fell from P_o to P_1, and the demanded capacity rose from Q_o to Q_1, as shown by the increase in demand (D_o to D_1) and the increase in supply (S_o to S_1).

Optimistic projections calling for ever-larger trade in nuclear reactors were made, even as fears of widespread weapon proliferation grew. Though restrictive nonproliferation policies were called for, changing economic factors discussed below became the main reasons for a greatly decreased trade in nuclear reactors.

C. Present Policies

The Nuclear Nonproliferation Act of 1978 was the culmination of nearly three years of legislative effort in the U.S. to promote stringent safeguards over our nuclear exports. Under this act, any nation that agrees to forgo weapon development and to accept a system of international safeguards consisting of inspection and verification through materials accounting can obtain nuclear reactors for electrical power from the U.S. After an 18-month transition period, the U.S. legislation will permit continued supply of nuclear reactors only so long as the receiving country accepts international inspectors to safeguard all its facilities. This legislation, often referred to as "de facto full-scope safeguards," exists today in all but five nonweapon states that have received or may receive U.S. nuclear materials: India, Egypt, Argentina, Israel, and South Africa.[23] We found that the recent negotiations to sell several nuclear reactors to Iran fell under the guidance of the Nuclear Nonproliferation Act of 1978 and did not appear to be hindered by the act.

We believe that recent agreements between demanders and suppliers of nuclear technology indicate that these bilateral agreements reflect the spirit and intent of the international agreements to limit nuclear proliferation. Agreements that were negotiated to include complete fuel-cycle facilities have been extensively criticized for the transfer of technology that contributes directly to nuclear proliferation, and they have been renegotiated. While recent agreements of cooperation for nuclear-power reactors incorporate safeguards, the general intent of "Atoms for Peace" and of IAEA promotion of nuclear technology for peaceful purposes does not appear to have been hampered.

We again state that economic considerations are overriding. As we showed in Section IV and illustrate in Fig. V-3, many rising supply costs have substantially lowered nuclear-reactor trade since 1975. Rising supply costs due to the factors mentioned previously have shifted the supply curve from S_o to S_1, causing an increse in price (P_o to P_1) and a decrease in quantity (Q_o to Q_1). We postulate that these economic reasons are what explain the acceptability of recent international agreements to limit nuclear proliferation.

D. Nuclear-Weapon Proliferation

A major fear is that LDCs that obtain nuclear-power reactors will use the fissionable material and the imported technology to build nuclear weapons. We state that this is possible; in fact, any nuclear fuel cycle can be modified to produce fissile material and serve as a foundation for building nuclear weapons. We further state that, although technological fixes can lessen the danger of weapon proliferation, they cannot by themselves prevent it.

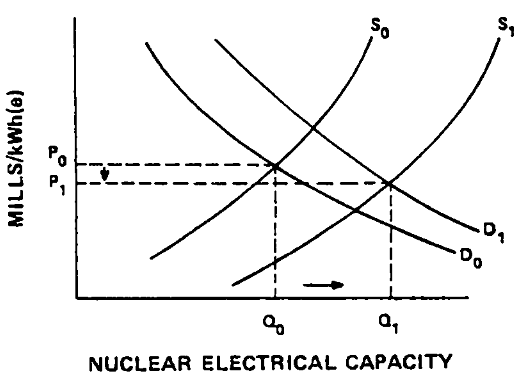

Fig. V-2.
Demand motivations and subsidized supply costs led to sizable reactor trade before mid-1970's.

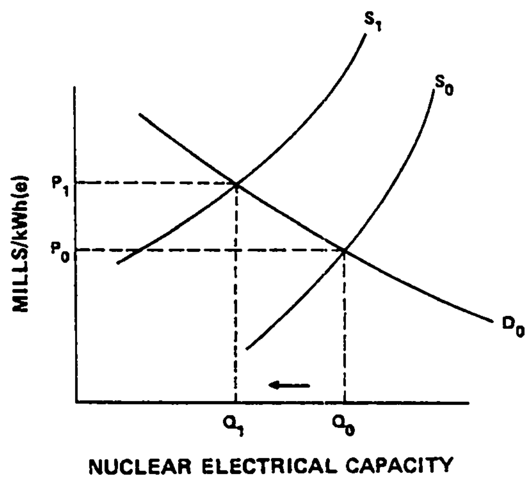

Fig. V-3.
Rising supply costs have made recent nonproliferation agreements acceptable.

We simply state that there can be a link between nuclear power reactors and nuclear weapons. But we again assert that economic factors are of overriding importance. To produce nuclear bombs by using the nuclear power path involves more expense, time, and expertise than any of the other seven paths not involved in power production. The other paths do not use nuclear power plants and are cheaper, shorter, and generally less sophisticated.

Economics is a powerful motive. A country wanting nuclear weapons can produce them by several routes that are more efficient than the nuclear power route. The link between production power plants and nuclear weapons is weak and tenuous.

We examined numerous references.[24] All but one support our assertion that the link between production power plants and nuclear weapons is weak. The single exception is the Pan Heuristics study[25] which asserted the political benefits of surreptitiously producing fissionable material under the guise of nuclear power production. But our other references do not support this conclusion. Beckmann points out that "nuclear proliferation has little, if anything, to do with power generation."[26] He uses the following facts to support his statement: (1) plutonium can be bred from the abundant ^{238}U by several paths without going to the large additional expense of producing power at the same time; (2) uranium can also be enriched to weapons grade, with moderately advanced technology; (3) laser enrichment may eventually prove feasible, and become an extremely cheap means of producing bomb-grade material.

Beckmann further shows that producing fissionable material under the guise of a power industry is naive. It would be the first place that the IAEA would look for infractions. In any case, political motives of the Soviet Union may lead them to provide or sell material directly to LDCs or "national liberation movements."[27]

Even the antibreeder Ford Foundation report concludes: "The United States is not in a position to stop the expansion of nuclear power. Moreover, advanced countries, and some developing countries, are not dependent on nuclear power to produce nuclear weapons. None of the present nuclear weapons states developed its weapons through nuclear power. Each followed the direct path of producing the fissionable materials in facilities designed specifically for the purpose."[28]

Westinghouse Electric evaluated 11 alternative routes to nuclear weapons: centrifuge isotope separation, research reactors, mass spectograph isotope separation, graphite pile, heavy-water reactor, diffusion isotope separation, laser isotope separation, Candu reactor, HTGR, LWR, and LMFBR. Table V-1 gives this evaluation. Note Columns 8-11, the power production routes, particularly Column 10 for our analysis. In terms of resources, these paths require high to very high amounts. Without reprocessing, the accessibility of fissile material is very low, except for the LMFBR. Finally, and we think most important, are the very high costs involved, and the long time before fissionable material becomes available. An examination of Column 2, the research reactor path, shows that resource requirements are low to moderate, and costs are low. We quote: "None of the routes is absolutely infeasible. Each country weighing the option of nuclear weapons capability would have different starting points, perspectives, and needs. Nothing can be categorically stated, but the least likely choice for a country interested in nuclear weapons capability would seem to be the costly and time-consuming route of national electric power program. Each present nuclear bomb country obtained its weapons material from reactors expressly dedicated to that purpose, and not from fuel from a power reactor fuel cycle. The bomb countries had weapons long before they had civilian power plants. China still has no civilian power but has exploded many test bombs. India took its plutonium from a research reactor through a limited capability reprocessing plant

TABLE V-1

THE NUCLEAR POWER ROUTE NO. 10 TO NUCLEAR WEAPONS IS THE MOST COSTLY AND TIME-CONSUMING ROUTE.[29]

Routes to Proliferation → / Evaluation Factor ↓	1 Centrifuge Isotope Separation (Uranium)	2 Research Reactors (Plutonium)	3 Mass Spectrograph Isotope Separation (Uranium)	4 Graphite Pile (Plutonium)	5 Heavy-Water Reactor (Plutonium)	6 Diffusion Isotope Separation (Uranium)	7 Laser Isotope Separation (Uranium)	8 CANDU Reactor (Plutonium)	9 HTGR (Uranium)	10 PWR/BWR (Plutonium)	11 LMFBR (Plutonium)
RESOURCES											
Technological Sophistication	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	VERY HIGH	HIGH	HIGH	HIGH	VERY HIGH
Facilities Requirement	MODERATE	LOW	MODERATE	LOW	MODERATE	MODERATE	LOW	HIGH	HIGH	HIGH	VERY HIGH
Instrumentation Capability	MODERATE	MODERATE	HIGH	HIGH	HIGH	HIGH (Many Stages)	MODERATE	VERY HIGH (Reprocessing)	MODERATE	VERY HIGH (Reprocessing)	VERY HIGH
Personnel Requirement	MODERATE (200–500)	LOW (~50)	MODERATE (200–500)	LOW (~100)	MODERATE (100–200)	MODERATE (200–500)	LOW (10–50)	HIGH (2000–10,000)	HIGH (2000–10,000)	HIGH (2000–10,000)	HIGH (2000–10,000)
DIFFICULTY OF ROUTE											
Availability Of Information	MODERATE	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	MODERATE	VERY LOW	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Accessibility of Fissile Mass	HIGH (Nat U)	MODERATE	HIGH (Nat U)	MODERATE (Low Burnup Pu)	MODERATE (Low Burnup Pu)	HIGH (Nat U)	HIGH (Nat U)	VERY LOW (Reprocessing)	HIGH (1st Core)	VERY LOW (Reprocessing)	VERY LOW
COST AND SCHEDULE											
Cost	MODERATE ($\$10^8$)	LOW ($\$10^7$)	MODERATE ($\$10^8$)	LOW ($\$10^7$)	MODERATE ($\$10^8$)	MODERATE ($\$10^8$)	LOW ($\$10^7$)	VERY HIGH ($\$10^9$)	VERY HIGH ($\$10^9$)	VERY HIGH ($\$10^9$)	VERY HIGH ($\$10^9$)
Schedule (years to completion)	VERY HIGH (>12)	VERY LOW (Now)	VERY HIGH (>12)	MODERATE (4–7)	MODERATE (4–7)	MODERATE (4–7)	VERY HIGH (>12)	HIGH (8–12)	HIGH (8–12)	HIGH (8–12)	VERY HIGH (>12)
RISKS											
Risk to Personnel	LOW	HIGH	LOW	HIGH	HIGH	LOW	LOW	HIGH	LOW (1st Core)	VERY HIGH	VERY HIGH
Risk to Project Detection	MODERATE	LOW (Low Accountability)	HIGH	LOW	HIGH	MODERATE	VERY LOW	MODERATE	LOW (1st Core)	HIGH (Recycle)	HIGH
WEAPON CAPABILITY											
Rate of Fissile Production	HIGH	VERY LOW	VERY LOW	LOW (1 wpn/yr)	LOW (1 wpn/yr)	LOW (small plant 3 wpns/yr)	HIGH (23 wpns/yr)	MODERATE (8 wpns/yr)	VERY HIGH (1st Core)	HIGH (14 wpns/yr)	HIGH (11 wpns/yr)
Weapon Reliability	VERY HIGH (Enr U)	HIGH (Low ^{240}Pu)	VERY HIGH (Enr U)	HIGH (Low ^{240}Pu)	HIGH (Low ^{240}Pu)	VERY HIGH (Enr U)	VERY HIGH (Enr U)	LOW (much ^{240}Pu)	VERY HIGH (Enr U)	LOW (much ^{240}Pu)	LOW (Coprocessed Pu)

and not from its LWR Tanapur plant. Many of the 46 nations with research or power reactors possess the personnel, organization, infrastructure and resources to acquire at least a primitive nuclear weapon capability."[29]

We reiterate that economics is a powerful motive. An LDC desiring a nuclear weapons capability using internal means would be motivated to obtain fissionable material through a research reactor, not a national power program. If external supplies of material become available to LDCs through China, the Soviet Union, or another country, then the problem becomes a political one requiring strong political actions by the United States. Restricting sales of nuclear power plants to LDCs that need them should not be a part of this policy.

E. Future Policy

Our future policy must include the proper mixture of nonproliferation safeguards yet recognize that economic motivations will be the predominant impetus driving nuclear-power transfers.

Recent restrictive pronouncements on nuclear-power transfers have been palatable because of rising supply costs. Overly restrictive or unilateral U.S. steps to halt completely our nuclear power exports to LDCs will be self-defeating, especially if demand motivations rise in the future. The LDCs will turn to other suppliers, circumventing safeguard controls by the U.S. To maintain safeguard controls, the U.S. must be an active supplier of power reactors to LDCs. Our future policy must reflect the economic realities of the energy crunch on the LDCs.

We showed that rising supply costs have made nuclear power trade decrease significantly in the latter half of the 1970's. We foresee a modest spread in power reactors that will not be counter to nuclear-proliferation objectives.

Our future policy must recognize LDC economic motivations. An overly restrictive U.S. policy will force demanders to seek alternative suppliers, as we show in our Fig. V-4.

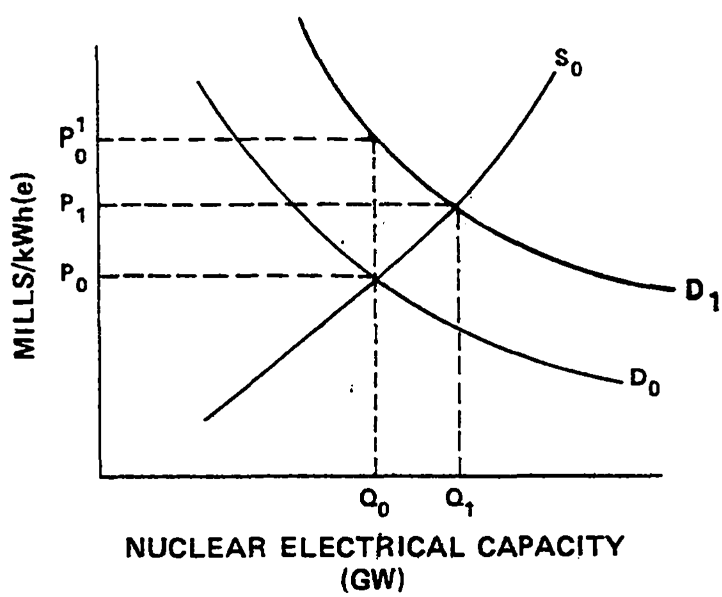

Fig. V-4.
If LDC demand rises, attempts by one country to constrain capacity at Q_0 will fail because other suppliers will step in.

Here we show equilibrium at price P_o and quantity Q_o. If alternative energy sources become more costly in the future, LDC demand for nuclear energy will rise from D_o to D_1. Market equilibrium will then occur at a higher price P_1 and a higher quantity Q_1. Our policy, with adequate safeguards, must recognize that a nuclear capacity of Q_1 will be demanded by the LDCs and supplied by the developed nations. A unilateral decision by a supplying nation to artifically limit capacity at Q_o (with a resultant higher world price at (P_o^1) will limit its future nuclear power reactor sales and thus degrade its influence upon safeguard controls. Other nations will become the principal suppliers of nuclear power reactors, perhaps with a lower safeguards technology or more liberal views on safeguards.

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APPENDIX

NUCLEAR-POWER-REACTOR SUPPLIES

Table A-1 shows that the United States has been the leading foreign exporter of nuclear power reactors. Westinghouse and General Electric have been the primary suppliers of the 57 reactors that had been ordered through April of 1977. The light-water-reactor technology developed by these two companies dominates the world nuclear-reactor market. These two companies have pursued aggressive marketing policies, and we found that their reactor production and sales have included the most rigid safety and environmental standards. In compliance with U.S. nonproliferation policies, American companies have marketed neither enrichment nor reprocessing technology.

The U.S. initiated a very aggressive marketing approach that included subsidized reactors offering strong incentives to LDCs. The U.S. Ex-Im Bank offered loans at 4.5% interest to be paid over 15 years and commencing only after completion of construction. The AEC agreed to guarantee the enriched-fuel requirements for 20 years and the quality of the fuel elements. A buy-back of spent fuel ensured that the back end of the fuel cycle would not restrict reactor sales.[30]

The U.S. revenues from the nuclear market amounted to $3.2 billion in reactor facilities and $700 million in separative work through 1974. Since 1974, the U.S. share of the nuclear-reactor export market has been dropping significantly as other industrialized nations have become suppliers. The U.S. share of the reactor market in the 1980's, however, is estimated at $1 billion per year. We also found that roughly a third of U.S. capacity for enrichment services, 70 million separative work units (SWU), has been ordered by foreign customers for delivery in the 1977-1985 period. With an assumed average charge of $80 per SWU, the revenue expected from this source will be about $6 billion. An example of the magnitude of fuel sales is provided by a Japanese 1978 advance payment of $1 billion for U.S. enriched uranium to be delivered over the next 7 to 10 years. This agreement may also be increased to $1.5 billion, with delivery to start in mid-1979.[32]

West Germany has two suppliers of nuclear reactors, the German Kraftwerk Union (KWU) and Siemens. These companies have made numerous international sales and are actively seeking additional orders in all open markets. They have sold reactors to Argentina, Austria, Brazil, Iran, the Netherlands, Spain, Switzerland, and Luxemburg. The German Kraftwerk Union has actively sought export markets for its reactors in an effort to fill its manufacturing capacity and achieve the greater the economies of large-scale production. The company's management desires export markets for 40 to 50% of its production.[33] In pursuing this goal, KWU aggressively sought the order for Yugoslavia's first nuclear power plant but lost out to Westinghouse. The company has also been negotiating to build a 1300-MWe nuclear-power plant in East Germany.

TABLE A-1

LEADING SUPPLIERS OF NUCLEAR-POWER REACTORS*[31]

Supplied to	By U.S.A.	By W. Germany	By France	By Canada	By Sweden	By U.S.S.R.
Argentina		(1) 319		(2) 1,200		
Australia						
Austria		(1) 692				
Bangladesh						
Belgium			(7) 5,480			
Brazil	(1) 626	(2) 2,400				
Bulgaria						(4) 1,760
Canada				(20)11,874		
Chile						
China (PR)						
Colombia						
Cuba						
Czechoslovakia[1]						(4) 1,760
Denmark						
Egypt						
Finland					(2) 1,320	(2) 860
France			(44)36,041			
Germany, DR						(7) 2,710
Germany, FR	(1) 237	(26)24,250				
Hungary						(4) 1,760
India	(2) 400			(2) 400		
Indonesia						
Iran		(2) 2,400	(2) 1,800			
Iraq						
Israel						
Italy[2]	(7) 5,105					
Japan[3]	(9) 7,100					
S. Korea	(2) 1,169			(1) 629		
Libya						
Malaysia						

*Numbers in parenthesis gives number of power reactors, and other numbers represent total nuclear power capacity in MWe.

TABLE A-1 (continued)

Supplied to	By U.S.A.	By W. Germany	By France	By Canada	By Sweden	By U.S.S.R.
Mexico	(2) 1,320					
Netherlands	(1) 55	(1) 477				
Norway						
Pakistan				(1) 125		
Peru						
Philippines	(2) 1,252					
Poland						(1) 440
Portugal						
Romania						(1) 440
Saudia Arabia						
South Africa			(2) 1,844			
Spain	(14)11,768	(1) 1,000	(1) 480			
Switzerland	(6) 4,033	(1) 920				
Syria						
Taiwan	(6) 4,924					
Thailand						
Turkey						
U.K.[4]						
Uruguay						
U.S.A.	(210)204,827					
U.S.S.R.						(25)14,365
Venezuela						
Yugoslavia	(1) 615					
Luxemburg		(1) 1,300				
Sweden	(3) 2,600				(7) 4,740	

[1]Czechoslovakia domestically supplied itself (1) 110

[2]Italy domestically supplied itself (1) 40; U.K. supplied Italy (1) 220

[3]Japan domestically supplied (19) 12,667

[4]The U.K. supplied Italy (1) 220; Japan (1) 160; U.K. (39) 11,780

Largely because Germany lacks domestic fuels, the head of energy research and development in the Ministry of Science and Technology for West Germany, J. Schmidt-Kuster, believes that reprocessing is an absolute necessity for Germany. Despite serious reservations in Washington, Bonn concluded a complete nuclear-fuel-cycle agreement with Brazil. West Germany has been cooperative on other nonproliferation issues and, perhaps partly because of Washington's expressed concern, built several controls into its agreement with Brazil. The controls are similar to those applied by the U.S. on its exports of nuclear materials and equipment. Since the initial agreement, West Germany has agreed to withhold further sales that include the entire fuel cycle.[34] West Germany, as a part of the URENCO Consortium, has agreed to modify its position on foreign sales. As of September 1, 1978, the consortium will supply the uranium to Brazil, and the plutonium from spent fuel will be stored under safeguards.[35]

France, like Germany, has two nuclear-reactor producers. France has entered agreements to supply nuclear reactors to Belgium, Iran, South Africa, and Spain. The French have constructed a major uranium enrichment plant at Pierrelatte in Southern France. They produce all their own enriched uranium, using the same gaseous-diffusion process as the United States. In conjunction with Italy, Spain, Belgium, and Iran, the French are building a huge addition to the Pierrelatte facility. It will begin operation in the early 1980's and will ship enriched uranium to customers around the globe.[36]

The French are critically short of domestic alternatives to nuclear power strongly desire to achieve energy independence and security by developing a fast-breeder reactor. France and her European partners are pushing the development of fast-breeder reactors fueled with plutonium.[37] The French now have a 250-MWe breeder called Phenix and are building a 1,200-MWe version called Super Phenix. Their interest in the breeder stems from its ability to produce 50 times more electricity than a light-water reactor consuming the same amount of fuel. Though it takes 140 tons of natural uranium per year to fuel today's generation of light-water reactors, it would take only 1.5 tons to power a fast-breeder reactor.

France has also become one of the world's largest fuel reprocessors. In an initial agreement, France has offered to sell reprocessing capabilities to Pakistan. The French government has since announced that the portion of this agreement covering reprocessing facilities would not be honored in view of the danger that weapon-grade fuel would contribute to nuclear-weapon proliferation. Pakistan is not willing to accept this attempt at a renegotiated agreement and has indicated that it may cancel the entire contract.[38]

The French have contracts to reprocess fuel for Japan, Belgium, Germany, Switzerland, the Netherlands, Sweden, and Spain. Because of internal politics, German officials doubt that their country will recycle fuel from other nations; but France plans to make it a big business.

Great Britain has not received a foreign order for a nuclear power plant for seven years. Reactors have been supplied to only Italy and Japan, and they were very small reactors. However, Britain has entered the fast-breeder competition with the fast-breeder reactor at Dournreay, Scotland.

Two other countries, Sweden and Japan, are also suppliers of nuclear reactors. Sweden has two suppliers but has exported only to Finland. Japan has three suppliers, each using U.S. reactor technology obtained through licensing agreements with U.S. vendors. Japanese companies are seeking export markets in Asia and South America by asserting that their designs, based on early U.S. technology, are proven, whereas U.S. technology offering reactor systems with the latest advanced concepts are of uncertain reliability.

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