Science and Global Security, 17:68–76, 2009
Copyright © Taylor & Francis Group, LLC
ISSN: 0892-9882 print / 1547-7800 online
DOI: 10.1080/08929880902953039

The Fast Reactor and Its Fuel Cycle Developments in Japan: Can Japan Unlock its Development Path?

Tatsujiro Suzuki

Graduate School of Public Policy, The University of Tokyo, Tokyo, Japan

This paper reviews the history, status, and probable future of fast reactor and associated fuel cycle development in Japan. The fast breeder reactor and its closed fuel cycle have been the cornerstone of Japan's nuclear-energy development program since the 1950s. For economic, technological, and political reasons, Japan's development and implementation of these technologies is significantly delayed. The budget for fast breeder reactor development has steadily declined since the mid-1990s, and its commercialization target has slipped from the 1980s to the 2050s. An accident at the Monju prototype reactor contributed to delays and triggered a fundamental shift from R&D and early commercialization to an emphasis on advanced fuel cycles.

Nevertheless, Japan is still committed to fast-reactor development. This paper examines the motivation for its continued commitment to a fast reactor program and concludes that several non-technological factors, such as bureaucratic inertia, commitments to local communities, and an absence of R&D oversight, have contributed to this entrenched position. Japan is currently reorganizing its R&D programs with the goal of operating a demonstration breeder reactor by approximately 2025. This effort is in response to the government sponsored "Nuclear Power Nation Plan" and the Bush Administration's Global Nuclear Energy Partnership. Breeder R&D programs face significant obstacles such as plutonium-stockpile management, spent fuel management, fuel cycle technologies, and arrangements for cost and risk sharing between government, industry and local governments. As a result, it is unlikely that fast breeder reactor (FBR) and fuel cycle development programs will move forward as planned.

Received April 2, 2009; accepted April 9, 2009.
The author acknowledges special thanks to Prof. Frank von Hippel, Prof. Harold Feiveson, Dr. Thomas Cochran and Dr. Tadahiro Katsuta for valuable comments and Ms. Michelle A. Marean for detailed editing.
Address correspondence to Tatsujiro Suzuki, Graduate School of Public Policy, The University of Tokyo 7-3-1, Hongo, Bunkyo, 113-0033. Tokyo. E-mail: tatsu@pp.u-tokyo.ac.jp

PROGRAM OVERVIEW: HISTORY AND STATUS

Origin and Outline of the Program

Japan's FBR program was conceived in the Japan Atomic Energy Commission's (JAEC) first Long Term Plan, published in 1956.[1] Among various reactor types under review, the JAEC selected the FBR and its closed fuel cycle[2] as the preferred technologies for R&D and endorsed the importation of LWR technology from the U.S.

The JAEC's 1967 Long Term Plan concluded that the FBR should be the mainstream of future nuclear power generation[3] and the government established the Power Reactor and Nuclear Fuel Development Corporation (PNC) as the primary R&D institution for FBR and nuclear fuel cycle development. The Plan envisioned that an experimental fast reactor would be developed during the 1970s, a prototype FBR Monju in the 1980s, and the first commercialized FBR by the late 1980s.

Japan's first FBR reactor was the experimental Joyo (Eternal Sun), built at the Japan Nuclear Cycle Development Institute's Oarai Engineering Center. Joyo achieved criticality in 1977 at an initial power level of 50 MWt. Power was increased to 75 MWt in 1979, and to 100 MWt with its Mark II core, which achieved criticality in 1982. From 1983 to 2000, Joyo operated as an irradiation test bed for fuels and materials for future Japanese fast reactors. Since 2003, Joyo has been operating at 140 MWt with its Mark III core, and in April 2007 it completed its 6th duty cycle. By 12 March 2007, Joyo had operated for 70,000 hours. In the 30 years between 1977 and 2007 Joyo operated approximately 40 percent fo the time.

The Prototype FBR Monju (280 MWe) was developed in parallel with Joyo, but construction was delayed and it did not achieve criticality until 1994. On 8 December 1995, Monju experienced a serious sodium leak and fire when intense vibrations caused the failure of a thermo-couple attached to the secondary sodium loop. The sodium reacted with oxygen, producing a fire that melted the steel structure in the room. No injuries were reported and no release occurred since the sodium in the secondary loop was not radioactive.

PNC's cover-up of the accident caused a social and political uproar that delayed the repair and restart of Monju. In June 2001, PNC submitted a relicense application for Monju, which was granted in December 2002. Legal challenges against PNC surrounding the relicensing and restart caused further delays and on 27 January 2003, the Kanazawa branch of Nagoya's High Court reversed its 1983 approval to build the reactor. Just over two years later, on 30 May 2005, Japan's Supreme Court ruled for PNC, thereby clearing all legal barriers for the restart of Monju. Restart was scheduled for October 2008 but, as of March 2009 the reactor is still off-line.

Japan Atomic Power Company (JAPCO) finalized plans for a 660MWe demonstration fast breeder reactor (DFBR) in 1994. The project experienced delays because of the Monju accident and was eventually canceled in the late 1990s.

R&D on reprocessing of spent fuel from fast reactor started in mid-1970s, and reprocessing of spent fuel from Joyo was conducted at the first experimental facility (Chemical Processing Facility:CPF) from 1982. Following the experiences gained at the CPF, PNC started construction of a recycle equipment test facility (RETF) in 1995, which is the first pilot-scale reprocessing facility for fast reactor spent fuel, the counterpart of the Tokai pilot reprocessing plant for LWR spent fuel. The Tokai plant adopted imported French technology but the RETF intends to employ Japanese technologies currently under development under the cooperative program with Oak Ridge National Laboratory (ORNL) of the U.S. The first phase of construction was completed in 2000, but its scheduled completion date is currently unknown.

Declining Budgets and Slipping Targets

While Japan's public commitment to the FBR and closed fuel cycle has not wavered, the FBR R&D budget has been steadily declining. The FBR program share of total nuclear R&D peaked at 35 percent in early 1970s during the construction of Joyo. In 1989 it fell to 20% (¥77 billion) during peak construction at Monju. Since 1989, both the FBR budget and its share of Japan's total nuclear R&D budget has steadily declined and by 2005 it had had fallen to 5% (¥27 billion) of the total budget. Cumulative spending on FBR R&D from 1956 to 2007 was ¥1,480 billion representing approximately 12% of total spending. Figure 1 shows the budget trends for all nuclear energy and FBR related R&D.

According to the JAEC's Long Term Plan, the target date for FBR commercialization is also slipping. In 1956, the Long Term Plan anticipated commercialization in the 1970s. In 1967, the year that the PNC was established, the FBR commercialization was pushed back to the 1980s and the PNC decided that an Advanced Thermal Reactor (ATR) was required as an interim reactor between the LWR and FBR. In 1987, the JAEC confirmed that LWRs would remain the main power generation source for the foreseeable future, and the commercialization target for FBR was pushed back again to the 2020–2030s. The most recent JAEC Framework for Nuclear Policy,[4] which supersedes the Long Term Plan, has revised the goal for FBR commercialization to approximately 2050, more than 70 years later than the original date set in 1956.

PRIORITY SHIFTS AFTER THE MONJU ACCIDENT

The Monju accident triggered a significant shift in Japan's FBR program. After the accident, the JAEC established an ad-hoc "Roundtable Committee on FBR" to develop new policies. Prof. J. Nishizawa of Tohoku University, who

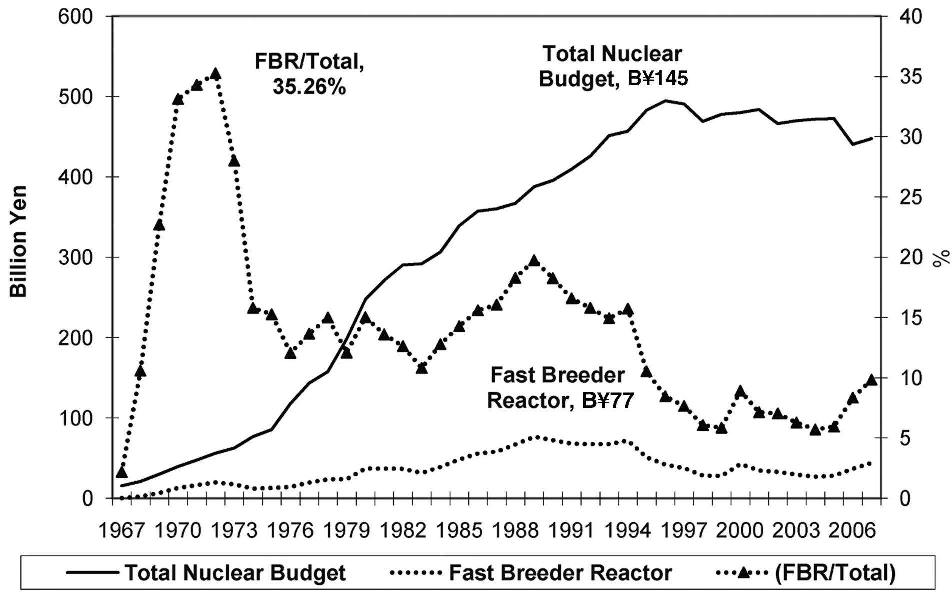

Figure 1: Japan's nuclear and FBR budget and its share trends from 1967–2006.

was not an FBR expert, chaired the committee. The Committee also included experts from outside the nuclear community including Mr. Yukio Okamoto (ex-Ministry of Foreign Affairs official), Prof. Sawako Takeuchi, an economist, and Prof. Hitoshi Yoshioka of Kyushu University, a nuclear critic. Although the Committee confirmed the continuation of FBR development, it recommended a more realistic and flexible approach toward FBR development, declaring that the FBR should be considered as a promising option (rather than the ultimate goal) and suggested "periodic review of R&D programs from the standpoint of technological and economic feasibility."[5] It also endorsed a more diversified R&D program to explore technical alternatives to existing FBR technologies.

Table 1: History of the commercialization schedule for breeder reactors in Japan.

Plan Year	Anticipated Completion	Comments
1956	1970	As a main power source of power
1967	1980	An advanced thermal reactor is required as an interim solution
1987	~ 2020 – 2030	LWR is selected as the main source of power for the foreseeable future
2000	~ 2030or later	Breeder reactors may be one of the future options
2006	2050 or later	

Following this report, the JAEC's Long Term Plan, published in 2000, established a goal "to maintain the technological option of FBR and its associated fuel cycle . . . in order to prepare for future energy problems," and recommended programs to explore "various alternatives to currently developed sodium-type FBR and PUREX (wet) reprocessing technology."[6]

STATUS

The 2005 Long Term Plan was renamed the Framework for Nuclear Energy Policy[7] and established a new FBR commercialization target of 2050. In 2006, the Sub-committee on Nuclear Energy Policy of the Government's Advisory Council on Energy published the Nuclear Power Nation Plan,[8] which laid out detailed policy measures based on the JAEC's Framework (Table 1). The Nuclear Power Nation Plan reiterates the 2050 commercialization target for the FBR and announced a goal of developing a post-Monju demonstration FBR by 2025. The associated Phase II "Feasibility Study on Commercialization of Fast Reactor Cycle Systems" (FaCT) compared various types of fast reactor designs and associated fuel cycle technologies, and tentatively identified a sodium-cooled fast reactor with advanced wet reprocessing technology as the preferred option.[9]

The study compared four basic fast-neutron reactor designs: sodium-cooled [1.5 GWe] with metallic fuel, helium-cooled [1.5 GWe] with nitride fuel, lead-bismuth-cooled [0.75 GWe] with nitride fuel, and water-cooled [1.356 GWe] with MOX fuel. Unit construction cost estimates for a sodium-cooled FBR would be the least ¥180,000/kWe compared with approximately ¥200,000/kWe for the other designs. Four basic options for advanced reprocessing and fuel technologies were evaluated: 1) Advanced wet reprocessing plus simplified pelletized MOX fuel; 2) Metal electro-refining reprocessing plus injection cast metallic fuel; 3) Advanced wet reprocessing plus vibration packing (Sphere-pack) MOX fuel; and 4) Oxide electro-refining reprocessing plus vibration packing (Vipac) MOX fuel. The most economical option for the advanced wet reprocessing plus simplified pelletized MOX fuel is a large (200t/year) plant (~¥0.5 ~0.66/kWh) with alternatives costing up to ¥1.6/kWh. These estimates represent development targets that are required in order for FBRs to be competitive with LWRs.

The Nuclear Power Nation Plan also set out important principles for future development of FBR and fuel cycle systems. First, it established a cost-sharing principle for the DFBR project to distribute costs between the utility companies and the government. It specified that the private sector would invest an amount equivalent to the cost of a commercial LWR, significantly reducing the financial risk for utilities.[10]

Another important principle of the Nuclear Power Nation Plan was that the second commercial reprocessing plant after the Rokkasho plant should be timed to the pace of FBR development and deployment. It suggested that planning for the second reprocessing plant start at around 2010.

In 2007, the government increased the FBR R&D budget for the first time since the late 1990s to ¥44 billion in response to these new programs and principles. In 2007, and it is now approximately 10% of the total nuclear budget. This budget increase was prompted partially by international developments, notably the announcement of the U.S. Global Nuclear Energy Partnership (GNEP). However, the Japanese R&D program does not have any specific budget item for GNEP.

THE SOCIO-POLITICAL FACTORS BEHIND JAPANS ENTRENCHMENT IN FBR TECHNOLOGY

Despite the marked slippage of FBR commercialization targets, why have Japanese commitments to the FBR remained, at least publicly, unchanged? There are three possible explanations.

Organizational Commitments

In 1967, special law established PNC with the mission to develop indigenous FBR and its associated fuel cycle technologies. This mission endured after the Monju accident in 1995 when PNC was renamed the Japan Nuclear Fuel Cycle Development Institute (JNC). JNC subsequently merged with the Japan Atomic Energy Research Institute (JAERI), a national research institution responsible for fundamental nuclear technology (including fusion) and nuclear safety research and in 2006 became the Japan Atomic Energy Agency (JAEA). JAEA was established with the continued mission of developing FBR and fuel cycle technologies. With this legal commitment to FBR cycle programs; it may not be easy for Japan to evolve its nuclear research agenda.

Local Politics

Local politics with respect to nuclear facilities is complex and influential. Government financial incentives, called kofu-kin, reward communities for accepting nuclear-related facilities and play a large role in local politics. Once a local community accepts a nuclear facility, it receives annual payments (in billions of yen) from the government. Kofu-kin and tax revenues from nuclear facilities are a major component of local budgets. Despite a strong resentment about the cover-up after the Monju accident, the local community has a significant incentive for restarting the plant.

Another factor driving FBR and fuel cycle policies is the difficulty of finding spent fuel storage sites. Because on-site storage pools are reaching their capacity, reprocessing is the only alternative. The rationale for reprocessing becomes more persuasive if it paves the way towards the commercialization of FBR.

Lack of Oversight

JAEC is the primary government entity authorized to review and make decisions on Japan's nuclear R&D programs. While JAEC may advise R&D institutions to revise their goals and schedules, it typically endorses their R&D plans.

In 2001, The Council for Science and Technology Policy (CSTP) was established by the Basic Law on Science and Technology within the reformed Prime Minister's Office and is chaired by the Prime Minister. Its primary function is to review R&D plans submitted by government agencies. It grades major R&D programs from S (most important) to A, B, C (least important). It is intended to strengthen the Prime Minister's ability to override agency R&D budgets driven by vested interests. The Monju project received a grade of "S" and the FaCT[11] program received an "A" and therefore there is no indication that CSTP will override development plans for the Monju project or the FaCT program.

FUTURE PROSPECTS AND MAJOR ISSUES

Although the Nuclear Power Nation Plan set a goal for completion of a DFBR by 2025 and commercialization by 2050, there are obstacles that may compromise these goals.

One obstacle is plutonium stockpile management. Japan has more than 46 tons of plutonium (8.7 tons in Japan, approximately 37 tons in Europe) of separated plutonium in stockpile, but its MOX recycling program has made little progress. When the Rokkasho reprocessing plant (800 ton HM/year) begins full operation, the stockpile is likely to increase. Since reducing the plutonium stockpile should be a top priority for Japan, "breeding" is not likely to be an important policy goal for Japan's nuclear power program.

A second obstacle relates to spent fuel management and its impacts on fuel-cycle technology. Japan has been reviewing various reprocessing and MOX fuel fabrication methods, including pyro-processing technology developed in the U.S. for fast reactor metallic fuel. Historically, spent fuel management, and not plutonium demand, has driven Japan's reprocessing requirements. If this focus is maintained, it is likely that Japan will build a second plant, using wet technology, to reprocess uranium oxide spent fuel. So far, Japan's R&D in reprocessing technologies has focused on the classic PUREX process. If Japan's pursues its MOX-recycling plans, spent MOX fuel will accumulate and Japan may want to reprocess this fuel. The technological choice for the second reprocessing plant is a complex policy issue.

A third obstacle is the matter of cost and risk sharing among stakeholders. Overall, it is not clear how much FBR fuel cycle programs will cost and who will bear those costs. The Nuclear Power Nation plan proposes a cost sharing arrangement for a DFBR, but future cost sharing arrangements are uncertain. Meanwhile, one of the goals set by the Ministry of Economy, Trade and Industry's next generation LWR program is to extend the life-times of the reactors to 60–80 years. If this goal is achieved, the need for the FBRs may not materialize even after 2050.

CONCLUSION

Japan remains officially committed to the FBR and closed fuel cycle systems. However, the FBR commercialization date has receded far into the future while the FBR R&D budget has been steadily shrinking. Japan's continued commitment to the FBR appears largely driven by socio-political factors affecting Japan's management of the back-end of the LWR fuel cycle and R&D management. The new Nuclear Power Nation Plan restated Japan's interests in FBR and advanced fuel cycle programs due in part to international developments, especially the U.S. GNEP initiative, which will likely lose support in the Obama Administration.

NOTES AND REFERENCES

1. Japan Atomic Energy Commission (JAEC), "Long Term Plan for Research, Development and Utilization of Nuclear Energy," 1956. (in Japanese).

2. In a "closed" fuel cycle a chain-reacting material, such as plutonium, is separated out of spent fuel and recycled.

3. Japan Atomic Energy Commission (JAEC), "Long Term Plan for Research, Development and Utilization of Nuclear Energy," 1967. (in Japanese).

4. Japan Atomic Energy Commission (JAEC), "Framework for Nuclear Energy Policy." October 11, 2006.

5. Report by the JAEC Roundtable Committee on Fast Breeder Reactor, "Basic Policy towards Development of FBR," December 1, 1997.

6. JAEC, "Long Term Plan for Research, Development, and Utilization of Nuclear Energy," 2000.

7. JAEC, "Framework for Nuclear Energy Policy," October 11, 2006. http://www.aec.go.jp/jicst/NC/tyoki/taikou/kettei/eng_ver.pdf.

8. Ministry of Economy, Trade and Industry, Advisory Committee on Energy, Committee on Electricity Industry, Sub-committee on Nuclear Energy Policy, "Nuclear Power Nation Plan," August 2006. http://www.meti.go.jp/report/downloadfiles/g60823a01j.pdf (in Japanese).

9. "Wet" reprocessing refers to variants of the nitric-acid-based PUREX process originally developed by the United States to recover plutonium for its nuclear-weapon program. Pyroprocessing would be an example of a "dry," i.e., waterless process in which

spent fuel is dissolved in molten salt, the heavy-metal oxides reduced to metals by reacting them with lithium and then the precipitated heavy metals electrorefined to separate the transuranics from the uranium.

10. This reflects the experience of Monju. Monju's construction cost increased from original ¥400 billion to ¥590 billion, the utilities' share was originally set to be about 15% of total cost (i.e., ¥60 billion). Utilities finally agreed to pay ¥109 billion, which was equivalent to the LWR construction cost (per kW). See Eugene Skolnikoff et al., "International Responses to Japan's Plutonium Programs," MIT Working Paper, 1995, p. 4.

11. The FaCT program was conducted from 1997 to 2006, exploring various types of fast reactor and fuel cycle technologies in order to select commercially viable fast reactor technologies. http://www.jaea.go.jp/04/fbr/top.html.