

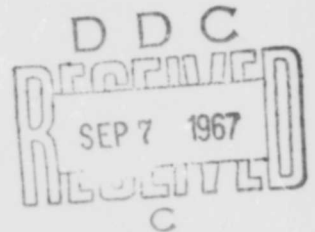
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AUGUST 1967

THE JAPANESE CIVILIAN NUCLEAR PROGRAM

Victor Gilinsky and Paul Langer

PREPARED FOR:
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PREFACE

This short description of the Japanese nuclear program, aimed at the non-technical reader, has been prepared in connection with RAND's research program on the status and future of civilian nuclear power. The purpose is to provide background for discussion of related policy issues. These issues are mainly related to the present United States commitment to prevent the spread of nuclear weapons and particularly to the recent efforts to secure a non-proliferation treaty. The treaty negotiations have coincided with a surge in the development of nuclear power and greatly enhanced prospects for its future commercial importance. Concern about the commercial implications of the proposed treaty on the part of a number of advanced countries has led to (apparently unforeseen) difficulties in the way of agreement. In these circumstances it is interesting to take a closer look at Japan's nuclear program.

The intent of this report is descriptive. Policy questions are not taken up--they may be the subject of a future publication. It is also not intended to present an economic analysis of the relation of nuclear power to other sources, although some of the relevant considerations are sketched out.

SUMMARY

The Japanese power industry is characterized by high fuel costs and a large degree of dependence on imported oil. While there are some prospects that power costs can be reduced, especially as the size of individual plants increases, the degree of dependence on imported oil is expected to continue to increase not only in the power industry but also in other sectors of the economy. In order to secure a new low cost energy source and to diversify the types of energy supplies Japan is turning to nuclear power. Perhaps more than any other country, Japan is anxious for the economic success of civilian nuclear power.

Despite a late start, the Japanese appear determined to build a substantial and, in so far as possible, a self-sufficient nuclear economy. Because Japan lacks significant uranium deposits, and has no early prospects for domestic enrichment facilities, the Japanese are seeking long term mining agreements with uranium producers and long term enrichment contracts with the United States. They plan to develop the domestic capability to service all subsequent phases of the nuclear fuel cycle. (Fuel fabrication and reprocessing facilities will be in operation in the early 1970's.) Enrichment technology is now being studied to determine the economic feasibility of constructing Japanese enrichment facilities some years from now. A small research program on isotope separation by means of gas centrifuges has been under way for some time.

A new (1967) Long Range Program submitted to the Government by the Japan Atomic Energy Commission calls for an installed nuclear electric generating capacity of about 6000 Mwe by 1975 and "at least" 30-40,000 Mwe by 1985. (Comparable to French or German plans.) This represents a considerable increase over earlier forecasts which have proved too conservative. The new Program recommends Japan import foreign technology in areas that are already developed while investing its own resources in the future technology. If successful, this "leap-frog" strategy may permit Japan to reach the front rank in nuclear technology after a decade or so of heavy dependence on foreign technology.

In the future the Japanese plan to install plutonium fueled fast breeder reactors of Japanese design to further lower power costs and drastically reduce the need for uranium. The plutonium to start these reactors will be produced by the previous generation of thermal reactors. It is estimated that Japan will have produced about 3 tons of plutonium by 1975 and about 35 tons by 1985.

The Long Range Program places special emphasis on the development of advanced power reactors, particularly the fast breeder. It is recommended that a new corporation be established to carry out this development program, which is expected to cost over \$500 million. A bill authorizing the new corporation has been approved by the Diet.

ACKNOWLEDGMENTS

The authors have benefitted from the criticisms of their colleagues William Hoehn, Dennis Holliday, Alice Hsieh, Milton Plesset, Albert Wohlstetter, Ciro Zoppo, and especially James Schlesinger. Albert Wohlstetter was also very helpful in making available to us several documents and Alice Hsieh provided some good advice in the absence of one of the authors (Paul Langer). We would also like to thank Joseph Mullen of Resources for the Future, Inc. for helpful comments. We are particularly grateful to Dr. Hayao Nasu, Manager of the U.S. Resident Office of the Japan Atomic Power Co. for several very useful discussions on the Japanese nuclear program.

ABBREVIATIONS

AGR	Advanced Gas-cooled Reactor
ALJ	<u>Atoms in Japan</u>
ATR	Advanced Thermal Reactor
BWR	Boiling Water Reactor
FBR	Fast Breeder Reactor
GE	General Electric Company
IAEA	International Atomic Energy Agency
JAEC	Japan Atomic Energy Commission
JAERI	Japan Atomic Energy Research Institute
JAFC	Japan Atomic Fuel Company
JAIF	Japan Atomic Industrial Forum
JAPC	Japan Atomic Power Company
JPDR	Japan Power Demonstration Reactor
kg./Mwe-yr	kilograms per megawatt electric per year
LWR	Light Water Reactor
MITI	Ministry of International Trade and Industry
m/kwh	mills per kilowatt hour
Mwe	megawatts electric
Mwt	megawatts thermal
OECD	Organization for Economic Cooperation & Development
PWR	Pressurized Water Reactor
SGHWR	Steam Generating Heavy Water Reactor
toe	tons oil equivalent (about 10^{10} calories)

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I. INTRODUCTION

The Japanese civilian nuclear program is entering a period of rapid development and expansion. Planners now look forward to the time when nuclear reactors will generate a substantial part of Japan's electrical power. A new Long Range Program adopted this year (1967) forecasts an installed nuclear electrical generating capacity of about 6000 Mwe (megawatts of electrical output) in 1975 and at least 30-40,000 Mwe in 1985. Furthermore, there are many indications that Japan intends to attain a large degree of autonomy in the development of nuclear power and hopes eventually to become an exporter of nuclear reactors. An informed, though partisan, observer has remarked, "not many countries have such ambitious plans... This clearly indicates that an atomic power boom, paralleled only in the United States, is now swelling in Japan."* Despite the fact that there is still only one small nuclear power plant operating in Japan (and operating poorly) a close look at Japan's present nuclear program suggests this enthusiastic comment is not wide of the mark.

The Japanese nuclear program seems practical both in regard to the nation's energy needs (see Section II) and the present level of nuclear technology. In the United States nuclear reactors have recently become competitive with conventional power plants in many areas with the result that there has been a tremendous boom in nuclear orders. In 1966 nuclear power accounted for more than half of the new electrical power capacity ordered in the United States. The latest AEC forecast estimates that in 1980 the United States alone will have a nuclear electrical generating capacity of 120-170,000 Mwe. By comparison the Japanese forecast, ten or fifteen percent of the U.S. figures, does not seem excessive since the relative electrical generating capacities are roughly in the same ratio.

*Editorial in Atoms in Japan, Feb. 1967, p. 4. Atoms in Japan (AIJ) is the official organ of the Japan Atomic Industrial Forum (JAIF).

The history of the Japanese nuclear program dates essentially from the time of the first Geneva Conference* in 1955. During 1955 and 1956 research programs were begun at a number of facilities and within one year the budget of the principal national laboratory, the Japan Atomic Energy Research Institute (JAERI), had reached the \$12 million level. In 1957 Japan's first nuclear reactor (JRR-1), a small U.S. research reactor, went critical at the JAERI Tokai nuclear facility near Tokyo.

During this early period expectations ran very high and many Japanese foresaw a rapid application of nuclear energy to various phases of civilian life. A rather ambitious Long-term Plan for Atomic Power Reactor Development^(1,2) drawn up in 1957 proved to be unrealistic. As in most other countries, the Japanese nuclear program began to run into a series of difficulties and delays. In the late 1950's it came to be realized that the hopes of the first Geneva Conference were premature and that economical nuclear power was not in the immediate future. But work continued and it turned out that while the initial optimism was excessive, so was the following pessimism.

Japanese industry slowly regained some interest in the use of nuclear energy. Japanese universities gradually built up with government funds their training and research facilities and began to lay the foundation for an independent Japanese scientific effort. The government-financed nuclear research organizations--primarily JAERI--were allowed to develop necessary research and engineering skills. A new Long-range Program on Development and Utilization of Atomic Energy^(3,4) adopted in 1961 provided for a build-up to an average annual outlay of \$30 million for research and research facilities. (The plan was drawn up as one response to the National Income Doubling Plan of 1960.)

The Long Range Program of 1961 recognized Japan's lack of development in the nuclear field and it urged strengthening of international cooperation in technical areas and heavy import of foreign technology.

*First United Nations International Conference on the Peaceful Uses of Atomic Energy.

The 1961 plan and subsequently evolving modifications of this plan aim at assigning priorities for the domestic research program so as to avoid duplication of foreign efforts--there is no thought of allowing the lag to continue indefinitely. The aim of this strategy, which follows Japan's traditional approach to the problem of overcoming a modernization lag, is to bring the Japanese, after a decade or so of heavy dependence on foreign sources, to the forefront of nuclear technology.

Meanwhile in 1962, the first Japan-made research reactor* went critical. And 1963 marked the start up of the first reactor to generate electrical power, the Japan Power Demonstration Reactor (JPDR) at Tokai-mura, a 12 Mwe General Electric Boiling Water Reactor. The choice for the first commercial nuclear power station was a 160 Mwe British natural uranium gas-cooled reactor. It was also built at Tokai-mura, under the sponsorship of the Japan Atomic Power Company (JAPC), a quasi-governmental enterprise established to introduce nuclear power. The station came up to full power in late 1966, about two years late, and generally speaking it has been a disappointment. But this unhappy initial experience seems to be part of the nuclear learning process in each country.

In the ten years 1956-1965 about \$500 million was spent in Japan on the development of nuclear power. About half of this sum was spent by the government and the other half by mining and manufacturing firms and utilities. In 1965 universities and government research institutes employed about 8000 "technical experts" on nuclear power and private companies employed another 2800.**

Just as the nuclear power research program dates roughly from the 1955 Geneva Conference the serious commercial application of nuclear power dates from the 1963 decision by Jersey Central to build a 640 Mwe nuclear power plant at Oyster Creek, N.J., with private

* JRR-3, a 10 megawatt heavy water reactor.

** Atoms in Japan, Feb. 1967, p. 13, quoting a JAIF report "10 Years of Nuclear Industry in Japan."

financing and with no AEC subsidy. The Oyster Creek decision was followed by a detailed report comparing the nuclear plant to alternative conventional plants. (The expected cost of power is about 4 mills/kilowatt-hour.) Until this time Japanese utilities were largely unaware of the potential of nuclear power. Since then the worldwide prospects for nuclear power have further improved.

Japan since 1965 has once more entered into a period of stepped-up nuclear development. The Japanese government continues to take the lead in research but it does so in a more determined way. Industry is venturing more actively into the construction of nuclear power plants and related fields providing for practical applications of nuclear energy. The rapid development of nuclear power has made the 1961 Long Range Problem obsolete. After a long period of reexamination and revision the new Long Range Program mentioned earlier was adopted this year. The Program is the formal expression of the consensus of science, industry, and government on the proper course for the development of nuclear power in Japan. Because the implementation of the program is still in a formative stage we shall defer a discussion of the program until Section VI. It will be preceded in Sections IV and V by a description of the ongoing Japanese reactor and fuel development programs and a sketch of Japanese plans concerning the main parts of the nuclear fuel cycle.

We shall begin in Sections II and III with a short description of the energy situation in Japan and the economic motives for the development of nuclear power and the organizational features of the nuclear program.

II. ECONOMIC MOTIVES BEHIND JAPAN'S NUCLEAR PROGRAM

The demand for electrical power in Japan has been rising rapidly each year. The average annual rate of increase of power capacity and power supplied has been over 10 percent for about a decade. This is shown in Table 1. The installed electric generating capacity in 1964 was less than Britain's (45,200 Mwe), but comparable to West Germany's (36,000 Mwe) and significantly larger than France's (26,700 Mwe). While the extraordinary rate of increase in Japanese electric power is expected to diminish it is still expected to be over 8 percent annually from 1965 to 1975.* Since about 1950, when electricity was produced mainly from domestic hydroelectric sources supplemented by thermal plants burning domestic coal, the increase in power plant fuel requirements has been met mainly by burning imported oil.

Table 1

ELECTRICAL POWER IN JAPAN^a

	Installed Capacity ^b (thousands of megawatts-electric)					
	<u>1948</u>	<u>1956</u>	<u>1958</u>	<u>1960</u>	<u>1962</u>	<u>1964</u>
Total	10.4	15.5	18.4	23.7	29.1	38.1
Hydro	6.4	9.6	10.8	12.7	14.1	15.6

^aTaken from Tables 143 and 144 of Ref. 5.

^bPublic and industrial. The average power output corresponds to about 55 percent of capacity.

In view of the rapidly increasing demand for electrical power, and the large degree of dependence on imported oil, it is argued that the introduction of nuclear power in Japan would (1) reduce the cost of electrical power, and (2) would increase the security of energy

*Long Range Electric Power Program for 1966-1975 of the nine Japanese electric power companies quoted in Atoms in Japan, Feb. 1967, p. 8. The total installed capacity in 1975 is expected to be about 87,000 Mwe (roughly 28 percent hydro, 65 percent thermal, 7 percent nuclear).

supplies. The high cost of imported fuel* and high interest rates on capital combine to make the cost of power in Japan very high. Until recently electrical power cost about 10 mills/kwh--about double the U.S. price and perhaps 50 percent higher than in Western Europe. The most modern oil fired plants in Japan now produce power at about 6 mills/kwh. Nuclear power plants now under construction in Japan will not meet this price. But it is expected in the nuclear industry that the larger nuclear plants coming into operation in the early 1970's will compete favorably with new conventional plants. Because of special conditions in Japan such as siting problems the need for aseismic design, and very high safety standards, the estimated cost of nuclear power in Japan is about 20-30 percent higher than in the United States for plants of around 300 Mwe. In general it is believed that nuclear plants have more potential for reducing costs in the future than conventional plants, especially as the unit sizes of power plants increase. (Nuclear power involves higher capital cost but much lower fuel costs per unit power.) Nuclear power bids are now undercutting conventional power bids in many areas of the United States and some privately financed nuclear plants now under construction are expected to produce electrical power at about 4 mills/kwh. The Japanese therefore have reasonable grounds for their hopes for economical nuclear power despite the somewhat higher interest rate on capital in Japan compared with the United States.

Any future comparison of nuclear and conventional power in Japan involves certain assumptions about the future price of oil. It is often suggested that oil prices can be lowered to permit oil fired power plants to continually undercut nuclear plants. To assess how far this is possible would take us too far afield. But it needs to be noted that, in any case, oil will probably be the main fuel in Japan for the rest of the century. Even if the goal of the new Long

* A ton of oil costs about \$17-20 in Japan. In Western Europe it costs about \$10-13 before taxes. However, including taxes, the price paid by generating stations in most Western European countries is about the same as in Japan (Ref. 6, p. 25).

Range Program is attained nuclear power will still only account for about 25 percent of electrical generating capacity in 1985. The widespread availability of cheap nuclear power would immensely improve Japan's bargaining position concerning the price of oil. The significance of this indirect effect was recently emphasized by Minoru Takahashi of Central Research Institute of Electric Power Industries: "Atomic energy can control the movements of the colossal oil industry."^{*}

The electrical power demand is, of course, only part of the total energy demand--less than a third.^{**} The rapid increase in electrical power demand since 1950 reflects Japan's very high rate of economic growth which is expected to continue for some time at only a slightly lower rate. The primary energy to fuel this expansion must for some years come from imported oil. (About 74 percent of the net increase in the years 1960-65 was met by oil.)^{***} Therefore there is no possibility of nuclear power pushing oil out of the picture in the foreseeable future.

An OECD study⁽⁸⁾ estimates that although in 1964 per capita primary energy consumption in Japan was still quite low, 1.4 tons of oil equivalent (toe) compared with 2.2 toe for Western Europe and 6.3 toe for the United States, that by 1980 it will rise to 3.6-4.1 toe, which surprisingly, exceeds the 1980 average estimated for Western Europe. The estimated breakdown according to sources is shown in Table 2. At the present time oil imports account for about 55 percent of Japan's total primary energy supply and this percentage is expected to increase to about 80 percent in 1980. (As recently as 1956 imports accounted for only about a quarter of the total primary energy supply.)

^{*} Discussion on the Japanese Viewpoint of the Nuclear Fuel Cycle, see Ref. 7.

^{**} Electrical power accounted for 27 percent of the energy consumption in 1965, and it is expected to use to 32 percent in 1975 and about 34 percent in 1985, Atoms in Japan, March 1967, p. 16 quoting report of the Overall Energy Research Council, Ministry of International Trade and Industry.

^{***} Atoms in Japan, March 1967, p. 15.

Table 2

JAPAN - ENERGY SUPPLY & DEMAND IN TERMS OF PRIMARY SOURCES^a

(Millions of tons of oil equivalent^b)

	<u>1960</u>	<u>1964</u>	<u>1970</u>	<u>1980</u>
Total Required	86.3	134.3	238	465
<u>Indigenous</u>	<u>49.3</u>	<u>50.7</u>	<u>58</u>	<u>62</u>
Coal	41.2	40.2	46	46
Gas, Oil	1.4	2.6	4	7
Hydro	6.7	7.9	8	9
<u>Imports</u>	<u>37.0</u>	<u>83.6</u>	<u>180</u>	<u>402</u>
Oil	30.9	73.6	165	368
Coal	6.1	9.7	14	18
Nuclear ^c	---	---	1	16

^aTaken from Table 20, Ref. 8.

^b1 toe = 10¹⁰ calories.

^cNote that 10⁶ toe corresponds to a nuclear capacity of about 0.5 Mwe so the above nuclear estimates are very conservative.

Considerations of security of fuel supplies suggest that the oil should not all come from one region (about 90 percent now comes from the Middle East) and Japan hopes to develop oil fields in several new areas (Indonesia, Australia, Alaska, Canada). The introduction of nuclear power by reducing the overall oil requirements would serve the same goal. Although Japan has negligible uranium reserves (now estimated at about 3000 tons of uranium in low grade ores) and will have to import almost all of the uranium for its power program, this will still help to diversify its energy supplies.

However, it is possible to change the fuel situation still further and the same motives that lead Japan's planners to nuclear reactors, cheap power and stability of supplies, lead on to an advanced type of reactor--the fast breeder. Plutonium fueled fast breeders produce more plutonium as a by-product than they consume in the generation of power. They are therefore essentially independent

of the fuel cost (that is, the cost of natural uranium). Reactors of this type are being developed in the U.S., Soviet Union, U.K., France and West Germany. Prototypes of about 300 Mwe are under construction in the Soviet Union and the U.K. and all of these countries expect to begin large scale commercial installation of fast breeders starting around 1980. Breeders further reduce the fuel costs of nuclear power with (hopefully) only a small increase in capital costs. Because they are able to convert uranium into plutonium almost completely, the required uranium input per unit power is reduced to 1 or 2 percent of the amount formerly required.* At this point even Japan's meager uranium reserves may be of some importance.

Less critical but still significant is that introduction of nuclear power promises to reduce foreign exchange outlays. The cost of imported fuel now makes up almost 20 percent of the total Japanese foreign exchange outlay.⁽¹⁰⁾ Initially, because the first few nuclear plants will be imported, the foreign exchange loss will be greater than for oil plants. But when the Japanese begin to build their own nuclear plants the lower fuel component of nuclear power costs will permit a considerable reduction in foreign exchange loss, perhaps 50 percent less than for comparable oil fired plants.⁽¹⁰⁾ Even in the early stages when nuclear plants are mainly imported the Japanese plan to construct a large number of components domestically.

Finally, the Japanese believe that introduction of nuclear power will have a beneficial effect on their technological structure. Nuclear power requires a higher level of technical skills than conventional power and the development of these skills in service industries will help modernize Japanese industry and will generally foster scientific and technical progress. Even at comparable power costs, the Japanese believe it is better to use a "technologically intensive" industry to improve their country's ability to benefit from future technological advances.

* Breeders are discussed more fully in Section V. See also Ref. 9.

III. ORGANIZATION AND SPECIAL FEATURES OF THE NUCLEAR PROGRAM

The basic administration organization of the Japanese nuclear program has remained largely unchanged since its inception in 1956 when the basic law was adopted and the Japan Atomic Energy Commission (JAEC) was formed.

The JAEC, officially headed by the Director of the Science and Technology Agency, provides advice on atomic matters to the Prime Minister. The Basic Atomic Energy Law (Paragraph 5) invests this Commission with power not only to plan and deliberate on but also to participate in the decisions concerning the study, development, and use of atomic energy. The Basic Law stipulates that the Prime Minister must "respect" the decisions of the Commission. This is also the agency from which emanate the basic nuclear policies and long-range plans for Japan's nuclear development. The six members of the Commission are generally appointed by the Prime Minister from among scientists, but usually also include one or two former government officials and individuals with background in public utility administration. By law, Commission members may not be active in politics.

Overall administrative responsibility for the program rests with the Director of the Science and Technology Agency which in turn is linked to the Prime Minister's Office as a so-called "Outer Agency." (See the organization chart below.) The Agency Director is a Minister of State with cabinet rank who may (as is currently the case) double as Education Minister. Concern with nuclear matters (which constitute but one, although a major, function of the Agency) is concentrated in the Agency's Atomic Energy Bureau which in turn has several functional sections such as the Policy Section, the International Cooperation Section, Nuclear Fuel Section, Isotope Section, Atomic Reactor Section, Radiation Section, and so forth.

The Bureau (or its sub-sections) is also responsible for the various government-sponsored research institutes operating in the field of nuclear research. By far the most important of these and the focal point of the Japanese nuclear program is the Japan Atomic Energy Research Institute (JAERI) which carries on most of its work

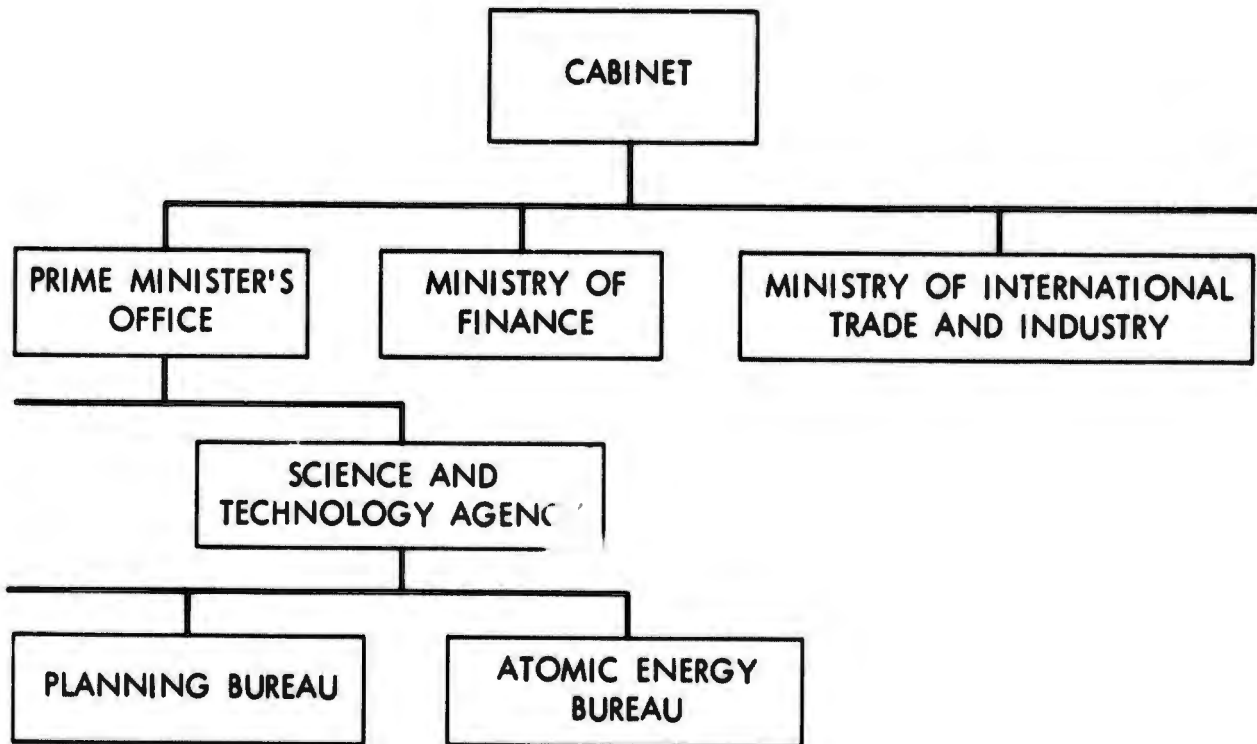


Fig. 1 - Organization chart showing the position of the Science and Technology Agency.

at Tokai, northeast of Tokyo in Ibaragi Prefecture. In late 1966, the JAERI scientific and technical non-administrative staff numbered more than 1,300 individuals. Other government-sponsored research institutes and training schools (such as the Radiological and Radio Isotope Institutes) supplement the Institute Program. The Japan Atomic Fuel Corporation (JAFC) has been the government company responsible for research and development relating to nuclear fuels. Its functions will now be taken over by a new agency (to be discussed in Section VI).

The draft budget presented to the National Diet on April 1, 1967 calls for the formation of the new research group, tentatively called Agency for Power Reactor Development, to assume prime responsibility for development of advanced types of reactors, the "advanced thermal reactor" and the "fast breeder."*

*There appears to be a struggle between the Science and Technology Agency and the Ministry of International Trade and Industry (MITI) for control of the advanced programs.

The Japanese government also plays an important role in promoting nuclear research through the financing of such work in the government-operated universities, which constitute the major reservoirs for future nuclear engineers and scientists and provide the principal contributions to basic research.

In addition, the Diet's Lower House has a sub-committee on Atomic Energy Policy which provides a forum for public discussion of government plans and policies. A White Paper on Atomic Energy is issued annually providing rather detailed information on the field.

The Japan Science Council is meant to play an advisory role to the Prime Minister's Office. The Council constitutes a gathering of select scientists and scholars (including social scientists). While it is an advisory body on all matters pertaining to science and learning it is dominated by individuals who tend to reflect strongly the ideological and political orientation of their peers or at least of their politically more active colleagues. Since the cooperation of the academic community is indispensable to the implementation of government science policy, the representatives of the Science Council occupy a powerful position in determining future science policies. In fact, since the Council is the highest repository of Japanese scientific achievement, its members must inevitably be called upon to provide the Atomic Energy Commission, the Science and Technology Agency, etc. with the scientific advice on which long-range nuclear plans will have to be based. Thus, the new Long Range Program for Japanese nuclear development originated in the discussions of sub-committees of the Japan Science Council.

Finally, as in other spheres of Japanese policies, the influence of business--especially big business--makes itself felt also in the formulation of nuclear plans. Government loans, subsidies, licenses for international support, and government guidance are indispensable to the budding Japanese atomic industry. On the other hand, the government cannot move toward implementation of its nuclear development plans without active business and industry cooperation and support. The resulting relationship is a delicate one involving hard bargaining and an enmeshing of private with public interests. This is primarily

reflected in the creation of several quasi-government organizations in which private interests and the government are partners.

The Japan Atomic Industrial Forum (JAIF), an industry-wide organization representing all major Japanese companies having an interest in nuclear developments, has existed now for a decade. It plays a role similar to the role of the Atomic Industrial Forum in the United States. As the import of nuclear reactors and the construction of nuclear power stations became complex enterprises, and also big business, various industrial and utility companies and financial groups have combined to act together for risk-sharing purposes and to enhance their competitive position. The alignment of these groups has generally followed that of the traditional zaibatsu (big business combines) and each group in turn tends to enter into a close business relationship with a particular U.S. manufacturer such as Westinghouse or General Electric. Since each of these groups wields considerable political influence, their weight is also being felt in Japan's development plans for nuclear energy.

Several other special features of the Japanese program deserve mention. Its late start, while a drawback in many respects, has also provided opportunities for short-cuts in planning, organization, research and development. It creates logical conditions suggesting a leap-frogging technological strategy which Japan is in fact now pursuing vigorously as is indicated in the other sections of this Memorandum.

A further advantage is the traditional close working relationship between government and private enterprise characteristic of much of Japan's economic and military development in modern times. There is a long-standing tradition of government and private enterprise working together toward the attainment of national goals. This partnership normally provides sufficient flexibility to allow for the requisite government financing of undertakings which require large initial or continuing investments and do not hold promise of immediate financial return. Responsiveness to government direction on the part of private enterprise is another aspect of this traditional partnership.

On the other hand, the Japanese nuclear program is currently subjected to legal restrictions perhaps more stringent than those experienced by any other major nuclear power. Japanese health and safety regulations are generally rather strict. All the power reactors operating or under construction are also under international safeguards of the International Atomic Energy Agency (IAEA).⁽¹¹⁾ In any case, military nuclear programs are forbidden by Japanese law. Article 2 of Section One of the Basic Atomic Energy Law (Law No. 186 of December 19, 1955) stipulates that "research, development, and utilization of atomic energy are limited to the peaceful uses" and prescribes that its programs and results must be made public.

Another interesting feature of the nuclear program is the regulation of foreign investment by Japan's Foreign Capital Induction Law. Even after a recent liberalization an individual foreign firm cannot acquire more than 7 percent of an existing Japanese company, and the total foreign share cannot exceed 20 percent without special government approval. New enterprises set up by foreign firms can be approved even if the foreign share is quite large. But the nuclear industry was not included in the liberalized categories because it is considered a strategic industry that needs to be protected.*

* Atoms in Japan, June 19, 1967, p. 37.

IV. REACTOR AND FUEL PROGRAMS

A. PRESENT REACTOR PROGRAM

The present status of the first few Japanese power reactors operating or under construction is shown in Table 3.

Table 3

POWER REACTORS OPERATING OR UNDER CONSTRUCTION*

<u>Electric Power Co.</u>	<u>Reactor Type (Vendor)</u>	<u>Capacity (Mwe)</u>	<u>Completion Date</u>	<u>Approximate Cost</u>	<u>Estimated^b Power Cost (mills/kwh)</u>
JAERI ^a	BWR(GE)	12.5	In operation	---	---
JAPCo	GCR(British GE)	160	In operation	\$120 million	18
JAPCo	BWR(GE)	320	1970	\$ 90 million	8
Tokyo	BWR(GE)	400	Late 1970	\$105 million	7
Kansai	PWR(Westinghouse)	340	Late 1970	\$ 96 million	7

* See Figure 2.

^a Japan Power Demonstration Reactor

^b These estimates are very rough. Also the accounting procedures of the various companies are not the same.

The total capacity of the reactors listed in Table 3 is about 1230 Mwe. In addition another nine nuclear power stations with a total capacity of about 4500 Mwe are planned for completion before the end of 1975. These are shown in Table 4. Another 6250 Mwe of nuclear capacity is planned for construction starts before 1975 but will come into operation after 1976. The projections of the several electric power companies vary in reliability but the overall totals are generally accepted.

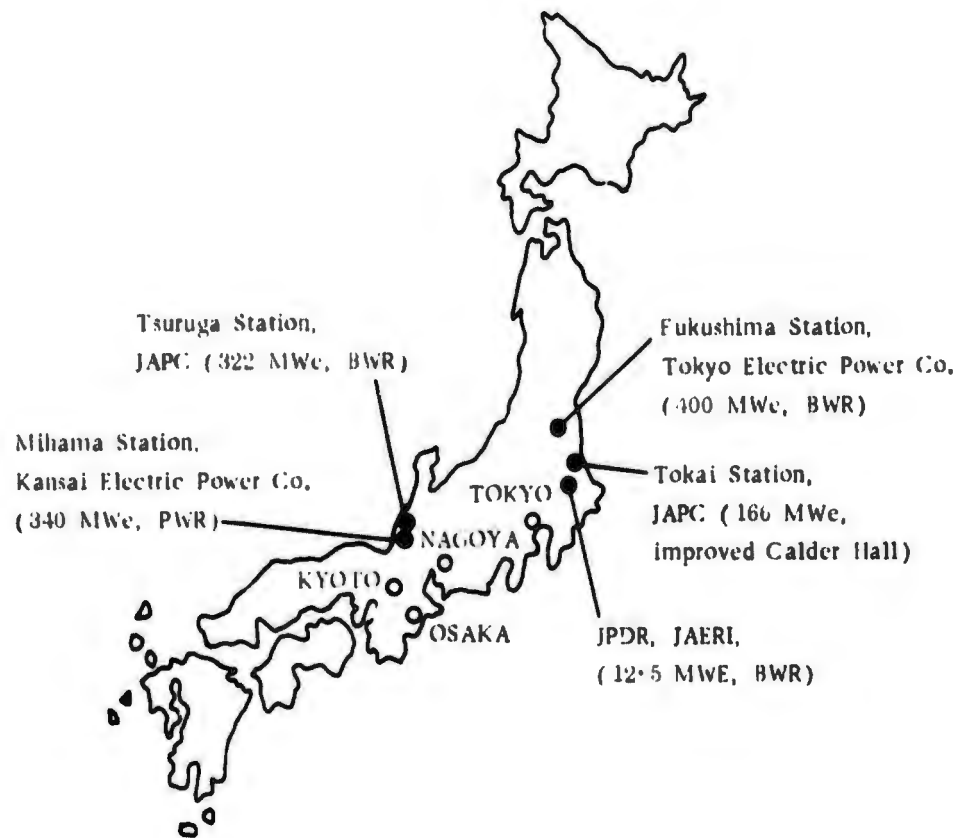


Fig. 2 - Japanese Power Reactors in operation or under construction in March 1967.

Table 4

PLANNED NUCLEAR POWER REACTORS TO BE OPERATED BY 1975^a

<u>Electric Power Co. (Reactor No.)</u>	<u>Capacity^d (Mwe)</u>	<u>Construction to be Started</u>	<u>Operational</u>
Chubu No. 1	350 (500)	May, 1968	Feb. 1972
Tokyo No. 2 ^c	600 (780)	Dec, 1968	1972
Kansai No. 2	450 (500)	Dec, 1968	1972
Kansai No. 3	700	Aug, 1970	1974
Chugoku No. 1 ^b	350 (500)	Oct, 1970	1974
Tokyo No. 3	600 (780)	Dec, 1970	1974
Chubu No. 2	500	Jan, 1971	1974
Kyushu No. 1	350 (500)	Sept, 1971	1975
Tokyo No. 4	600 (780)	1972	1975

^aLong Range Electric Power Program, Atoms in Japan, Feb. 1967, p. 8.

^bChugoku has chosen a BWR to be built by Hitachi under license to GE, at a cost of about \$85 million (Atoms in Japan, May 67, p. 26).

^cTEPCo has appointed GE to construct a 780 Mwe reactor instead of using a domestic manufacturer to build the smaller reactor. The decision still requires MITI approval (Atoms in Japan, June 1967, p. 25).

^dThe figures in the parentheses indicate recent tentative revisions mainly to bring the sizes in line with the standard reactor sizes adopted by GE and Westinghouse (The Japanese Economic Journal, July 18, 1967, p. 10).

Since the 1961 Long Range Program looked forward to the construction of a nuclear electrical generating capacity of 1000 megawatts and only another 6-8,500 megawatts from 1970 to 1980 it now appears that the 1961 program will be easily exceeded. Of course, the prospects for economical nuclear power have improved tremendously since then. The latest reports forecast an installed Japanese nuclear capacity in 1980 of about 15-20,000 megawatts.* If this turns out to be correct the Japanese nuclear power program would be roughly comparable to the French and German programs (and about one-eighth the size of the U.S. program).

*The new (1967) Long Range Program forecasts "at least" 30-40,000 Mwe in 1985. See Section V.

The reactors to be installed in Japan over the next ten or fifteen years will be mainly the "proven" U.S. light water reactors (LWR). Because of Japan's relatively high interest rates this type of reactor, which involves a lower capital investment, is the most economical. The Japanese plan to import foreign designs for the present generation of thermal reactors and to do research on these types only where it is necessary to adapt them to Japanese conditions (for example, earthquake-proof designs). In this way the main Japanese research efforts can be devoted to future technology to permit Japan to "leap-frog" into a prominent position in nuclear power some twenty years from now. The advanced research effort will be discussed in Section V.

B. PLUTONIUM

Uranium fueled power reactors produce plutonium as a by-product during the generation of electric power. The rate of plutonium production per unit installed power depends on the type of reactor and average power level. The types of reactors being installed and presently under construction, in Japan, U.S.-type Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR),* produce plutonium at the rate of about 0.2-0.3 kilograms per electric megawatt per year if operated on the average at about 80 percent of capacity.** The single power station now operating, the Tokai-mura natural uranium reactor, produces plutonium at a greater rate of, perhaps, 0.5 kg/Mwe-yr but no more reactors of this type will be ordered. However, until about 1971 the Tokai-mura station will be Japan's only domestic plutonium producer (aside from the small JPDR). Therefore, since the station is rated at about 160 Mwe, but operates at a relatively low load factor, Japan will produce less than about

*These all fall into the category of "thermal reactors." Thermal reactors got their name because they use slow, or "thermal," neutrons to initiate fission. The "fast" neutrons that emerge after fission are slowed down by a moderator such as water or graphite. "Fast" reactors use the fast neutrons directly.

**The reactors actually produce plutonium at a greater rate but much of it is burned in place. The numbers given above apply to the output when the reactor is operated in a normal manner. The units are usually abbreviated to kg/Mwe-yr.

80 kg of plutonium per year for the next few years. This rate will go up sharply in the early 1970's, to perhaps 1000 kg per year soon after 1975.* If the forecast for 1980 of 20,000 Mwe is reached Japan will be producing about 5000 kg of plutonium per year in the early 1980's.

The plutonium will be valuable commercially. It can be "re-cycled," that is, it can be substituted for uranium-235 in thermal reactors thereby reducing the requirement for enriched uranium; alternately it can be used to start up fast breeders.^(10,12,13) Both of these possibilities will be discussed in Section V. Technical studies suggest that the value of plutonium in fast breeders may be as much as twice its value in thermal reactors. However, commercial fast breeders will not be available until perhaps 1980 so each plutonium producer must decide whether to stockpile plutonium in anticipation of its use in fast breeders or whether to burn it in thermal reactors, or sell it. This is a complicated decision which involves the predicted performance of fast breeders and the price of money in the country, since to obtain present worth the future high value must be appropriately discounted. However, for the next several years there will in general be a shortage of plutonium because a fast breeder research and development program will require at least 1000 kg, and perhaps several times that amount.

C. FUEL CYCLE

For the same reasons that Japan is turning to nuclear power, to achieve a lower power cost and to attain a greater degree of self sufficiency, it is also anxious to develop the domestic capability to perform all the industrial steps associated with the production of nuclear power.** The main steps are indicated in the highly simplified

*This assumes about 5000 Mwe installed by 1975, probably a conservative estimate. There is also a lag of about 2-3 years from the time a reactor is started to the time when the first batch of plutonium has been removed and processed.

**The Editor in Atoms in Japan wrote recently (Feb. 1967): "A country seriously trying to achieve nuclear independence must have the complete facilities for all processes involving nuclear fuel."

flow diagram (Fig. 3) for the nuclear fuel cycle of a power reactor using slightly enriched uranium fuel, the type to be installed in Japan for at least the next ten years. Although the only part of the fuel cycle presently (mid-1967) in commercial operation in Japan is the nuclear reactor, the Japanese plan to have the others, with the exception of isotope separation, in commercial operation in the next few years. We shall have more to say about the exception.

1. Uranium Mining

The starting point of all nuclear power is the mining of uranium ore. Japan has very limited known reserves* (about 3000 tons uranium oxide) and therefore must look to obtaining uranium from other countries. However, in order to secure favorable long term contracts for uranium suppliers, Japan wants to take her own capital, personnel, and technology to countries where reserves are available to prospect and to operate new mines and refining facilities in cooperation with the uranium-rich countries. In December, 1966, the Mitsubishi Metal Mining Company entered into a three-year contract with Rio Algom Mines of Canada on joint prospecting in Wyoming. Under the contract Mitsubishi is entitled to receive half of the uranium mined.** This is the first instance of Japanese prospecting abroad, but teams have been sent to Canada and Australia and very likely there will be more agreements of this type.

The uranium requirements of the Japanese nuclear economy will, of course, depend on the amount of nuclear power, but also on the type of reactor. However, a rough estimate based on previously mentioned forecasts indicates that the cumulative requirement up to

* Although a promising uranium deposit has been discovered this year near the Nigyo-toge mine. The Geological Institute of Japan believes that about 20,000 tons of uranium oxide may be found (at reasonable extraction costs) in the future. For example, see Takaharu Kawai, "Uranium Resources in Japan," (Ref. 14). Mr. Kawai is the Vice President of the Nippon Mining Co.

** Atoms in Japan, Dec. 1966, p. 2.

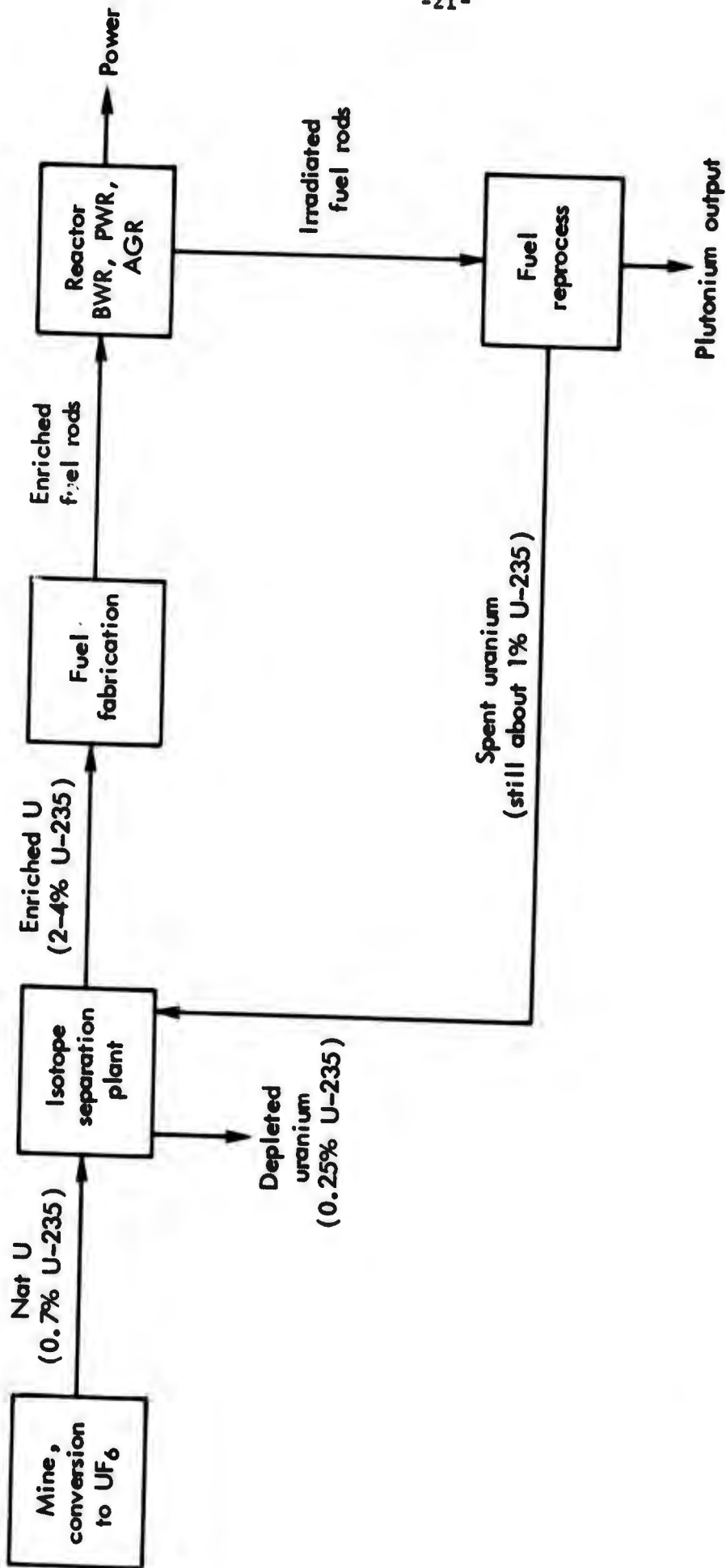


Fig. 3 - Simplified flow diagram for the nuclear fuel cycle of a power reactor using slightly enriched uranium fuel. According to one estimate the fuel cycle costs can be broken down as follows: natural uranium 0.27, conversion charge 0.05, enrichment charge 0.35, fabrication cost 0.40, reprocessing credit 0.13, plutonium credit - 0.13, and spent uranium credit - 0.07.

1975 will be over 10,000 tons of uranium* and over ten times that amount by 1985.

2. Enriched Uranium

Practically speaking, the United States is now the only source of enriched uranium for Japan.** It is therefore considered very important by the Japanese to reach an agreement for a long term contract assuring adequate access to enriched uranium. The current agreement with the United States provides for a total of 2.7 tons of uranium-235 (in the form of slightly enriched uranium). This is only enough for the first LWR at Tsuruga and the fuel for the other stations under construction has not yet been secured. Negotiations are under way to secure a lifetime (30 year) supply for the approximately 6,000 Mwe of capacity to be completed before 1975. This would come to about 130 tons of uranium-235 (or about 5200 tons of 2.5 percent uranium-235).

Though the United States has repeatedly guaranteed access to its enrichment facilities at reasonable prices for the relatively distant future there is the possibility that Japan will develop her own enrichment facility. The 1961 Long Range Program stressed:

The Government will make positive efforts to secure (a) supply of nuclear fuel on (an) international basis, particularly the enriched uranium, demand for which is expected to increase in the future.

but also,

Furthermore, the Government will take into consideration the possibility of production of enriched uranium at home, and push forward research in this field from an early stage.***

* Naojiro Tanaka, "Atomic Power Development and Nuclear Fuel Procurement" (Ref. 14). Mr. Tanaka is Managing Director of TEPCo. Very roughly, a light water reactor consumes about 0.2 tons U/Mwe-yr. However, an initial core load may be about a four year supply. The uranium is burned in slightly enriched form, say 2.5 percent uranium-235. It takes about 5 tons of natural uranium to produce 1 ton of 2.5 percent uranium-235. For example, a typical 1000 Mwe BWR consumes about 40 tons of 2.5 percent uranium-235 (which comes from about 200 tons of natural uranium) per year and the initial core contains about 200 tons of 2.5 percent uranium-235 (which comes from about 1000 tons of natural uranium).

**Other countries known to have isotope separation facilities are the U.S.S.R., the U.K., France, and China.

***Ref. 3, p. 11.

This position has been reiterated in the latest (1967) Long Range Program (see Section VI).

Enrichment technology is the only area connected with civilian nuclear power that has remained largely secret and discussions of possible enrichment in Japan immediately raise difficult questions of technology, economics, and foreign relations, especially with the United States. But as the entire Japanese nuclear program becomes more commercial the economics of enrichment and the possibilities for a domestic isotope separation plant are discussed more frankly.* Although the Japanese have shown little interest in operating gaseous diffusion plants there has been a small centrifuge program underway for some time.

While up to now centrifuges have not been developed to the point where they can compete commercially with gaseous diffusion plants they may hold considerable interest for the future. The cost of enriched uranium produced by centrifuge becomes relatively independent of the size of the plant at fairly low capacities, whereas gaseous diffusion plants must be large in order to be economical. Therefore if the performance of centrifuges could be improved, or the cost per unit sufficiently reduced, it would be economical to run small enrichment plants. In addition, only small amounts of electricity are required. While these advantages hold great attraction for countries with relatively modest requirements for enriched uranium they are also the factors that have caused centrifuges to be regarded by the United States as a threat with respect to the possible spread of nuclear weapons. The United States program is highly classified** as are the programs in other countries but so far the Japanese program is open. (Classification would, in fact, be contrary to Japanese law.)

The Japanese centrifuge project is conducted mainly at the Tokyo Institute of Technology (Nuclear Chemical Engineering Laboratory).

* For example, at the Fifth National Symposium on Atomic Energy, Tokyo, Feb. 14-15, 1967 (Ref. 7), and the JAIF Seminar on Power Reactor Fuels, Tokyo, May 17-19, 1967 (Ref. 14). See also Ref. 15.

** The AEC has recently taken action to end private work on the gas centrifuge method of isotope enrichment. See Wall Street Journal, March 23, 1967.

It was started by Prof. Y. Oyama in 1959 and since 1962 it has been under the JAFC. Mechanical and material problems have been handled by Nippon Atomic Industry Group Co. and the centrifuges produced by Toshiba Turbine Co.⁽¹⁶⁾ The present status of the program was discussed at the Fifth National Symposium on Atomic Energy, Tokyo, Feb. 14-15, 1967.* The program is budgeted at a rather modest level-- reportedly \$28,000 for this fiscal year to be raised to \$100,000 next year,** and the performance so far has been rather modest. But work is proceeding in material and fabrication technology, as well as theoretical analysis. The present goal is to develop a machine with a peripheral velocity of about 400 meters/sec.*** Atoms in Japan suggests,

There is a feeling ... especially among the younger generation of nuclear experts, that no amount of discussions on technical or economic feasibility can lead to any concrete results unless continuous efforts are made to gradually build up our own capabilities ... What is at issue now is to find means of increasing R&D investment and thus speed up the works, aiming at early experiments with UF₆ and leading further to technical and economic evaluation of production scale facilities.†

3. Fuel Fabrication

The annual demand for enriched fuel in Japan will rise from about 200 tons per year in 1970 to about 1300 tons per year in 1980.†† Japan plans to fabricate its own fuel from imported enriched uranium. The Japanese government has decided that after November 1968, at the latest, private ownership of enriched uranium and plutonium

* Ref. 7, see especially the lecture "Development of Uranium Enrichment Technique in Japan" by Kunio Yoshimura of the Nippon Atomic Industries Group Co.

** Nuclear Industry, May 1967, p. 39.

*** For an unclassified description of centrifuges, and the significance of such velocities, see Ref. 17.

† Atoms in Japan, Feb. 1967, p. 18.

†† Misai Imai, "Fuel Cycle, Fabrication, and Reprocessing" (Ref. 14). Mr. Imai is President of the JAFC.

will be approved. Private organizations will thereafter be free to enter into transactions with foreign suppliers of enriched uranium or enrichment services.*

The first planned fuel fabrication plant will be a private joint venture with U.S. General Electric.** The plant will produce about 60 tons/year of uranium fuel assemblies. (As indicated above, a typical 1000 Mwe BWR contains about 200 tons of enriched fuel and consumes about 40-50 tons per year.) The plant will be operated by the newly formed Nippon Nuclear Fuel Co. (40 percent GE, 30 percent Hitachi, and 30 percent Toshiba). Several other companies have requested government approval to enter the fuel fabrication field.*** The fabricators' plans to meet the coming demand for fuel are shown in Table 5.

4. Fuel Reprocessing

After the uranium fuel rods have been fully irradiated in a reactor they still contain valuable amounts of fissionable material. In the case of natural uranium fuel the fully irradiated rods are put through a chemical separation facility (or, reprocessing facility) only in order to remove the contained plutonium. The fuel usually no longer contains useful amounts of fissionable uranium-235. However, if the fresh fuel is slightly enriched (about 2-4 percent uranium-235) then the fully irradiated (or, spent) fuel still contains about 1 percent uranium-235 and it may be important to recover this material, in addition to the plutonium, for the economical operation of the nuclear plant.

A Japanese reprocessing plant capable of handling about 200 tons of spent fuel per year is planned for a construction start in 1968 and operation in 1971. The plant, located at Tokai-mura, was to be operated by the JAFC and will now be under the JAFC's successor (see Section VI). The design is being provided by the French firm Saint-Gobain Techniques Nouvelles, the main contractor for the slightly smaller Eurochemic reprocessing plant in Belgium.†

*Atoms in Japan, October 1966, p. 3.

**Nucleonics Week, April 27, 1967, p. 7.

***Atoms in Japan, Feb. 1967, p. 23.

†After the U.S. apparently cut off negotiations with the Japanese for a similar plant. See John W. Finney, "AEC Puts a Curb on Its Foreign Aid," New York Times, July 4, 1966.

Table 5

FUEL FABRICATION PROJECTS^a

<u>Firm</u>	<u>U.S. technology imported from</u>	<u>Project</u>	<u>Capacity</u>
Mitsubishi Atomic	Westinghouse	PWR fuel	Phase 1 (after 1970) 100t/y Phase 2 (after 1973) 200t/y
Mitsubishi Metal Mining	Nuclear Materials & Equipment Co.	Research reactor fuel (Conversion to UO ₂ powder) ^b	
Nippon Nuclear Fuel	General Electric	BWR Fuel	Phase 1 60t/y Phase 2 100 t/y Phase 3 200 t/y
Furukawa Electric	Metal and Controls Inc.	Research reactor fuel	
Sumitomo Atomic Energy	United Nuclear Corp.	Power reactor fuel	Phase 1 (1970) 15 t/y Phase 2 (1972) 30 t/y Phase 3 (1974) 60 6/y
		Research reactor fuel (conversion to UO ₂ powder)	

^aMizai Imai, "Fuel Cycle, Fabrication, and Reprocessing," (Ref.14).

^bEnriched UF₆ gas is first converted to UO₂ powder which is then fabricated into pellets and packed into tubes.

The design and engineering services will cost the Japanese about \$1 million and the total plant cost will be about \$36 million. This plant will have the capacity to handle all Japanese spent fuel until the middle 1970's. At capacity the plant will reprocess about 0.7 tons of 4 percent enriched fuel per day and will separate about 1.8 kg of plutonium per day. It is expected that it will be necessary to construct a 1 ton per day capacity plant in the late 1970's.*

D. MARITIME REACTOR

The development of nuclear powered ships has for some time been included in the Japanese nuclear program. The 1961 Program stated:

... it is considered desirable to make an increased effort for the construction of large sized and high speed ships in order to meet an increasing demand for transportation. In this connection, nuclear powered ships, having advantage when built in large size and with higher speed, are expected to play an important role in the future.

... it is considered necessary to develop nuclear powered ships in as early a time as possible and thus to establish its building technology.**

The nuclear ship program is under the direction of the Japan Atomic Powered Vessel Corporation. The original plan was to build a 6900 ton oceanographic ship with a 36 megawatt pressurized water reactor for a total cost of about \$10 million, later raised to \$18 million. In July, 1966, Mitsubishi Atomic Power Industries was appointed by the Japan AEC as builder of the reactor, with the hull to be constructed by Ishikawajima-Harima Heavy Industries. But the project snagged on the question of the relative amounts of private and government financing. These issues are now resolved and over \$21 million were included for this project in the 1967 government budget. The latest plan (March, 1967) is to build a 8,300 ton specialized freighter for the transport of nuclear fuel*** using the same reactor.

* Atoms in Japan, June 1967, p. 12.

** Ref. 3, pp 18-19.

*** Atoms in Japan, Feb. 1967, p. 23 and March 1967, p. 10.

It is clear that the Japanese are very much concerned about retaining their lead in shipbuilding. In a recent lecture* in Tokyo JAEC Commissioner Yamada said:

In our country, having considered the development of the technology of ship-reactors, and having compared the nuclear ship and the currently-used ship, we might be able to compete economically in the fields of fast container ships and larger oil-tankers.

The building of the first nuclear ship will establish technological structure and provide the experience of ship-building and navigating. Moreover, it is necessary to improve and promote the research of an economic ship reactor. As for the second nuclear ship, the first nuclear container ship seems proper. Also the investigation and research for the development of a nuclear submarine which has the advantages of nuclear characteristics is necessary.

The Japanese were counting on some assistance from Westinghouse on the maritime reactor design but it appears that the United States is clamping down on export of this technology, even for civilian application, apparently at the urging of V.Adm. Rickover.**

* T. Yamada, "New Long Range Program for Development and Utilization of Atomic Energy" (Ref. 7).

** See U.S. Blocks Maritime Assistance to Japan, Nucleonics Week, June 8, 1967, p. 1.

V. DEVELOPMENT OF ADVANCED REACTORS

A. INTRODUCTION

The Japanese government does not sponsor research on "proven" reactors--the light water and gas cooled reactors being produced in the United States and Western Europe. The Japanese recognize that they are now lagging behind other advanced countries in nuclear technology but they intend to be among the leaders, say, twenty years from now. With this characteristically long range view they plan to get the first generation reactors from abroad and to invest their relatively limited resources mainly in future technology.

It is generally accepted in nuclear industries all over the world that the present type of uranium fueled thermal reactors will eventually be replaced by plutonium fueled fast breeder reactors. The development of fast breeders would be especially attractive for Japan which has scant uranium resources and at present no isotope separation facility. It therefore has to depend on foreign uranium mines and isotope separation facilities to supply the slightly enriched uranium which is consumed in present day "proven" reactors--mainly the American LWR's. The main effort of the Japanese power reactor research and development program will therefore be directed toward the production of a Japanese fast breeder.

A somewhat smaller effort will probably be directed toward the development of an intermediate generation reactor of the heavy water type with very good fuel economy. This "Advanced Thermal Reactor" would fill the gap before the introduction of fast breeders and it would serve as insurance in case the breeder development was delayed.

The new (1967) Long Range Program to be described in Section VI calls for a new organization, tentatively called Power Reactor and Nuclear Fuel Development Agency to run the Fast Breeder and Advanced Thermal Reactor Projects.

B. FAST BREEDER

The present types of thermal reactors--the so-called proven types--make very poor use of the uranium fuel. Only about 1 percent of the mined uranium is consumed and the rest is discarded. That is, these reactors burn only the uranium-235 that makes up one part in 140 of natural uranium (the rest is uranium-238) plus a little plutonium-239 that has been formed by neutron capture in uranium-238.* As a result, these reactors require large amounts of uranium fuel. And while there is considerable disagreement over the extent of the world reserves of readily accessible uranium ore it is generally agreed that they will not last beyond the turn of the century if the generation of nuclear power continues to be based essentially on the burning of uranium-235. That is, it would be necessary to use less accessible ores and this would prohibitively increase the nuclear fuel costs.

However, if the uranium-238 could be entirely, or almost entirely, converted into plutonium-239 the fuel needs could be reduced by perhaps a factor of 50 and fuel costs could be substantially lowered. This can be done in the plutonium fueled fast breeder reactor that first converts the uranium into plutonium. They are called "breeders" because they produce more plutonium than they consume, and "fast breeders" because they are unmoderated and hence use "fast" neutrons.**

The basic element of a fast breeder is a relatively small core of plutonium (about 3 kg of plutonium per Mwe) mixed with uranium. The core is surrounded by a "blanket" of uranium-238 which captures neutrons and is thereby slowly converted to plutonium. Heat is carried away by a coolant such as liquid sodium which rapidly streams through the system. The core and blanket are periodically reprocessed,

* Uranium-235 and plutonium-239 will support a chain reaction and so are called fissionable, although strictly speaking all heavy elements can be fissioned by sufficiently energetic neutrons. Uranium-238, which cannot by itself support a chain reaction but can be turned into a fissionable material by neutron capture, is called a "fertile" material.

** That is, there is no component that corresponds to the water, heavy water, or graphite moderator in a thermal reactor.

the plutonium in the core is replenished, and the excess plutonium is used to start up new fast breeders. The net input to the system is natural or depleted uranium and the net output is the excess plutonium. A flow diagram of the nuclear fuel cycle for a fast breeder is shown in Fig. 4. The ratio of the plutonium produced to the plutonium used up depends on the design but is estimated typically about 1.4, and the time it takes to accumulate enough excess plutonium to start another reactor of the same size is estimated typically about ten years. This is about the same as the doubling time for the electrical energy demand in most countries. That means that if all the electrical power were produced by breeders they could produce enough excess plutonium to keep up with the increasing demand for power.

Although fast breeders will probably have a clear advantage over thermal reactors in fuel costs, in order that they produce power more cheaply it is also necessary that the breeders should not be much more expensive to build than present day reactors. Roughly speaking, a major saving will have been effected only if the capital cost of fast breeders can be held to perhaps one and a quarter of the cost of present day reactors. Whether, or when, this can be done has not yet been definitely settled.

The incentives for Japan held out by the successful development of an economical fast breeder are clear. Aside from cheaper power the uranium requirements of the entire nuclear economy, thermal reactors and breeders, would be drastically reduced^(10,18,19) by about a factor of 2 up to the year 2000, and much more later. In particular, since most of the uranium is required in slightly enriched form the introduction of breeders will significantly reduce the need for enrichment services. This would permit Japan to be less dependent on U.S. enrichment facilities without having to construct her own. Mr. Murata, the Director of the Atomic Energy Bureau of the Science and Technology Agency has stated:

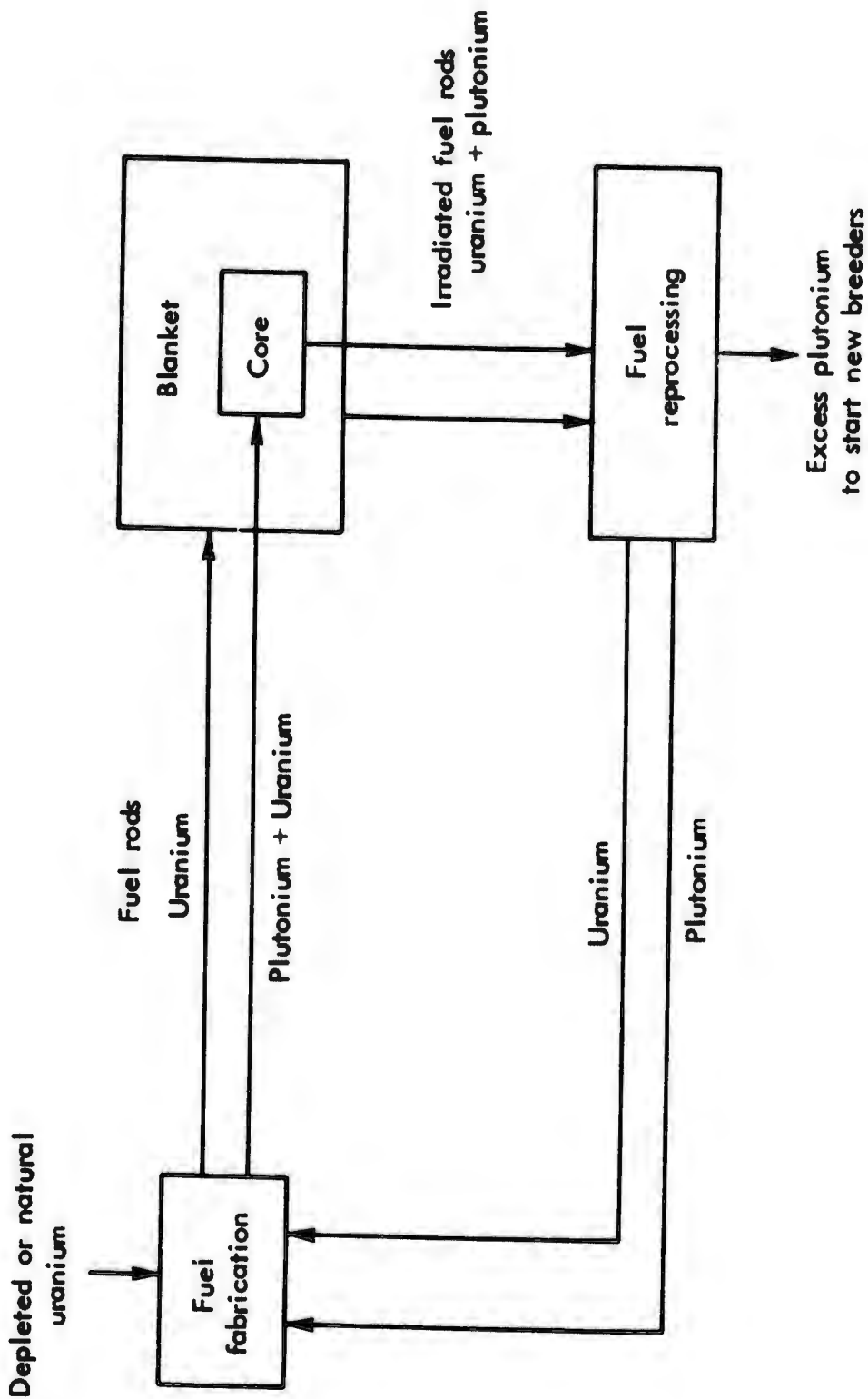


Fig. 4 - Simplified flow diagram for the nuclear fuel cycle of a plutonium fueled fast breeder reactor. In steady state the net input is uranium and the net output is plutonium but the initial plutonium for the core must be externally supplied.

It is desirable for this country, with scant energy resources and extremely large demand for energy, to expedite practical use of fast breeder reactors and derive the great benefit it will bring about, as this type of reactor is considered ideal from the stand-points of both economy and security in power supply ... Japan is qualified to maintain the position as an industrial country and so develop further only if she succeeds in the development of the fast breeder reactor which is bound to occupy the main portion of power generation in the future.*

The development program outlined by Mr. Murata⁽¹⁰⁾ looks forward to the construction of a 200 Mwe prototype fast breeder to be started up in the late 1970's. This would be followed by a fast breeder demonstration reactor of about 1000 Mwe to be started up in the early 1980's. In the next ten years it will be necessary to develop the required technology, particularly in the areas of core safety, cooling systems, and fuels.

A large critical facility is being constructed at JAERI to study the core characteristics of large plutonium fueled cores.** It will be fueled with plutonium about 1969 and will be used to mock up the prototype and demonstration reactor cores. In common with most other countries Japan is concentrating its effort on sodium cooling and some aspects of sodium technology have been under study at Hitachi, Ltd., and JAERI. Plutonium fuel for fast breeders is currently under study at JAERI and the Atomic Fuel Corp. An experimental reactor of about 100 Mwt is planned at JAERI to start up around 1975 to conduct fuel irradiation experiments.

The procurement of plutonium is necessary in order to carry out this plan. Japan's first reprocessing plant is expected to start operating around 1971 so it should be possible to fuel the 200 Mwe prototype and 1000 Mwe demonstration reactors with Japanese plutonium. However, it will be necessary to depend on imported plutonium for the critical facility and experimental reactors. Probably several hundred kilograms of plutonium will be required for those two facilities.

* Ref. 10, p. 9.

** It went critical with enriched uranium fuel in April 1967.

The plans outlined here more or less parallel similar efforts in the United States, Soviet Union, Britain, France and West Germany with perhaps a lag of about five years. The development of a fast breeder is a costly and complex enterprise* which involves research and development activities in many fields. Because Japan has started late and has limited resources it is anxious to amplify its efforts through international cooperation. There is now a joint program with the Atomic Power Development Associates at the Fermi reactor in Michigan and JAERI has entered into an information exchange agreement with the UKAEA and will probably enter into a similar agreement with EURATOM. Cooperation with European countries, and especially Britain, appears to be preferred to cooperation with the United States. The reason seems to be that the United States has such extensive resources that cooperation tends not to be a two-way street whereas the relations established with countries that hope to profit from the joint effort seem to be sounder.

C. ADVANCED THERMAL REACTOR (ATR)

Until recently the nuclear power development plans of advanced countries reflected the expectation that the development of nuclear reactors would proceed from the present proven types to fast breeders through an intermediate generation of so-called "advanced convertors."** These include various types of advanced reactors that have better fuel economy than the proven reactors either through better neutron economy, as in heavy water moderated reactors, or higher thermodynamic efficiency, as in high temperature gas cooled reactors. Introduction of these reactors would permit a reduction in uranium requirements, and hopefully a reduction in power costs, without a very early commitment to the still unproved fast breeders. There are strong indications, however, that in official circles in the United States and Western Europe the importance of advanced convertors has been exaggerated.

*The United States now spends more than \$50 million a year on fast breeders in the initial stages of the R&D process. The total program, including several prototypes, may cost \$2 billion over about ten or fifteen years.

**See, for example, Ref. 19.

Their development has lagged and there is now considerable doubt whether they will ever be very important commercially, at least in the United States. The light water reactors are being improved more rapidly than first expected, and at the same time there seems to be an increasing shift of R&D funds and enthusiasm from advanced convertors to the development of fast breeders. It now looks as if the nuclear industry in the United States and Western Europe may move directly from the present proven types to fast breeders.*

In Japan, however, the development of an advanced convertor has an added attraction. Japan does not have a domestic proven reactor program under way and the fast breeder program is expected to result in a commercial reactor perhaps fifteen or twenty years from now. It is felt that there needs to be an intermediate development program which will produce a commercial reactor in, perhaps, ten years. This will serve a number of purposes. In addition to lowering the power costs the Japanese would like to reduce their dependence on imported uranium and, especially, the dependence on enriched uranium. An Advanced Thermal Reactor (ATR), as the advanced convertor is called in Japan, using natural uranium perhaps slightly enriched with domestic plutonium would reduce uranium consumption and would also insure the nuclear industry against an excessive delay in the fast breeder program.

The ATR selected is a boiling water-cooled heavy water moderated reactor similar to the British Steam Generating Heavy Water Reactor (SGHWR)** to be fueled with natural uranium slightly enriched with plutonium, although the initial core may use slightly enriched uranium. The fuel cycle for this type of reactor is illustrated in Fig. 5. The SGHWR is considered to have considerable promise for producing cheap power because its capital cost is (optimistically) expected to be comparable with other light water systems and its fuel costs are expected to be lower because of the saving on enrichment costs. The

* See Ref. 6, p. 39.

** A 100 Mwe prototype is being built at Winfrith Heath (See Atom, December 1966, p. 274).

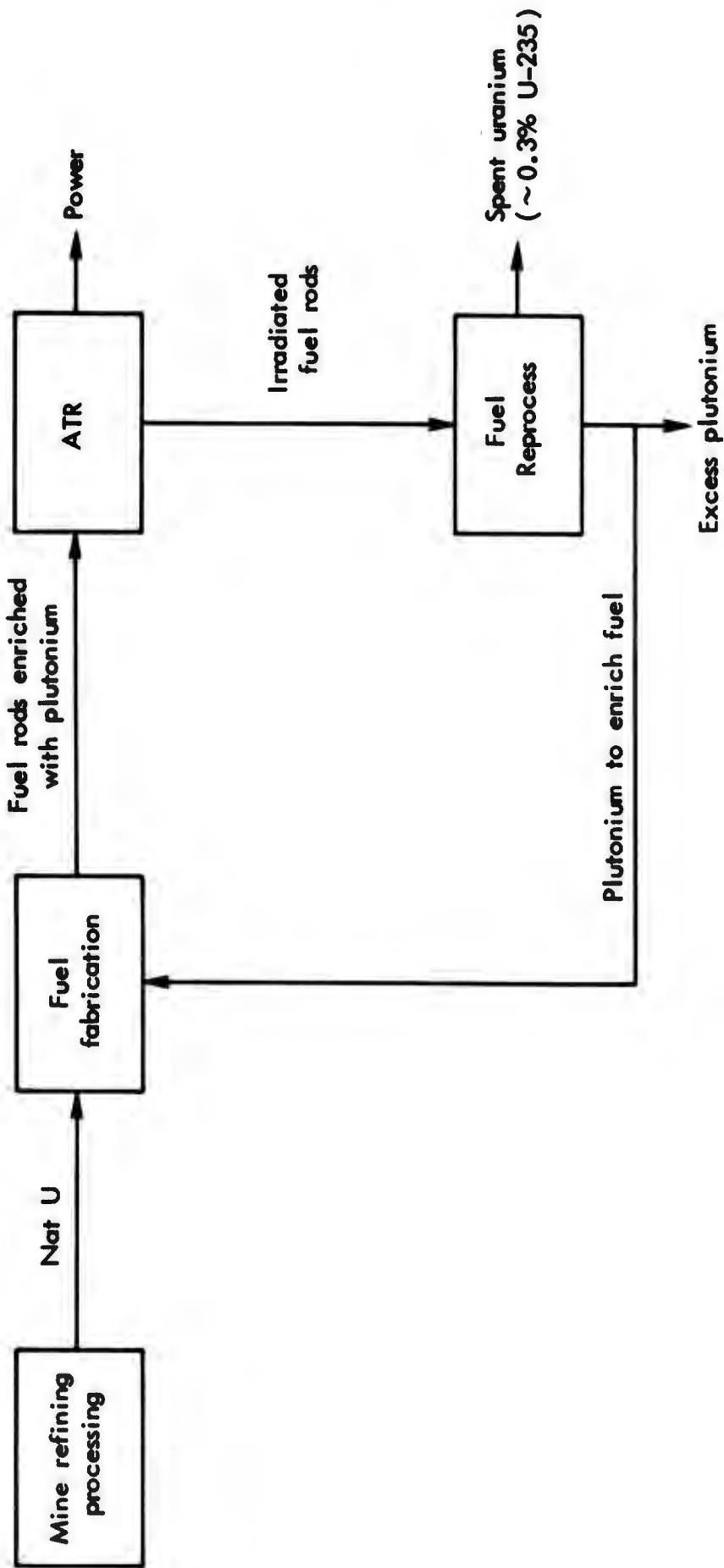


Fig. 5 - Simplified flow diagram for the nuclear fuel cycle of an advanced thermal reactor burning natural uranium slightly enriched with plutonium.

investment in the heavy water moderator is more than off-set by the lower cost of the first fuel charge. The research and development program is supposed to start in 1967 and a prototype is to become critical in 1974.*

The motivation for the development of a Japanese ATR as contrasted with the acquisition of foreign designs for light water reactors is influenced by the recognition that Japan needs experience in managing a major reactor development program by herself. It has been suggested that a successful program will give Japanese industry confidence in its ability to deal in all parts of reactor manufacture. The relatively short range ATR program will provide Japan with useful technology that can be exchanged for more technology--it will mark Japan early as one of the contributors and not just one of the consumers. All of these advantages must be weighed against the diversion of resources from the fast breeder project, which from a long term view is by far the more important.

* See Atoms in Japan, May 1967, pp 7-9.

VI. NEW LONG RANGE PROGRAM

A. FORECASTS AND PLANS

As we have indicated earlier in the five years after the acceptance of the 1961 Long Range Program the circumstances surrounding the commercial application of nuclear power changed so much that the program becomes rather outdated. In September 1966 the Japan AEC established a Long Range Program Special Subcommittee to draft a revised program that would reflect most accurately the improved prospects of civilian nuclear power. The New Long Range Program for Development and Utilization of Atomic Energy has now been adopted by the JAEC and submitted to the Cabinet. It covers in some detail the development of nuclear power up to 1975 and also considers the long term outlook to about 1985.

The basic philosophy of the Long Range Program was stated in a recent lecture by AEC Commissioner T. Yamada at the 1967 National Symposium on Atomic Energy:*

First of all, it should be mentioned that the development and utilization of atomic energy is to aim only at peaceful industry.

Secondly, autonomy should be maintained in exploitation of atomic energy. We must admit we are behind in starting the exploitation of atomic energy ... However, we must promote the development and utilization of atomic power independently so as to obtain a stabilized amount of energy within the country and to promote technical standards and intensify the industrial development of the country.

... It requires many years until atomic energy may be applied for practical use. Also we must know this program involves costly risks. In order to promote the program efficiently with limited resources, the program must be pursued systematically.

* T. Yamada, "New Long Range Program for Development and Utilization of Atomic Energy" (in Japanese), (see Ref. 7). The symposium is co-sponsored by the Atomic Energy Society of Japan and twenty-eight other academic societies. This annual event is the occasion for highlights of the year's major nuclear topics to be presented to the Japanese academic world.

The official plan* forecasts an installed nuclear electrical generating capacity of about 6000 Mwe in 1975 and "at least" 30-40,000 Mwe in 1985, or about 25 percent of the total in 1985. (We have been guided by these figures throughout this Memorandum.)

As in previous plans it is expected that the technology of proven types of reactors, mainly light water reactors (LWR) using slightly enriched uranium, is to be imported from abroad. In this area the objective of the Japanese nuclear industry should be to build up a broad national manufacturing capability. Nuclear power based on proven reactors is expected (by the authors of the plan) to become competitive with Japanese oil fired plants in the early 1970's. It is considered very important to secure long term contracts to secure an adequate supply of natural and enriched uranium for the reactors now being installed. Furthermore, the report states,

as demand for enriched uranium will increase on a global basis from now, Japan should make complete preparations for enriching uranium at home in the future.**

Moreover, Japan needs to develop the domestic capability to service all phases of the nuclear fuel cycle.

Special emphasis is placed on directing the main nuclear power research effort toward developing advanced reactors of Japanese design. The power reactor program, to be carried out by a new agency specially organized for this purpose, would aim at the development of an Advanced Thermal Reactor (ATR) and a Fast Breeder Reactor (FBR). The ATR will start on slightly enriched uranium but will thereafter be enriched with plutonium (to reduce the dependence on enriched uranium). The LWR's and ATR's will provide plutonium for the next generation, the FBR's. A prototype ATR should be started around 1970 and economical commercial application should start around 1980. An experimental plutonium fueled FBR should be started around 1970 and construction of a prototype should begin by 1975. Economical commercial use of FBR's should come around 1985.

* Described in Atoms in Japan, April 1967, pp 9-12.

** Long Range Program (draft) as drawn up by AEC Long Range Program Committee, as reported in Nihon Keizai, March 23, 1967.

If the forecasts of the Long Range Program are realized than Japan will have produced about 3 tons of plutonium by 1975 and about 35 tons by 1985.

With respect to nuclear ships the report recommends construction of the first Japanese nuclear ship is to be started in 1967 and completed by 1971, and work on a second ship is to be started in the 1971-1974 period. Two or three more ships of the same type should be operated by private enterprise with government subsidy. The report suggests that in about 10 years 30 knot nuclear powered container ships and mammoth tankers will probably be competitive with conventional ships.

B. POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT AGENCY

It has been the view of Japanese nuclear circles that advanced reactor development program in order to be successful must be entrusted to a new nuclear power development agency formed for this purpose. It was strongly believed that none of the existing organizations had the capability to successfully carry out this program. These views were equally strongly opposed by the Ministry of International Trade and Industry and the Electric Power Development Co. The argument seems to turn on the question of whether the development of nuclear electrical power plants should be the responsibility of a nuclear agency or an electrical power agency. The Prime Minister has now declared in favor of the Japan AEC and the Science and Technology Agency and the new draft budget submitted to the National Diet on April 1, 1967, included funds for the formation of the new organization.*

Because it has been the policy of the government not to approve the setting up of any new public corporation a compromise was reached which called for the reorganization of the Atomic Fuel Corporation and its absorption by the new agency. This means that the new agency,

* Atoms in Japan, April 1967, p. 13.

tentatively called "Power Reactor and Nuclear Fuel Development Agency," will combine reactor R&D with prospecting, mining, milling, and reprocessing. The dual role of the new agency has caused some apprehension among those concerned about the success of the reactor development program. The new agency is supposed to start operating in October 1967 and would be under the jurisdiction of the Science and Technology Agency. At this writing, the bill for setting up the new corporation has just been approved by the Diet, and Goro Inoue, Chairman of the Chubu Electric Power Co. has been named President.*

The bill authorizes the corporation to carry out all research and development which is necessary for the attainment of commercial power reactors. It is estimated that about \$550 million will be spent over 10 or 15 years to develop an ATR prototype and an FBR prototype. This sum includes the construction of the prototypes and about \$100 million would come from private sources. (The cost estimates may prove to be rather low. For example, the amount allotted to the FBR program, on the average about \$30 million a year, is less than half of present yearly expenditure on fast reactors in the United States** in the early stage of the program.

C. NEW NUCLEAR BUDGET

The draft of the national budget for fiscal 1967 includes about \$43 million for nuclear development. In addition the government has made guarantees of about \$16 million for the following years. The 1967 figure represents an increase of about 20 percent over fiscal 1966.

* Nucleonics Week, August 3, 1967, p. 8.

** Estimated at about \$66 million in fiscal 1968 (Hearings before the Joint Committee on Atomic Energy, March 14-15, 1967, p. 1086).

Table 6

MAJOR ITEMS IN ATOMIC ENERGY BUDGET FOR FISCAL 1967(DRAFT)^a

<u>Items</u>	<u>1966 Budget</u> <u>(\$ million)</u>	<u>1967 DBudget</u> <u>(\$ million)</u>
	(3.9) ^b	(6.9)
JAERI	22.5	25.1
	(2.5)	
Atomic Fuel Corp.	5.3	4.2
		(3.2)
Power Reactor Development Agency	---	3.8
		(2.8)
Nuclear Ship Development Agency	0.5	2.1
National Institute of Radiological Services	1.8	1.9
National Research Institutions	<u>1.6</u>	<u>1.6</u>
	(7.2)	(15.5)
Total (including all other items)	35.3	42.5

^aAtoms in Japan, March 1967, p. 3.

^bFigures in brackets represent government guarantees for the ensuing years.

D. COMMENTS

It is probably still too early to judge the Japanese effort. The implementation of present plans will probably become much clearer in a year or two. Rather than come to any particular evaluation of the Long Range Program we would instead like to draw the attention of the interested reader to three points where developments in the near future may have far-reaching significance:

1. The organization of the new Power Reactor and Nuclear Fuel Development Agency. The success of the entire Long Range Program will depend, to a large extent, on the effectiveness of this new agency. The bill authorizing the new corporation has just been approved by the Diet and as we have indicated, the bill already involves a certain degree of compromise with the original sole purpose of advanced power reactor development. It remains to be seen whether the new corporation will be organized and staffed in a way that will provide for the successful completion of the R&D tasks assigned to it in the Long Range Program, especially the development of a Japanese Fast Breeder Reactor. The Agency should take final shape toward the end of 1967 or the beginning of 1968.

2. The Advanced Thermal Reactor Program. The reasoning behind the development of an ATR, whose usefulness would be limited to a fairly short time period before large scale introduction of fast breeders, does not seem entirely convincing. It is generally conceded the long term system toward which advanced nuclear power development is tending is the fast breeder system. The ATR, on the other hand, derives its significance in the Japanese program largely from special conditions in Japan which may seem less significant in the coming years. These conditions are: a late start in nuclear development and no domestic enrichment facilities (see Section V). The arguments that Japan needs early experience with a complete reactor development program and that it should reduce its dependence on foreign enriched uranium are compelling but not overwhelming. It is also possible to argue that an ATR program would divert needed funds from the FBR program which in the long run is much more

important. Furthermore, if adequate funds are available, it may be wiser to take more than one approach to breeder development, as in West Germany where the steam cooled breeder is being developed in addition to the sodium cooled breeder. It is therefore possible, and we are only speculating here, that the Japanese may decide to drop the ATR program. This would indicate a more determined attitude toward the FBR. It would also increase, for a number of years, the enriched uranium requirements of the Japanese nuclear economy because in the absence of the ATR more light water reactors would be installed.

3. Uranium enrichment. The only part of the nuclear fuel cycle for which the Japanese have not made public definite plans is the enrichment of uranium. Although for the present Japan will obtain enriched uranium from the United States, it seems unlikely that this situation will continue indefinitely. In a relatively short time from now, Japanese reactors can be expected to require the services of fairly large enrichment facilities. For example, around 1980 Japanese reactors will probably consume annually enough enriched uranium to fully occupy enrichment facilities approximately one-quarter the total capacity of the present United States diffusion plants.* Such facilities would be large enough that, while the United States will probably offer toll enrichment at rather attractive prices, it is still possible the Japanese, and others, may be able to come sufficiently close to the U.S. price to justify construction of their own facilities. These might be gas diffusion plants, as in the United States, or they may employ some other method of enrichment. Other countries appear less inclined to prejudge the economics of enrichment. (For example, in West Germany there is a program on jet separation of isotopes, a method that was never seriously

* This result can be arrived at in the following way: In 1980 Japan will probably have over 15,000 Mwe of light water reactors. These would consume annually the equivalent of about 750 tons of 2.5 percent uranium-235 which can be supplied by about one-eighth of U.S. enrichment capacity. If the rate of installation of reactors is such as to double the nuclear electrical generating capacity about every four years then new reactors cores (containing about a four year supply of fuel) more or less doubles the enriched uranium demand.

considered in the United States.)⁽²¹⁾ We have earlier described the Japanese centrifuge program; its progress over the next few years will determine whether the centrifuge method is commercially attractive. Whatever the method of enrichment, the construction of a plant should probably begin about 1975 for 1980 operation and the technology for such a plant should then be ready in the early 1970's.

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