A Preliminary Assessment of the Adoption of Innovative Technologies in the Fast Reactor Cycle Technology Development (FaCT) Project in Japan

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Abstract

JAEA has been implementing the FaCT project in cooperation with electric utilities toward the commercialization of fast reactor cycle system before 2050. In this FaCT project, many innovative technologies with technical challenges are actively used in order to provide significant improvements in economic competitiveness, enhancement of safety & reliability, sustainability, and nonproliferation. The work of deciding on the adoption of innovative technologies by the end of JFY2010 is in progress. This paper describes current preliminary assessment results.

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1. Introduction

A fast reactor with fast neutrons is capable of burning low-decontaminated TRU fuel such as Pu and long-lived minor actinides (MAs: Np, Am and Cm) as well as breeding fuel. By taking advantages of these features, fast reactors and their related fuel cycles will provide harmonic solutions for the global issues of energy resources and environments, and are expected to contribute to building a sustainable society in the future. Japan Atomic Energy Agency (JAEA) has been implementing the “Fast Reactor Cycle Technology Development (FaCT)” project in cooperation with electric utilities toward the commercialization of fast reactor cycle system in Japan before 2050.
In the FaCT project, a combination system of “the Japan Sodium-cooled Fast Reactor (JSFR) with oxide fuel, the advanced aqueous reprocessing, and the simplified pelletizing fuel fabrication” has been adopted pursuing full-actinides recycling in a closed cycle, where many innovative technologies with technical challenging issues are actively used in order to provide significant improvements in economic competitiveness, enhancement of safety and reliability, sustainability, and nonproliferation[1-3]. As for the JSFR, a 500-750MWe-class demonstration reactor is planned to start its operation around 2025, which should be accompanied with almost the same innovative technologies for the 1,500 MWe-class commercial reactor. Therefore, the conceptual design study for both reactors and related research and development (R&D) have been vigorously promoted so far by JAEA, electric utilities and MHI/MFBR, which are the core companies for conceptual design and R&D for the demonstration JSFR. The conceptual designs of both commercial and demonstration fast reactor cycle facilities are scheduled to be presented with R&D programs for their realization in 2015. The first important milestone of the FaCT project is reached in JFY2010. Currently, a preliminary assessment of whether innovative technologies can be adopted or not is underway among the project executive organizations. The decision will be made by the end of JFY2010 based on the results of design study, experimental and/or analytical studies. This paper describes the progress of the preliminary assessment.

2. Fast reactor cycle system and its innovative technologies

2.1. Fast reactor system [2]

The JSFR is an advanced loop-type MOX-fueled SFR selected in view of its potential advantage in the in-service inspection and repair (ISI&R) capability of equipment in the primary sodium system as well as the perspective for the economical plant configuration (e.g., a compact reactor vessel (RV) suitable for severer seismic conditions in Japan, and a potential for future innovation that enhances economic efficiency by suppressing the secondary cooling circuit). Figure 1 shows a bird’s eye view of the JSFR. Indeed, the economic competitiveness, which can be achieved by pursuing a compact system design with high reliability on the premise of safety enhancement, has been a crucial issue for the commercialization of the SFR and the full replacement for the Light Water Reactors (LWRs) in the future. In this context, the JSFR pursues the enhancement of economic performance, safety and reliability on the basis of the applicability of innovative technologies. As shown in Fig. 1, constituent parts of the plant of the JSFR incorporate innovative technologies, categorized into ten in terms of plant design system, whose feasibilities are to be supported by accomplishments of some R&D issues.

![Diagram of JSFR Innovative Technologies](image)

Fig.1 Preliminary Assessment of Innovative Technologies for JSFR
2.2. Fuel cycle system [3]

Fuel cycle system consists of the advanced aqueous reprocessing called the New Extraction System for TRU Recovery (NEXT), and the simplified pelletizing fuel fabrication. While a fast reactor admits the reprocessing plant to provide lower-decontaminated U and U/Pu/MA products for fuel fabrication process, complete remote operation and maintenance are required to deal with extremely strong radiation dose from MAs and FPs in the fuel fabrication plant. Current MOX pellet fabrication route, however, consists of many steps of powder handling work for which it is very difficult to adopt remote handling technology. Reducing powder handling work in pellet fabrication route is strongly recommended to realize full actinides recycling. A simplified pelletizing fuel fabrication has a favorable feature from this aspect. Further, the fuel cycle system has many advantages in improving economy, reducing wastes, proliferation resistance, and so on.

In the NEXT system, a wrapper tube of fast reactor spent fuel is removed (disassembled) and a fuel pin bundle is sheared. The sheared core and blanket fuel elements are mixed and dissolved into nitric acid in a continuous dissolver. Most of uranium (U) is recovered as uranyl nitrate hexahydrate (UNH) crystal from the dissolver solution before extraction process. In a typical condition, about 70% of U is required to be recovered in order to make the ratio of residual U to Pu in the solution almost equivalent to the composition of the fast reactor core fuel. After U crystallization, Pu is recovered together with U and neptunium (Np) by co-recovery (co-extraction & co-stripping) using centrifugal contactors without a purification cycle. Minor actinide (MA) elements such as Am and Cm are recovered from the raffinate of solvent extraction using extraction chromatography. Pu/MA/U contents for fast reactor core fuel fabrication are adjusted at the mixing stage of nitrate solution. Therefore, isolation of Pu does not occur throughout the entire process. For realizing the NEXT system, six issues, as shown in Fig. 2, have been identified as the innovative technologies to be developed.

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Fig.2 Preliminary Assessment of Innovative Technologies for Fuel Cycle System

In the Simplified pelletizing fuel fabrication system, Pu/MA/U-containing nitrate solution is converted to source MOX powder with good homogeneity by microwave heating co-conversion process. The source MOX powder is then granulated by a tumbling granulation method to improve powder flowability and compressibility. The die cavities of the pressing head are filled up to the top with the powder, which is then pressed into green pellets. In this process, good flowability of the powder provides good dimensional accuracy of the pellets because the amount of the source powder placed in the die cavity stays constant. In this process, we use a die lubrication method in which the lubricant is sprayed directly onto the surface of the die before being pressed. The lubricant content in a green pellet is very small, and the de-waxing process can thus be eliminated. The green pellets are sintered to create pellets with high density. Then, the oxygen to metal (O/M) ratio of the pellets is reduced by heating it in a mixture of H₂ and Ar gas. For the simplified pelletizing systems, five issues, as
shown in Fig. 2, have been identified as the innovative technologies to be developed.

3. A preliminary assessment of the adoption of innovative technologies

3.1. Fast reactor system [2,4-6]

Based on the progress in the R&Ds and design including features of the innovative technologies in plant-configuration equipment, “Adoptable technologies” were selected by assessing compatibility from the following four viewpoints: “Design feasibility”, “Manufacturability”, “Operability & Maintainability” and “Overall economics.” Here, the “Design feasibility” means that component and system designs are feasible and that the performance reaches the design targets. The selected technologies will be adopted for the JSFR design, and related R&D for conceptual design and performance demonstration of the systemand components including the innovative technologies will be carried out from 2011.

Regarding the innovative technologies for the JSFR, currently, the following six technologies have been identified as adoptable, recommended by JAEA and electric utilities: As for 2) Safety enhancement technologies, Self-Actuated Shutdown System (SASS) with a Curie-point electromagnet[7,8], as a passive reactor shutdown system, can enhance the prevention capability against progression into core disruptive accidents (CDAs); Re-criticality free core can enhance the molten fuel discharge through the inner duct in the fuel subassembly in case of CDAs[9], so that the severe energetics due to excursion could be avoided coupled with restricting core performance such as sodium void reactivity worth. As for 4) Two-loop cooling system of large diameter piping made of high chromium, which has high strength in the elevated temperature and a low thermal expansion coefficient, experimental studies on the hydraulics (flow-induced vibration phenomena due to high coolant velocity) in the pipe elbow[10] and on the fabrication capability of seamless pipes are being carried out. Moreover, the design of high chromium steel pipes is modified taking account of the Type-IV damage to the welding part[11]. 7) DHRS by natural circulation consists of a combination of the one loop of direct reactor auxiliary cooling system (DRACS) and the two loops of primary reactor auxiliary cooling system (PRACS). The effectiveness is confirmed by plant dynamics calculations for design basis events (DBEs) such as a loss-of-offsite-power accident[10]. As for 8) Simplified fuel handling system (FHS), results of a variety of developmental studies on the FHS, including tests with full-scale mockup of a fuel handling machine[12], have shown good applicability of the relevant innovative technologies for the design conditions such as a UIS with a slit, a specific fuel subassembly with an inner duct, and MA bearing fuel. 9) Steel plate reinforced Concrete Containment Vessel (SCCV) has a potential to shorten the construction period with a unit construction method aiming at achieving a high level of economic performance. Experimental studies are being carried out to understand the basic thermal and/or mechanical behavior of components consisting in SCCV in case of assuming sodium leak[13]. 10) Advanced seismic isolation system for SFR functions horizontally and consists of a combination of the laminated rubbers thicker than existing ones and the oil dampers[14]. This system is effective to reduce the seismic load, while keeping the wall thickness of RV thin enough to restrict the impact of thermal stress.

The possibility of adoption for the other four technologies is also under discussion, in parallel with the consideration of necessity of study on alternatives based on the current concern for each of these technologies. As for 1) High burnup fuel with ODS cladding material, the shortening of time for irradiation tests and its solubility during reprocessing are points to be discussed, and alternative materials such as high Ni steel or PNC316 at an early stage of operation for the demonstration JSFR are being investigated. For 3) Compact reactor system, several design measures such as the upper internal structure (UIS) with a radial slit, FHS, “Hot vessel” concept and a high performance radial shielding with Zr-H are taken to realize this concept[15]. The measures except the “Hot vessel” concept are acceptable, however measures to enhance the design margin for seismic reliability even on the latest severer seismic conditions and for thermal stress are of significance. Some design options for the enhancement, e.g., RV with wall-cooling flow channel which allows a thicker RV wall to improve the stiffness of RV, shall be investigated. For 5) Integrated pump-IHX component, the rotational stability of the long pump drive shaft is one of the crucial issues. Therefore, an alternative to separate the pump and IHX shall be investigated. For 6) SG with double-walled straight tube, the fabrication capability of full scale (40 m long) double-walled straight tube is a crucial issue, and othertube ideas with anti-wastage guard tube or clad, or two SGs per loop are being investigated.

3.2. Fuel cycle system [3,16]

A technology that could be judged applicable to dedicated commercial facilities for fast reactor fuels, if R&D is continued, will be defined as adoptable. “Adoptable technologies” were selected by assessing compatibility from the following three viewpoints: “Technical feasibility”, “Attainment analysis on development targets and design requirements” and “Reliability.” Here, the attainment analysis was performed to evaluate economics, the amount of wastes generated, the recovery ratio of actinides, non-proliferation and so on. The selected technologies will be adopted for the conceptual design, and related R&Ds will be carried out from 2011.

Regarding the innovative technologies for advanced fuel cycle system, currently, the following six technologies have been identified as adoptable, recommended by JAEA and electric utilities:
As for 1) Disassembling and Shearing, the system performance was confirmed by engineering-scale system tests using simulated assemblies of “Monju.” Optimum shearing-length was selected for obtaining highly fragmented fuel to provide efficient fuel dissolution[17]. As for 2) Highly effective fuel dissolution, dissolution at high concentration required for the following U crystallization process, was confirmed by some fundamental tests using irradiated fast reactor “Joyo” MOX fuel and simulation. A rotary drum-type continuous dissolver was designed for compact and high throughput, and the system performance was confirmed by engineering-scale mockup tests[18]. As for 4) Highly effective extraction system with group separation of U-Pu-Np, an optimum process condition for recovering U, Pu and Np with enough recovery rate and decontamination factor (DF) was established using the dissolver solution of the irradiated “Joyo” fuel. Centrifugal contactors providing the compactness and high throughput has been developed by engineering-scale dissolver contactor system tests[19]. As for 7) Microwave heating denitration and granulation, a dish type container was selected; The technical feasibility was confirmed by the manufacturing examination for a large dish-type container and the simulation for a large-scale microwave heating device. It was confirmed that granulated powder with excellent physical properties could be produced at a desired yield rate by tumbling granulation[20]. 8) Die wall lubrication pelletizing tests were performed by using a considerable amount of cold mock-up powder and some amount of MOX powder, and excellent lubrication performance was confirmed in a wide range of operation conditions. The mass-production ability of die wall lubrication pressing machine was also confirmed by observing pressing speed using examination equipment. 12) Cooling system for high heat generating MOX fuel with MA, etc. is essential for realizing a mass-production plant. Therefore, cold mock-up tests simulating a bare wire-wrapped bundle with/without a wrapper tube have been performed to develop the heat removal system and the evaluation tool. Obtained data shows that such cooling system is expected to be feasible[21-23].

The possibility of adoption for the other five technologies is also under discussion, in parallel with the consideration of necessity of study on alternatives based on the current concern for each of these technologies.

For 3) Effective U pre-recovery by crystallization, beaker-scale experiments with dissolver solution of irradiated “Joyo” fuel were carried out and the behavior of some FPs in U crystallization has been investigated. Rotary kiln-type crystallizer was designed for high throughput, and the performance was confirmed by engineering-scale crystallizer tests[24]. The UNH crystal purification technology can provide more highly DF. As for 5) MA recovery by extraction chromatography, a combination of TODGA and R-BTP in several extractants is promising for recovering MAs and rare-earth elements, as well as separating MAs among them[25,26]. Further experimental data including throughput, the recovery yield of Am and Cm, and DF should be accumulated, and the prospect of safety should be confirmed. 6) Salt-free process for waste reduction has a potential for reducing the volume of waste drastically. Basic data for the solvent washing with salt-free reagents, hydrazine carbonate and hydrazine oxalate were collected[16]. However, further experimental data using real solvents/washing liquid waste should be accumulated. 9) Sintering and O/M ratio adjustment technologies have almost technical feasibility. However, further experimental data should be accumulated to confirm the mass-productivity of the low O/M ratio MOX[27]. As for (10) Studies on physical properties of MOX fuel with MA, because it is a fundamental study to support both fuel production and fuel design technologies, and provide basic data for each innovative technology development, it shall be included in the assessment for each innovative technology[28]. As for 11) In-cell automatic operation and remote maintenance, a feasibility test for remote maintenance was performed and the feasibility was confirmed by using cold mock-ups of some kind of in-cell equipment [29]. However, further accumulation of evaluation data including design study is required in order to develop highly reliable in-cell equipment.

4. Conclusions

Toward the present milestone in the FaCT project, the evaluation work to decide whether the innovative technologies can be adopted for the JSFR and its related fuel cycle is in progress. So far, on the basis of the progress in design study and R&Ds on the relevant innovative technologies, six out of the ten technologies for the JSFR and six out of the twelve technologies for fuel cycle system are judged to be adoptable in the preliminary assessment by JAEA, manufactures and utilities. The other technologies are under discussion including the utilization of alternative ones. The decision will be made by the end of 2010.

References