Status of Nuclear Fuel Cycle Technology Development

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OVERVIEW: The Japan Framework for Nuclear Energy Policy has now committed the country to reprocess all spent fuel used by LWRs and temporarily stockpile spent fuel exceeding the country's reprocessing capacity (Rokkasho Reprocessing Plant with a reprocessing capacity of 800 t a year) in interim storage. It is also projected that Japan's Pu-thermal (plutonium in thermal reactors) plan will proceed thus enabling the use of MOX fuel using plutonium recovered at Rokkasho Reprocessing Plant in commercial LWRs. Meanwhile, remodeling work on the prototype FBR "Monju" has resumed, and the reactor is expected to achieve criticality in the near future. Investigations will start on the best reprocessing policy in 2010 for spent fuels held in interim storage, assuming, as expected, that a viable FBR design is completed around 2015 and plants are built and put into commercial operation about 2050. As steady progress continues on the reprocessing of spent fuel from LWRs, interim storage solutions, and development of a viable FBR, investigation must focus on the optimum nuclear fuel cycle supporting the transition from LWRs to FBRs after 2050. Hitachi is closely involved in work on the Rokkasho Reprocessing Plant, "Monju," interim storage, and other key aspects of the nuclear fuel cycle, and is also working on longer term fuel cycle and waste disposal issues to support the transition to FBRs.

INTRODUCTION

FOR Japan, a relatively resource-poor nation, a viable nuclear fuel cycle is critically important to ensure a long-term stable supply of energy, and the use of at least partly domestically produced plutonium from FBRs (fast-breeder reactors) is particularly important to the nuclear fuel cycle. Uniquely, Japan is the only non-nuclear power permitted by the international community to reprocess spent nuclear fuel. In light of global warming, increasing cost of fossil fuels (a

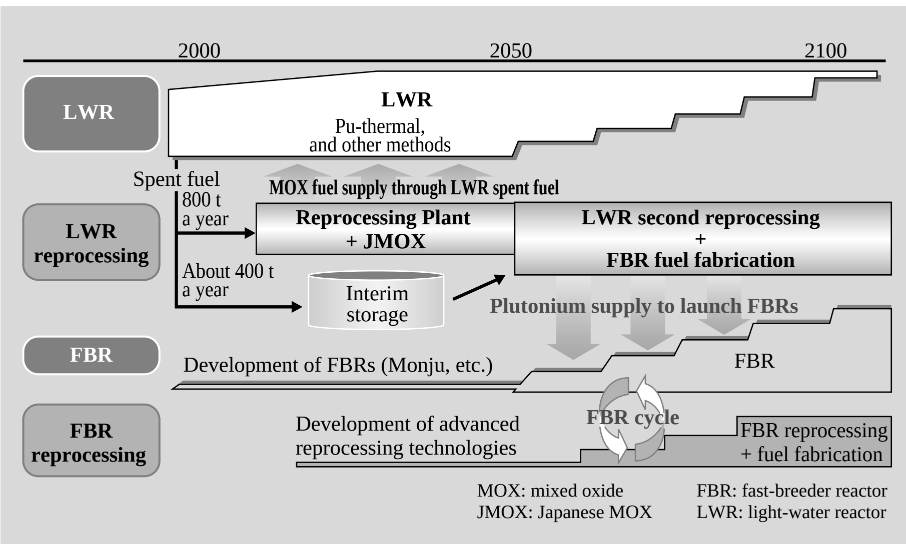

Fig. 1—Nuclear Fuel Cycle over Next Century.
Plutonium recovered by the Rokkasho Reprocessing Plant will be used in the country's LWRs. Plutonium recovered from the second reprocessing plant for LWRs will be used as fuel for the initial deployment of FBRs, and plutonium recovered from FBR reprocessing will be recycled in FBRs.

depletion theory), limited uranium resources, growing stocks of spent fuel, and other thorny problems, the completion of the LWR (light water reactor) fuel cycle at the Rokkasho Reprocessing Plant and the smooth transition to the future FBR cycle are extremely important. Processing and disposal of radioactive waste materials is a challenge that must be solved if we are to move ahead with nuclear power, and particularly the safe management of high-level nuclear wastes recovered through the reprocessing of useful uranium and plutonium is essential. This paper reviews the status of Hitachi's initiatives relating to the Rokkasho Reprocessing Plant, prototype FBR "Monju," processing and disposal of radioactive wastes, and the nuclear fuel cycle during the transition to FBRs.

NUCLEAR FUEL CYCLE

Fig. 2 shows a schematic of the nuclear fuel cycle. In the current LWR fuel cycle, most of the spent fuel produced by the power companies is stored in onsite pools, while some spent fuel is transported for storage in pools at Rokkashomura in Aomori Prefecture. To help address problems associated with the storage and management of spent fuels from nuclear power plants, the Recyclable-Fuel Storage Company was recently established in Mutsu City in Aomori Prefecture on November 21, 2005.

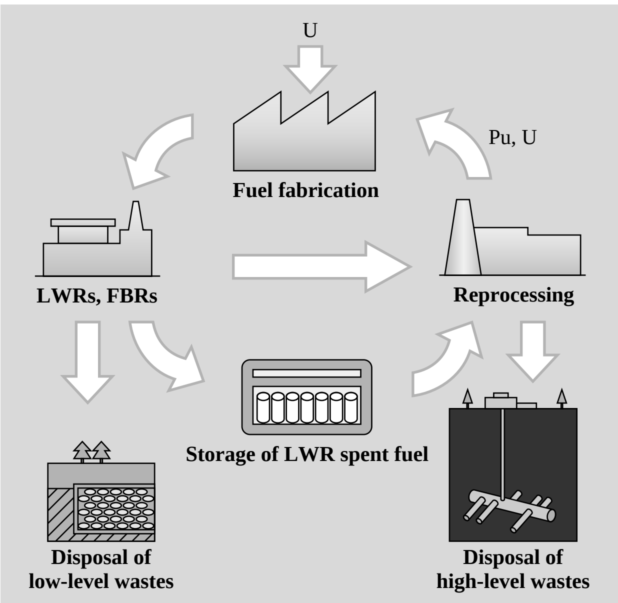

Fig. 2—Fuel Cycle Overview.
After uranium is used in an LWR, plutonium and uranium are recovered through reprocessing. MOX fuel (mixed oxide, a blend of plutonium and uranium) will be used provisionally in LWRs and in future FBRs.

As of July 2006, the Tokai Reprocessing Plant operated by the Japan Atomic Energy Agency (JAEA) had processed 1,123 t of spent fuel, and some of the recovered uranium is being used in LWRs[(1)]. The nuclear fuel cycle of LWR uranium is already fairly well established, and attention is now focused on a commercial fuel cycle for uranium and plutonium at the Rokkasho Reprocessing Plant and after that a fuel cycle for FBRs.

On April 20, 2005 Japan Nuclear Fuel Limited (JNFL) applied to the Ministry of Economy, Trade and Industry (METI) to begin producing MOX (mixed oxide) fuel (a blend of plutonium and uranium), and JAEA started remodeling work on "Monju" on September 1, 2005. As of July 2006, some 186,000 drums of low-level waste have been buried at the underground disposal site at Rokkashomura. Disposal of high-level wastes is more challenging, and active research continues to explore the best solutions while at the same time considering possible candidate sites for disposal of high-level wastes.

NUCLEAR FUEL CYCLE: HITACHI INITIATIVES

Rokkasho Reprocessing Plant

JNFL is now conducting the final commissioning test (so-called "active test") in anticipation of the opening of Japan's first commercial LWR reprocessing plant now under construction and scheduled for completion in August 2007 with a design reprocessing capacity of 800 t of uranium a year. The test began on March 31, 2006, the first step "active test" items for each building at the plant were completed on June 26, 2006, and the second step "active test" began on August 12, 2006.

As the primary construction contractor, Hitachi is charged with building several key structures at the site including the separation facility and the low-level waste processing facility. Hitachi is also in charge of designing, fabricating, building and test operating the shearing and dissolver off-gas treatment facility, the high-level waste processing facility, the acid recovery facility, the low-level waste processing facility, and other key systems.

All the materials and systems were subjected to a series of tests conducted in phases leading up to the actual operating state to ensure that the equipment performs up to rated capacity and operates safely and stably: we began with "water test" in Spring of 2001 using water, steam, and air, and this was followed by "chemical test" beginning in Fall 2002 where again the functions and capabilities of systems were evaluated using various non-radioactive chemical agents. In assessing decontamination factors of the low-level waste evaporator using lithium nitrate, we had excellent results that were well above rated requirements.

"Uranium test"—tantamount to in-service operation using deplated uranium—began in December 2004. Hitachi's radioactive waste management system was evaluated in the comprehensive building tests as part of the uranium testing, and the final comprehensive verification tests were completed on January 22, 2006. The uranium tests continued with the series of "active test," a comprehensive series of tests using spent fuel.

"Monju"

The prototype FBR "Monju" operated by JAEA has been shut down since a sodium leak accident occurred in the plant's secondary cooling system in December 1995 during partial output trials. Following the accident, efforts have been made to get the project back on track through comprehensive safety evaluations of the plant's safety features and sodium leak prevention measures, obtaining approval to renovate the reactor, and obtain local approval through talks with the Fukui Prefecture Monju Safety Investigation Examination Ad-hoc Committee. As a result of these efforts, a remodeling plan that addresses the sodium leak and other issues was drafted in February 2005, the green light to resume work on "Monju" was received from local authorities (Fukui Prefecture and Tsuruga City), and the actual remodeling work got underway in September 2005. Once the refurbishment work is done in about 17 months, the plant will again have to pass through another year of rigorous structural and plant verification trials, and is expected to resume operation (achieve criticality) in the near future.

The remodeling work will encompass:

(1) Replacement of the thermometers in the secondary cooling system (removal of the old thermometers)

(2) Measures to ensure there is no possibility of sodium leaks, and

(3) Work to improve the blow-down performance of one of the evaporators

Hitachi's role relates to the second area, and the company has been specifically charged with electrifying the drain valve in the primary system, installing insulation in the walls and ceiling of secondary system vessels, and implementing a comprehensive leak monitoring and detection system.

(a) (b)

Fig. 3—Transportable Dry Metal Storage Casks: 1/3 Size Model Drop Test (a), and Actual-size Cask (b).
Actual-size dry metal casks have been fabricated using design methods established through rigorous testing of all components and model drop tests, and we continue to perfect the actual manufacturing process.

Interim Storage of Spent Fuel

Hitachi has developed a dual-purpose dry metal cask for transport and interim storage designed to maximize the number of used fuel assemblies that can be contained. The casks have a simple-to-fabricate structure and are made of materials that will not deteriorate over long periods of time to ensure cost-effectiveness and long-term reliability. One-third scale drop tests were done to verify the integrity of the materials and make an overall assessment of the design, and full-scale dry casks were fabricated to further refine the design of the final casks for actual use (see Fig. 3).

Disposal of Radioactive Wastes

Hitachi has developed a number of technologies for dealing with radioactive waste materials from nuclear power and reprocessing plants including a method of solidifying wastes so they can be safely buried in underground storage vaults, and processing procedures that significantly reduce nuclide emissions to lessen adverse environmental impact. Solidification significantly increases the packing density of wastes in liquid or powder form, and Hitachi's in-drum solidification method is in full compliance with radioactive waste underground disposal standards in terms of solid strength and rate of porosity. And for dealing with solid radioactive wastes, we developed a continuous mixing system that features a far simpler configuration than the conventional batch cement mortar mixing method.

Another recent development to alleviate environmental impact is a system that uses ozone to decompose organic material in laundry and shower wastewater, while filtering out radioactive cladding. Ozone decomposition is commonly used for removing relatively low concentrations of organic material such as toxins or odors from sewage or wastewater. However, instead of the conventional aeration method, our system continuously injects ozone along a tank circulation line and is thus able to decompose very high concentrations of organic matter in laundry and other kinds of wastewater. The system uses ozone gas to decompose detergent components, human waste, and other organic matter found in wastewater into carbon dioxide. This is a major new development, for by using a simple filter to process radioactive solids, it reduces the volume of secondary wastes to less than 1/20th the volume that is captured using the conventional activated carbon method.

NUCLEAR FUEL CYCLE RELATED TECHNOLOGIES

Fuel Cycle during Transition Period

During the transition from LWRs to FBRs, it is crucial to provide FBRs with just the right amount of plutonium to meet demand—not producing too little or too much—while flexibly accommodating a range of uncertain factors. According to the FBR deployment scenario envisioned by the Framework for Nuclear Energy Policy, existing LWRs will be shut down and successively replaced by FBRs beginning around 2050. Considering the rate with which FBRs come on line, during the initial phase and latter half of the transition period, about 2 Gigawatts (GWe) a year will be available, but during the middle phase of the transition only about 0.5 GWe a year will be available. This calls for a scheme enabling the demand/supply balance of plutonium to be flexibly controlled during the transition period.

To address this situation, Hitachi came up with the FFCI (flexible fuel cycle initiative) that assumes a fuel cycle with an interim buffer of recycle material (see Fig. 4). Essentially the FFCI provides that the bulk of uranium (about 90%) is separated and removed from LWR spent fuel. As FBRs start to come on line, the remaining recycle material is diverted to the FBR fuel cycle as is. The plutonium is recovered from the recycle material and delivered to FBRs as fuel. This gives us a greater degree of flexibility so, if the projected deployment of FBRs slows down or is delayed for some reason, we can store the recycle material temporarily, and have it available when the pace of FBR deployment resumes.

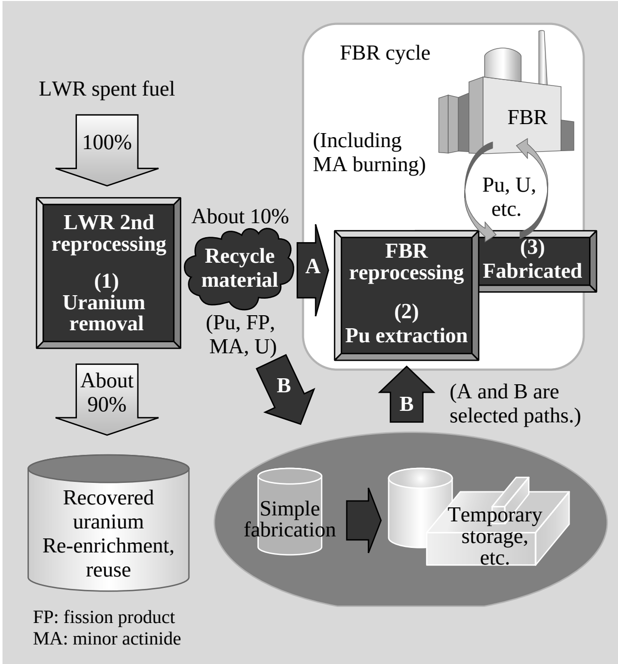

Fig. 4—FFCI during Transition Period.
After separating the bulk of uranium from LWR spent fuel and recovering plutonium from remaining recycle material, the products are supplied to FBRs. If development and deployment of FBRs is delayed, the recycle materials will be held in temporary storage.

Although the FFCI calls for construction of LWR reprocessing facilities a few years earlier during the transition period than the conventional fuel cycle approach, the capacity and capabilities of those facilities can be downscaled by about half. Another significant advantage of the FFCI concept is that the amount of LWR spent fuel that needs to be stored would also be reduced by about half(2). The technical challenges of the FFCI are simple treatment of the recycle material and temporary storage, and efforts are now underway to develop optimum solution to meet these challenges.

Radioactive Waste Disposal

Commercialization of disposal of low-level radioactive waste from nuclear power plants by burial at underground sites was completed in 1992. To address the problem of disposing of high-level radioactive waste, the Nuclear Waste Management Organization of Japan (NUMO) was established in October 2000 and charged with finding an acceptable site so that final disposal can begin in the latter 2030s. Regarding TRU (transuranium) wastes—radioactive waste that includes elements that are beyond uranium on the periodic table—the issue was addressed in the Second TRU Report[3], where the technical feasibility and prospects for safe disposal of TRU elements was discussed.

Hitachi has been closely involved in seeking technical solutions for disposing of TRU wastes. In collaboration with the Taiheiyo Consultant Co., Ltd., Hitachi was commissioned by METI in 1999 to investigate geologic disposal options, and commissioned by the Radioactive Waste Management Funding and Research Center to develop and evaluate the confinement performance of a TRU waste package made of high-strength ultralow-permeability concrete[4]. This technology was described in the Second TRU Report as an alternate technology. Addressing the issue of high-level radioactive waste disposal, Hitachi received funding through METI's Innovative and Viable Nuclear Energy Technology Development Project in 2004 to build a micro-chemical probe for geological environment diagnosis that would be inserted down a deep bore hole to assess retardation of nuclide migration and other geochemical characteristics in situ[5].

CONCLUSIONS

This paper highlighted recent developments in nuclear fuel cycle technology. Steady progress continues to be made regarding the nuclear fuel cycle that will provide Japan with energy self-sufficiency and help roll back global warming without relying on foreign resources. While nuclear power cannot supply all of Japan's energy needs, there is a general consensus that it will remain a basic source of energy for the country well into the future. It goes without saying that safety, security, and quality are the priority concerns, and Hitachi is very much committed to further development and deployment of extremely reliable equipment and systems relating to the nuclear fuel cycle.

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