Chapter X

The International Nuclear Industry

Preceding page blank

Chapter X

The International Nuclear Industry

The concern over proliferation has emerged largely as a consequence of the growth of the peaceful use of nuclear energy. Measures to control proliferation will therefore interact with several aspects of the nuclear industry: the real or perceived need for nuclear power to fill future energy demand, the means by which this need will be fulfilled, and the economic interests of nuclear corporations and their parent countries. This chapter begins by discussing the need for nuclear energy and its appropriateness for advanced and developing nations. It then presents a plausible projection of the growth of nuclear power worldwide by the year 2000. This projection leads to an estimate of the spread of facilities and movement of materials created by the nuclear industry. Finally, the value to the United States of nuclear exports is estimated. All these subjects are treated in greater detail in appendix IV, volume II.

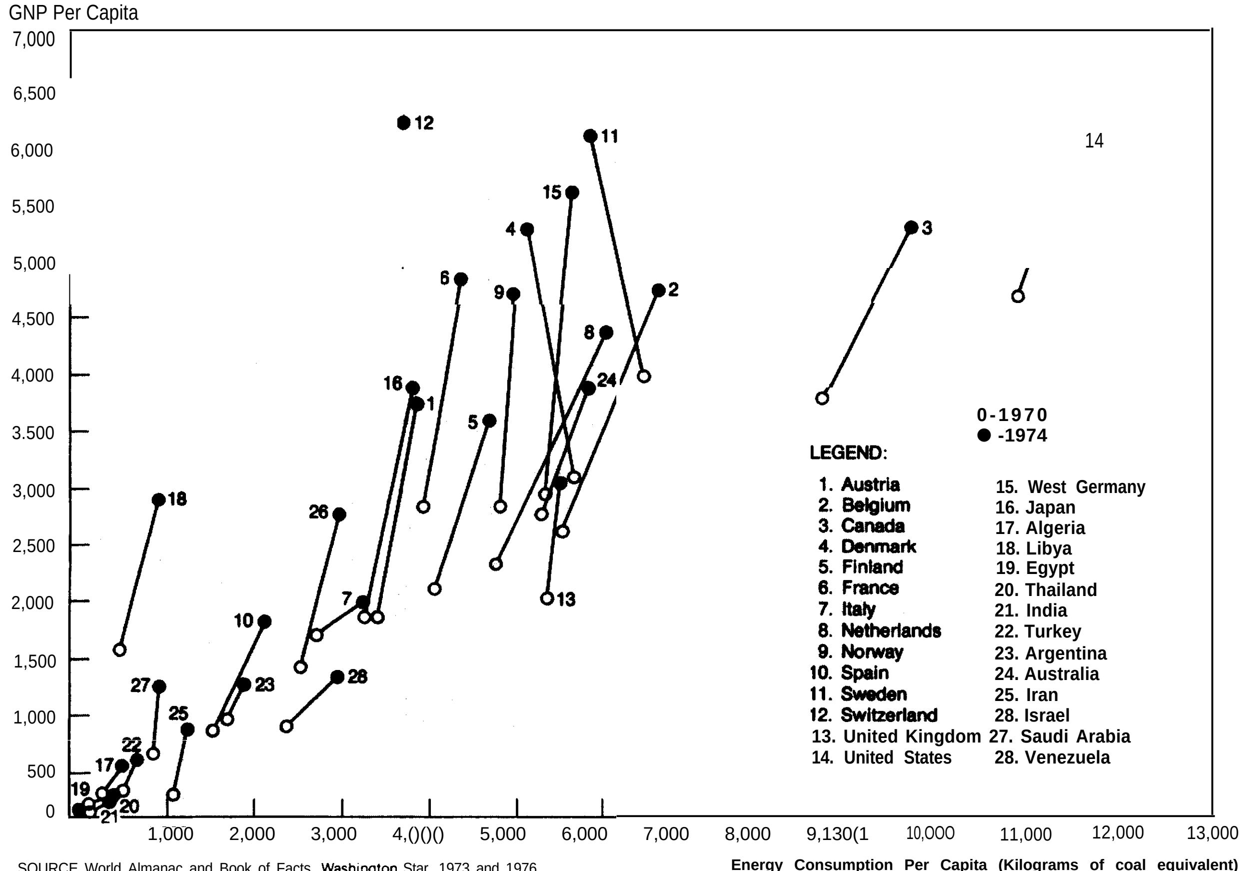
THE NEED FOR NUCLEAR POWER

The extent to which various nations may rely on nuclear power will depend on their total energy demand and the alternatives available to meet that demand. One difficulty in assessing the energy demand of a nation is that the relationship between a nation's economy and its energy use is still not well understood. Obviously, energy consumption is in someway connected to a nation's standard of living as measured by the accessibility of goods and services: Highly industrialized countries use much more energy per capita than the less developed countries (LDCS). Nevertheless, different nations accomplish similar functions with very different requirements for energy. The per capita energy consumption for a variety of nations is related to the per capita gross national product in figure X-1. This comparison between nations is only a rough one, because both energy and economics are measured differently by different nations. For instance, the numbers do not include noncommercial energy such as firewood, which can amount to half an LDC'S total energy consumption. Nevertheless, it does indicate that the United States might maintain economic growth with substantially less than historic energy growth. This possibility is less apparent for other industrialized nations and quite improbable for the LDCS.

The explanation for these differences lies partially with the patterns of historical development of natural resources. The United States was endowed with vast supplies of energy resources and showed an increasing casualness towards them as its primary energy dependence shifted from fire-wood to coal to oil and gas. This shift, depicted in figure X-2, was engendered chiefly by the low

Preceding page blank

Figure X-l.
Relation of GNP and Energy Consumption



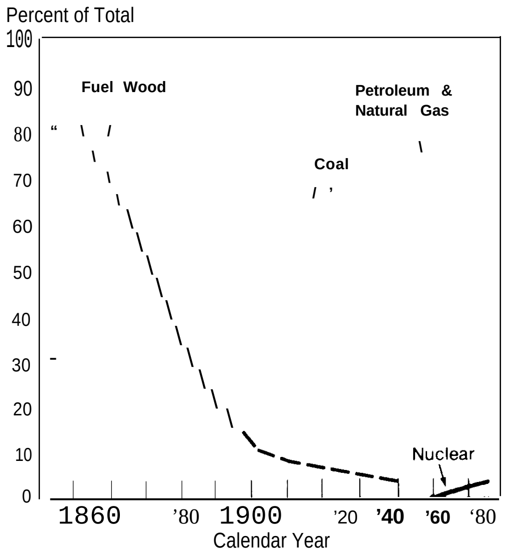
SOURCE World Almanac and Book of Facts, Washington Star, 1973 and 1976, and 'World Energy Supplies 19501974," United Natlons, 1976.

cost and convenience of resource extraction and use. Other nations, constrained by limited resources and high costs, have developed more frugal patterns of use. Most other nations have also been shifting towards increasing use of oil and gas as energy sources, Even though few industrialized nations outside of the United States have substantial reserves of cheap oil and gas, most have been relying increasingly on imports of these fuels rather than on coal. Most LDCS do not have significant reserves of either oil or coal (part of the reason for their lack of industrialization) and are still in the early stages of a shift from noncommercial fuels to imported oil, at least for use in industries and cities where the traditional sources are impractical. In most cases, foreign exchange considerations have led governments to impose high fuel taxes to minimize consumption. A graph of the worldwide use of commercial energy resources, shown in figure X-3, illustrates the rapid rise in oil consumption since 1945. Figure X-4 details this trend for several groups of nations.

Even if the energy consumption growth rate can be reduced, these patterns of energy use will have to change. In particular, the use of oil is not a long-term solution. The United States has been increasing its purchases of this fuel on the world market because of increasing consumption and declining domestic production. It now appears likely that U.S. production will continue to decline, and by the year 2000 it will certainly be much lower than it is now. Some OPEC members could produce at a substantially higher rate than at present, but they generally will not find it to their advantage to do so. Even at present rates of production, oil-rich lands such as Saudi Arabia

Figure X-2.

U.S. Energy Consumption Patterns



SOURCE ERDA 76-1, "A National Plan for Energy Research, Development and Demonstration Creating Energy Choices for the Future."

could find their production declining in about 20 years. Thus oil prices are very likely to become much higher than they are now. Figure X-5 shows estimates of the proved world reserves and estimated ultimate recoverable oil resources. The latter figure is especially subject to error, but the important points are that there is a limit which could easily be much lower and that most of the very cheap oil has already been discovered. The U.S. Geological Survey, for instance, has recently sharply lowered its estimates of U.S. resources. At present consumption rates, the estimate of ultimate recoverable oil in figure X-5 will last 83 years. If consumption increases at 3 percent per year, it will last only 40 years.

A partial return to coal is therefore inevitable despite a considerable aversion to its use. Major problems center on the inconvenience and expense of extracting and using it in an environmentally acceptable way. World coal reserves are shown if figure X-6. The known recoverable reserves provide an energy resource not much greater than that of the estimated total recoverable oil. The addition of the estimated recoverable reserves of coal raises the energy value to over five times that of oil, and improved mining techniques could recover much more. Production in Europe is not expected to change significantly over the next 10 years and the cost of extraction there is high[1]. Large amounts could be exported by the United States, Australia, South Africa, Canada, and the U. S. S. R., but in the United States at least there would be considerable opposition to the domestic environmental damage incurred for exports. Among the LDCS only India and South Korea have substantial coal production.

Nuclear energy has been widely considered to be the only viable alternative. Unlike coal, it is not readily suitable for, uses other than producing electricity. This is not felt to be a disadvantage by its promoters. Electricity is the most convenient form of energy, and is expected by many to become the dominant mode of consumption. It can be generated from a variety of sources simultaneously and used efficiently. Most countries have seen their electricity consumption grow faster than their overall energy use, and they expect this trend to continue. The biggest drawback to electricity is its expense. The equipment to generate it is costly and the fuel to produce it is used inefficiently: because of the thermodynamic processes involved in a steam-electric plant, about two units of fuel are lost as low-grade heat for every one that is converted to power.

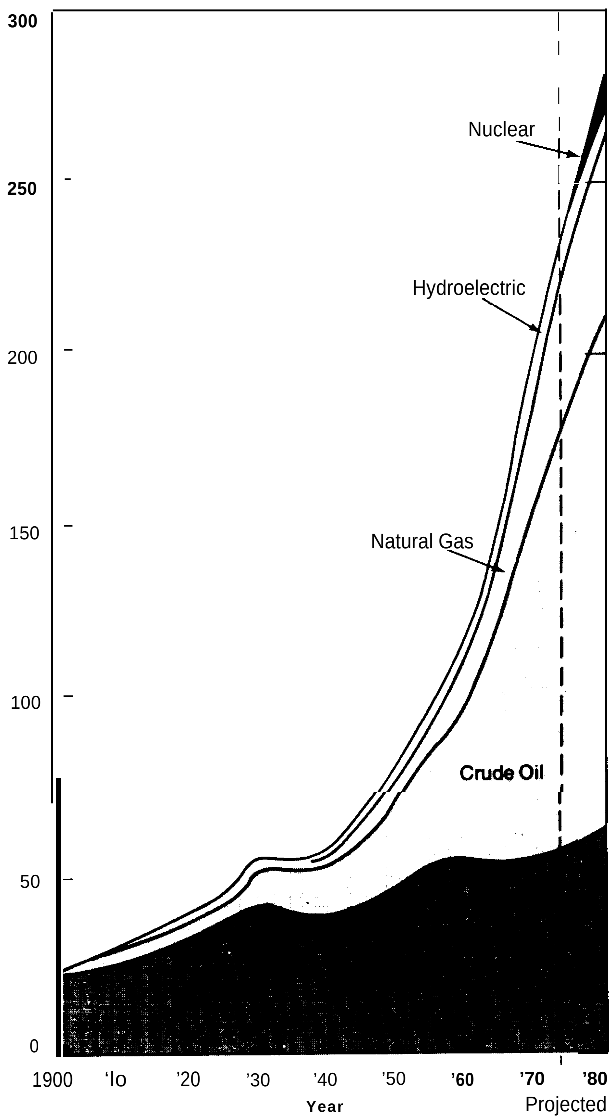
The major uses of electricity are to produce heat and light, perform work (operate machines), operate electronic equipment, and perform certain tasks (such as electrolysis) which depend on the unique nature of electricity y. When tasks such as low-temperature space heating can be performed as well by the combustion of fossil fuels, electricity can seem very expensive and inefficient. As oil and gas are depleted in the future, the only choice may be between electricity and the direct use of coal with all the difficulties it entails. Even though technology may produce more attractive direct-use options such **as**

[1] *World Energy Outlook*, Organization for Economic Cooperation and Development, Paris, 1977.

Figure X-3.

Changing Use of Energy Resources in the Twentieth Century

Annual Energy Production and Consumption (Quadrillion Btu 's)



SOURCE Survey of Energy Resources World Energy Conference 1974

generation in a relatively few sites thereby allowing the use of equipment that can achieve higher efficiency and economies of scale, and easing management by the utility. It also necessitates the transmission of power over long distances and makes each plant a substantial fraction of the entire grid capacity, Nuclear power marks the culmination of this process (except possibly for hydroelectric plants which are even larger, generally require remote siting and are not well suited for other purposes).

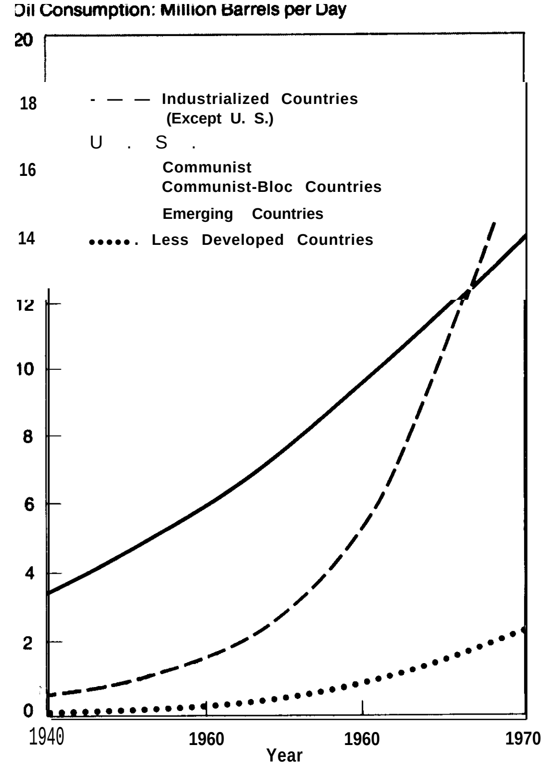
Although eventual fossil-fuel resource depletion is one of the major elements behind the desire for nuclear power, the present generation of reactors use uranium so inefficiently that this nuclear-resource base is comparable to that of oil. Nevertheless, the advent solar energy or synthetic fuels, significant growth in electricity consumption is probable.

Electricity can be generated from water power (hydroelectricity), steam-turbine plants (fossil fuel, nuclear, solar, or geothermal), photovoltaics or open-cycle engines (gas turbines or diesels). The trend has been to increase the size of plants and to centralize

Figure X-4.

Oil Consumption for Selected Groups of Nations

Oil Consumption: Million Barrels per Day



SOURCE: "Survey of Energy Resources," World Energy Conference, 1974.

Figure X -5

World Estimated Ultimate Crude Oil Recovery, January 1, 1975*

(Billions of barrels of oil)

	Discovered ultimate recovery	Undiscovered Potential-Resources Expected	Range	Total Remaining"	Energy Value Quads (10^{15} Btu)
Russia & China et al.	**136**	300	**70-700**	**436**	2529
United States	**49**	85	**50-150**	**134**	777
Canada	11	**70**	**40-110**	**81**	470
Total N. America	59	155	100-250	213	1235
Middle East	**549**	**150**	75-280	699	**4054**
Other foreign:					
Greater N. Sea	**23**	45	**20-80**	**68**	394
Other W. Europe	**2**	12	**7-17**	**14**	81
North Africa	**42**	33	**15-60**	**75**	435
Gulf of Guinea	**32**	**30**	**15-50**	**62**	360
Other Africa	—	**8**	**3-15**	**8**	46
Northwestern S. America	**29**	**32**	**20-50**	**61**	354
Other Latin America		**50**	**23-95**	**69**	400
Southeast Asia	19	**32**	**18-50**	**58**	336
Other Far East	9	**58**	**20-120**	**67**	389
Antarctica	—	**20**	**5-50**	**20**	116
Total other Foreign	182	320	**300-500**	502	2912
Total worldwide	821	925	600-1,400	1,746	10127

'Joint Committee on Atomic Energy "Project Interdependence" 1976
"'As of January 1, 1973

of breeders would transform this uranium *into* an effectively inexhaustible energy source. Another major factor in the desire for nuclear power is the promise of relatively cheap energy. This claim is considerably harder to substantiate. Capital costs have risen dramatically over the past several years and the price of uranium has risen faster than that of petroleum. Even with these higher costs, however, most countries will still find electricity generated from nuclear power cheaper than that from imported oil.

Assumptions that high electric growth rates must be maintained and that nuclear power is the only way to fulfill that demand are not universally accepted. Alternatives proposed to reduce the need for nuclear power are:

- Electricity from other sources: The use of coal could be greatly expanded. Plants fueled with imported coal could be cheaper than nuclear plants in some cases, and much cheaper than those fired by imported oil in many others. New sources could be emphasized as they become available, including wind power, solar electric, and combustion of trash. Cogeneration could be implemented (a steam turbine is coupled with industrial-process steam boilers or district-heating plants in such a way that additional heat energy is nearly 100 percent converted to electricity y).
- Non-Electric Replacements: Fossil fuels and new energy sources used directly as heat sources would in some cases be more efficient than electricity produced from either nuclear energy or these fuels themselves.

Figure X-6.
Solid Fossil Fuel Resources by Continents, and Nations with Major Resources*

Country or Continent	Recoverable Reserves	Energy Value Quads (10^{15} BTU)	Estimated Undiscovered Recoverable Reserves	Total Estimated Resources
USSR	136,600	2,456	273,200	5,713,600
China, RR. of	60,000	2,090	300,000	1,000,000
Rest of Asia	17,549	655	49,479	106,053
United states	181,781	5,095	383,562	2,924,503
Canada	5,537	131	9,034	106,777
Latin America	2,803	68	9,201	32,828
Europe	126,775	2,495	319,807	607,521
Africa	15,628	382	30,291	58,844
Oceania	24,518	485	74,689	199,654
World Total	591,191	13,857	1,402,273	10,753,680

"Survey of Energy Resource, " World Energy Conference, 1974

. Conservation of Electricity: Strict measures (such as increased insulation and use of heat pumps) could free enough existing generation capacity so that new plants would not be needed for a period. Alternatively, a nation could reject the energy-intensive, high-consumption society now generally accepted as a goal.

The desirability and feasibility of these alternatives have to be weighed against those factors both favoring and opposing nuclear power. Factors that suggest nuclear energy be considered are:

1. Lack of cheap alternatives. Even oil-rich nations may opt for nuclear energy if it appears to be cheaper than the world price of their own oil;
2. Expectation of continued fuel price escalation. A nuclear powerplant that is only marginally economical now may become very attractive in a decade, because nuclear power economics are much less sensitive to fuel prices than are fossil plants;
3. A large and growing electricity demand;
4. A desire to diversify the energy supply;
5. The need to guarantee a fuel supply by storage or rapid procurement, both of which are impractical for fossil plants because of the cost and quantity of the fuel;
6. A desire for the prestige which comes from demonstrating the ability to handle high technology;
7. The hope that nuclear power will help provide a shortcut to technological advancement;
8. The feeling that there will be no alternatives to nuclear power in a few decades and that massive deployment will then be impossible without a long learning period.

The absence of one or more of these factors will reduce the desirability of nuclear power. In addition, there are several arguments against a nation choosing nuclear power:

1. The high initial cost for nations with a capital shortage (especially LDCS). Even when the purchase is financed by an exporting nation, only a limited amount of credit is available and the ability to borrow for other purposes will be reduced. This problem has evidently not yet been overwhelming for the LDCS, who seem to prefer the more expensive heavy water reactors;
2. An increased dependence on nuclear supplies for critical parts and material. The range of suppliers is narrower than

that for most other transactions, and this may strike some as neo-colonialism;

3. Absence of technological depth and experience to handle nuclear plants. imported reactors have generally lower capacity factors, which may indicate that the risk of accidents could be higher;

4. Increased vulnerability to non-state adversaries or to enemies in case of war. Sabotage of a nuclear powerplant could cripple a nation's power supply and cause substantial damage;

5. The problem of nuclear waste disposal. If a nation reprocesses its own spent fuel, other nations may be unwilling to accept the wastes. A small waste-disposal program could be relatively expensive and seems unjustified except for nuclear weapons states, who in any case have to dispose of large quantities from weapons programs. Note that a program for the return of spent fuel to supplier countries automatically solves the problem.

6. A power system so small that the nuclear plant would be too large a fraction (more than 10-15 percent) of the overall capacity. A single plant larger than this diminishes total system reliability because a sudden outage would have too great an impact. Development of a nuclear plant that is economical on a smaller scale would greatly enhance its appropriateness for an LDC;

7. Industrial demand insufficient to permit operation of the plant at full capacity around the clock:

8. Lack of a suitably sophisticated work force, such that operation of facilities would place undue demands on the supply of skilled manpower. Note that the work force dedicated to reactor operation need not be very large.

Whether the above factors tip the scale in favor of nuclear power is a judgment that each individual nation must make for itself. The decision by a nation to take its first step toward a nuclear power program may be a momentous one. A miscalculation in the decisionmaking process can be a very expensive mistake. The LDCS in particular must be careful since they will be relatively more damaged should nuclear power turn out to be inappropriate. Since most of the potential Nth countries identified in chapter IV are in this group, proliferation concerns might best be served if supplier nations make a special effort to find appropriate alternative energy sources for them. At present, little energy research is directed at the needs of LDCS. Energy-producing devices could be developed at relatively low R&D expenditures to especially suit the problems of LDCS, which are: difficulty in financing high capital cost projects; shortages of highly skilled manpower; and an abundance of unskilled labor. Examples might be waste digesters to produce methane gas and efficient ovens for producing charcoal (the present method loses 80 percent of the energy, and firewood is becoming critically scarce in many parts of the world). This approach might be reminiscent of colonialism for some LDCS unless such devices are also implemented in the advanced nations, but the latter may also find them useful.

PROJECTIONS

Many estimates of worldwide energy and nuclear growth have been made. These have generally been based on exponential extrapolations of historical growth curves. Until *1973,* this method proved reasonably accurate. The real price of energy had been declining, and consumption was increasing faster than the general economy. The sudden quadrupling of oil prices starting in 1973, followed by the rapid escalation of other fuel costs, produced a surge of interest in nuclear energy. Since then, much of this new interest has waned. The latest nuclear projection by the Organization for Economic Cooperation and Development (OECD) is in fact lower than that of 1973. The primary reason for this decline is economic. Nuclear capital and fuel costs have soared along with oil, and

92-592 0 - 77 - 1 '7

Figure X-7
World Nuclear Capacity*
(1000 **Megawatts)**

	1975	1960	1$85	1990	2000
U.S. Rerference Case	39	67	145	250	510
Other Nations	29	100	230	425	1030
Total	68	167	375	675	1540
IAEA/OECD (lower bound)	69	179	479	875	2005

"Edward J. Hanrahan, et al., "World Requirements and Supply of Uranium," presented at the Atomic Industrial Forum Conference, Geneva, Switzerland, Sept. 14, 1976.

economic growth projections are substantially lower, partly because of the higher cost of energy. Thus, the first reaction to the oil price rise was to continue the previous patterns of consumption by turning to new sources, while the later trend was to adjust to new high energy costs by consuming less.

The previous section considered the various factors influencing an individual nation to choose or reject nuclear power. An accurate projection of the nuclear growth in each country would require an exhaustive and complex analysis of both the total electrical power demand and the various alternatives to meet this demand, No projection has yet been based on such an analysis. Several less complete projections are described in appendix IV of volume II.

Even if such a projection had been done, it probably could not adequately treat unpredictable developments such as the cohesiveness of the OPEC cartel. The best projections remain largely guesses based on estimates of the major parameters. Nevertheless, planners need a framework for their discussions, and proliferation control must be based on an understanding of the expected material flow and availability of facilities. They must rely on the less complete studies that have been done.

Projections of nuclear energy growth have been made in recent years by the IAEA and the OECD. The most recent official forecast is a 1976 ERDA modification of an IAEA study. The results are shown in figure X-7 and compared with the 1975 IAEA/OECD study from which it was derived.

Figure X-8 shows the distribution of the 1975 IAEA/OECD projection. Significant points to be drawn from figures X-7 and X-8 are that the United States is reducing estimates of its own nuclear growth more than most other countries and now anticipates a growth rate lower than others. These are largely because of forecasts of a reduced economic growth rate and substantial opportunities for conservation in the United States.

Figure X-8.
Nuclear Power Growth Estimate
(1000 Megawatts)*

	1975	1980	1985	1990	2000
Australia				1	6
Austria	—	0.7	3	6	14
Belgium	1,7	3.5	9.5	16.5	30
Canada	2.5	7,2	18.4	41	115
Denmark	—	—	1.8	4.9	11.4
Finland	—	1.5	3.9	4.9	13
France	2.3	20.4	56	90	170
Germany	3,2	19.1	44.6	77	134
Greece	—	—	0.6	1.2	4
Ireland	—	—	0.7	2	6
Italy	0.6	1,4	26.4	62	140
Japan	6.6	17	49	84	157
Luxembourg	—	—	1.2	1.2	1.2
Netherlands	0.5	0.5	3.5	7.5	16
New Zealand	—	—	—	1.2	3
Norway	—	—	—	1.8	4
Portugal	—	—	1.4	3.3	8
Spain	1.1	8.7	23.7	42	80
Sweden	3.2	7.4	11.3	16.3	24
Switzerland	1	3.8	8	8	12
Turkey	—	—	0.6	2.2	16
United Kingdom	4.8	11.1	15.4	31	115
United States	40.1	82.2	205	386	1,000
OECD,					
High Estimate	68	185	484	890	2,080
Low Estimate	68	171	437	774	1,685
African region[1]	_	—	3.1	6.9	29
American region[2]	0.3	3.6	14,4	35	147
Asian region[3]	0.7	5	28.2	72	224
Total Emerging & LDC's	**1.0**	**8.6**	**45.7**	**113.9**	**400**
TOTAL (High Estimates)	**69**	**194**	**530**	**1,004**	**2,480**
Low Estimate	**69**	**179**	**479**	**875**	**2,005**

[1]Algeria, Egypt, Iraq, Kuwait, Morocco, Saudi Arabia, South Africa, Tunisia.

[2]Argentina, Brazil, Chile, Colombia, Cuba, Mexico, Jamaica, Peru, Uruguay, Venezuela.

[3]Bangladesh, Hong Kong, India, Indonesia, Iran, Israel, Korea, Malaysia, Pakistan, Philippines, Singapore, Taiwan, Thailand.

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

The most recent projections of total electrical power demand for individual LDCS was a 1974 Market Survey by the IAEA. The results of this IAEA study for those LDCS and emerging nations also listed in the OECD report are shown in figure X-9. This figure has been overtaken by recent events as shown by the comparison with more recent OECD figures, but it does give an idea of which nations will be considering nuclear power and what their alternatives are.

The developing nations heavily committed to nuclear (i.e., planning to install more than 10,000 MW by the year 2000) are Brazil, Mexico, Argentina, Egypt, India, Iran, Taiwan, South Korea, Pakistan, Philippines, and Singapore. These are either emerging nations with expectations of becoming major industrial powers by 2000 or industrializing LDCS with especially poor resources. Exceptions may be South Korea with its large coal deposits and Egypt with potential oil reserves. All have nuclear projects underway. A major effort with far-reaching ramifications would be required to convince these nations to eliminate their planned use of nuclear energy altogether. Only those nations with a lower anticipated dependence on nuclear power, as listed in figure X-9, might accept a total substitution of alternatives should that prove desirable. Many already have a start in nuclear technology however, as detailed in appendix IV of volume II, and some are planning on a very high eventual nuclear fraction of their total power capacity.

Even allowing for a reduction in projections, nuclear energy is expected to be a major energy source for the world. The 1,540,000 MW of nuclear capacity in the year 2000 (figure X-7) would produce a total of about 100-Quads (101s Btu) per-year of thermal energy, nearly twice the present rate of coal consumption shown in figure X-3. Producing this much nuclear capacity will be difficult and may well not be achieved. If the world economy continues to grow however, finding alternatives may be even harder.

THE MOVEMENT OF NUCLEAR MATERIALS AND EQUIPMENT

The previous section summarized projections of the growth of nuclear power expected in the future. The impact this growth might have on proliferation depends largely on the characteristics of the international nuclear industry. The capabilities of reactor-supplier nations are particularly important in estimating the success of any unilateral or multilateral proliferation-control measures. The spread of those facilities that are most sensitive to proliferation+nrichment and reprocessing plants—is also critical. Such plants not only give their operators the means to produce weapons material but also reduce their vulnerability to international sanctions. (These and other facilities less critical to proliferation control are discussed in appendix IV of volume II). Finally, the location and adequacy of the supply of uranium fuel itself affects fuel supply strategies, such as guaranteed fuel, and determines when measures that might increase proliferation problems—such as recycling plutonium or relying on the breeder reactor—are really needed. The worldwide distribution of reactors and their supporting facilities is depicted in figure X-10.

Reactors

The nations and enterprises that presently manufacture reactors are listed in figure X-11. The export market has been restricted to the United States, Germany, France, and the U. S. S. R., for light water reactors (LWRS) and to Canada for heavy water reactors (HWRS). Italy and Great Britain also have the spare capacity to export if they can find a market. Japan and Sweden will continue to import, as their manufacturing capability is less than domestic demand.

The general pattern of growth has been for a nation to import its first few reactors and then develop its own manufacturing capability, possibly under a licensing agreement. India is now in the middle of this process, building a capability for producing heavy

Figure X-9.

Projected Distribution of Installed Electric Capacities in Developing Nations by Plant Type*

(1000 Megawatts)

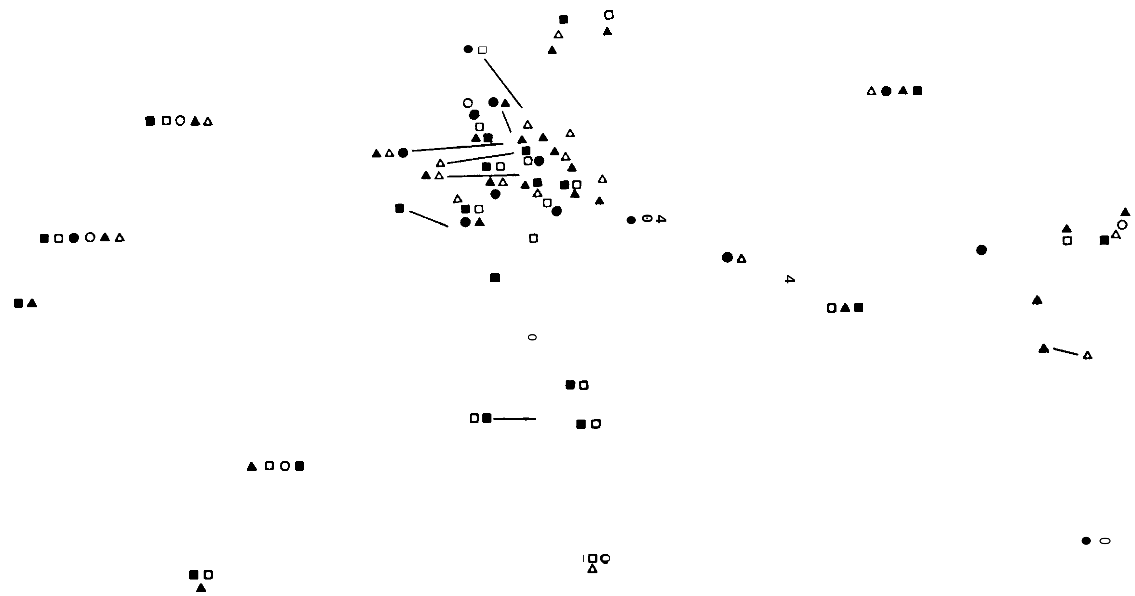
	1980				1990				2000			
	Conv.	Nuclear	Hydro	Total	Conv.	Nuclear	Hydro	Total	Conv.	Nuclear	Hydro	Total
American Region												
Brazil	3.1	0.6	22.0	25.7	3.1	11.4	49.2	63.7	3.1	46.9	52.3	102.3
Mexico	8.6	0.7	6.9	16.2	9.1	21,6	8.6	39.3	9.4	68.0	10.6	88.0
Argentina	5.4	1.5	4.0	10.9	4.9	8.1	8.5	21.5	3.9	18.1	15.8	37.8
Venezuela	6.4	-	1.2	7.6	6.4	4.4	3.4	14.2	6.4	8.4	9.8	24.6
Colombia	3.4	-	2.6	6.0	3.4	1.7	6.5	11.6	3.4	5.3	12.5	21.2
Peru	1.6	-	1.8	3.4	1.6	1.3	3.6	6.5	1.6	3.0	7.0	11.6
Chile	1.1	-	1.6	2.7	1.1	1.7	2.4	5.2	1.1	3.7	4.9	9.7
Cuba	2.5	-		2.5	2.6	2.1	-	4.7	2.6	5.5	-	8.1
Jamaica	1.0	-		1.0	1.0	1.8	-	2.8	1.2	5.8	-	7.0
Uruguay	1.0		0.3	1.3	1.1	1.1	0.5	2.7	1.1	3.1	0.6	4.8
Region Total	34.1	2.8	40.4	77.3	34.3	55.2	82.7	172.2	33.8	167.8	113.5	315.1
African Region												
Egypt	2.8	-	2.4	5.2	2.6	5.0	2.4	10.0	2.5	12.6	2.4	17.5
Israel	3.8	-		3.8	3.8	3.9	-	7.7	5.0	7.4	-	12.4
Kuwait	1.3	-		1.3	1.3	1.3	-	2.6	2.2	3.2	-	5.4
Iraq	1.1	-		1.1	1.1	1.1	-	2.2	1.8	2.6	-	4.4
Morocco	0.3	-	0.6	0.9	0.3	0.4	1.0	1.7	0.3	1.6	1.3	3.2
Algeria	0.4	-	0.4	0.8	0.4	0.5	0.8	1.7	0.4	1.8	1.3	3.5
Nigeria	0.8	-	0.1	0.9	1.1	0.5	0.3	1.9	0.8	2.6	1.0	4.4
Tunisia	0.4	-	0.1	0.5	0.8	0.2	0.2	1.2	0.8	1.6	0.2	2.6
Saudi Arabia	0.4	-		0.4	0.8	0.2	-	1.0	0.8	1.4	-	2.2
Region Total	11.3	0	3.6	14.9	12.2	13.1	4.7	30.0	14.6	34.8	6.2	55.6
Asian Region												
India	25.5	4.2	22.3	52.0	26.0	31.4	43.0	100.4	27.0	130.0	60.0	217.0
Iran	6.3	-	3.0	9.3	6.4	10.0	8.0	24.4	6.5	28.0	10.0	44.5
Taiwan	6.1	2.9	(a)	9.0	10.0	10.3	(a)	20.3	14.9	22.4	(a)	37.3
Korea	4.7	1.2	0.7	6.6	4.7	9.8	2.3	16.8	4.7	24.5	2.3	31.5
Thailand	3.0	-	1.3	4.3	3.1	3.7	2.2	9.0	3.1	9.6	4.3	17.0
Pakistan	3.5	0.1	2.9	6.5	3.2	4.9	4.8	12.9	3.3	15.9	7.3	26.5
Philippines (Luzon)	2.7	-	1.0	3.7	2.8	4.8	2.0	9.6	3.9	12.0	2.8	18.7
Hong Kong	3.5	-		3.5	3.6	3.2	-	6.8	4.9	7.3		12.2
Singapore	1.8	-		1.8	1.8	4.3	-	6.1	1.8	14.9		16.7
Malaysia (Peninsular	1.0	-	0.6	1.6	1.3	1.3	1.4	4.5	1.3	5.0	2.3	8.6
Indonesia (Java)	0.8	-	0.7	1.5	0.8	1.7	1.8	4.3	1.1	5.7	3.0	9.8
Bangladesh	1.1	-	0.1	1.2	1.1	4.0	0.5	5.6	1.1	9.7	0.8	11.6
Rsgion Total	60.0	8.4	32.6	101.0	64.8	89.9	66.0	220.7	73.6	285	92.8	451.4
Sub-Total	105.4	11,2	76.6	193.2	111.3	158.2	153.4	422.9	122	487.6	212.5	822.1
Percentage	54.6	5.8	39.6	100	26.3	37.4	36.3	100	14.8	59.3	25.8	100

(a) Not available

"Derived from IAEA Market Survey for Nuclear Power in Developing Countries, 1974.

Figure X–10.

Worldwide Distribution of Reactors and Their Supporting Facilities



● Assured Uranium
o Potential Uranium
* Operating/Under Construction Enrichment Plant
0 Planned Enrichment Plants
4 Reactors Operating/Under Construction
Q Planned Reactors

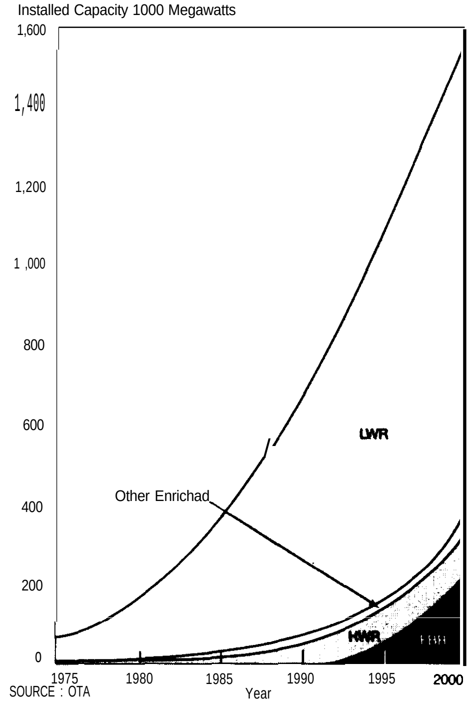
SOURCE: Nuclear Engineering International, November 1976, Vol. 12, No. 250.
Nuclear News, Mid-February 1977/Vol. 20, No. 3.

Figure X–11.
Principal Suppliers of Reactors

HWR	
Atomic Energy of Canada Ltd.	Canada
Kraftwerk Union	Federal Republic of Germany
Canadian General Electric	Canada
LWR	
Kraftwerk Union AG	FRG
Framatronne	France
Atomenergoexport	USSR
ASEA-Atom	Sweden
General Co.	USA
Westinhouse Co.	USA
Toshiba	Japan
Hitachi	Japan
Combustion Engineering	USA
Babcock and Wilcox	USA
Ansaldo Meccanico'co Nuclear SpA	Italy
Mitsubishi Heavy Industries	Japan
Gas Colled	
General Atomic	USA
Nuclear Power Co.	United Kingdom

SOURCE: OTA

Figure x-12.
World Nuclear Capacity Projection



SOURCE : OTA

water reactors derived from its Canadian imports despite total withdrawal of Canada's assistance. Few other nuclear importers, however, will be tempted into the business of reactor manufacturing. The necessary infrastructure is too expensive and demanding to be worthwhile even to provide domestic needs. Entering the reactor export business would be even harder because of the stiff competition and difficulty in demonstrating a reliable product to a new customer.

The growth of various types of reactors most likely to be installed worldwide through the year 2000 are shown in figure X-12. This figure indicates the continued predominance of LWRS, the increasing popularity of HWRS and the entrance of breeders near the year 2000.

Uranium

Those nations with economically recoverable resources of uranium are listed in figure X-13. Interestingly, few of the Western reactor suppliers will be major exporters of natural uranium. Despite their large reserves, Canada and Australia may have restrictive policies limiting their uranium exports. The United States has substantial reserves, but even these may not be enough for domestic needs. The other nations on the list can be expected to export uranium.

Although economically recoverable resources seem to be concentrated in a few countries, most other countries do have some deposits and more may be discovered as exploration is accelerated. Some may find it politically advantageous, even if not economical, to mine and mill uranium to ensure a fuel supply for domestic plants.

The figures presented in figure X-13 do not represent an estimate of ultimately recoverable resources. They have been collected largely

Figure X -13.
Uranium Reserves and Resources •
Data Available November 1.1976

Cost Range	Reasonably Assured Resources (1000 Metric Tins)	Estimated Additional Resources (1000 Metric Tins)	Total (1000 Metric Tons)
Algeria	28		28
Argentina	20.6	39	59.6
Australia	243	80	323
Brazil	10.4	8.8	19.2
Canada	172	605	777
Central African Republic	8	8	16
Denmark (Greenland)	6	10	16
Finland	1.9	—	‘ 1.9
France	55	40	95
Gabon	20	10	30
Germany	1	4	5
India	29.2	23.3	52.5
Italy	1.2	1	2.2
Japan	7.7	—	7.7
Korea	2.4		2.4
Mexico	6		6
Niger	50	30	80
Portugal	6.9	—	6.9
South Africa	462	74	536
Spain	103.5	106.8	210.3
Sweden	300	—	300
Turkey	31	0.4	3.5
United Kingdom	1.8	4	5.8
United States	493	812	1305
Yugoslavia	6.5	15.2	21.7
Zaire	1.8	1.7	3.5
Total (rounded)	2041.0	1873.2	3914.2

‘Nuclear Engineering international, November 1976

for purposes of short-and mid-term planning. Two factors could result in a considerable expansion of the figures. The first is confirmation of more speculative deposits not included here. In the United States, 1,430,000 metric tons have been estimated by ERDA as possible or speculative, and as vast areas of the world have yet to be prospected no estimate at all has been made for them. It is conceivable, although far from definite, that several times the total in figure X-13 eventually will be identified as recoverable. The second factor would be the use of higher cost ores. Nuclear power is relatively insensitive to the price of the fuel, so this possibility cannot be precluded as cheaper deposits are consumed. It is well known that enormous quantities of uranium, far exceeding any projected demand, exist in very low-grade forms such as shales, granite, and sea water, but tapping these resources is not feasible under present techniques. Much less is known about middle-grade ores since the abundance of high-grade ores has limited the interest in them. Middle-grade ores may in fact be virtually nonexistent, as is exhibited by some materials, or they may present a resource base mid-range between the high- and low-grade resources. Much exploratory work remains to further define both these factors,

The adequacy of worldwide reserves of uranium for the projected growth of nuclear

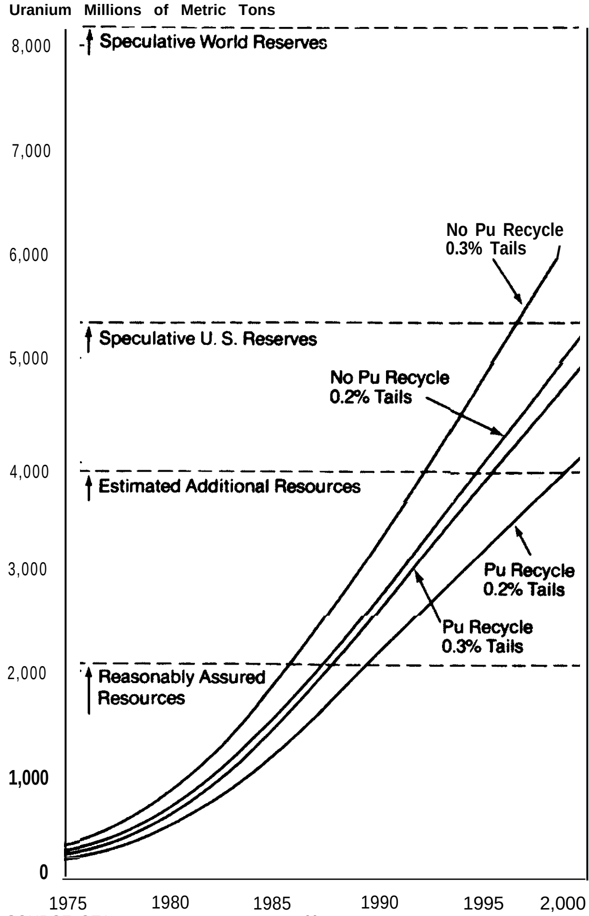
Figure X – 14.
Reactor Characteristics for 1000 MWe Plants[1]*

	BWR	PWR	STD HTGR	CANDU (THOR)	CANDU
Thermal efficiency, %	34	33	39	30	30
Initial core (and blanket*) average					
Irradiation Level, MWD_{th}/MTU	17000	22600	54500	18500	6900
Fresh Fuel Assay, Wt% U^{235}	2.03	2.28	93.15	93.15	0.711
Spent Fuel Assay, Wt% U^{235}	0.88	0.74	~60	~60	0.31
Fissile Pu recovered, kg/MTU [2]	4.8	5.8		—	1.7
Feed Required, ST U_3O_8					
at 0.2% tails	.494	.422	.367	.520	.199
at 0.3% tails	.581	.498	.458	.646	.199
*Feed Required, ST ThO_2[3]		—	42.5	160	
Separative Work Required, 1000 SWU[3]					
at 0.2% tails	239	222	388	519	
at 0.3% tails	185	174	311	441	
Replacement Loadings (Annual rate at steady state; 75% capacity factor)					
Irradiation Level, MWD_{th}/MTU	27500	32600	95000	27000	9600
Fresh Fuel Assay, Wt% U^{235}	2.73	3.21	93.15	83.15	0.711
Spent Fuel Assay, Wt% U^{235}	0.84	0.90	30		0.15
Fissile Pu Recovered, kg/MTU[2]	5.9	7.0			2.3
Feed Required, ST U_3O_8[3]					
at 0.2% tails	0.144	0.154	0.065	0.020	0.125
at 0.3% tails	0.179	0.191	0.106	0.024	0.125
*Feed Required, ST ThO_2[3]	—		8.7	41.5	—
Separative Work Required, 1000 SWU					
at 0.2% tails	105	117	85	19	
at 0.3% tails	84	94	73	16	
Replacement Loadings (Annual rate with Pu recycle[5], 75% capacity factor)					
Fissile Pu Recycled, kg.	.163	.167			
Fissile Pu Recovered, kg/MTU[2, 6]	8.1	9.5			
Feed Required, ST U_3O_8/MWe[3, 4]					
at 0.2% tails	0.121	0.128			
at 0.3% tails	0.148	0.158			
Separative Work Required, 1000 SWU[3]					
at 0.2% tails	82	93			
at 0.3% tails	66	75			
Lifetime[7] Commitment Required, 30-year life, ST U_3O_8/30 (Replacement requirement) + Initial Core and Blanket					
Without Pu recycle					
at 0.2% tails	4460	4810			3580
at 0.3% tails	5500	5660			3580
With Pu recycle					
at 0.2% tails	3460	3500			
at 0.3% tails	4210	4310			
With Thorium and U^{233} recycle					
at 0.2% tails			2580	1350	
at 0.3% tails			3200	1870	

1 MW_{th} is thermal megawatts; MWe is net electrical megawatts; MWD_{th} is thermal megawattdays; MTU is metric tonnes (thousand of kilograms) of uranium; and ST U_3O_8 is short tons of U_3O_8 yellowcake from an ore processing mill. One SWU is equivalent to one kg of separative work.
2 After losses..
3 For replacement loadings, the required feed and separative work are net, in that thev allow for the use of uranium recovered from spent fuel. Allowance is made for fabrication and reprocessing losses.
4 Includes natural uranium to be spiked with plutonium; 0.0067 ST U_3O_8/MWe for BWR and 0.0067 for PWR.
5 Plutonium available for recycle ratchets up each pass because not all of the plutonium charged is burned. Therefore, more plutonium is recovered from mixed-oxide fuel than from standard uranium fuel, and this increment increases with each cycle (5-6 years par cycle) requiring several passes to reach steady state. The data shown represent conditions for the 1960's when most reactors will be discharging fuel which has only seen one recycle pass.
6 Average for all fuel discharged with full recycle of self-generated plutonium. For mixed-oxide fuel (natural U spiked with self-generated plutonium) the spent fuel from BWRS contains 5.11 kg Pu per MTU and from PWRS, 18.7.
7 Lifetime commitments assume operations at 40% Capacity Factor (CF for the first year, 65% CF for the next two years, followed by 12 years at 75% CF. Thereafter, CF drops 2 points per year, reaching 35% in the last (30th) year.
● ERDA-1, "The Report of the Liquid Metal Fast Breeder Reactor Program Review Group," January 1975.

Figure X-15.

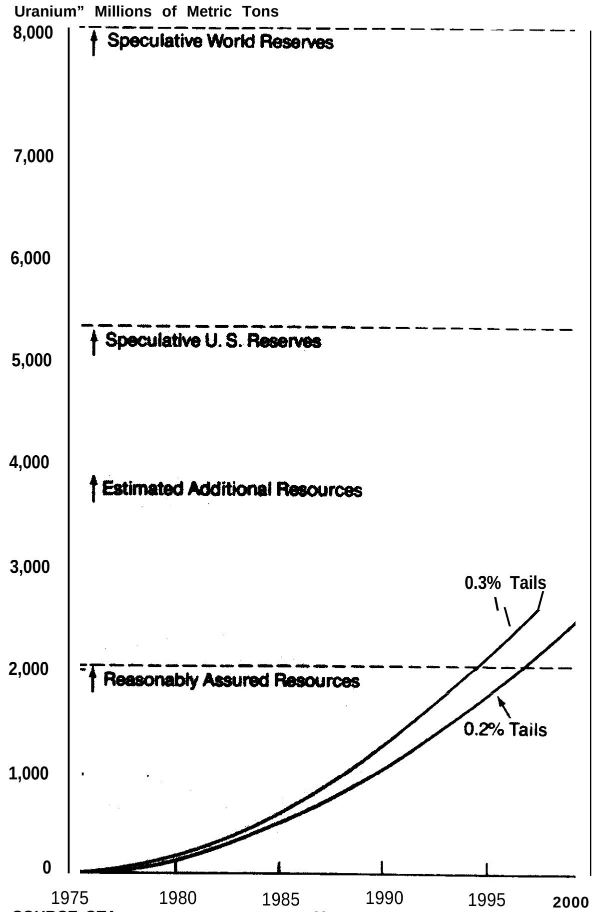
Cumulative Lifetime Uranium Commitments



SOURCE OTA

Figure X-1 6.

Cumulative Consumption of Uranium



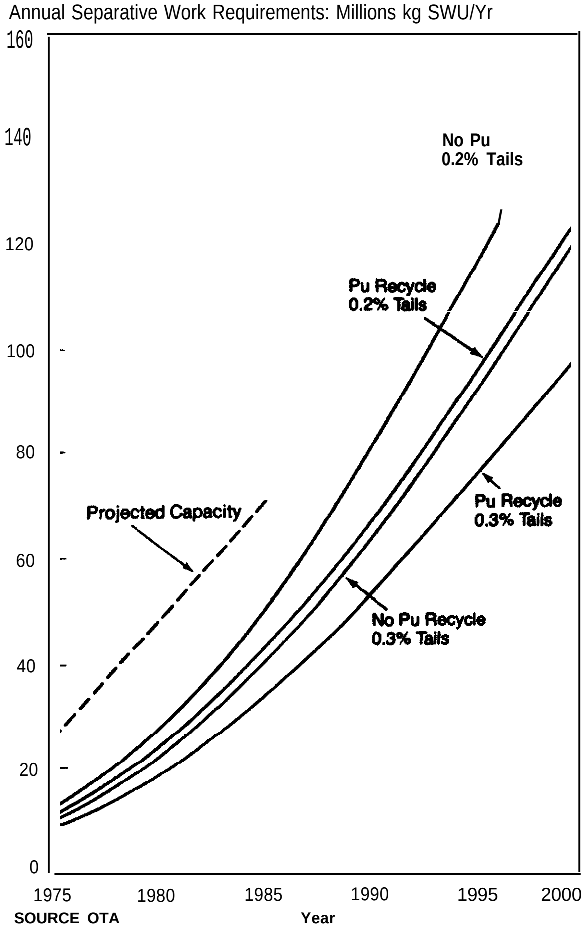
SOURCE OTA

plants depends upon a variety of complex factors. One is the efficiency with which various reactor types use this resource. The abundant LWRS use more than HWRS, and breeders could operate for decades on the uranium that has already been mined. The utilization of uranium also depends upon the operation of the enrichment plants required for LWRS (See chapter VII and appendix V of volume II for technical details of all aspects of the nuclear fuel cycle). If the demand for enrichment services is high, a plant can be operated in a mode that provides a more enriched product but also requires more uranium feed. If more efficient enrichment techniques (such as the laser isotope separation) are developed, they might be able to recover some of the useful fuel now left in the tails.

Another factor influencing the adequacy of uranium reserves is the fuel burnup of a reactor: The fuel would be more completely burned if the LWRS operated at full power for the expected 80 percent of the year rather than at the current average of 60 percent of the year. (A realistic goal might be 70 percent.) At the lower percentage of full-power operation the fuel could be left in the reactor several months longer. However, reactors continue to be refueled at regularly scheduled yearly intervals because it is most economical to time the refueling with the required annual shutdown for maintenance. This leaves a substantial amount of unburned enriched uranium in the spent fuel which could be recovered, along with the generated plutonium, by reprocessing. This step would undoubtedly be advan -

Figure X-1 7.

World Annual Separative Work Requirement



SOURCE OTA

tageous from an energy resource conservation viewpoint but it is far from certain that recycling will become widespread.

The amount of uranium that will be needed by each of the presently available reactors over their lifetimes are shown in figure X-14. These figures can be translated into the demand that will be placed upon uranium resources by the growth of nuclear powerplants. The projected installed capacity as a function of time is plotted on figure X-12. The required cumulative lifetime commitments (allotting to a reactor at the start of operation the entire supply of fuel it will use in its lifetime) for this projection are shown in figure X-15 for enrichment tails of 0.2 percent and 0.3 percent, with and without plutonium recycle. The actual day-by-day cumulative consumption is shown in figure X-16. Both figures show the reserves of-figure X-13, the 1,430,000 metric tons of U.S. possible or speculative reserves, and an estimate of the equivalent world reserves based on the same ratio of speculative to reserves figures as in the United States. This latter figure is purely empirical and is included only to give an idea of the possible magnitude of world reserves. The lifetime commitments reach the estimated total resource base of figure X-13 in 1999 with Pu recycle and in 1995 without it, assuming ample enrichment capacity. If the more speculative reserves are confirmed, uranium may not be a constraint on reactor construction until well into the next century, even without recycling. If, however, even the present estimates turn out to be optimistic, a serious shortage could develop in the 1990's. Actual consumption would not be limited until well after the year 2000, with or without recycle. Thus, nuclear growth could continue past the 1,000 reactors that will commit the estimated base, but this expansion could only be pursued if there were considerable confidence that a fuel supply would emerge to allow the reactors to complete their normal expected lifetimes, This supply might come from new ore discoveries, breeders, laser enrichment of tails, or new recovery techniques for tapping the vast reserves of low-grade, presently uneconomical, ore such as the Chattanooga shales or sea water.

Enrichment

Enrichment plants are essential for LWRS, which must use fuel with a higher concentration of the uranium isotope U^{235} than occurs naturally, The adequacy of enrichment facilities in meeting present and future demands of LWRS will affect the motivations of various nations, either to build their own enrichment plants or to purchase a reactor type such as the HWR that does not require enriched uranium. Global enrichment capacity is plotted against requirements in figure X-17. The U.S.S.R. has been credited with 7 million separative work units (SWUS), but it is not known if that much actually will be available. It is apparent that new capacity

Figure X -18.
Enrichment Plants*

Nation	Type	Location	Capacity Million SWU	Operation Date
U.S. ... ..., ...	Diffusion	Oak Ridge, Term.	4.73	
	Diffusion	Paducah, Ky.	7.31	
	Diffusion	Portsmouth, Ohio	5.19	
			17.23	
	Diffusion	Improvements and Uprating	**10.5**	**1975-85**
	Diffusion	Portsmouth, Ohio (add on)	**8.75**	**1985**
	Centrifuge (Proposed)		**1.6** to **9.0**	**1982-1989**
USSR .. .., ..., ...	Diffusion	Siberia	**7-1o**	—
United Kingdom	Diffusion-	Capenhurst	0.4-0.6	—
	Centrifuge	Capenhurst	**0.2**	**1977**
	Centrifuge (Proposed)**	Capenhurst	**1.6**	**1982**
Netherlands	Centrifuge	Almelo	**0.2**	**1977**
France .. .., ...	Diffusion	Tricastin	**10-8**	**1978-1981**
	Diffusion	Tricastin	**9-1o**	**1985**
Japan . . . . **.., ..**	**Centrifuge (Proposed)**		**2**	**1988**
Brazil	Jet (Proposed)		**2**	**1989**
South Africa	Jet (Proposed)		5	—

"Nuclear Engineering International, **November 1976**
'"Expansion could beat Almelo or in **Germany Instead**

will be needed by the 1990's, especially if reprocessing is delayed (plutonium 'can substitute for enriched uranium). Because the construction time for new plants is about 8 years, plants should start in the early 1980's if growth projections are to be met, The enrichment facilities in operation are listed in figure X-18.

The United States has been the major supplier of enrichment services, even to other reactor suppliers, although its dominance is now declining. All large-scale operating plants are the gaseous diffusion type, and most of these are in the United States, The next series of large plants will probably be the centrifuge type, which promises to be more economical, Both are very high-technology processes based on proprietary or classified information. Thus, although centrifuge plants can be built on a small scale and more economically than diffusion plants, not many countries beyond these listed in figure X-18 are likely to undertake commercial enrichment. The nations most likely to enter the enrichment market are Australia and West Germany. If new techniques under development (such as jet-nozzle or laser isotope separation) prove practical, this picture may change drastically. Both Brazil and South Africa are currently developing enrichment plants based on the jet-nozzle technique—Brazil to supply its domestic needs and South Africa to enter the export market. Another new feature that may contribute to the spread of enrichment technology is the participation by some nations (such as Iran) in an enrichment consortium such as Coredif.

Figure X -19.

World Reprocessing Plants*

Location	operator		Type of Plant	Capacity te/y	Date operational	status
Us.						
Barnwell S.C.	AGNS		Commercial, oxide	1500	1979-82	Depending on GESMO decisions
U.K.						
Windscale	BNFL	1	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
		2	New commercial oxide plant	1000	1984	For expected domestic requirements part of United Reprocessor's plan
		3	New commercial oxide plant "overseas"	1000	1987	Awaiting decision on public acceptability of overseas contracts
France						
La Hague	CEA	1	Nat. U metal	800	1968	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
		2	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	Current shut down for modification
India						
Trombay	IAEC		Pilot scale nat. U oxide	60	1965	

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

"Nuclear Engineering International, February 1976.

Reprocessing

Reprocessing is considerably less mature than other stages of the fuel cycle. Interest in reprocessing has been limited, both because it is not essential to any reactor now marketed and because its costs have escalated very rapidly as the difficulties of handling plutonium and highly irradiated fuel have become more apparent. If breeder reactors enter the market they will require reprocessing plants. A major argument for building reprocessing capabilities now is to gain experience and to produce plutonium stockpiles for the initial breeder cores. Additional advantages of reprocessing are its contribution to resource conservation and the role it is expected to eventually play in permanent waste disposal.

Despite these advantages, reprocessing has become the focus of much of the opposition to nuclear power. The reason is that reprocessing potentially exposes plutonium with all the resulting implications for health, safety, and proliferation.

At present the only operating reprocessing plant for LWR fuel is a small commercial facility in France that has been running since May 1976. The weapons countries all operate large noncommercial reprocessing plants, and several countries reprocess spent fuel from other types of reactors. The older magnox reactor in Great Britian requires reprocessing for its magnesium-clad fuel. The facilities for LWR fuel that are expected to begin operating in the next few years are listed in figure X-19. Several others have been shut down because of obsolescence. If all spent fuel were to be reprocessed, considerably more capacity than is currently planned would be required. The planned and required capacity is shown in figure X-20. The alternative is simply to increase the temporary pool storage for spent fuel (at some expense), or to devise quasi-permanent storage for it, if processing is to be deferred indefinitely.

Commercial reprocessing plants are expensive and technologically demanding facilities, A minimum size plant might be designed to handle 500 tons of spent fuel per year, equivalent to the discharge of about 25000 MW of installed capacity. Very few nations will have such a large capacity in this century. Hence international reprocessing centers may become economically advantageous.

Even though reprocessing facilities make sense only if serving a large number of reactors and are not essential to LWRS or HWRS, Brazil and Pakistan have signed contracts to import them.

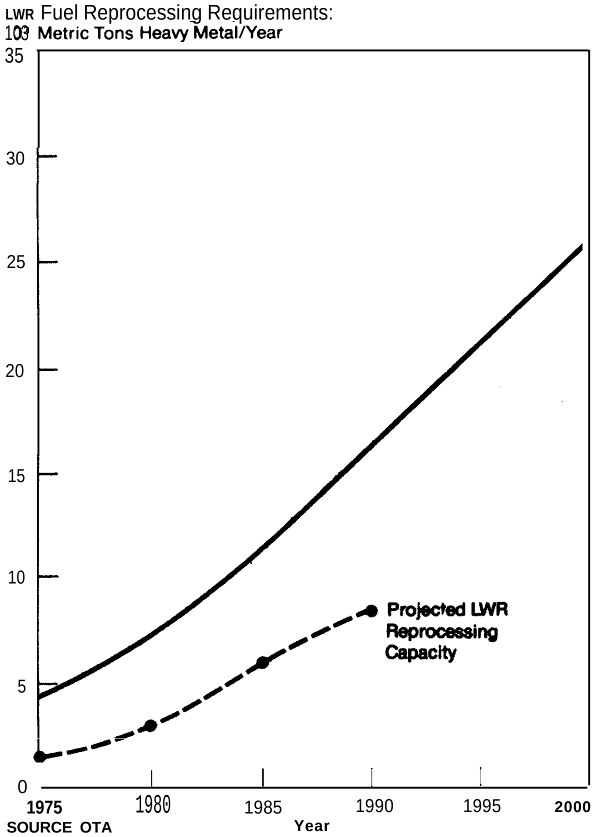
U.S. NUCLEAR EXPORTS

The United States has been the leader in the development of nuclear energy for both domestic use and export. The LWR was developed in the United States, and is now the major reactor of all supplier nations except Canada and the United Kingdom. Most imported reactors have been purchased from the United States and American enrichment plants will be fueling most of the world's LWRS for at least the next decade. The benefits of these exports were not seriously questioned for many years. Not only was nuclear energy seen as a benefit to mankind in general, but nuclear exports were expected to generate sizable profits while maintaining America's technological advantages. There is considerably more controversy now over nuclear power in general and exports in particular, but American companies have simultaneously found them increasingly important to fill spare capacity.

The chief U.S. exports have been reactors and their associated equipment. Engineering and construction services have also been important. The only fuel-cycle service of note so far has been enrichment. The United States has refused to transfer the sensitive technologies of enrichment and reprocessing.

The U.S. share of the reactor export market has been dropping markedly, as indicated by figure X-21. In the future the United States will be selling less to the other industrialized nations, as so many have gone into business

Figure X-20.
World Annual LWR Fuel Reprocessing Potential Requirements



SOURCE OTA

for themselves, and more to the developing countries. The U.S. share of the latter market is likely to be 35 to 40 percent in the early 1980's, but drop to 25 to 30 percent by the late 1980's. This market share amounts to 13,000 to 17,000 MW capacity and an export value of $5 to $7 billion by 1990. The U.S. share of the European market will decline to 5 percent by 1990. Combined with sales to Japan, these exports could total 30,000-35,000 MW, but this would amount to only $5 to $7 billion since the advanced nations supply more of the plant themselves. Total revenue from reactor sales should be $10 to $14 billion.

The reactor export market is a very competitive one, especially because most suppliers are capable of producing more reactors than they can use domestically. The success of any single exporter will depend upon a variety of factors:

1) Governmental export policies: Some other suppliers have added enrichment or reprocessing technology as inducements for their reactor sales, but all recently seem to be agreeing to withhold these technologies as the United States has done. Canada has taken the lead in restricting its exports to signatories of the NPT or its equivalent (full fuel cycle safeguards).

2) Adequacy of enrichment services: In 1974, the United States stopped accepting further orders for enrichment services because its capacity was fully booked. As a result, the U.S. reputation as a reliable supplier of enrichment was damaged. If the United States fails to expand its enrichment capacity or imposes high charges for the services, nations may be more reluctant to purchase American reactors.

3) Financial assistance: Most reactors are sold under advantageous credit terms. Changes in one nation's policy will affect all exporters.

4) Industrial capacity: Although most suppliers now have excess capacity, Canada may soon be booked up because of the strong interest expressed by LDCS in the CANDU reactor.

5) Quality of reactor exports: The United States is still respected as a reliable supplier of proven products that are subject to strict standards of design, construction, and safety, It may, however, have to adapt its reactors to the developing-nation market by such innovations as smaller reactors.

6) International political influence: A given supplier will be helped if its government has a special relationship with an importing nation, and is willing to use that influence.

As these various factors change they may alter the above projections. Barring major policy changes, however, U.S. reactor exports are expected to be about $1 billion per year.

Figure X-21.
Suppliers of Exported Reactors
(Megawatts)

NATION	'64	'65	'66	'67	$1	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	8U	'81	'82	83	'84	83	'86
												YEAR OF INITIAL OPERATION											
United States	150	:	—	237	1	958	660	90U	656	—	1565	809	—	4035	6164	4745	3675	2542	4764	907	907	—	1
West Germany	—	1	—	—	1	—	—	—	—	477	319	—	—	692	920	—	1200	1200	997	1245	1245	—	1
Canada	—	1	—	—	1	—	—	—	125	202	—	—	—	—	—	—	600	—	629	—	—	—	1
France	—	1	—	—	1	—	—	—	480	—	—	1650	—	—	—	—	1835	—	3822	1822	—	—	1
USSR	—	1	—	—	1	—	—	—	—	—	—	—	—	420	420	—	—	—	—	—	—	—	1
Sweden	—	1	—	—	1	—	—	—	—	—	—	—	—	—	660	—	660	—	—	—	—	—	1
United Kingdom	—	1	159	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1

*Derived from Nuclear News, Mid-February 1977/Vol. 20/Nov. 3

This sum is a small but significant part of total exports ($100 billion in 1975 with a trade surplus of $11.5 billion) and could have a large impact on the balance of trade.

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 separative work units (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. 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.

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

The 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 developed sufficient capacity to provide reprocessing services to foreign customers.