Nuclear Fuel Cycle Technologies for Long-term Stable Energy Supply

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OVERVIEW: Although the safe operation of nuclear power generation is the most important consideration in using nuclear power as a reliable long-term source of electrical energy, uranium, like oil, is a finite resource and so fuel recycling is also essential. Naturally occurring uranium passes through mining, conversion, enrichment, and fuel fabrication stages before it is used in nuclear reactions in existing LWRs to produce electrical energy. The intention for the spent fuel produced by this process is to place it partially in interim storage and to process it at the Rokkasho Reprocessing Plant. The plutonium recovered by fuel reprocessing is currently recycled in LWRs and in the future will be recycled in FBRs. Because an FBR can produce more plutonium than the uranium it consumes, it can act as a reliable source of energy for a thousand years or more. In addition to LWRs, Hitachi is also actively involved in the interim storage, fuel reprocessing, FBR, and radioactive waste management businesses as well as the development of associated technology.

INTRODUCTION

THE G8 Hokkaido Toyako Summit Leaders Declaration issued at the G8 summit held in Toyako in Hokkaido stated that: " We witness that a growing number of countries have expressed their interests in nuclear power programs as a means to addressing climate change and energy security concerns. These countries regard nuclear power as an essential

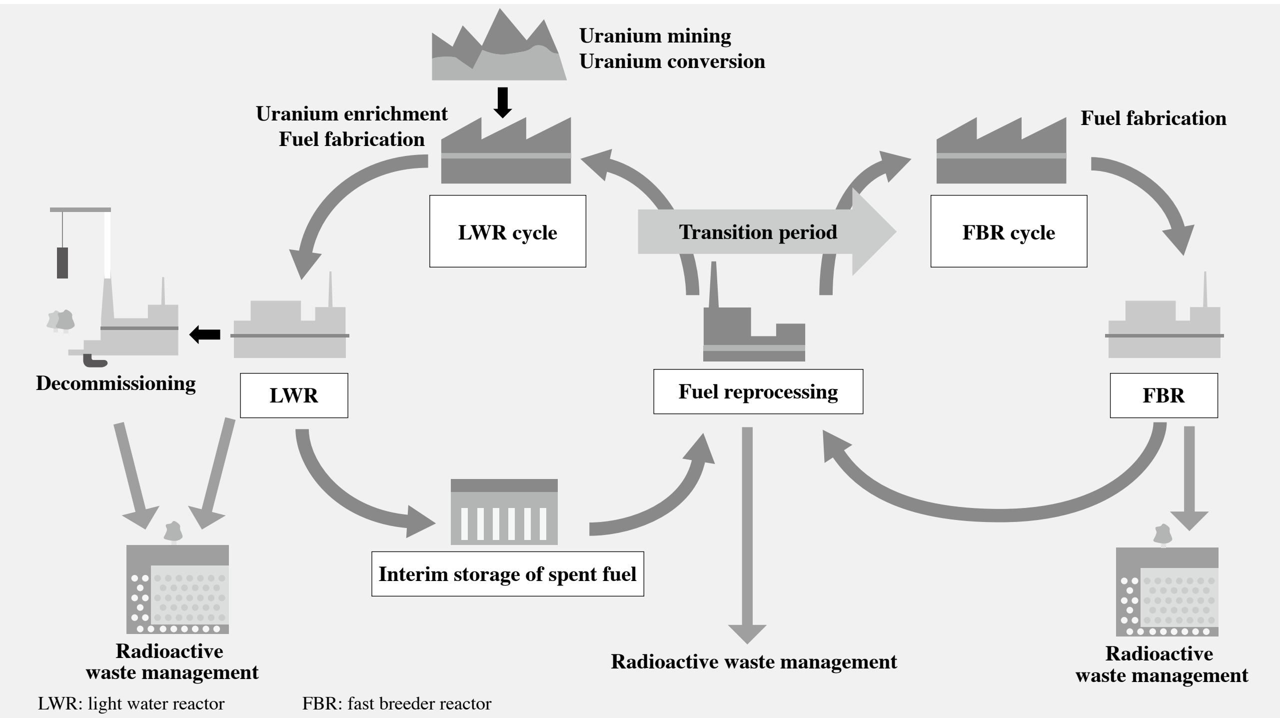

Fig. 1—Nuclear Fuel Cycle.
The plutonium recovered by fuel reprocessing is currently recycled in LWRs and in the future will be recycled in FBRs. The transition from an LWR cycle to an FBR cycle will ensure long-term security of supply for nuclear energy.

instrument in reducing dependence on fossil fuels and hence greenhouse gas emissions. We reiterate that safeguards (nuclear nonproliferation), nuclear safety and nuclear security (3S) are fundamental principles for the peaceful use of nuclear energy."

Like oil, uranium is a finite resource and the fuel cycle is an essential element in ensuring peaceful and sustainable use of nuclear energy.

This report describes the direction being taken in Japan regarding the fuel cycle, Hitachi's involvement in the nuclear fuel cycle, and the current state of technology development (see Fig. 1).

FUEL CYCLE TRENDS IN JAPAN

In addition to LWRs (light water reactors), Hitachi is also actively involved in the interim storage of spent fuel, reprocessing of spent fuel, FBR (fast breeder reactor), and radioactive waste management businesses as well as in research and development.

Spent fuel from LWRs is stored in a pool at the power station and some is transferred to the storage pool at Japan Nuclear Fuel Ltd.' s reprocessing plant at Rokkasho Village in the Kamikita District of Aomori Prefecture (referred to below as the Rokkasho Reprocessing Plant). An off-site interim storage facility is also to be constructed in Mutsu City in Aomori Prefecture.

A total of 1,140 t of spent fuel from LWRs had been reprocessed at the Tokai Reprocessing Plant operated by the Japan Atomic Energy Agency as of November 2008, and construction of the Rokkasho Reprocessing Plant with a maximum annual capacity of 800 t of uranium is approaching final completion. Investigation and development work is underway on reprocessing technologies for the transition period from LWR to FBR operation and for the equilibrium period of FBR.

The FBRs operated by the Japan Atomic Energy Agency are the "Joyo" test reactor and the "Monju" prototype reactor, with the "Monju" facility due to be restarted in the near future. Research and development of commercial-scale reactors is also underway and a demonstration reactor, which it is hoped will commence operation in 2025, is being designed with commercial reactors in mind.

A number of different technologies for radioactive waste management are already in use or are under development. Disposal of low-level radioactive waste is already in commercial operation at Rokkasho and a search is currently underway for candidate sites for high-level radioactive waste disposal.

INTERIM STORAGE OF SPENT FUEL

The Recyclable-Fuel Storage Center of the Recyclable-Fuel Storage Company that is planned for construction in Mutsu City in Aomori Prefecture applied for establishment permit in March 2007. Hitachi plans to supply metal casks used for both transportation and storage which the group designed itself and which are produced under an integrated quality management and assurance program. Hitachi is also testing the practicality of transport equipment to be used at the center (see Fig. 2)[1]. Other ways in which Hitachi is involved in supporting Japan's first interim storage project include support for safety deliberation at the center.

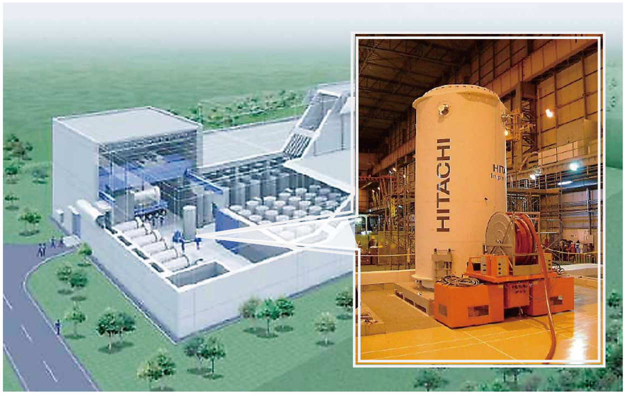

Fig. 2—Recyclable-Fuel Storage Center and Photograph of Actual-size Cask and Transportation System.
The image on the left shows the Recyclable-Fuel Storage Center planned for construction in Mutsu City in Aomori Prefecture (source: Recyclable-Fuel Storage Company web site), and the photograph on the right shows a cask and transportation system produced by Hitachi as a full-scale prototype.

FUEL REPROCESSING

Rokkasho Reprocessing Plant

One of Hitachi's roles at the Rokkasho Reprocessing Plant is as the construction coordination company responsible for managing construction of the separation building and low-level liquid waste treatment building in the main facility, and the other role is as lead contractor for the design, manufacture, installation, and commissioning of various equipment including a shearing and dissolver off-gas treatment facility, high-level liquid waste processing facility, acid recovery facility, and low-level liquid waste processing facility (see Fig. 3).

To ensure that the equipment can perform its required functions and operate safely and reliably, it has been tested in a series of trials using different materials whereby each trial gets progressively closer to the actual operating conditions. These trials tested the functions, performance, and other characteristics of each item of equipment and consisted of the "water operation tests" run from April 2001 which used water, steam, and air, the "chemical tests" run from November 2002 which used chemicals that did not include any radioactive materials, the "uranium tests" run from December 2004 which used uranium, and the "active tests" run from March 2006 which used spent nuclear fuel. The active tests for the main facilities are almost complete and have confirmed that the equipment for which Hitachi is responsible can also deliver the required performance.

Fig. 3—Rokkasho Reprocessing Plant.
A view of the Rokkasho Reprocessing Plant (source: Japan Nuclear Fuel Ltd. web site). The facility has a maximum annual capacity of 800 t of uranium and incorporates technologies from France, the UK, Germany, and Japan.

Development of the Next-generation Reprocessing Technology

Hitachi has been developing the FLUOREX (fluoride volatility and solvent extraction) method, a reprocessing technology which combines the fluoride volatility process and solvent extraction process[(2)]. The technology is intended for use during the transition period from LWR to FBR. Fig. 4 gives an overview of the FLUOREX process. The FLUOREX reprocessing system uses a fluorination process to separate out the majority of the uranium in spent fuel from LWRs (which is approximately 96% uranium) prior to the solvent extraction process. This reduces the size of the solvent extraction equipment and also reuses the recovered uranium.

The volatile UF_6 (uranium hexafluoride) goes to gaseous phase in the fluorination process and is recovered as high-purity UF_6 by separating impurity elements in the purification process with adsorbing materials. Because most elements other than uranium are non-volatile, they remain in the fluorination residue in solid form. This residue is passed through an oxide conversion process (fluorine recovery), dissolved, and then the solvent extraction process used to separate and recover the uranium and plutonium mixture from the other elements with a high level of purity.

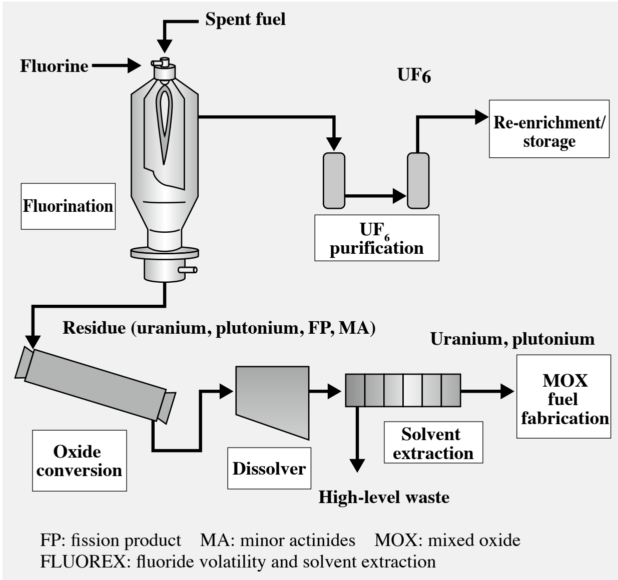

Fig. 4—Process Flow of the FLUOREX Reprocessing Method.
Most of the uranium contained in spent nuclear fuel from LWRs is separated and recovered as a high-purity UF_6. Also a solvent extraction process is used to recover high-purity uranium and plutonium mixture from the fluoride residue.

The research and development of the FLUOREX method was funded by the Ministry of Economy, Trade and Industry and the Ministry of Education, Culture, Sports, Science and Technology, and undertaken in cooperation with institutions in Japan and overseas.

Development of Flexible Fuel Cycle System

Hitachi is also involved in the research and development of the FFCI (flexible fuel cycle initiative) fuel cycle system concept for the transition period [(3)].

In the transition period from LWRs to FBRs, reprocessing facilities must process spent fuel from both LWRs and FBRs and supply fuel to both types of reactor. In particular, because the initial load of plutonium required when commissioning FBRs is recovered from LWR spent fuel, flexibility in the fuel cycle, including the reactor and fuel fabrication steps, is very important. FFCI first extracts the bulk of the uranium from LWR spent fuel and then the remaining material is inserted directly into the FBR cycle, if the introduction of FBRs is on schedule. If the FBRs are delayed, the material is placed in temporary storage until introduction of the FBRs gets underway.

In the FFCI, LWR reprocessing only extracts the uranium. Plutonium and uranium recovery and FBR fuel fabrication are performed as part of FBR reprocessing. This reduces the size of the LWR reprocessing facilities and effectively eliminates the LWR spent fuel. FFCI is also under development as government-funded research.

FBR

"Monju"

The Japan Atomic Energy Agency's "Monju" prototype FBR reactor has been shutdown since an accident in December 1995 involving a sodium leak in the secondary cooling system during a test operation at partial output. Since this accident, the plant has been through a comprehensive safety inspection, safety investigations covering a range of areas including countermeasures to sodium leaks, permitting (approval for changes to the design and construction), and the "Special Committee to Investigate and Survey the Safety of Monju" held by Fukui Prefecture. Having obtained the agreement of the local population, work on upgrading the facility started in September 2005 and was completed in May 2007. Tests to confirm the appropriateness of this work were completed in August 2007 and tests to confirm that the equipment has been maintained in the same sound condition it had prior to the sodium leak accident are ongoing with the hope of reaching criticality in the near future.

In summary, the upgrade work consisted of: (1) replacement and removal of temperature sensors used in the secondary cooling system, (2) improvements relating to the sodium leak, and (3) improvements to blowdown performance of the evaporator (one of the steam generation systems). Hitachi's role was part of the sodium leak improvements (2) and included conversion of primary drain valves to electrical operation, the installation of insulation in the secondary chamber walls and ceiling, and the installation of a comprehensive leak monitoring system. During the subsequent confirmation tests, work done by Hitachi included preparing test designs and evaluating the results, especially for the primary cooling system which Hitachi had supplied.

Development of Technology for Demonstration Reactor and Commercial Reactor

Hitachi's involvement has covered design and research of demonstration reactor and investigation of commercial reactor concepts, along with the development of specific technologies for the reactor core and safety, structure and ability to withstand earthquakes, heat flow, materials, equipment, sensors and control, and so on. Based on these experiences together with Hitachi's experiences in the development, manufacture, installation, and maintenance of actual systems, mainly relating to the primary cooling system at "Monju," Hitachi has an active role in the establishment of system concepts and the development of equipment, heat flow, and material and structural technologies with the aim of commencing operation of a demonstration reactor in 2025 and a commercial reactor in 2050.

RADIOACTIVE WASTE MANAGEMENT

Radioactive Waste Processing

Hitachi has developed technologies for processing the radioactive waste from nuclear power stations, reprocessing plants, and similar facilities that include solidification to allow the waste to be safely buried and waste inspection technologies for ensuring its safety. These technologies are currently in use.

Hitachi has developed a solidification technology called "in-drum solidification technology" that increases the amount of radioactive waste in liquid or powder form that can be contained, and produces solid material with strength, porosity and other characteristics that comply with the standards for land-based disposal. This technology is expected to enter practical use in the near future. Hitachi has also developed a "continuous mixing facility" for the solid radioactive waste which uses simpler equipment than the batch-based mortar mixing method used in the past. This equipment is already installed in three plants and is currently under construction at another.

The waste inspection technology developed and commercialized by Hitachi is a non-destructive evaluation method used on radioactive waste that has been stabilized in a drum. The technique uses the "spectral correction method" to measure the type and volume of radioactive material contained in the drum. The equipment has already been installed at four plants.

To ensure that radioactive waste processing equipment that has been in use for several decades can last for a long time, work is also in progress on replacing equipment that has deteriorated with age and out-of-production parts.

Radioactive Waste Disposal

As a step towards the development of technology for the disposal of TRU (trans-uranium) waste, Hitachi has been working with Taiheiyo Consultant Co., Ltd. since 1999 on research commissioned by the Radioactive Waste Management Funding and Research Center as part of the “Investigation into Geological Disposal Technologies” program sponsored by the Ministry of Economy, Trade and Industry. Part of this has been the development of non-destructive inspection techniques for the quality management of containers for disposing of TRU waste made of high-strength/high-density concrete. This inspection technique aims to prevent groundwater entering through cracks, voids, or other defects in the containers and coming into contact with the waste by detecting defects that have the potential to become preferential groundwater seepage paths.

In the field of geological disposal of high-level radioactive waste, Hitachi also received assistance between 2004 and 2007 from the Ministry of Economy, Trade and Industry’s Innovative and Viable Nuclear Energy Technology Development Project to work with relevant institutions and universities on the development of technology for geological micro-chemical probes able to perform in-situ measurement of bedrock water quality and material migration characteristics in a borehole. Tests at a deep bore hole belonging to the Japan Atomic Energy Agency were carried out in January 2008 during which the world’s first successful simultaneous in-situ measurements of bedrock diffusion coefficient and distribution coefficient were made at a depth of approximately 112 m[4].

CONCLUSIONS

This report has described the direction being taken in Japan regarding the nuclear fuel cycle and the status of Hitachi’s related businesses and technological developments.

Internationally, nuclear power is undergoing a renaissance as evidenced by the renewed nuclear power and fuel cycle activity in the USA after a 30 year hiatus. Expectations are high that nuclear energy can provide a primary energy source that helps minimize global warming and not affected by the climate conditions. Particularly for countries such as Japan with a low level of energy self-reliance, the nuclear fuel cycle is very significant because it reduces dependence on resources obtained from overseas.

In the future, Hitachi will continue to work on technology development and the manufacture of highly reliable equipment with safety and security as its top priorities.

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