Appendix IV: International Nuclear Industry

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Appendix IV

International Nuclear Industry

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I INTRODUCTION

The objectives of this study are to present a comparative, analysis of various estimates (such as those by the IAEA and ERDA-52) of the probable rate of growth of the international nuclear industry, to select a likely growth for the midterm, and to discuss the factors that stimulate or constrain that growth. We also examine the importance of nuclear exports to the United States.

The approach to this task will be to consider the role of energy use in the economic development of the less developed countries (LDCs), and to investigate the relative benefits of an expanding nuclear industry to the LDCs and to those nations who are the primary vendors of nuclear equipment. Vendor nations include the U.S., France, Germany, Canada, and several others that manufacture and sell reactors and associated equipment on the world market. To streamline the discussion, we assume a familiarity with the principles of nuclear energy and the terminology of the industry, including the features of the nuclear fuel cycle: mining and milling, conversion and enrichment, fabrication, power generation, reprocessing, and waste disposal. Because of the time and budget constraints of this effort, the format of this report will be confined primarily to a review of the IAEA, ERDA, and other reports on this subject with a comparative analysis of their forecasts for tile growth of the international nuclear industry. We also assume familiarity with the above named reports and will only review those aspects of the reports pertaining directly to this discussion.

As the situation regarding many aspects of the nuclear industry is in flux, exact predictions of forward capacity are impossible to make. Therefore, the emphasis will be on establishing a reasonable expectation and its implications. The nuclear power industry is a complex of activities and facilities that requires several advanced technologies and substantial investment. It serves one customer, the electric power producer, who in turn requires capital intensive, high technology equipment, and deals in a product which must be produced instantly on demand with high reliability. These facts and the additional, and important consideration that the nuclear industry has grown from an exclusive military interest have made it unique among modern industries.

Some segments of the nuclear industry, such as reactor supply and fuel fabrication have reached industrial maturity and can offer equipment and services on a fully competitive basis. Other portions of the industry have still not entered the open market. Enrichment, for example, is exclusively under government management in the several countries concerned and reprocessing has not yet demonstrated commercial feasibility. Even for the mature segment (that dealing with power plant and nuclear steam supply) major technical advances, such as for the breeder reactor, are possible before the year 2000. If these are achieved, major revisions in other segments are inevitable.

Furthermore, health and safety problems of the industry and the controls implemented to deal with these have been evolved through experience and the impact of public debate. These controls have raised the costs of, and forecast .costs for, using nuclear energy. The debate has delayed government decisions that affect industrial development as in the case of plutonium recycling from reprocessing.

Finally, further debate and consideration of the prospects of terrorism and nuclear proliferation have led to government restrictions and controls which, in prospect, limit the normal commercial activities associated with industrial operations. In sum, the industry is maturing, albeit slowly but its future is not clear with its economics, technology, controls, and public acceptance all uncertain and subject to substantial change.

II THE ROLE OF ENERGY AND POWER IN ECONOMIC DEVELOPMENT

A. Forecasting of Use

Many correlations have been developed to relate economic activity, national development, and energy use.* Highly industrialized nations use more energy and generally have higher standards of living than less developed areas. Relationships between GNP/Capita and energy use/Capita have historically shown reasonable correlation. The driving forces behind the relationships are not well understood, however, and recent changes in energy prices, combined with a downturn in business activity and changes in attitudes toward energy use have called these relationships into question.

Forecasts of power growth within nations or groups of nations have often relied on extrapolations of historic trends, usually by an exponential function. For industrial nations during the period 1910 to 1970, this was adequate to forecast general trends for a few years into the future. While major wars caused deviations from the forecasts, the general trends were quickly resumed. Increased emphasis on use of machinery, concentration of activity in urban regions, greater economic advantage gained, central generating stations that could benefit from economies of scale, and the most efficient technologies all favored power growth. An average electric power growth of 8.1% per annum throughout the world was observed in the period 1950-70, for example. The LDC's

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* For example, see the Ford Foundation Policy Report, "A Time to Choose."

electric power growth was more rapid, 10.3% over the same period. These growths were higher than the annual growth for energy use as a whole of about 5% for the world and 6% for the LDCs.

In the period beginning in the 1960s, the energy growth rate first increased and then later decreased under the influence of increased oil prices and the recessions of the early 1970s. These rapid changes have caused many people to question the undoubtedly simplistic forecasting by extrapolation of historical growth, a process that does not fully consider effects of market saturation, changes in public attitudes (life styles) toward use of energy and power and the sensitivity of energy use to real changes in energy price on the demand for energy and power. Questions about availability of supply are also important. How much? At what price? Eventually the two forces should come to a dynamic equilibrium; however, different balance points and exchange prices can be expected to be different in different regions and countries of the world. Production costs will differ, transportation requirements (and costs) will have an influence, and national policy expressed in tariffs, embargos, and interest rates will all influence the. supply-demand-price relationship. Thus, full forecasts of power demand require evaluation and projection of at least the following:

- Resource-reserve relationships for major fuels, oil, coal, gas, and nuclear fuels in the important supply regions.
- Production cost relationships for these various regions.
- Transportation routes and costs between major supply and demand regions.

- Analysis and forecast for major demand regions (countries) of the composition and sensitivity of demand. This must include estimates of efficiency and capital cost associated with energy consumption, opportunities for conservation, and forecasts of public attitudes to energy use and environmental protection measures applied to energy activities.

From these, the general (regional) prices of fuels can be reduced, and rates of consumption estimated. To forecast individual demand into LDCs requires further analysis and projection, including:

- Development of demand-price sensitivities in individual or at least characteristic economies. (The behavior of industrialized nations should not be assumed for the LDCs.)

- Estimates of the regional or local efficiency and capital costs of energy use.

- Forecasts of the individual LDC development patterns. (Will the economy be agricultural, industrial, or service oriented? If industrial, will the development concentrate on energy intensive or non–energy intensive industry?)

To our' knowledge, there are no existing energy studies forecasting world supply-demand-price that consider regional characteristics and the dynamics of the energy market place, so that no one has established more than guesses about future regional or world price of fuels and the proportion that each will be used. Lacking that information, analysts assume various exponential growths related to industrial development and divide fuel use according to general estimates of price differentials. Analyses generally begin with some assumptions that energy prices will be less than, equal to, or greater than (by specified amounts) the current price of Mid-East oil and much general argument is offered to support the position taken by the individual setting forth the assumption.

In many applications, electricity competes with other energy forms. For example, in the case of residential space and hot water heating, the lower fuel costs of oil and gas systems often outweigh the economic advantage of electrical heating due to the less expensive equipment and maintenance costs. Many examples of competition can also be found in industrial applications. In some cases, electricity has a clear advantage because of its cleanliness or its essential nature (e.g. , electrolysis). In others, it is handicapped because of energy losses in transmissions. It has one substantial disadvantage. It cannot be stored on an industrial scale.

Electric power growth has come because of the essential convenience of electricity. It can be generated at large, economically-efficient stations, transported to point of use, and applied directly to the required task in almost any required quantity and manner. The central generating station also can be more easily operated to reduce environmental pollution.

Electricity use in the LDCs is generally characterized by lower capacity factors than found in the developed countries. The reasons for the lower capacity factors obtained for many of the LDCs are undoubtedly varied. However, those LDCs that lack a substantial industrial demand based on 7 day-a-week, 24 hour-a-day operations are likely to have greater fluctuations between peak and average demand, and therefore lower capacity factor, than that shown in industrialized nations. The industrial demand of developed countries increases the use of off-peak power and tends to smooth out a system's load curve.

Fission produced electricity generally comes from large units with high capital and low operating costs. It is most economic to operate these plants at the highest possible rating, therefore nuclear power stations are usually considered for base load application. Some details relating to costs are given in Chapter III. These special characteristics of nuclear power are important to the overall considerations of its application, especially in developing countries. This will be elaborated in the following section.

B. Characteristics of Nations Using Nuclear Power

At the present time, only a few of the less developed countries use nuclear power. Those expected to join in the future are expected to have certain essential characteristics now present in the major nations. First is the lack of cheaper energy sources properly located. Hydro-electric resources or cheap fossil fuel such as surface mined coal or excess natural gas generally produce cheaper electricity provided that supply and demand segments arc geographically related. A second characteristic is a sizable and preferably a rapidly growing power demand. Third, the sizable demand must be in a single, integrated power system. (Or if it is spread between two or more, then at least one must be large enough to support a nuclear station. We do not judge here whether the minimum plant size is 100 or 600 NW.) Finally, the power load curves should be such that the nuclear power plant can usually be operated (for economic reasons) at its full capacity.

Subsidiary to, but also determining, the capacity at load factors are such things as compactness of the demand area---a small area for the distribution system is desirable, and the presence of industrial operations that require constant or sustained power.

The larger nuclear plants also require substantial cooling water, and preferably sites that are free from natural disturbances, e.g., earthquakes and tornadoes. (These latter can be accommodated, but at high capital cost.)

Nations intending to install nuclear power must have, or be able to acquire, a labor force suited to the development. This force is not inordinately large, and nations having the required size and industrial development will very likely have or can train the necessary manpower for power plant operation. (A further discussion is provided by Appendix A.) Management of government interests in the nuclear operations and construction also make demands.

III REVIEW OF MAJOR ALTERNATIVE FORECASTS

Even though we are faced with the incomplete data and uncertain relationships mentioned earlier, it is still necessary to forecast. Nuclear power forecasts abound. They include some by the International Atomic Energy Agency (IAEA) alone, and in connection with the Organization for Economic Co-operation and Development, Nuclear Energy Agency (OECD-NEA). The IAEA/OECD-NEA forecast was amended by a study group of the International Energy Agency. This, still further modified, has been published by the U.S. Energy Research and Development Administration. The more recent estimates, made between late *1975* and fall 1976, predict total world nuclear installed capacity as ranging between 160-200 GW in 1980, 550-1000 GW in 1990 and 1410-2480 GW in the year 2000.

The OECD forecasts, published in late 1975, are shown in Table 111-1. These projections are based on individual OECD member country estimates which can be merely national policy statements or, as in the case with the U.S. forecast, be based, at least in part, upon analysis of energy - GNP relationships with certain assumed relative fuel costs and the like.

Two less recent forecasts of nuclear power growth in LDCs have been those made by the IAEA in its Market Surveys of 1973 and 1974. In the first of these, the growth of l4 developing nations was based upon previous detailed surveys of individual power networks and growth expectations.

Table III-1

IAEA/OECD-NEA NUCLEAR POWER GROWTH ESTIMATES* (GWe)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	[illegible]
Australia														0.5	0.5	1	1	1	6
Austria	-	-	0.7	0.7	0.7	0.7	0.7	2	2	2	3	3	4	4	5	6	7	8	14
Belgium	1.7	1.7	1.7	1.7	1.7	3.5	4.5	5.5	6.5	8.5	9.5	10.5	12.5	13.5	11.5	16.5	17.5	18.5	30
Canada	2.5	3.3	4	4.8	6.1	7.2	8.3	9.5	12.5	14.7	18.4	22	28	30	36	41	46	51	115
Denmark	-	-	-	-	-	-	-	0.9	0.9	1.8	1.8	2.7	2.7	3.6	3.6	4.9	4.9	6.2	11.4
Finland	-	-	0.4	0.4	1.5	1.5	1.5	1.5	2.7	2.7	3.9	3.9	3.9	3.9	4.9	4.9	5.9	5.9	13
France	2.3	5	5.9	7.7	13.2	20.4	27.2	33.8	40.8	47.8	56	62	69	76	83	90	97	104.0	170
Germany	3.2	7	9.1	10.6	14.1	19.1	24.6	28.5	32.6	39.6	44.6	51	57	64	70	77	82	87.0	134
Greece	-	-	-	-	-	-	-	-	-	0.6	0.6	0.6	1.2	1.2	1.2	1.2	1.8	1.8	4
Ireland	-	-	-	-	-	-	-	-	-	0.7	0.7	0.7	1.3	1.3	1.3	2	2	2	6
Italy	0.6	1.4	1.4	1.4	1.4	1.4	3.4	7.4	12.4	19.4	26.4	32	38	45	53	62	70	79	110
Japan	6.6	9	11	13	15	17	24	30	36	41	49	51	60	67	73	81	88	95	157
Luxembourg	-	-	-	-	-	-	-	-	-	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Netherlands	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5	2.5	2.5	3.5	3.5	4.5	5.5	6.5	7.5	7.5	8.5	16
New Zealand ...	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	1.2	1.2	1.2	1.2	3
Norway.........	-	-	-	-	-	-	-	-	-	-	-	-	0.9	0.9	0.9	1.8	1.8	1.8	4
Portugal	-	-	-	-	-	-	-	0.7	0.7	1.4	1.4	2.3	2.3	2.3	3.3	3.3	3.3	4.3	8
Spain	1.1	1.1	3	4.8	6.7	8.7	11.7	14.7	17.7	20.7	23.7	27	30	34	38	42	46	50	80
Sweden	3.2	3.2	4.7	5.6	6.5	7.4	8.3	8.3	9.3	10.3	11.3	12.3	13.3	14.3	15.3	16.3	17.3	17.3	24
Switzerland	1	1	1	1.9	2.9	3.8	4.8	5.8	6.9	6.9	8	8	8	8	8	8	8	8	12
Turkey	-	-	-	-	-	-	-	-	-	0.6	0.6	0.6	1.6	1.6	2.2	2.2	2.2	3.3	16
United Kingdom .	4.8	7.2	8.4	10.4	11.1	11.1	11.1	10.6	12.5	14.7	15.4	16.3	19	23	27	31	37	43	115
United States ...	40.1	47.5	54.5	61.8	69.2	82.2	102	126	152	179	205	234	266	301	341	385	432	481	600
OECD, High Estimate	68	88	106	125	150	185	234	287	348	416	484	518	622	703	791	890	981	1079	[illegible]
Low Estimate	69	86	101	118	139	171	215	264	324	376	437	491	553	620	692	774	847	926	665
African région[1] .	-	-	-	-	-	-	0.5	1.4	1.4	2.3	3.1	3.9	3.9	5.4	5.4	6.9	7.7	8.9	29
American région[2]	0.3	0.3	0.9	0.9	2.8	3.6	4.4	7	8.6	12.2	14.4	18	22	26	31	35	41	47	147
Asian région[3] ...	0.7	0.9	2.3	2.9	4	5	8.3	12.1	15.8	21.7	28.2	35	44	51	61	72	81	94	224
TOTAL (High Estimate)	79	99	110	129	157	[illegible]	247	307	374	[illegible]	[illegible]	605	692	785	888	1 004	1 113	1 229	180
Low Estimate .	69	87	105	122	146	[illegible]	227	285	342	409	479	542	615	693	778	875	961	1056	605

1 Algeria, Egypt, Iraq, Kuwait, Morocco, Saudi Arabia, South Africa, Tunisia.
2 Argentina, Brazil, Chile, Colombia, Cuba, Mexico, Jamaica, Peru, Uruguay, Venezuela.
3 Bangladesh, Hongkong, India, Indonesia, Iran, Israel, Korea, Malaysia, Pakistan, Philippines, Singapore, Taiwan, Thailand.

* From "Uranium Resources, Production and Demand , Joint OECD/NEA-IAEA Report, Paris, December, 1975.

The second report was extended to consider projections for 41 additional countries. Another forecast, critical of the IAEA approach, was made recently by Richard J. Barber Associates. However, this too seems to use the Market Survey as a base.

Those forecasts made before late 1973 were largely out-dated by the sharp jump in oil prices and the rearrangement of thinking which followed the oil embargo. A similar situation occurred because of the rapid escalation of capital costs and spot purchase uranium fuel prices noted during the 1974-76 period. These cost increases produced a significant effect on the economics of nuclear systems in competition with fossil fired plants.

The general trend of these various forecasts has been toward progressively smaller nuclear capacity projections. Reduced energy demand, increases in nuclear fuel cycle and plant capital costs, and practical operating experience with lower than expected nuclear plant capacity factors are among the reasons for these increasingly conservative forecasts. In view of these considerations, and accounting for the potential development of a worldwide market in coal, and the potential increased use of hydropower and surplus gas, we believe that the most conservative of the major reports, the IEA estimate as modified by ERDA, is the most realistic.

The IAEA forecast approach used in the 1974 market survey formed the basis for much of the work and analysis which followed. The IAEA market surveys will therefore be discussed in detail in the following paragraphs.

A. IAEA Market Survey

Table III-2 lists the fourteen countries considered in the 1973 IAEA market survey. Each of these countries provided basic data and counterpart staff, and participated with IAEA teams in site surveys. Included in the individual country data was that on projected population and GNP growth. A relationship (based upon historical data for 111 countries in the period 1961-1968*) between GNP/capita and electric energy generation/capita was established. This relationship was then used to project annual electricity consumption to the year 2000 for each of the 14 countries in the Market Survey. In addition to these IAEA projections, some of the countries involved provided their own forecasts. For the 5 cases in which there were appreciable differences, they were included as high forecast cases above the more conservative IAEA projections.**

Table III-2

COUNTRIES INCLUDED IN THE 1973 IAEA MARKET SURVEY

Argentina	Mexico
Bangladesh	Pakistan
Chile	Philippines
Egypt	Singapore
Greece	Thailand
Jamaica	Turkey
Korea	Yugoslavia

*This period saw a particularly rapid growth in electric power demand in countries such as South Korea.

**In each case the individual country forecast was higher than the IAEA.

The existing systems plus planned additions to about 1979 were used to construct the base system which was then expanded by the IAEA analysts to meet future demand using additions of economic base hydroelectric, base fossil, base nuclear, and intermediate and peaking fossil plants supplemented when possible by peaking load hydroelectric units. The expansion fitted new plants into the system to provide sufficient plant capacity to meet peak local and reserve criteria with each new plant added being chosen to obtain minimum present worth cost. Historical data from the individual countries about load patterns and "plausible" patterns of their future development were used by the agency and local officials to develop the load patterns. Capacity and reserve were chosen to reduce the generating systems' loss of load probability to as close to 0.005* as possible, with a maximum of .01. It was felt that this range of values would be acceptable to developing countries, although they would be unacceptable to industrialized nations. The maximum size of units to be added to the country's system varied between 5 and 20% of the peak load foreseen. It is important to note that the IAEA assumed nuclear power stations as small as 100 MW could be added to individual systems. The lowest capacity considered economic was 300 MW and only 9-10 units (from low and High forecasts respectively under reference market conditions) below 400 MW capacity, or a total of 3200-3500 MW, were assumed to be added by 1990.

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* Demand may exceed generating capacity for, at most, 0.5% of time during the year.

Capital, fuel and operating costs assumed were those of 1973 and earlier. In its capital cost estimates the IAEA used U.S.: data as developed by the Oak Ridge National Laboratory and the ORCOST program for their comparison. Capital costs for equipment were adjusted on a country by country basis considering the available international sources for equipment, country performance, transportation costs, etc. Materials costs were established for each country using construction and other cost indices. Labor costs and efficiencies were individually considered. In all cases the costs were estimated to increase at a uniform annual rate in all countries. Adjustments for varying plant size were made by standard scaling factors.

The reference case economic parameters used by the IAEA are set forth in Table III-3a and Table III-3b. The plant capital costs assumed here are based on data as of January 1, 1973, and therefore do not reflect the rapid increases noted in the mid 1970s.

Table III-3a

REFERENCE CASE ECONOMIC PARAMETERS, GENERAL

	Study Value[1]	Approximate Real Value
Discount Rate	8%	12%
Capital and O&M Cost Escalation	0%	4%
Fuel Oil and Gas Price Escalation	2%	6%
Depreciation	Linear	

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1 General inflation rate was assumed constant at 4%/yr.

Table III-3b

REFERENCE CASE ECONOMIC PARAMETERS, CAPITAL COST

Plant Size, MW	Type	Capital Cost $/Kw[2]		
		Max. Market Survey Nation	Min. Market Survey Nation	USA
300	Nucl	593	442	624
	Oil	268	206	315
600	Nuc[1]	439	322	460
	Oil	216	170	253
	Coal			287
1000	Nuc[1]	365	266	283
	Oil	189	146	223

[1]PWR
[2]Based on data of 1 January 1973

Electric power production is a capital intensive operation. Rapid expansion of plant requires both the generation of excess revenue and borrowings. Current estimates place capital costs in the range of $1000/KW for large nuclear plants and $600 to $750/KW for coal plants, significantly higher than those found in Table III-3b.* At these costs, a modern, large station is a substantial additional investment for all but the largest of electric utility systems. Costs of $1000/KW are far from the $200/KW costs forecast for nuclear power stat-ions in the early 60's and much has been said about the difficulties of capital formation to finance nuclear power growth.**

The higher capital investment may impact on developing nations with low gross national product. However, the developing countries may find is possible to raise the capital required, perhaps through favorable loans

*More detailed discussion of capital costs and capital cost differentials will be found later in this chapter.

**From the viewpoint of the electrical utility systems (especially those in the U.S.) who have previously operated with declining real costs for new capital plant (because of technological innovation and economy of scale) and fuel costs and who now must both change their financial viewpoint and justify the change to consumer-conscious regulatory commissions, the change in cost is undoubted traumatic.

made by the exporting country, e. g., Federal Republic of Germany--Brazil, or international agency loans. For the former loans there is little alternative use possible, for the latter, the LDC must justify the application of funds to nuclear power in contrast to other industrial or agricultural development.

Heat rate data, important to evaluation of fuel costs, were furnished by Bechtel Corporation and represent low average of design data for many plants. This data was checked by other experts. Fossil fuel costs were estimated by the IAEA (R. Krymn). The price for oil in each country was based upon the price of crude in the Persian Gulf, then estimated at $1.80\bbl for Kuwait 31° API. Transport costs to country harbors were then estimated, e.g., $O.83/bbl to Rotterdam. Escalation of 6% was assumed for the crude oil price over the period considered. Costs of coal and lignite were established for each country having indigenous reserves. These were essentially each country's estimate of its production cost, a general escalation of cost of 4% was used. Fuel oil was priced at 95% of crude. In no case was tax on import duty added to the base cost of oil.

Nuclear fuel costs were estimated by IAEA from published data; the basic cost assumptions are shown in Table III-4. Interest was charged at 8% and payments were made at reasonable intervals as the fuel progressed from step to step in the processing and fabrication chain. Fuel costs resulting from the calculation for an equilibrium case are shown in Table III-5.

Table III-4

NUCLEAR FUEL CYCLE COSTS, IAEA MARKET SURVEY, 1973

	$	Unit	Loss %
Concentrate	7	lb/u308	
Conversion	2.60	Kg U	0.5
Enrichment	32	SWU	0.0
Fabrication--first core	110	Kg U	1.0
--equilibrium core	80		
Recovery Cost--first core	44	Kg U	1.3
--equilibrium core	40		
Plutonium Credit	10	g Pu fissile	

Other Data

Bum up 13,000 rising to 31,000 MW d/t

Enrichment 2.41 rising to 3.48% U235

Final fissile Pu 0.46 rising to 0.72%

Load Factor 80%

Table III-S

FUEL CYCLE COSTS, EQUILIBRIUM CASE

	U.S. mil/Kwh
Concentrate	0.681
Recovered U	-0.104
Recovered Pu	-0.228
Conversion, net	0.079
Enrichment, net	0.730
Fabrication	0.392
Recovery	0.131
	1.681

No transportation costs to individual countries were charged and general inflation of 4% per year was assumed.

In 1974 the IAEA issued a supplementary report which reflected the higher oil prices of that year and new nuclear cost figures while extending the report to 41 other countries, including 5 in Eastern Europe. The same general methodology was used but some modifications were noteworthy.

Detailed analyses of capacity additions were made for 2 countries to determine the fraction of total electric capacity additions that would be nuclear. These results were extended to the 12 other countries in the original Market Survey. Data on population, GNP and electricity consumption were collected for the 41 countries. These data were used as before to project electricity capacity to 2000. The load order analysis was changed to consider "practical" as well as economic solution factors in meeting each load. Break even load factors for nuclear plants compared to oil fired plants, using oil delivered at $\$6.00/10^6$ k cal($9/bbl) with updated capital costs for. both nuclear and oil fired plants were computed as they applied to each of the Market Survey countries. The break even plant capacity factors for small plants obtained ranged from 73.2% for a 100 MW unit at highest capital cost ($1052/KW), to 29.9% for a minimum cost 400 MW unit ($471/KW). For plant sizes larger then 400 MW, nuclear plants with even smaller capacity factors would remain economically competitive with oil. The results of the 1974 IAEA forecast are presented in Table 111-6.

The two IAEA market studies were completed before the total Impact of the oil price rise was felt and therefore neglected both the ultimate (current price) rise in oil and increase in nuclear fuel and capital costs. Other IAEA assumptions, namely high plant capacity factors, availability of small nuclear plants, and low inflation (discount) rates gave greater cost

Table III-6

1974 IAEA MARKET SURVEY, SCHEDULE OF NUCLEAR CAPACITY ADDITIONS FOR 1981-1990 (MW)

	1981	1982	1983	1984	1985	1986	1987	1988	1989		Total
Central and South America											
Mexico	600 800	800	2 x 800	2 x 1000	2 x 1000	2 x 1000	2 x 1200	2 x 1200	3 x 1200	1200 1500	20 900
Brazil	-	-	-	-	800	800	2 x 1000	2 x 1200	2 x 1200	2 x 1200	10 800
Argentina	-	600	-	600	800	800	800	1000	1000	1000	6000
Venezuela	600	600	600	600	-	600	600	-	800	-	4400
Columbia	-	-	-	500	-	-	600	-	-	600	1700
Peru	-	-	-	400	-	-	400	-	500	-	1300
Chile	-	-	-	300	300	300	400	-	400	-	1700
Cuba	250	250	-	300	300	-	300	300	400	-	2100
Jamaica	-	150	150	150	150	150	200	200	300	300	1750
Uruguay	-	150	-	200	200	-	250	250	-	-	1050
Costa Rica	-	-	-	-	-	-	150	-	150	-	300
Panama	-	-	-	-	-	-	-	-	150	-	150
Dominican Rep.	-	-	-	-	-	-	-	-	150	-	150
Ecuador	-	-	-	-	-	-	-	-	150	-	150
Bolivia	-	-	-	-	-	-	-	-	150	-	150
Guatemala	-	-	-	-	-	-	-	-	150	-	150
El Salvador	-	-	-	-	-	-	-	-	150	-	150
										Total	53 500
Europe Middle-East and Africa											
Spain	2 x 1000	1000	2 x 1000	1200	2 x 1200	2 x 1200	1500	2 x 1500	1500	2 x 1500	20 000
Yugoslavia	-	600	600	800	800	2 x 800	2 x 800	1000	1000	2 x 1000	10 000
Greece	500	-	500	500	500	600	600	600	600	600	5000
Turkey	600	-	-	600	-	600	800	800	2 x 800	-	5000
Egypt	-	-	600	-	600	600	600	2 x 600	600	800	5000
Israel	400	400	400	400	-	400	400	500	500	500	3900
Kuwait	150	150	-	200	200	-	200	200	250	-	1350

Table III-6 (cont.

Iraq	-	150	-	150	-	200	200	-	200	200	1100
Ghana	-	-	-	-	150	-	-	150	-	-	300
Morocco	-	-	-	-	-	-	200	-	200	-	400
Algeria	-	-	-	150	-	-	150	-	-	150	450
Nigeria	-	-	-	-	-	-	150	150	-	200	500
Lebanon	-	-	-	-	-	-	-	-	-	-	0
Cameroon	-	-	-	-	-	-	-	-	-	-	0
Syria	-	-	-	-	-	-	150	-	150	150	450
Albania	-	-	-	-	-	-	-	-	150	-	150
Uganda	-	-	-	-	-	-	-	-	150	-	150
Tunisia	-	-	-	-	-	-	-	-	150	-	150
Zambia	-	-	-	-	-	-	-	-	150	-	150
Saudi Arabia	-	-	-	-	-	-	-		150	-	150
										Total	54 200
Asia and Far East											
India	2 × 800	2 × 800	2 × 1000	2 × 1000	2 × 1000	2 × 1200	3 × 1200	3 × 1200	3 × 1200	4 × 1200	27 200
Iran	600	600	600	800	800	800	800	1000	2 × 1000	2 × 1000	10 000
Taiwan	600	600	600	600	600	2 × 600	800	800	800	800	7400
Korea	600	600	600	600	600	800	800	1000	2 × 1000	1000	8600
Pakistan	-	600	-	600	-	-	600	600	2 × 600	2 × 600	4800
Thailand	200	300	-	400	500	500	-	600	600	600	3700
Philippines (Luzon)	-	600	-	-	600	800	800	-	1000	1000	4800
Hong Kong	300	300	-	400	400	-	400	400	500	500	3200
Singapore	250	250	2 × 250	250	400	400	2 × 400	400	400	600	4250
Malaysia (Peninsular)	-	200	200	-	200	250	300	-	300	300	1750
Indonesia (Java)	-	-	200	200	200	-	200	300	300	300	1700
[illegible]	-	150	-	200	-	200	-	200	-	200	950
Bangladesh	200	200	250	250	400	400	500	600	600	600	4000
										Total	82 350

Table III-6 (cont.)

	1981	1982	1983	1984	1985	1$?8G	1987	1988	1989	1990	Total
<u>Centrally Planned Economies</u>											
Poland	400	400	400	400	400	800	800	100	1200	1200	70!)0
Romania	400	·	400	400	400	400	609	600	1000	1000	S200
Czechoslovakia	400	400	600	600	600	800	1000	1000	1200	1200	7500
Bulgaria	400	400	400	400	600	600	600	600	800	800	5690
Hungary	400	·	400	400	400	400	400	600	600	600	4000
										Total	29800

advantage to nuclear plants than now seems justified. These factors were seemingly taken into account in the more recent OECD\IAEA review of December 1975 and further the reviews of early 1976.

B. Barber Study

A study by R. J. Barber Associates was published in 1975 which used different economic assumptions. These included higher capital costs, higher fuel cycles costs, a lower plant operating factor and a higher discount rate. Barber's capital costs, are based on the data given in WASH 1345. While Barber argues that the capital costs in the LDCs might well be 25% higher than in the U.S. , he does not use that factor. He lists minimum cost estimates and conservative cost estimates to be used by the LDC planner as

Plant Cost Estimates, 1000 MW Nuclear Station*
$/KW

	Minimum	Conservative
PWR	598	745
Coal	485	600
Oil (no SO_2 abatement)	372	460

*1981 startup

Nuclear fuel costs were estimated at 4.39 mils/kWhr and 5.17 mills/kWhr for favorable and unfavorable assumptions about the various parameters. (Oxide feed was assumed at $20/lb U_3O_8, enrichment at $75/SWU, and discount rate at 20 and 25% and capacity factors at 60 and 50% for the favorable and unfavorable cases respectively.)

Fossil fuel prices are discussed at length in the Barber report. A range of possible prices was presented. Generally it was assumed that oil could range from as low as $6.50 a barrel to more likely prices of $8-9/barrel.

Indigenous coal is offered as a viable alternative to oil and nuclear fueled plants. Several coal prices are quoted but fuel cycle prices of 6.12 mills/kWh assumed.

Most important to the comparisons made is Barber's assumption that nations with high internal inflation will use higher discount factors. Barber assumes a "reasonable medium" discount rate of 20% and suggests that rates as high as 25-30% may be applicable in certain situations.

The Barber study also assumes that nuclear power plants smaller than 600 MW will not be available and eliminates them from consideration. While it mentions taxes and tariffs it makes no assumptions about them, apparently following the IAEA lead. An attempt to include these effects into the economic evaluation would be fruitless, for taxes and tariffs can be used by an LDC to encourage or discourage the use of nuclear (or other) power. Even though the Barber study disagrees with many aspects of the IAEA approach, and with the explicit data used, it still uses the IAEA Market Survey as the framework for its analysis. In addition, all other studies discussed seem tied to the IAEA data base and approach.

C. Other Studies

The IAEA market survey of 1974 formed the basis of an OECD\IAEA survey of 1975. This latter report took advantage of the passage of time by considering the escalation of construction costs during the 1974-75 period and the continued existence of the OPEC cartel. It is primarily, however, a digest of national plans of the participating countries as reported in the spring of 1975.

In the fall of 1975 and the spring of 1976, the International Energy Agency conducted another survey which projected further changes in nuclear plant construction and fuel cycle costs. This survey was subsequently revised by ERDA in a paper entitled "World Requirements and Supply of Uranium."* Some of the results of various nuclear growth projections are summarized in Table III-7. SRI has regrouped this published data in certain cases in order to provide direct comparisons between the studies.

D. SRI Analysis

In assessing these studies, SRI has not attempted a new analysis of electric power demand or nuclear power share. It has examined the latest data presented on nuclear power costs and tested the stated assumptions for reasonableness. In general, SRI has used high capital and fuel cycle costs.

SRI has assumed that for the earlier periods of development, the developing nations will use tall stacks to dilute but not capture SO_2 emissions from coal-fired plants, resulting in capital costs in the $775/kW range. (It assumes the coal mined will have less than 270 sulfur.) SRI further assumes once through cooling, for nuclear and coal-fired power stations. These assumptions result in capital costs below the maximum assumed for U.S. built plants.

* paper by E.J. Hanrahan, R.H. Williamson, and R. B. Presented at the Atomic Industrial Forum's International Conference on Uranium, Geneva, September 1976.

Table III-7

COMPARISON OF PROJECTIONS FOR THE GROWTH OF NUCLEAR GENERATING CAPACITY GWE)

Study and projected years

	IAEA (1974 study)			IAEA/OECD-NEA (1975 study)			ERDA (1976 study, modified IAEA data)			Barber (1975 study)
	1980	1990	2000	1980	1990	2000	1980	1990	2000	2000
World*				179- 194	875- 1004	2005- 2480	160- 1 1	620- 715	1410- 1650	
Non-U.S.*				97- 112	490- 619	1005- 1480	100	425	1030	
LDCs**	20	196	572	17+	159+	500+				
13 LDCs considered by Barber Report***	11	130	426							317

* Does not include Eastern Bloc countries.

** Includes 34 of the most important LDCs, but does not include any Eastern Bloc countries.

*** These 13 are projected by IAEA data (as modified by Barber Report) to generate over 90% of the nuclear power in the LDCs. They are Mexico, India, Brazil, Iran, Taiwan, Korea, Argentina, Pakistan, Singapore, Egypt, Philippines, Turkey, and Thailand.

\+ Includes South Africa (which is not considered among the 34 countries of the 1974 IAEA study).

++ This is a modification of IAEA data. The Barber Report still considers this modified estimate to be high.

SRI has estimated ranges of coal and oil prices as part of other project work. We find that several coal producing sections of the world such as Australia, S. Africa, and the Western U.S. could deliver coal to seacoast power plants in developing countries at prices ranging from low values of $17-24/ton. (Actual prices could be higher if the demand grows.) We believe that world oil supply estimates cited by Barber are optimistic and the prices for delivered oil on the low side. However, SRI's analyses also have indicated that supplies of oil will be adequate through the end of the century and that prices may moderate by 1980 when expressed on a constant dollar basis (see attached article by V. Eugene Harless in Appendix B).

Capital costs of nuclear power plants with once through cooling will lie in the $925/KW range for a 1985 starting plant.* We do not believe that the rapid changes in capital cost observed from 1970 to 1975 will necessarily continue. Much learning has taken place, retrofitting during construction should diminish, and labor efficiencies rise with the advent of standardized plants. Experience and better planning should also reduce the time required for plant construction. A reduction of 2-3 years seems possible with concomitant reduction in interest cost during construction. We believe that costs of $80/kg-SWU for enrichment, and $250-300 per kg of metal reprocessed are possible. This produces fuel cycle costs that are as high as 7 mils/kWh.*

Barber has suggested plant factors of 60 and 50% and perhaps lower. At least some of the unfavorable operating experience encountered with

*V.S. Boyer, "The Economics of Nuclear Power." Speech presented at the Third Congressional Seminar on the Economic Viability of Nuclear Energy, January, 1976 current plants has been caused by retrofit and regulatory caution, especially in the U.S. Learning has been an expensive process in many aspects of reactor operation. Reactor suppliers and customers are both paying more attention to factors that improve plant on-line time (better maintenance scheduling and refueling procedures, for example). Recent data have shown that of all light water plants above 150 MW throughout the world, 75% had an annual capacity factor of greater than 50%, and 69% had a cumulative factor above 50%. U.S. experience shows an average annual capacity factor of 58% through the end of 1975. Three other countries with four or more reactors have achieved higher values: W. Germany (73%), France (70%) and the U.K. (66%). These data include plants such as Brown's Ferry 1 and 2 that were shut down for repair for approximately 8 months during the year, and other plants subject to extensive modification. On the other hand several plants have exceeded 80% capacity factor for a year or more. SRI has assumed a 60% capacity factor in its analysis. This may be considered conservative.

Given the previously stated assumptions by SRI concerning prices of nuclear and coal power generation systems and nuclear fuel cycle costs, break even coal costs can be developed for various plant sizes and fixed charge rates. Table III-8 shows these costs for plants of 600 MWe and 1100 MWe capacity installed in the mid-1980s.

Table III-8

MID-1980s BREAK EVEN COAL COSTS ($/TON)*

Fixed Charge Rate	Plant Size 600 MWe	1100 MWe
10%	28	23
15%	35	28
2 0%	42	32
25%	49	37

*Assumptions: Nuclear plant capital costs--$925/KW (1100 MW), $1135/KW (600 M-w)
Coal-fixed capital costs--$690/KW (1100 MW), $775/KW (600 MW)
Capacity factor--6O%
Nuclear fuel cycle cost--7.3 mils/kWhr at assumed capacity factor

As the above table indicates, moderate cost coal, hydropower and perhaps surplus gas could be competitive with nuclear power in the LDCs*. Although an independent country-by-country study might be desirable for confirming the competitive nature of nuclear power, the scope of this study precludes such an effort. We believe that the lowest estimate developed, that of the IEA as modified by ERDA, will be most representative of the future. This low estimate can be raised by many factors. Some of these are not of direct economic consequence. For example, incentives that seem to favor the spread of nuclear power include export pressures of nuclear suppliers, desire for alternate energy supply on the part of the installer, desire to prove modern attitudes and advance

*The competitive picture changes when developed country economics is considered . In the first place we expect that requirements for $S0_2$ removal. instead of tall stack dispersal will add extra operations and capital costs and could decrease plant efficiency markedly. Partially counterbalancing this will be the added cost. of natural draft cooling towers added to the nuclear plant. Other factors may also he important.

industrial training, particularly on the part of less developed countries, and interest in nuclear weapon capability.

In addition to making less developed countries dependent upon developed countries, the extraordinary support requirements of nuclear plants creates pressure among the developed countries to export nuclear products. The support structure is expensive and unique, if domestic power requirements are not adequate to fill the order work of the various support facility, then the owner-operators and perhaps the country in which the plant is operated falls under pressure to export nuclear power elsewhere, to the LDCs for example.

We have not attempted a detailed analysis of the manufacturing capacity, engineering abilities and other support services related to nuclear power development. However, it is likely that the U.S. and several European countries have excess capacities "for reactor production and in nuclear support services. The temporary, if not permanent change in the rate of growth of electricity consumption, deferments in construction because of that change and higher capital costs, delays, postponements or cancellations of nuclear power prospects because of public opposition and related regulatory and judicial rulings has upset the growth of nuclear power stations. Therefore, existing and planned support installations in some segments of the industry are without adequate developed country markets.

The rapid changes in nuclear power plant planning--first, a rapid increase following the oil embargo and' large step increase in oil price and second, a rapid slowdown or cancellation phase following delays in authorization and rapid capital cost increases--have interacted throughout all segments of the industry --including the fuel cycle as well as the manufacturing and engineering support segments. Pressures also exist in these segments to stabilize activity and encourage moderate growth. Thus exporting countries may decide to offer trade incentives, including favorable loans, an action which reduces the effective discount rate.

Additional incentives for the development of nuclear power are the desire for diversification of energy supplies and the relative ease with which uranium and plutonium fuel supplies can be transported and stockpiled. All of the front-end fuel cycle materials can be shipped economically by air with the exception of the original ore. Thus shipping delays are not crucial. It is usual for a nuclear power station to have several weeks, or more likely, months of fuel supply in new fuel elements on hand so that temporarily interruptions due to embargo, strike etc. , are not so disruptive. Fossil fuels do not have these advantages, which can be important to LDCs with transport, harbor clogging, and similar problems.

It is obvious from their optimistic forecasts that many LDCs plan to have nuclear power play an important role in their development. In many regions this energy source represents the most economical means of generating electricity and also allows for a diversification of energy resources and a greater degree of energy self-sufficiency.

Without the nuclear option, those countries that do not possess sufficient indigenous hydrocarbon supplies or hydropower resources would have to rely on imported fossil fuels. This implies a strategic dependence on others for a continuous supply of energy. The possible consequences of such dependence were felt by most LDCs during the 1973 oil embargo and in the price jump that followed.

In oil importing LDCs, a high oil price makes a strong impact on agriculture and industry. There are very few non-essential uses of energy in LDCs. High oil prices mean higher costs for the fuel and fertilizer required for domestic food production and for the boiler fuel used in electric power generation and industrial heat processes.

South Korea, for example, paid $300 million for oil imported during 1973 but during 1974 this figure increases to $1.2 billion. The effect on the Korean economy was widespread; the price increases greatly hurt Korea’s balance of payments, sparked further inflation and hindered industrial production.

The price of fuel is only a small part of the cost of electricity from nuclear power generation. The economics of nuclear plants are therefore less affected by fluctuations in the price of fuel than fossil plants.

Nuclear power is seen by most LDCs as a means of reducing high priced oil imports and dependence on foreign-supplied fossil fuels. However, it is very likely that these nations are currently too optimistic about the amount of relief from fossil fuel dependence that even ambitious nuclear programs might provide. Nuclear energy can only be used practically for base-load power generation and it is not likely that more than a small fraction of total end use energy consumption will be in the form of electricity for many years to come. (In Asia and Africa electricity presently accounts for less than 5 percent of total end use consumption, in Latin America this figure is about 10%; in OECD Europe and North America electricity presently supplies 15% of end use energy).

IV THE MOVEMENT OF NUCLEAR MATERIALS AND EQUIPMENT

With the assumption of moderate nuclear power growth generally, and in the developing countries especially, we examine the likely flows of nuclear materials. We describe country location of important facilities and speculate on growth patterns.

A. Uranium Supply*

Data on world wide uranium resources as well as projected uranium demand to the year 2000 have been compiled and published in a joint OECD/NEA - IAEA Report entitled, "Uranium Resources, Production and Demand" December 1975. These estimates (with updated U.S. and Canadian figures) are shown in Table IV-la for two categories of confidence and two levels of extraction costs. An updated and expanded version of this report is scheduled for reissue in May 1978. A relatively recent world wide resource estimate for uranium at $30/lb. U_3O_8 which reflects data published subsequent to December 1975 has been prepared by John H. Patterson, Division of Uranium Resources and Enrichment, ERDA, and was presented at the American Nuclear Society Executive Conference on Uranium Supply in January 1977. The data assembled by Patterson is reproduced in Table IV-lb and is annotated with several recent additions. The two resource categories used by OECD/NEA-IAEA, "Reasonably Assured Resources" and "Estimated Additional Resources" have been retained by Patterson rather than the four resource categories normally used in domestic ERDA resource estimates.

In the OECD/NEA-IAEA report (op. cit.) the term "Reasonably Assured Resources" refers

> 1? to uranium which occurs in known ore deposits of such grade; quantity and configuration that it could be recovered within the given production cost range, with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of ore-body habit. Reasonably Assured Resources in the cost category below $15/lb are considered as Reserves for the purpose of the present report.
>
> The term Estimated Additional Resources refers to uranium surmised to occur in unexplored extensions of known deposits or in undiscovered deposits in known uranium districts, and which is expected to be discoverable and could be produced in the given cost range. The tonnage and grade of Estimated Additional Resources are based-primarily on knowledge of the characteristics of deposits within the same districts."

From Table IV-1 it can be seen that the estimated total resources for both resource categories each contain approximately 2.4 million short tons Of U_3O_8 at $30/lb. Of U_3O_8. About 80% of the reasonably assured uranium is

*This section prepared by Lorin R. Stieff.

Table IV-la

World Uranium Estimates

ESTIMATED ADDITIONAL RESOURCES
(1,000 tonnes U)
(Data available 1st January 1976

Cost range	< 15$/lb$U_3O_8$	15–30$/lb$U_3O_8$
Algeria	–	–
Argentina	15	24
Australia	80	–
Brazil	8·8	–
Canada (*a*)	303	302(*b*)
Central African Republic	8	–
Denmark	–	10
Finland	–	–
France	25	15
Gabon	5	5
Germany	1	3
India	0·8	22·5
Italy	–	1
Japan	–	–
Korea	–	–
Mexico	–	–
Niger	20	10
Portugal	–	–
South Africa(*e*)	6	68
Spain(*d*)	8·8	98
Sweden	–	–
Turkey	0·4	–
United Kingdom	–	4
United States(*c*)	500	312
Yugoslavia	–	15·2
Zaire	1·7	–
Total (rounded)	980	890

(8) Categories are by reference to price.
(b) Estimates in this price range are preliminary, restricted only to principal deposits, and thus very conservative.
(c) Does not include 54,000 tonnes U as a byproduct from phosphates or 15,000 tonnes U as a by-product from copper production which might be recovered in the period to the year 2000.
(d) includes some 80,800 tonnes U reasonably assured resources in ignites in the cost range $15-30/lb U_3O_8 for which the availability is uncertaln.
(e) The 350,000 tonnes U total uranium resource for South Africa as given in Part II has also been Supplied apportioned as a best estimate to the various resource categories although reservations have been expressed concerning the accuracy of split figures.

(a) Categories are by reference to price.
(b) Estimates in this price range are preliminary, restricted only to principal deposits, and thus very conservative.
(c) The following additional potential resources of greater uncertainty are indicated by the US.
Possible resources <30$/lb: 978.10^{3}tU
Speculative resources <30$/lb: 454.10^{3}tU
(d) Includes some 63,800 tonnes U estimated additional resources in lignites in the cost range $15-30/lb U_3O_8 for which the availability is uncertain.
(a) The 350,000 tonnes total uranium resource for South Africa as given in Part II has also been supplied apportioned as a best estimate to the various resource categories although reservations have been expressed concerning the accuracy-of the split figures.

URANIUM INVENTORIES (tonnes U)
Australia 1750 (government); Canada 5580 (government); Japan S (producers); Mexico 40 (government); Portugal 350 (government); Sweden 200 (users); United States 55000 (government), 3300 (producers), 15000 (users) and West Germany 1370 (government). Information on stockpiles in other countries is presently not available.

WORLD URANIUM RESOURCES BY CONTINENT – $30/LB U_3O_8 @)

(EXCLUDES EASTERN BLOCK COUNTRIES)
THOUSAND TONS U_3O_8

	REASONABLY ASSURED	ESTIMATED ADDITIONAL
NORTH AMERICA	880	1.860
Us.	640	1,060
CANADA	225	787
MEXi CO	8	0
DENMARK (GREENLAND)	8	13
AFRICA	500	160
SOUTH &SW AFRICA	359	96
NIGER	65	39
ALGERIA	36	0
GABON	26	13
C.A.R.	10	10
ZAIRE	2	2
EUROPE	520	140
SWEDEN	390	0
FRANCE	72	52
SPAIN	30	56
YUGOSLAVIA	9	20
PORTUGAL	9	0
FINLAND	3	0
GERMANY	1	5
ITALY	2	1
U.K.	2	5
AUSTRALIA	430	100
ASIA	60	30
INDIA	38	30
JAPAN	10	0
KOREA	3	0
TURKEY	4	1
SOUTH AMERICA	40	60
ARGENTINA	27	51
BRAZIL	14	11
TOTAL (ROUNDED)	2,400	2,400

NOTES

Table IV-lb

a) "Foreign Uranium Sources - Status and Developments", John A. Patterson, American Nuclear Society, Executive Conference on Uranium Supply, Moneterey, California, January 26, 1977.

b) Most recent ERDA estimates.

c) New discoveries should result in significant increases in this estimate.

d) This estimate reflects the uranium contained in the black shales of Sweden. It is unlikely that this uranium will be available at $30/lb U_3O_8.

e) Company Data.

f) Government Estimate.

confined to six countries, the United States, Canada, Australia, South and South West Africa, France and Niger. The large, reasonably assured supply of very low-grade uranium associated with the Swedish black shales probably should not be included in the table because the uranium from this source will not be available at $30/lb. U_3O_8, and because the substantial environmental consequences associated with extraction from this source have not been resolved.

The total of approximately 2.4 million short tons of U_3O_8 in the category of Estimated Additional Resources is dominated by only two countries, the United States and Canada. These two countries possess approximately 1.85 million short tons or roughly 75% of these resources. It is unlikely that these figures reflect the true world distribution of the Estimated Additional Uranium Resources. Rather, this large subtotal reflects the substantial exploration and resource appraisal efforts that have been made by both the United States and Canada. It seems reasonable to believe that the categories of Reasonably Assured and Estimated Additional resources will increase as comparable exploration and appraisal efforts are made in other parts of the world.

Thus the short term and probably even the mid-term supply of uranium appears adequate. Nevertheless, it is necessary to add that prudence dictates a much more conservative view of the tonnages of uranium that will actually be mined, milled and available. This prudence stems from the fact that serious errors in judgement on the long-term availability of uranium will have profound economic and political impacts particularly on the major industrial nations; that certain major decisions directly dependent on reliable long-term uranium resource estimates must be made now or in the near future, such as national commitments to nuclear power and the decision on breeder reactor development; and that it is difficult, if not impossible, at this stage to assign limits of error to the estimates of "Reasonably Assured Resources" much less the "Estimated Additional Resources". Further, even though the quantities of ore in discovered reserves may be adequate through a certain date, the time required in developing them may necessitate the discovery and development of new deposits.

The uncertainty surrounding these appraisals is due, in part, to some of the following factors:

- Insufficient geologic information on the occurance, distribution, theories of origin and controls of ore deposition required to make the necessary extrapolations involved in the quantitative estimates of additional resources.

  Inadequate statistical methodology applicable to the special problems associated with uranium resource appraisal.

- Limitations in the availability of the relatively large amounts of risk capital required for the exploration and development of uranium mines and mills.
- Shortages in the supply of trained miners, skilled mill workers and qualified professional staffs.
- Uncertainties, even in the four major suppliers of uranium, concerning national attitudes towards nuclear energy and non-proliferation, national policies governing the development of uranium resources and the sale of uranium, and the stability of the political institutions essential to the orderly development of a major natural resource and the confidence that long-term contracts will be fulfilled.

Patterson (op. cit.) estimates that the current annual world requirement for U_3O_8 of approximately 25,000 short tons is expected to increase to almost 200,000 short tons annually by the year 2000. The implied rate of growth for both the mining and milling segments of the industry is formidable and can be achieved only with considerable encouragement. The OECD/NEA-IAEA report is not so optimistic. It states (op. cit.):

> "In general, however, only 'Reasonably Assured Resources' can be considered for specific planning and forecasting in the short and medium term and even the availability of much of these resources is constrained. If it were assumed that the present 'Estimated Additional Resource' could be confirmed and developed, the total of the two categories would still be inadequate to meet the long term uranium requirement which has been estimated at up to four million tonnes by the year 2000, possibly reaching 10 million tonnes of uranium by the year 2025."

These projections have been reduced, but the urgency of the uranium resource problem is still generally recognized. The concerted action by industry as well as governments required to forestall serious problems in the late 80's and 90's is still in the formative stage.

B. Conversion

Conversion is now concentrated in the four countries which operate large-scale enrichment facilities--the U.S., UK, France and the USSR.

The capital costs of this process are not high, approximately $50 millions for a plant that will fuel 82 reactors at equilibrium. See Table IV-2. The technology requirements are not large. Production of florine, arid its associated electric power requirement, is the primary technical task. A 10,000 tonne/y plant requires about 300 workers and about 65 x 10^6 kWh/y of electricity (or an assured capacity of 7 NW).

Countries supplying substantial volumes of uranium ore may wish to convert concentrate to UF_6 to take advantage of the value that can be added. In addition, the modest capital cost and technology requirements will not present a problem. Therefore, conversion can be expected to spread to countries without present capacity for it, such as Australia.

Table IV-2

CAPITAL COST* OF NUCLEAR FUEL CYCLE FACILITIES
NECESSARY TO SUPPORT A 1100 MWe LIGHT WATER REACTOR
UNDER EQUILIBRIUM CONDITIONS AND NUMBER
OF REACTORS SUPPORTED BY A LARGE COMMERCIAL FACILITY

Fuel Cycle Facility	Capital Cost of Facility per 1100 MWe Reactor (in millions of dollars)	Number of 1100 MWe Reactors Supported by Facility
Mining (surface)	2.33	6
Mining (underground)	2.84	3
Milling	10.47	7
Conversion	0.61	82
Enrichment	26.98	101
Fuel Fabrication (no Pu recycle)	1.75	27
Fuel Fabrication (with Pu recycle)	6.12	7
Reactor Plant	460.0	
Fuel Reprocessing	3.65	69

*lnstant construction mid-1974 costs.

C. Enrichment

Enrichment, now concentrated in the U.S., the USSR, France, and the UK may be spread more widely, especially through the centrifuge and nozzle diffusion techniques. At the present, world enrichment capacity is $25\text{-}28 \times 10^6$ kg SWU per annum, primarily in the U.S. and USSR. All of this is not needed today and some "reproduction" is being undertaken so that future capacity additions can be delayed. New capacity is now being added by URENCO plants in Holland and the UK, and Eurodif (Coredif) expects to be in production about 1980 with a plant which will realize 10.8×10^6 SWU.

These additions plus U.S. uprating of its government owned diffusion plants (an additional 10.5 x 10^6 SWU) will bring the total capacity by 1985 to over 50 x 10^6 kg SWU (it could rise as high as 70 x 10^6 kg SWU). Table IV-3 lists existing and planned commercial plants and significant pilot plant operations.

Equilibrium operation nuclear electric plants using enriched uranium are stated to require from 119 to 137 kg SWU/y per MW of capacity at 65% capacity factor. If we assume all future plants use enriched uranium--an obvious oversimplification that emphasizes the need for separative work capacity--and an average equilibrium consumption of 120kg SWU/MW (60% plant factor), we find that the current capacity and postulated additions to 1985 will supply the enrichment necessary for the continuous running of about 385,000 MW. (In this and succeeding calculations we consider that nuclear power is produced only by LWRs. The contribution of HWR and other converters is estimated to be less than 5 percent before the mid 1990s. Breeder reactors should have little effect before that time.)

Enrichment plants operating before '85 will generally be in the nations that now produce enriched uranium. The FRG (recently announced in public press) will make additions before then. It must be noted that the French organized and operated COREDIF and EURODIF organizations have additional partners, notably Iran and Spain, but also including Belguim and Italy, who will contribute financial and other support. After 1985, other nations plan to provide enrichment services. Brazil and the Union of South Africa will be using varieties of the jet nozzle process if current plans are carried forward. Japan has announced its intent to use the centrifuge process. Iran may build its own plant, etc.

Table IV-3*

STATUS OF PROCESSES FOR ENRICHMENT**

Owner	Location	Capacity 10S SWU	Schedule Operation
Gaseous diffusion process			
Operating plants			
ERDA	Oak Ridge, Tenn.	4.73	
	Paducah, Ky.	7.31	
	Portsmouth, Ohio	5"19	
Total, US		17.23	
USSR	Siberia	7-10'	
CEA	Pierrelatte, Franca	0.4-0.6	
UKAEA	Capenhurst, England	04-06	
China	Lanchow, China	?	
Under construction			
Improvement and uprating of ERDA plants - adds		10-5	1975—1 985
Eurordif (CEA. Iran, Belgium. Italy, Spain)	Tricastin, France	108	1978—1981
Under construction			
ERDA	Portsmouth Ohio	8-75	1985
Coredif (Eurodif, CEA Iran)	Tricastin, France	9—1 O	1985
Canadif (CEA Ouebec, Canada)	James Bay, Quebec	?	?
Gas centrifuge process			
Operating plants			
Urenco-Centec (UK, Holland, Germany)	Capenhurst England Almelo, Holland	0-4 to 2-0	1977—1982
Under coonstruction			
Urenco--Centec	Capenhurst England Almelo, Holland	Adds 8	1985
Exxon Nuclear Co.	USA	1"o to 3.0	1982—1986
Centar Associates	USA	0.3 to 3.0	1932—1988
Garrett Nuclear Corp.	Texas	0.3 to 3.0	1982—1989
	Japan	2	1998
Separation nozzle process			
Karlsruhe Nuclear Center	Steag A.G.	0.002	Shut down in 1972
Nuc!ebras	Brazil	2	1989
South African process			
UCOR	Valindaba, S.A.	0.006 5	Pilot unit ready being considered
Laser-based processes			
		Working material	
Avco-Exxon	Everett. Mass.	U metal vapor	
Lawrence Rad. Lab.	Livermore. Calif.	U metal vapor	
Los Alamos Sci. Lab.	Los Alamos	UFa Vapor	

* From Nuclear Engineering International, November 1976.

** **Presented by Manson Conference, June 1976.

\+ Believed that 3M SWU available for export.

The capital investment required for enrichment is small compared to that required for nuclear-electric power plants; it has been estimated capital costs will range from $200 to $370 per SWU\y. A representative capital cost of $310 per SWU converts to an expenditure of about $27 millions required to supply a single 1.100 MW nuclear power plant. See Table IV-2. (Compare this cost with the approximately one-half billion dollar cost for the nuclear power station.)

The diffusion process has a generally reported cost of 200-300 $\SWU only in large size. The unit cost rises rapidly with decreasing size. The economics of centrifuge and nozzle processes are much less sensitive to size and can be installed in smaller units. The centrifuge uses much less power (about 1/10 that of the diffusion), while the nozzle processes use somewhat more power than the diffusion process. Large diffusion plants require approximately 2,000 kWh\SWU. URENCO and others expect that their centrifugation plants (as small as 0.3 - 1 x 10^6 SWU\yr) will be competitive with large diffusion plants in the range of 9 x 10^6 SWU/yr. Thus, once centrifuge enrichment becomes a proven commercial process, it is likely that plants could be built to economically serve a nation with a nuclear electric capacity as small as 3,800 MW.

Even though some developing countries could afford the capital investment and match their enrichment needs with an economic centrifuge plant, other factors may discourage that choice. Centrifugation requires an equipment supply industry that must produce exceptionally precise and high quality, high speed, rotating machinery

More skilled operating manpower will be necessary for a centrifuge plant than for a diffusion plant. This is due largely to the maintenance requirements imposed by the large number of precision centrifuges. We nave estimated, from ERDA data, that 1,000 workers are required to operate a 9 x 10^6 SWU/y diffusion plant. It is likely that the centrifuge plant will require two to three times as many workers per unit output, for example from 250 to 300 workers for a 10^6 SWU plant.

Thus we do not expect the number of nations producing enriched uranium for a commercial electric utility market to increase greatly in number. Instead of just the U.S., UK, France and the USSR capable of serving world needs, we might foresee the following:

Australia	much discussion, but expected opposition from environmentalists and unions would make enrichment unlikely in the near term
Brazil	(already has announced plans for 1989 production)
Federal Republic of Germany	announced plans for a 10^6 SWU/y plant
Iran	(will have completely independent industry and direct knowledge, through COREDIF, of diffusion process)
Japan	(announced plans for 1988 production - centrifuge)
South Africa	(announced plans for larger pilot plant; nozzle)

Several factors could limit growth. A very important one is the potential for change in reactor type. A switch to heavy water moderated reactors or to plutonium-uranium breeding reactor systems would eliminate the need for expansion of enrichment services, and a gradual decrease in loading for the plants already' built as they pass from service. Thus investment in enrichment has a high speculative element, as indicated by the unwillingness of U.S. companies to invest in this sector of the nuclear industry without government protection.

A smaller practical increment in investment is offered by the centrifuge* and nozzle processes but these are still not fully demonstrated on large scale and thus have some risk. Also, as pointed out above, the greater mechanical complexity of the system and the specialized mechanical industry needed *to* support it could be difficult for a developing country to supply.

It is possible that others of the more wealthy, highly industrialized nations will supply enrichment services. They have shown no particular interest thus far in such activities. On the other hand, political decisions pending in the Netherlands have tended to slow plant development and may remove that country as a producer.

D. Fuel Fabrication

In the fuel fabrication segment of the industry the capital investment required is not as large and the economics of scale less important when compared with other fuel cycle activities. Substantial skill is required in welding (automatic) processes and quality inspection and and control. However, a nominal 600 tonne/y plant, sufficient in size to supply about 30,000 MW of nuclear generation capacity, requires a direct work force of only about 500 workers. The capital investment for such a plant is small, as shown in Table IV-2.

Currently commercial scale production facilities for oxide fuels are operating in 9 industrialized countries. See Table IV-4. Of the total capacity, nearly 80% is in two countries--the U.S. and Japan--and the U.S. has three/quarters of that fraction. Other producing countries

* Centrifugation is a unit process, therefore plant capital costs vary nearly linearly with size.

Table IV-4*

1.WR FUEL FABRICATION CAPACITY (Tonnes Heavy Metal/yr)

Countries	.1974	1975	Planned 1978	Projected 1980	Projected 1985
Belgium	200	200	400-600	400-800	600-1,200
Denmark					200-400
France		200	220	500	>1,100
Germany	270	670	1,000	1,400	2,000
Italy	300	300	300	600	(600)
Japan	910	(910)	(910)	(910)	(910)
Netherlands	30	30	30	120	200
Spain			300	400	800
Sweden	250	250	400	400	(450)
UK	100	100	100	(loo)	(loo)
USA	3,050	2,750	3,350	8,200	8.200
Total	5,110	5,410	7,110	13,230	15,560

( ) Minimum figures.
*From "Uranium Resources, Production and Demand," Joint OECD/NEA-IAEA Report, Paris, Dec. 1975.

are increasing their production capacity more rapidly than the U.S. ; but it still will dominate the world with an estimated 60% of the world capacity in 1980 (excluding the USSR).

The announced capacities for LWR fuel fabrication in 1985 of over 15,000 tonnes metal would be sufficient to fuel 783,000 MW of capacity at the assumed 60% capacity factor. (If fueling of new plants is required as well, then the fuel fabrication plants can handle over 500,000 MW of existing plant.) Expansion beyond this projected capacity, necessary only after about 1988, can occur in several countries. Developing nations such as Iran with large nuclear power programs in prospect, could build fuel fabrication plants. Brazil has announced its intention to do so; others can if they wish. (But see Section IV-F.) Many of the fuel fabrication facilities are likely to incorporate provisions for plutonium recycle after this is demonstrated in the major nuclear countries.

E. @recessing

The recovery of the slightly enriched uranium and of the plutonium discharged from power reactors and their preparation for reuse is the final step in the fuel cycle. While the recovery step could improve the economics of nuclear power by reducing the requirements for uranium and for enrichment services, it is not essential for LWR systems and is not now used for HWR fuel cycles. It would be essential to the operation of breeder reactor *systems* when and if they become commercially viable. (SRI estimates there will be no noticeable direct impact of breeder systems on the nuclear fuel industry until 1995.*) At the present time, reprocessing of uranium metal fuel elements is available through government owned and/or controlled facilities in France and the UK. These countries have plants run by government controlled corporations (those with greater than 50% government ownership). In the U.S., similar facilities exist and are operated by industry in contract to the government in its plutonium producing operations. Facilities also exist in the USSR and presumably in China.

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* Even though the French and others have operated prototype breeders, the expected time periods required for construction and commercialization of a full-scale plant account for this estimate. Breeders could have a more immediate indirect impact on the fuel cycle, however. Anticipation of their future development may cause some stockpiling of retrieved plutonium in competition with its potential use in mixed-oxide fuels for LWRs.

No commercial scale facilities for the reprocessing of oxide fuel **are** in operation. The one commercial plant that did operate in the U.S. is shut down and has been effectively abandoned by its owner. Another plant with 1500 tons/y capacity at Barnwell, S.C., could be put into operation in 2-3 years after decisions regarding licensing and waste treatment are reached. Modified metal processing plants (with special additions to handle oxide fuel) may be available in 1977 in France and slightly later in the UK. Full scale processing plants specifically designed for oxide fuels are not expected until after 1980. The status of current and planned plants (excepting those of COMCOM) is shown in Table IV-5. Additional capacity (approximately 1000 te/a) may be available in Spain. by 1985-90.

These facilities are more capital intensive than many other of the fuel cycle plants. Thus costs may rise beyond those quoted in Table IV-2. In the U.S., the single commercial plant that was operated **and the one under construction have suffered from regulatory actions that required retrofit and/or redesign, and costs have escalated. Operation of a large plant may only be justified by nationally generated reactor fuel that amounts to 500 t/y or more, equivalent to about 25,000 MW of installed capacity. The plant would require an estimated 500 workers to operate.**

Because of the capital investment, not many LDCs would decide to build commercial plants. However, pilot size facilities **could be constructed and used to produce plutonium for weapons or other use.**

Again, Brazil has **announced its intent to engage in reprocessing.**

Table IV-5

SUMMARY OF REPROCESSING PROJECTS AROUND THE WORLD*

Location	Operator	Type of plant	Capacity e: y	Date operational	Status
U.S.A.					
West Valley N.Y.	NFS	old,	300	1966 to 1912	530 is processed before snut down for expanslon
		Expanded, cxrde	750	early 1980s	Dependent on new con. struction permit present form
Midwest Morris, Ill.	GE	Oxide, advanced process	300	—	Currently providing fuel storage
Barnwell S.C.	AGNS	Commercial, oxide	1500	1977-78	Depending on GESMO decisions
—	Exxon	Commercial oxide	—	mid - 1980s	Looking for site
U.K.					
Windscale	BNFL	Nat. U metal	1500–2500	1964	Operating near full capacity Head end improvement programme in hand
		Oxide head end	300	1972 to 1973	Operated but shut down for investigation of incident and subsequent modification
		Refurbished oxide head end	400 •	1977–78	Will feed into nat. U separation plant depending on availability of capacity
		New commercial oxide plant	1000	1984	For expected domestic requirements part of United Reprocessor's plan
		New commercial oxide plant "overseas"	1000	1987	Awaiting decision on public acceptability of overseas contracts.
France					
La Hague	CEA	Nat. U metal	800	1966	Main plant for reprocessing EdF nat. U fuel but due to be changed over to oxide
		Oxide head end	150 to 800	1976	Phased build up feeding into existing separation plant
		New commercial oxide plant	1000	1985	Detailed design just starting
Marcoule	CEA	Nat. U metal fuel	900–1200 •	1958	Early military plant. Will take over commercial nat. U from La Hague
Germany					
Karlsruhe WAK	KEWA	Pilot scale oxide	40	1970	Operating with fuel of increasing burnup
—	PWK/KEWA	Commercial oxide plant	1500	1984	Design specification being prepared. Site to be selected
Japan					
Tokai Mura	PNC	Demonstration scale oxide	200	1976	Non-active commissioning
—	PNC	Commercial oxide plant	1000	late 1980s	Projected if site can be found
Belgium					
Mol	Eurochemic	Multi purpose semi-commercial international plant	60	1966	Shut down. Future in doubt. Has been used for reprocessing development
Italy					
Saluggia Eurex 1	CNEN	Pilot scale oxide	10	1969	Currently shut down for modification
India					
Trombay	IAEC	Pilot scale nat. U oxide	60	1965	

Note: Several other pilot and laboratory scale plants have and are being operated for development of reprocessing technology. Commercial reprocessing of research reactor fuel has also been undertaken in several plants around the world. Fast reactor oxide fuel has been reprocessed in pilot scale plants in France and the U.K. and a plant for mixed thorium uranium oxides was built in Italy but has not been operated.

*From Nuclear Engineering International.

Japan and Germany are definitely interested. Other nations, including Iran, Pakistan and South Korea, have discussed the possibility of importing the technology. Spain, perhaps Italy, and others would seem likely candidate countries for full scale reprocessing activities.

F. Fuel Cycle Summary

The major elements of the fuel cycle cost much less than the reactor they support (when each unit is made to an economical size) as was shown in Table IV-2, and countries which can finance reactors can finance the support elements. However, if the fuel cycle plants (at an economical size) are sufficiently large to load from 7 to 101 reactors**, their installation will require that most of the developing nations seek an export business.

Even with the optimistic assumption of the 1974 IAEA Market Study, none of the countries considered in that study would, by themselves, generate the fuel through-put necessary to justify in the year 1990 the large scale plants considered economic by the U.S. Smaller sized fuel cycle plants could perhaps be considered by Mexico, Brazil, Argentina, Spain, Yugoslavia, India, Iran, Korea, Poland, Romania and Czechoslovakia on the basis of their indigenous nuclear power programs. These are all countries that:

1. Have large nuclear power programs in progress or well advanced in planning, or

* Germany Is a partner in United Uranium Processors with the UK and France

** The larger number refers to a 8.75 $\times 10^6$ kg-SWU\y diffusion enrichment plant. Centrifuge plants serving many fewer large reactors may prove economical.

2. 2. Were singled out as likely to have substantial growth by the IAEA analysis, and

3. Are, for the most part, not fully democratic, i.e. they are countries where government policies can be implemented without full consideration of public wish or direct business interest.

Fuel cycle activities, except for mining and milling, would not be a logical economic investment for the others unless they could attract extensive export trade.

G. Reactor Supply

The reactor supply business has been pursued in several industrialized countries. The U.S., Canada, the Federal Republic of Germany, France, Italy, Japan, Sweden, and the USSR have viable operating companies supplying nuclear reactors. See Table IV-6. These organizations purchase heavy and special equipment such as pressure vessels and nuclear-quality stainless-steel valves from a host of suppliers located in many of the other industrialized nations of the world! Many of the components of the now-coventional nuclear systems are larger than previously needed for other industries, and new plants suitable for handling extra large and heavy equipment have been built to fill the demand. Also exceptional quality is required for many components and new standards of manufacturing performance involving physical operations, inspection activity, and quality control are demanded. For several years general manufacturing capacity fell behind demand, but today, following a drop-off in the rapid growth of nuclear plant ordering, there is spare capacity in most if not all segments of the reactor supply industry. The existence of this spare capacity is one factor behind the several efforts to export nuclear

* Some examples are Austria, Finland, Netherlands, Belgium, Spain, and Switzerland

Table IV-6

PRINCIPAL SUPPLIERS OF HWR AND LWR REACTORS

HWR	
Atomic Energy of Canada Ltd	Canada
Siemans	FRG
Canadian General Electric	Canada
LWR	
Kraftwerk Union AG	FRG
Framatron	France
Atomenergoexport	USSR
ASEA-Atom	Sweden
General Electric Co*	USA
Westinghouse Electric Co*	USA
Toshiba	Japan
Hitachi	Japan
Combustion Engineering	USA
Babcock and Wilcox	**USA**
Ansaldo Meccanico Nuclear SpA	Italy
Mitsubishi Heavy Industries	Japan

*Also European based subsidiary or joint companies.

systems to **developing countries.**

It is **believed that for a reactor supplier to be fully competitive, it must** have a minimum of 4-6 orders per year. The reactor producers in the U.S. have relied on export business to fill their factories. Sales are hard for new suppliers. Proof of prior successful operation is an important factor for a reactor sale. Examination of the history of nuclear power development indicates that the purchaser ordinarily requires a high degree **of** confidence in the supplier (a not unreasonable demand). This is evidenced in several ways. For example, a long term supplier-user relationship was required in the U.S. Of those companies who entered the reactor supply business, full acceptance has been given only to companies who had long standing relationships with utilities. In the international market, government guarantees or favorable loans have undoubtedly influenced the selection of particular suppliers. The existence of a strong relationship between vendor and purchaser seems important here as well. This must be supplemented by aggressive marketing and seemingly a demonstrated ability to field and operate reactor systems. For example, India, Italy, Japan, Spain, and Switzerland bought their first reactor systems from recognized suppliers in Canada, the UK, and the USA after the suppliers had built and planned reactors in operation in their own countries. Now all of these countries have their own nuclear component suppliers, many of which operate under license, producing systems whose design was proven in Canada or the U.S.

If developing countries are to enter the market they must overcome fierce competition from experienced suppliers. The optimistic IAEA Survey does not indicate sufficient reactor business in any LDC in the period 1985-1990 to justify market entry, and any such entry based on export could only come at substantial cost. We recognize there can be exceptions. India is now attempting to build a reactor supply business matched to its modest reactor needs. Its department of atomic energy is engaged in the construction of 880 MW of HWRs now expected to be operational between 1978-82.

The possibility of India making significant entry into the reactor export business within the next ten to fifteen years is small. In doing so, India would enter into competition with the AECL and Canadian industry which have more experience and will probably have greater production capacity. No Indian-built reactors have as yet become operational, and as stated above, demonstrated success is an important consideration to LDC buyers. In addition, the funds that most vendor nations make available to LDCs as an aid to financing a nuclear project are not readily available for India to lend.

V THE VALUE OF U.S. NUCLEAR EXPORTS

Exportation of nuclear-related equipment, materials, and services has had a significant effect on the growth of the U.S. nuclear industry. The two largest American reactor manufacturers, Westinghouse and General Electric, have together installed almost 6,000 MW of operating nuclear capacity in foreign nations, and are supplying over 19,000 MW of capacity to foreign plants currently under construction. Sale of these nuclear steam supply systems (NSSS) accounts for the largest share of the revenue obtained from U.S. nuclear exports. Other major contributors include "balance-of-plant" (non-NSSS) equipment, engineering and construction services, and enrichment services provided by the U.S. government. The dollar values of these purchases greatly outweigh the revenues from the other nuclear exports.

A primary incentive for the export of nuclear-related commodities is the favorable cash flow that accompanies the sale of capital-intensive equipment. Additionally, exports can be used to increase NSSS production if domestic ordering falls. Reducing idle production capacity can be extremely important, since much of this capacity is unique to the nuclear industry and very costly.

Noneconomic factors can also provide some incentive for nuclear exports. For example, because of the continuing replacement parts requirements, technical aid, and fuel cycle services, some influence can be gained by the exporting nation. This argument has been raised in support of the continuation of U.S. nuclear exports. It is reasoned that the safeguards required on American exports and an American presence in the world nuclear scene will ensure our standards are met.

Nuclear Plant Exports

This country has historically led the world in nuclear technology. The light water reactor concept, which was pioneered by the United States, is now by far the most commonly used reactor system around the world. Until relatively recently, America was the only exporter of LWRs, but several other free-world nations have now developed LWR export capability (based largely on U.S. technology and license arrangements). The most important of these are Germany and France, which have already penetrated the world reactor market with major sales. These nations can be expected to increase their share of the market in the future. In addition, Japan, Sweden, and Italy may also be expected to become exporters over the coming years. The USSR currently exports LWR systems to the Eastern Bloc countries, but is not expected to capture a significant portion of the free world market.

Heavy water reactors, which employ natural uranium fuel, have been successfully marketed by Canada.* These systems typically require a higher initial capital investment than LWRs, due largely to the high cost of heavy water. However, the fuel cycle costs are lower because the uranium enrichment step is not required. In addition, the use of a natural uranium fueled reactor is desirable to many smaller nations because of the freedom it provides from dependence on those larger countries that possess enrichment facilities.

As noted previously, the United States has installed nearly 6,000 MW of nuclear capacity in foreign countries. Seven percent of this figure (two reactors for India with a combined output of 396 MW) was exported to LDCs; the remainder went to European nations and Japan. Total reactor shipments to LDCs have accounted for 1,254 MW of capacity, as shown in Table V-la. The four non-U.S. supplied reactors were HWRS, and comprised about 68 percent of nuclear capacity installed to the LDCs.

Table V-1b lists the exports to LDCs of reactor systems for plants presently under construction or on order. In order to show current trends, these orders are split into three categories: those which have expected commercial operation dates before the end of 1980, between 1980 and the end of 1985, and after 1985. In the first time category, the American-supplied capacity is approximately 4,700 MW or 72 percent of the total

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* One was also exported by Germany.

Table V-1a

OPERATING REACTORS IN THE LDCs

LDC	U.S. Supplied (MW)	Year of Commercial Operation	Non-U.S. Supplied (MW)	Year of Commercial Operation
Argentina			319 (German HWR)	1974
India	198	**1969**	207 (Canadian HWR)	1973
	198	**1969**	207 (Canadian HWR)	1976
Pakistan	___		125 (Canadian HWR)	1972
Total	396		858	Total 1,254*

* American, 32 percent
Non-American, 68 percent

Table V-lb

REACTOR PLANTS UNDER CONSTRUCTION OR
ON ORDER IN LDCs

Commercial Operation	U.S. Supplied (MW)	U.S. (percent)	Non-U.S. Supplied (MW)	Non-U.S. (percent)	Total
1977-1980	4,657	72%	1,800	28%	6,457
1980-1985	4,570	38	6,817	62	11,987
Beyond 1985	0	0	600	100	600

LDC market. The only foreign competition over this time period comes from Canada and Germany.

When reactors starting up in the LDCs during the next time period, the end of 1980 to the end of 1985, are considered, the situation is quite different. The U.S.-supplied nuclear capacity is approximately 4,600 MW, down only slightly from the preceding period. However, the American-supplied fraction of the overall LDC market drops to 38 percent. For this period, Canada and Germany have increased their share, and France has entered the export market with two large reactors. To date, only one order has been placed by an LDC for a reactor starting up beyond 1985. This is for a Canadian HWR that will be shipped to Argentina.

The apparent trend is toward a smaller American share of the LDC reactor market In fact, no new orders for LDCs have been placed with American vendors for the last two years. (Exceptions are two reactors that progressed from the letter of intent to the ordered stage during the period.)

The share of the LDC market that the United States captures in the future will depend upon many factors. Important among these will be the cost and also the reliability of American nuclear plants.

Reliability can have a major impact on the planning of an LDC, because a nuclear plant would typically represent a relatively large fraction of the LDC's total generating capacity. The on-line refueling capability of the CANADA reactor system is attractive in this regard.

Another important consideration will be the type of governmental restrictions that are placed on nuclear-related exports. It has been reported that. Iran had investigated the possibility of purchasing some American reactors but felt that the agreement required by the U.S. government was too demanding. American export policy also prohibited the transfer of enrichment and reprocessing technology to other nations. In fulfillment of a contract signed with Brazil, Germany will not only supply nuclear generating plants, but will also provide the know-how for the construction of a demonstration enrichment facility. Canadian reactors can be expected to remain a strong competitor with American LWRs for the LDC's market. The CANADA system has many characteristics that are desirable to the LDCs. As mentioned previously, employment of a natural uranium fuel allows freedom from dependence on those countries that will be exporters of enrichment services. This factor would be especially important if LDC planners view the currently proposed enrichment capacity around the world as being inadequate to meet the expected demand. The

1974 reversal of the AEC's policy of booking orders for enrichment services may have contributed to this view. In addition, recent occurrences such as the defeat of the nuclear fuel assurance bill and the continued erosion of private interest in enrichment could have only further reinforced the fear of enrichment shortages.

CANADA reactors are built in a smaller size than most LWRs presently being made. A typical CANADA plant is in the 600 MW range, whereas that of a new American LWR is about 900 MW. The lower capacity of CANADA units makes them more suitable for use in LDCs, which typically have low total system capacities. Compared with LWRs, CANADA reactors are more efficient in the production of plutonium, and are also able to produce a grade of plutonium more suitable for weapon production. In addition, the on-line refueling capabiility of these reactors would enable plutonium to be removed without shutting down. These would be important characteristics to a nation that wanted to acquire a nuclear weapons capability or give the appearance of developing this capability.

It now appears that several countries may invest heavily in CANADA systems in the future. Argentina has ordered a series of these reactors, and Korea, with two American LWR plants currently under construction, has chosen a CANADA for its third plant. Mexico has ordered two U.S.-built reactors for its first nuclear plants. However, the Mexican government has now requested a technical proposal for construction of a 600 MW CANADA,

and is reportedly leaning toward this type of technology. India plans to produce its own HWR based upon Canadian technology, and is purchasing heavy water from the USSR. The possibility of India making significant export sales within the next ten to fifteen years, however, is small (see Section IV G).

Three factors could work against the future spread of the CANADA system. These are Canada's potential lack of capital to help LDCs finance plants, the strong export safeguard measures adopted by the Canadian government, and potential limitations in the reactor production capability of Canada. It is believed that after meeting its own reactor needs in future years, Canada may have only about one reactor per year available for export. At the present time, however, the Canada vendors (along with reactor manufacturers in general) are facing the opposite problem of not enough orders.

Political factors can also be expected to affect reactor sales to the LDCs to a certain extent. For countries that have close American ties, there will be some influence to purchase U.S. equipment. As can be seen by the cases of Mexico and Korea, however, this influence is not a guarantee for reactor sales. Some LDCs have also developed a mistrust of larger countries, and the superpowers in particular. This feeling could influence them to place orders with smaller vendor nations such as Canada.

It is very difficult to predict the future of reactor sales, but trends can be evaluated and estimates made. As noted, the American share of the LDC reactor market has been dropping ,and it appears likely that this trend will continue. The data suggest that the United States can be expected to supply between 35 and 40 percent of the LDC plants starting up in the 1980 to 1985 period. A drop in this fraction, to the 25 to 30 percent range, would be a reasonable expectation for the latter half of the next decade. Using the estimates for nuclear growth considered to be the most representative of the future (see Chapter III), U.S. industry should receive orders for 5,500 to 7,500 MW of capacity starting up in the LDCs in the former period, and 8,000 to 10,000 MW in the latter period. These estimates would result in a total installation of 18,000 to 22,000 MW of American-supplied capacity in the LDCs during 1977 to 1990. The future revenue to the United States that will result from the sale of these power plants could be expected to range from $5 to $7 billion in 1976 dollars.

American industry has supplied approximately 5,500 MW of currently operating nuclear capacity to developed foreign nations. The largest share of these orders has gone to Japan, which accounts for almost half

of the total. Table V-2 lists American-supplied reactors for plants in this group of nations that are currently under construction or on order. Spain can be noted as the major buyer of American plants in this category, accounting for 60 percent of the 17,000 MW U.S. export market to developed countries.

Many of the same factors that were noted earlier as affecting export sales to LDCs will play a part in determining future sales to developed nations as well. In the case of developed countries, however, the possibility of the buyer becoming a reactor producer is much more likely. Japan has developed LWR production capability and currently has operating reactors built by its indigenous industry, and American reactor sales to Japan have suffered because of this. In addition, the remaining share of the Japanese market, which will be open to imports, may be less available for U.S. vendors, because Japan is reportedly investigating the possibility of importing reactors from Germany or Canada in the future. Spain is currently developing indigenous manufacturing capability for many reactor components and hopes by 1980 to be producing complete NSSS units.

The fraction of reactor installation in developed countries, which is open to the world market, can therefore be seen to be decreasing. Also, competition from other reactor exporters is becoming stiffer for

Table V-2

U.S. SUPPLIED REACTORS ON ORDER
OR UNDER CONSTRUCTION IN DEVELOPED COUNTRIES

Japan		Spain		Sweden		Yugoslavia	
Capacity (MW)	Start-Up	Capacity (MW)	Start-Up	Capacity (MW)	Start-Up	Capacity (MW)	Start-Up
1,120	1977	883	1977	912	1977	632	1979
1,067	1977	900	1977	912	1979		
1,120	1978	900	1978				
		883	1978				
1,067	1979	882	1979				
		882	1979				
		935	1980				
		939	1981				
		939	1981				
		1,036	1981				
		970	1982				

these markets. These factors can be expected to result in a smaller American share of the reactor market in developed countries.

Table V-3 shows the American-supplied and total nuclear capacities that are currently under construction or on order in Western Europe for **the** periods from 1977 through 1980 and 1980 through 1985.* The American share of orders for plants starting **up in the first time period accounts** for 18 percent of Western European installations. In the second time period, this share has dropped to 9 percent. Considering this trend and the envisioned development of the Western European reactor production capability, an American share of approximately 5 percent would be likely in the period from 1985 to 1990.

Using the expected growth of nuclear capacity in Western Europe, American-supplied capacity in this region would range from 6,000 to 8,000 MW installed for plant start-up between 1980 through 1985 and 4,000 to 7,000 MW in the succeeding five years.' These estimates result in a capacity of 19,000 to 24,000 MW to be installed between 1977 and 1990. The contribution from reactor exports to Japan would increase this range to 30,000 to **35,000** MW of orders for American vendors over the same time period. The revenue (in 1976 dollars) to the United States obtained in the period **1977** through 1990 because of these nuclear plant sales **would be in the range**

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* The countries within this grouping, plus Japan, are the only developed countries expected to make significant purchases of U.S. reactors.

Table V-3

AMERICAN SUPPLIED AND TOTAL NUCLEAR CAPACITIES UNDER CONSTRUCTION OR ON ORDER IN WESTERN EUROPE*

Commercial Operation	U.S. Supplied (MW)	U.S. (percent)	Non-U.S. Supplied (MW)	Non-U.S. (percent)	Total
1977-1980	8,700	18%	40,300	82%	49,000
1980-1985	3,900	9	38,200	91	42,100

* Includes Yugoslavia.

of $5.5 to $7 billion. When this is combined with the revenue expected from reactor sales to LDCs over the same period, the total value of American reactor plant exports would be between $10 and $14 billion.

Exported reactor plants currently make up a moderate share of the nuclear capacity produced by American industry. For American-built plants starting up from 1977 through 1980, the exported fraction is 30 percent. For the entire period from 1977 through 1985, this fraction will be approximately 18 percent.* Once again, the long-range trends are difficult to predict. It can be expected, however, that although the relative importance of foreign reactor sales is decreasing, these sales will continue to represent a significant potential source of income to American manufacturers through 1930 and probably beyond.

Nuclear Fuel Cycle Exports

As noted earlier in this chapter, the sale of enrichment services is another large contributor to the revenues obtained from nuclear-related exports. American capacity is currently committed through 1985, and no orders have as yet been taken beyond that date. Roughly one-third of this capacity (about 70 million SWU) has been ordered by "foreign customers for delivery in the 1977 to 1985 period. Assuming an average charge of $80 per SWU, the revenue expected from this source will be about $6 billion.

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* Tile shares of American-built plants starting up in the LDCs in the 1977 to 1980 and 1980 to 1985 periods are 8 and 6 percent, respectively.

Because of the many uncertainties surrounding the development of new enrichment facilities in the United States and elsewhere, it is difficult to estimate the potential export value of this service above that which is already committed. New U.S. capacity will face competition from new centrifuge and diffusion enrichment plants under construction and planned for Europe. However, if the U.S. has spare capacity, some enrichment services will be exported.

The export of fuel fabrication services presents a smaller revenue to the United States than does the sale of power plants or enrichment services. This process does not require a large capital investment and is not highly technical; therefore, in the future, many countries can be expected to be marketing fuel fabrication services. This will produce strong competition for this market. In addition, the U.S. industry may be nampered by the uncertainty about long-term permission to export fuel services and by the existence of government-supported activities in other countries. The value of the export of fuel fabrication services can be expected to be on the order of $1.5 to $2 billion through 1985.

Tile future of spent fuel reprocessing in the United States is still very uncertain. Even if the decision is soon made to go ahead with reprocessing and plutonium recycle, it would be many years before a commercial industry had developed sufficiently to provide reprocessing services to foreign customers, The effect of an American embargo alone on the export of nuclear-related commodities would not be expected to have a major effect on the use of nuclear power around the world. Competing manufacturers such as Germany currently have spare reactor production capacity and could increase their exports. In addition, fuel cycle services (with the possible exception of enrichment in the short term) could be readily obtained on the open market.

It is not clear what influence an American embargo would have on the export policy of the other exporting nations. If it was to have a major effect, then the use of nuclear power in many of the LDCs could be significantly reduced.

VI CONCLUSIONS

In the current economic, political, and social climate many difficulties arise in trying to forecast the future need for energy. The continued influence of the OPEC cartel and rapid escalation of construction costs have unsettled traditional methods for calculating economic equilibrium. Formerly reliable assumptions relating energy demand and electricity share to macro-economic parameters have been questioned and new ones suggested.

In analyzing the role that nuclear power will play in the world, SRI has evaluated the latest data available and drawn from other on-going studies. For clarity, this task was divided into four segments:

1. The role of energy and power in economic development
2. Review of the major alternative forcasts
3. The movement of nuclear materials and equipment
4. The value of U.S. nuclear exports.

The following conclusions have been drawn with regard to these major topics.

1. The role of energy and power in economic development

    - The quantitative nature of the relationship between economic growth and energy use in developed countries has been reevaluated in many studies recently (for example, the Ford

Foundation Policy Report). However, it is certainly still true that if the LDCs are to continue to sustain any measure of economic growth, they will require increasing energy consumption.

- A full forecast of power demand for the LDCs would require a projection of the developmental pattern of each country (for example, agricultural, industrial, or service orientation), projections of regional fuel prices, demand-price sensitivities, generation plant capital costs and regional efficiency of energy use.

- Certain characteristics predispose a nation to the use of nuclear power. The more important of these are a lack of cheap and conveniently located alternative energy sources, and a sizable (and preferably rapidly growing) power demand in a single integrated system. Other factors favoring nuclear power are compactness of demand area and the presence of industrial operations with constant power requirements.

2. **Review of** the major alternative forecasts of installed nuclear capacity.

- Jumps in the price of oil (and other energy sources) following the 1973 embargo, coupled with rapid capital cost increases in the 1974-75 period, outdated many of the cost assumptions of the earlier forecasts (such as the IAEA market surveys).

- **Direct comparison among the various forecasts is difficult because they deal with different groups of countries and** different time frame. However, it is apparent that the more recent the study, the lower the value estimated for nuclear capacity growth. The major factors contributing to this are:

A decreased expectation for the growth of energy demand around the world due to decreases in projections of population and GNP growth, recent much higher average prices for energy, increased emphasis on conservation and improvements in the efficiency of energy use.

Increasing experience concerning the rising costs and difficulties encountered in the construction and operation of nuclear power plants.

Public opposition to nuclear power around the world has become increasingly effective.

- It seems now that nuclear fuel cycle costs and nuclear plant capital costs may range as high as 7 mils/kW hr and $925/kW respectively, for a plant beginning operation in the mid-1980s. These cost estimates are higher than those in the other studies reviewed in Chapter III.

- In general, the forecasts reviewed did not adequately consider the available alternatives to the use of nuclear power. For example, increasing use of indigenous coal and development of a world-wide trade in steam coal are likely. SRI believes that tanker-type shipment of coal could" be achieved to supply seaside power stations in the LDCs with coal at prices as low as $17-$24/ton. For these special locations, coal would be an obvious and economical choice.

- Competition to nuclear development could also come from hydropower and the use of natural gas that is currently a wasted by-product of much oil production.

- Partially offsetting some of the above factors are certain non-economic incentives that could be influential in expanding nuclear development. These might include export pressures by nuclear suppliers, the desire for developing diversified sources of energy, the prestige accompanying use of a modern technology, and possible interest in developing nuclear weapons capability, or the appearance thereof.

- Our own estimate of nuclear power growth is quite consistent with that of the International Energy Agency as modified by ERDA, the most conservative of the forecasts reviewed in this report.

3. The movement of nuclear materials and equipment. The primary conclusions for this topic can best be summarized by first considering each segment of the nuclear fuel cycle:

- Uranium Supply - Uranium ore supplies at foreward production costs of less than $30/lb are expected to be adequate for the study period of this report. Canada, Australia, South Africa, Gabon, and Niger will be the initial exporters; other nations will undoubtedly become suppliers at later dates.

- Enrichment - Large-scale enrichment facilities, all based upon the gaseous diffusion process, now exist in only four nations. (The extent of capacity in one other country, the Peoples' Republic of China, is unknown.) Alternate processes (notably centrifugation) promise to allow economical plants at smaller sizes, and such plants are currently under construction in Europe. However, a large increase in the number of nations providing commercial enrichment services is not expected, due largely to the technical complexity and capital costs involved.

- Fuel Fabrication - Commercial scale facilities for the fabrication of oxide fuels are currently operational in six countries. This technique does not require high technology or large capital expenditure, therefore it could potentially spread to those less developed countries planning large nuclear capacities such as Iran (Brazil has already announced its intention to fabricate fuel). On economic grounds alone, many facilities are likely to incorporate plutonium recycle if feasibility is demonstrated in the major nuclear countries.

- Reprocessing - No commercial scale facilities for the reprocessing of oxide fuels are currently operational, but several industrialized nations are expected to provide this service by the mid 1980s. Due to the capital investment and technical requirements of a full-scale reprocessing plant, not many LDCs could be expected to build such facilities. However, pilot size plants could be constructed and used to produce plutonium for weapons or other use.

Brazil has announced its intent to develop a pilot reprocessing plant, and several other LDCs have also discussed the importation of reprocessing technology. However, current indications are that all of the important industrialized nuclear countries are committed to an embargo on future export of reprocessing technology.*

- **It** is important to note that the large fuel cycle operations considered economic in the U.S. are too large to be supported by the nuclear capacity of any developing country, at least until. after 1990. This is true even if the most optimistic **forecast, that of the IAEA Market** Survey, is used. If an export market could be established, smaller but reasonably competitive plants especially for enrichment and fuel fabrication could be considered by 11 countries. These are Mexico, Brazil, Argentina, Spain, Yugoslavia, India, Iran, Korea, Poland, Romania, and Czechoslovakia. (Other activities including fuel reprocessing for plutonium recovery could be established if sufficient government support or incentives were offered.

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*Nuclear Engineering International, January 1977.

- **Large scale** commercial use of breeder reactors is not expected before the year 1995. Breeders would therefore not have a significant direct impact on the nuclear fuel cycle before the end of this century. However, anticipation of future breeder development may cause some stockpiling of retrieved plutonium in competition with its potential use in mixed-oxide fuels for LWRs.

4. The value of U.S. nuclear exports

- The commercial importance to the U.S. of exporting nuclear materials and services resides largely in the sale of reactors, associated nuclear generating plant equipment, and enrichment services. The dollar values of these purchases greatly outweigh the revenues expected from the export of other nuclear services and materials.

- In the past, the U.S. has captured a very large fraction of the reactor export market. However, with increasing competition from other vendor nations, the American share is expected to fall. For the case of exports to the LDCs, the fraction of U.S.-supplied nuclear capacity beginning commercial operation from the start of 1977 through the end of 1980 will be greater than 70%. In the succeeding five year period, 1980 through 1985, the American share is down to 38%.

- The major factors contributing to this downward trend are uncertainties in the future availability of enriched uranium from the U.S., governmental regulation of nuclear export sales, and reluctance of LDCs to become even more dependent on U.S. industry.

- Total foreign nuclear capacity currently committed to startup between 1977 and 1985, that is being supplied by American reactor vendors is in the 25,000 to 27,000 MW range. (Approximately 9,000 MW of this figure is scheduled for export to developing countries.) The future revenue to the U.S. accruing from these plant sales can be expected to reach $0-s billion.

- Additional new orders for plants coming on line by 1985 will likely push total exports to the 34,000-38,000 MW range, of which 10,000-12,000 MW would be to developing countries.

- By 1990, American-installed nuclear capacity in the developing countries could be expected to range from 18,000 to 22,000 MW. The revenues accrued from these sales would be on the order of $5 to 7 billion.

- The withdrawal of American reactors from the world market could have some political influence on the use of nuclear power in some of the developing nations. However, because of the many competing vendor **nations that can be expected to have excess production capacity, an American export embargo alone would not significantly hinder the ability of LDCs to obtain reactor systems. It is not** obvious to what extent an American embargo would influence other vendor nations to limit their exports of nuclear materials. This influence could be important, however.

- Enrichment services supplied by the U.S. government also have a major impact on the value of nuclear exports. About 70 million SWU is currently committed to foreign customers through 1985. Assuming an average charge of $80/SWU, the revenue obtained from this source will be near $6 billion. Beyond 1985, it is uncertain how much U.S. enrichment capacity **will be available to provide for export.**

Appendix A. Nuclear Power Plant Manpower Requirements

The operation of nuclear power plants, per se, requires the skills and abilities common to other large thermal stations. More careful training is usually given to nuclear plant operators but they are recruited from the general body of utility plant workers. It has been estimated that 95 skilled workers are required for normal operation of a nuclear power station of 1,100 MW capacity and 65 and 80 and required for oil and coal fired stations of 800 MW size respectively.

Maintenance of nuclear stations can require larger numbers of skilled workers with ability to work carefully under conditions of stress and in unusual environments. The radiation fields that can be encountered can limit the working time of an individual worker. These same fields may also require remote operations and thus reduce worker productivity. The presence of radioactive materials can require the use of protective clothing, masks, etc. These tend to reduce worker efficiency and can impair work quality as well. Many more workers of a given skill (e.g., welder) may be required for maintenance of nuclear power plants.

While large utility systems in industrialized nations usually have the required reserve of manpower for maintenance, it is not clear that developing countries can easily have the reserve manpower that may be necessary for nuclear power station maintenance. Importation of such manpower is possible, but it’s use could decrease the apparent cost advantage of nuclear power.

Construction of nuclear power stations requires large numbers of skilled workers, many of whom must be certified or otherwise specially qualified. This labor is generally available in industrialized nations but scarce in developing countries.* Even in the USA there is evidence that proper construction labor is sometimes in short supply. The combined pressures of the World Trade Center construction in NYC, the rapid construction of an automobile plant in Ohio and the first wave of nuclear power plant construction in the late 1960s created labor shortages, a competition for labor through overtime authorization, and an inflated construction cost for all projects. Similar effects have been noted during the construction of the Alaskan pipeline. Relevant to this problem of labor scarcity is the experience of Babcock and Wilcox who attempted to establish a plant at Madison, Indiana, a labor surplus area, for the construction of LWR pressure vessels. B. and W. recruited and trained previously unskilled labor for the plant operations. As the labor force became trained in specialty welding and other related skills, it was rapidly depleted by recruitment from other employers and moved to other areas at higher wages. This could happen to the native construction labor force in a less developed country.

In addition to the large numbers of construction laborers required, a large staff with diverse skills is essential for nuclear plant construction. The erection of a nuclear power plant requires trained engineering staff for quality control, general engineering, design and other functions. The number **of** engineering man-hours has risen to about 2 million over the past several years as experience has shown the need. This particular labor requirement will not impact on all developing countries equally as some will purchase plant supply services from developed countries. Only a few, e.g., India, will do the engineering support work themselves.

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* **This statement is generally true** although even projects in industrialized countries must provide specialist training to many workers.

ENERGY ECONOMICS NEWSLETTER

VOL. 2, NO. 1 JANUARY 1977

APPENDIX B

Energy in a Changing World

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During the last, few years, crude oil prices have increased to levels that most of the world's people would have considered unbelievable in 1970. Pronouncements have asserted that crude oil supplies would not be adequate to meet aggregate demand by 1990 or even earlier. SRI'S Energy Center is frequently asked what the availability and prices of primary energy resources will be in the future and how energy will affect future economic developments and political decisions. Single and multiclient studies covering future energy developments for various countries and for the world have been prepared. Work is in progress on a multiclient effort entitled "World Energy Study- 1950 to 2000," which will provide further insights into these questions. A few observations from these projects are given below.

- Future petroleum prices may moderate when expressed in constant dollars, but they are unlikely to return to 1970 levels.
- Petroleum supplies probably will be adequate for the remainder of the 20th century.
- Demand for petroleum is expected to increase at lower rates than earlier forecasts had indicated because of conservation measures and substitution of other energy Sources.
- Investment and operating costs for energy production, processing and distribution, which in many cases had increased more rapidly than inflation during tile early 1970s, are anticipated to increase at substantially lower rates during the next few years because of active competition among suppliers of the various energy sources.

World supplies of crude oils were abundant and low in cost after World War II up to the early 1970s. This materially contributed to the rapid postwar industrial recovery of the developed countries and the concomitant long period of general prosperity. Although coal consumption increased moderately, the majority of the growing demand for energy was satisfied by the increased use of natural gas and oil.

However. storm clouds were gathering that would raise energy costs. modify energy usc patterns, and even affect future economic growth rates of the developed and developing countrics. The cumulative effects of several events w'erc anticlpated by very few people, and even these individuals did not perceive their full impact.

The 1960 reduction of 10 cents per barrel in posted crude oil prices for the Middle East was one of the important factors leading to the formation of the Organization of Petroleum Exporting Countries (OPEC). During the early 1960s, OPEC was primarily concerned with increasing the volumes of crude oil marketed. The Six-Day War in 1967 resulted in the closing of the Suez Canal, which necessitated the increased use of large tankers to transport crude oil around Africa for delivery to Europe and the United States. Several events occurred in 1970 including Syria's cutting of the tapline in May and its refusal to allow the line to be repaired; Libya imposed restrictions on crude oil production rates: the 1967 Clean Air Act in the United States was amended leading to increased oil imports to replace some high-sulfur coal use; the Environmental Protection Agency was created in the United States; oil tanker shipping costs increased; and Libya forced the oil companies to increase posted prices. which led to posted price increases in other OPEC countries.

During 1971. the Tehran and Tripoli Agreements provided for additional increases in posted prices, crude quality adjustments. and increased tax payments. The U.S. dollar was devalued late in 1971, and OPEC raised the principle of participation: the Geneva Agreement of January 1972 provided for protection of crude export values against further depreciation of the dollar.

Several Middle Eastern countries signed participation agreements early in 1973, as well as a supplement to the Geneva Agreement. Rapid economic growth with substantial increases in energy consumption rates was occurring in the consuming countries, and concern was growing over rising inflation rates. This set the stage for the Arab oil embargo in October during the Middle East hostilities. By the end of 1973, Saudi Arabian light crude oil had an f.o.b. price of about $9.50 per barrel, an increase of more than $8.00 per barrel over the mid-1 970 price.

An oil price increase of this magnitude was sufficient to precipitate a worldwide recession during 1974 in nearly all non-OPEC countries. This cot]-tributed to the positive benefit of moderating inflation rates. Economic recoveries were generally favorable in tile developed countries in 1975 accompanied by declining inllation rates, indicating that the developed countries had been able to adapt to higher energy prices.

What will happen during the remainder of the 20th century? Speeches have been given, articles written, and studies prepared covering nearly every possibility that might occur. A few of the more prevalent positions are repeated below. Since 1970 there have been recurring concerns that capital limitations will restrict future economic growth in developing and developed countries. Some believe that Inflation rates cannot be kept under control. which may lead to further recessions. There have been frequent pronouncements that the world will incur shortages of petroleum and uranium during this period, leading to reduced economic activity; also, there are those advocating the need for crash programs to develop nearly every possible substitute energy source, regardless of its economic viability. Some even believe that conditions will stabilize in a few years, resulting in economic and energy growth rates again becoming similar to those occurring in the 1960s.

Although all projections are subject to error because of the many variable factors, everyone (individuals, corporations. and governments) must provide for the future based on an assessment of what is likely to happen. SRI'S analyses lead to the conclusion that major events of the last five years will cause repercussions for many years. Petroleum prices, whether [hey increase or moderate on a constant dollar basis. are not likely to return again to 1970 levels. Economic activity. as measured by gross national product. is expected to increase at lowcr rates than prevailed in the 1960s. Population growth rates should slowly moderate.

The higher petroleum prices, lower rates of economic activity, and moderating population growth rates are anticipatcd to affect the demands for energy and the prirmary energy mixes. As an example of the magnitude of anticipated energy consumption in 1990. a fairly representative 1972 projection anticipatcd 116.3 million barrels per day of free world demand for oil and 214.0 million barrels per day of oil equivalent for total free world energy demand. SRI has estimated 1990 free world demands of 68.2 and 156.7 million barrels per day of oil equivalent. respectively (reduced forecasts of about 41 and 27 percent). The use o f oil is reduced more than total energy because of conservat ion measures and the substitution of other energy resources. However. SRI'S Energy Center believes that adequate oil supplies will be available through the remainder of this century. Conversely, coal, natural gas, and,. uranium uses will be accelerated because of high oil prices and consumer desires to diversify supply sources, especially from non-OPEC count ries.

Lower expected consumption of total energy and particularly the lower requirements for oil would have wide economic and political repercussions. Tanker requirements for transporting crude oil and petroleum products would be reduced. Additional pipelines would be required to transport natural gas. Explorat ion programs for uranium would be expanded as would the requirements for coal mining machinery and coal transportation facilities. Reduced economic activity and total energy consumption rates would adversely affect industry in general by lowering overall productivity y.

Although only a few examples have been given. SRI has prepared studies to quantify these effects in assisting clients to develop their future long-range plans_