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From the Fast Breeder Reactor to the Fast Reactor, and on to a White Elephant

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1. Introduction

Next-generation advanced reactors are currently a hot topic. This is due to Japanese Prime Minister Fumio Kishida's instruction to consider the promotion of nuclear reactor restarts, the removal of restrictions on reactor operating periods, and the development and construction of next-generation advanced reactors at the second meeting of the GX (Green Transformation) Implementation Council, a body under the auspices of PM Kishida himself. However, what exactly was meant by next-generation advanced reactor was not made explicit at the meeting.

So, what is the next-generation advanced reactor? In April 2022, the Ministry of Economy, Trade and Industry (METI) set up an "Advanced Reactor Working Group" (hereafter, WG), which began discussions on issues such as advanced reactor development and its social value. Of the 13 WG members, the author was the only one to participate from the nuclear-free camp. In July 2022, the WG completed an interim summary of arguments entitled "A Technological Roadmap for Advanced Reactor Development toward the Realization of Carbon Neutral and Energy Security (Draft Outline) ".

Table 1. Outline of Next-Generation Advanced Reactors and METI Prospects for Introduction

Reactor Type	**Reactor Features**	**Start of Construction**	**Start of Operation**
Advanced Light-Water Reactor	Large-scale light- water reactor with new technological features	Early 2030s	Mid-2030s
Small Light-Water Reactor	Nuclear reactor of power output capacity of up to 300MW.	Mid-2030s	Early 2040s
Fast Reactor	A nuclear reactor utilizing fast neutrons. Plutonium is bred in a blanket area surrounding the reactor core when fuel is loaded into the blanket (blanket fuel). As more plutonium is bred than used in nuclear fission, the reactor is called a fast breeder reactor.	2040	Mid-2040s
High-Temperature Gas Reactor	A nuclear reactor that uses helium gas as the coolant. As ceramics and other materials are used for the reactor core, the reactor can withstand higher temperatures than the light-water reactor.	2030	Mid-2030s
Nuclear Fission Reactor	A nuclear reactor that utilizes nuclear fusion.	Mid-2030s	Undecided

Source: Prepared by the author based on documents submitted to the Advanced Reactor Working Group, etc.

According to this roadmap, next-generation advanced reactors refers to five kinds of reactors: advanced light-water reactors (LWRs), small LWRs, fast reactors, high-temperature gas reactors, and fusion reactors. As an attachment to the Draft Outline, METI published a “Technological Roadmap toward Introduction” (Table 1) that indicates a schedule for the development of the different reactor types. Looking at the roadmap, the earliest advanced LWRs will be coming online in the mid-2030s. Further, for the fast reactor, thus far Japan’s most favored new reactor development, the thinking is that a demonstration reactor would start up in the mid-2040s. (A demonstration reactor is a nuclear reactor constructed and operated to gain insights into technological reliability and economic performance, and the pathway to a commercial reactor generally passes through the stages of experimental reactor, prototype reactor, and demonstration reactor.) Up to now, the fast reactor development plan targeted practical utilization by around 2050. This has been brought forward in the new roadmap, but the grounds for bringing the development forward are unclear.

2. A History of Problems and Obsession

From the start, Japan’s nuclear power development had aimed at developing a fast breeder reactor (FBR). For instance, the first Atomic Energy Long-Term Plan by the Japan Atomic Energy Commission in 1956 already contained the statement, “The future goal of nuclear reactor development is the domestic production of the breeder power reactor.” The “breeder power reactor” means the FBR.

At the dawn of Japan’s introduction of nuclear power, all the advanced nuclear technology countries were surging forward toward the development of the FBR. At the time, as uranium resources were scarce and thought to eventually become exhausted, it was considered that the FBR would allay concerns over resource reserves. Each of the countries, however, ran into development difficulties. Various challenges became apparent, but especially problematic was that liquid sodium was used as the coolant. This is because sodium reacts violently with water. Russia’s FBR, the BN-600, for example, experienced 27 sodium leaks up to 1997, of which 14 leaks resulted in fires. This was not a problem unique to Russia. France, the USA and other countries also ran into problems associated with sodium. The feared uranium resource depletion also did not occur.

There was also the problem that the FBR might lead to nuclear proliferation. In the FBR, the core is surrounded by a “blanket” of uranium fuel, which breeds plutonium by absorbing fast neutrons. Plutonium exists in the form of both fissile and non-fissile nuclides, and the nuclide bred in the fuel blanket is highly fissile. With the existence of these two issues, many countries put the development of the FBR on the back burner. Countries that are even today striving to develop the FBR are France, Russia, China, USA, UK—the nuclear-weapon states—and Japan. After spending approximately two trillion yen on developing the prototype FBR “Monju”, a sodium leak accident in 1995 and other frequently occurring problems culminated in the termination of the project in 2016. From the start of operation in 1994 to termination 22 years later, Monju ran for a mere 250 days. Yet Japan has never abandoned FBR development, even though there is little prospect for Japan to build an FBR inside the country anytime soon.

What Japan then jumped at was the French fast reactor ASTRID program. The purpose of ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration) was not to breed plutonium, but to convert long-lived nuclear substances into short-lived ones using fast neutrons, which turned out to be very convenient for Japan. This was because, while uranium market prices fluctuate at an extremely low level, both France and Japan are facing severe problems with their excess civilian plutonium stocks. However, the ASTRID program, which was to be a joint program involving the two countries, was cancelled by France in 2019. France announced that it would not consider developing a high-cost fast reactor until at least 2050.

The next thing that Japan jumped at was the US VTR (Versatile Test Reactor) program. The US Department of Energy (DoE) set up this program in 2018 to conduct material tests for different types of fast reactors, and selected GE Hitachi Nuclear Energy (GEH) as the reactor vender. The construction cost has been set at a maximum of USD six billion, the total cost to be borne by the US government. Although the VTR is based on the FBR PRISM (Power Reactor Innovative Small Module) designed by GEH, it does not have a power generation capability. A memorandum of cooperation on the VTR was concluded between the governments of Japan and the USA in 2019, but this program has also fallen into a very awkward situation.

Paradoxically, this was related to the development of the fast reactor Natrium that GEH had begun jointly with the nuclear power venture company Terra Power (founded by Bill Gates). Currently, Terra Power has received support from the US DoE and is aiming to complete the construction of Natrium, whose design is also based on PRISM, by 2028. The VTR was initially planned to start operation in 2026, but delays in getting the construction underway led to a planned construction start in 2027 with completion in 2032. The VTR was intended to conduct the research necessary for Natrium, but the completion of VTR would be later than Natrium. If so, then the VTR is meaningless. At that point, the US Congress zeroed out funding for the VTR for 2022. The project Japan then jumped at next was the fast reactor Natrium. In January 2022, the Japan Atomic Energy Agency, Mitsubishi Heavy Industries, and Mitsubishi FBR Systems concluded a memorandum of cooperation with Terra Power.

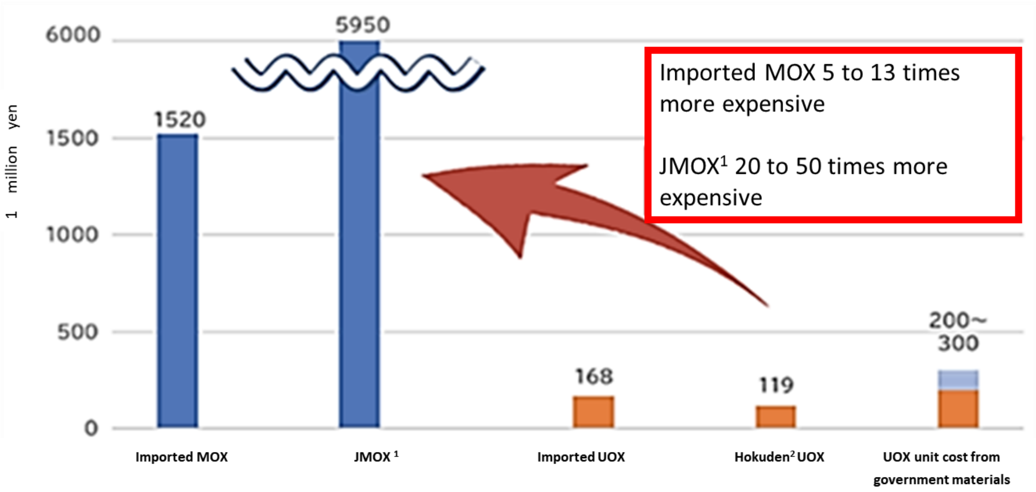
3. What on Earth is the Fast Reactor for?

Japan originally chose the FBR path for the purpose of energy security. There are no commercial-scale uranium resources in Japan, but the spent fuel from nuclear reactors contains plutonium. The idea is breeding to the "reduction of volume and toxicity level" of nuclear waste. In comparison with the direct geological disposal of spent fuel, the volume and toxicity of the material (nuclear waste) remaining from reprocessed spent fuel is reduced. This is obvious. Plutonium and uranium are recycled as fuel, and the remaining radioactive materials, such as iodine, noble gases, and tritium enclosed in the spent fuel, are released into the environment during reprocessing. In addition, the zirconium cladding and other radioactive materials covering the nuclear fuel rods are also separated out as nuclear waste. The resulting highly radioactive liquid waste is then solidified in glass to undergo geological disposal. In other words, "reduction of toxicity level" means either separating out toxic materials before geological disposal or releasing them into the environment.

A further problem is how to handle the MOX fuel, fabricated from separated plutonium, after it has been used. As spent MOX fuel generates considerably more heat and radiation than ordinary uranium fuel, it cannot be handled in the reprocessing plant now under construction at Rokkasho Village in Aomori Prefecture. Moreover, as the plutonium contained in spent MOX fuel consists largely of non-fissile plutonium, it is no longer efficient to recycle it as fuel. Further, since the determining factor for the site area of the depository in geological disposal is not the volume of the material to be disposed of but its degree of heat generation, in the end spent MOX fuel disposal results in almost no reduction in the size of the repository.

What can be done to realize the "reduction of volume and toxicity level" of nuclear waste? Firstly, the practical utilization of the fast reactor, and secondly it would require the finer separation of radioactive materials, not at the Rokkasho Reprocessing Plant, but at a new reprocessing plant.

However, is there any prospect of the fast reactor achieving practical utilization? For a reactor to reach the commercial stage, a positive economic performance is necessary. Natrium is claimed to be a fast reactor with an excellent economic performance, but with this being the maiden reactor, the necessary initial investment is forecast to be USD four billion (around 600 billion yen at an exchange rate of USD1 = JPY140). As the power capacity is rated at 345 MW, that calculates out at JPY1.7 million/kW. In general, the construction cost for a nuclear reactor in Japan being JPY400,000/kW, Natrium is roughly three times as expensive.



Note:
1. Domestically produced MOX
2. Hokkaido Electric Power Company

Figure1.Unit Cost of MOX Fuel and Uranium Fuel (UOX) (ton)
Source: Prepared by the author

For the fast reactor, it is not only the construction cost that is expensive; fuel costs are also significantly higher. The reason is that producing the fast reactor fuel requires a reprocessing process. As for light water reactors, when comparing MOX fuel with uranium fuel, domestically produced MOX fuel turns out to be 20 to 50 times more expensive than uranium fuel per ton (Figure 1). Fast reactor MOX fuel contains more plutonium than that for light-water reactors, which results in a much higher cost.

It is said that the initial investment for nuclear power generation is high but fuel cost is inexpensive, and thus nuclear reactors can provide relatively cheap electricity if reactors are kept running at a stable output level. But the initial investment for fast reactors is far higher than for a conventional nuclear reactor, and fuel costs are also several dozen times more expensive. Even supposing that the construction of new nuclear power plants should take place, is there any power company that would select a fast reactor? The same goes for a new reprocessing plant. It is estimated that the total cost of the currently under construction Rokkasho Reprocessing Plant is approximately JPY14.4 trillion. Is it feasible that a second reprocessing plant be constructed?

4. Conclusion

The FBR was at one time thought of as Japan's energy security trump card. However, the development ran into trouble due to technological difficulties, the dream of plutonium breeding receded into the distance, and its raison d'être shifted to a solution for the management of radioactive waste. Nevertheless, changing the signboard does nothing to dispel the technological difficulties. There is also no advantage in terms of economic performance. When nuclear power first arrived on the scene 60 years ago, it may have seemed that possible to utilize solar and wind power as extremely cheap power sources. Thinking of nuclear power as providing energy security is plainly out of date. possible to utilize solar and wind power as extremely cheap power sources. Thinking of nuclear power as providing energy security is plainly out of date.

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