Current status and future view of the fast reactor cycle technology development in Japan

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Abstract. The "Fourth Strategic Energy Plan" of Japan was approved by the Cabinet in April 2014. It states that nuclear energy is an important base-load power source as a low carbon and quasi-domestic source even after the TEPCO's Fukushima Dai-ichi Nuclear Power Station accident (1F accident), and Japan promotes nuclear fuel cycle in terms of the efficient use of resources and volume reduction and mitigation of degree of harmfulness of high-level radioactive waste and carries out fast reactor (FR) cycle R&D for the commercialization, taking advantage of international cooperation.

Japan Atomic Energy Agency (JAEA) is conducting several R&D activities for the commercialization of FR cycle primarily focusing on 1) the reduction in volume and toxic level of radioactive waste and 2) the improvement of the safety of FRs and utilizing international cooperation with bilateral frameworks such as ASTRID program with France and multilateral frameworks such as the Generation IV International Forum (GIF). In the nuclear fuel cycle R&D, SmART cycle project to conduct a small-scale minor actinide (MA) recycling using existing facilities is in progress. Regarding the Experimental FR Joyo, JAEA completed the replacement work for the damaged upper core structure (UCS) and it is preparing to make an application for earlier restart under the new regulatory requirements developed based on lessons learned from the 1F accident.

Meanwhile, the Council on FR Development was established in September 2016 to discuss and prepare a draft paper on policies concerning the future development of FRs in Japan. Based on the result, the Inter-Ministerial Council for Nuclear Power (Inter-Ministerial Council) made decision on the new policy for FR development in Japan and it states that a strategic roadmap will be compiled in 2018 for the realization of the policy. The Inter-Ministerial Council also decided that Prototype Fast Breeder Reactor Monju will not resume operation as a reactor and will be decommissioned.

Key Words: fast reactor (FR) cycle, new policy for FR development, Strategy Roadmap, decision on the decommissioning of Monju

1. Introduction

In order to secure a quasi-domestic energy source for a long term, Japan, which has few natural resources, started to promote R&D for fast reactors (FRs) aiming for the commercialization in the dawning era of the nuclear development. Triggered by the Long-Term Program for Research, Development and Utilization of Nuclear Energy, developed in 1956 by the Atomic Energy Commission (AEC), a full-scale design study on FRs and related R&D were commenced in around 1963, and the Experimental FR Joyo (Joyo) and the Prototype Fast Breeder Reactor (FBR) Monju (Monju) achieved first criticality in 1977 and 1994, respectively.

Monju had suffered a sodium leak accident in 1995 followed by an In-Vessel Transfer Machine falling accident but high expectations were placed on its restart both at home and abroad [1]. Since the late 1980s, an R&D project for the realization of a demonstration reactor has been conducted with the cooperation of private entities and the Government, and Japan has solemnly put an effort in accumulating knowledge [2],[3].

As it is essential for the development of an FR to be carried out together with the development of a nuclear fuel cycle, the promotion of the nuclear fuel cycle has been the basic policy of Japan since the initial stage of the FR development. The 4th Strategic Energy Plan in Japan [4], approved by the Cabinet in April 2014, states that the nuclear fuel cycle contributes to the resolution of the challenge related to disposal of spent fuels, the reduction of the volume and harmfulness of high level radioactive waste, and effective utilization of resources for mitigating the risks for and the burden on future generations. Japan will make efforts to create the nuclear fuel cycle while taking the past history into consideration and continuing to seek the understanding of relevant municipalities and the international community. It also states that Japan will promote reprocessing and plutonium use in LWRs and R&D of FRs, etc., through international cooperation with the U.S., France, etc. An FR further enhances the effect of the reduction of the volume and harmfulness of high-level radioactive waste and effective utilization of resources expected in the nuclear fuel cycle. Moreover, the depth of technologies and human resources cultivated so far will greatly contribute to the formation of technology infrastructures and is the source of the acquisition of cutting-edge technologies and international contribution. The significance of Japan's FR development does not change even when the situation has changed recently.

Meanwhile, there have been a variety of changes, such as the formulation of new regulatory requirements, the inauguration of Japan-France cooperation in developing FRs, and Electricity Systems Reform, in the environment surrounding the FR R&D recently, particularly since the TEPCO's Fukushima Dai-ichi Nuclear Power Station (1F) accident in March 2011. In light of the latest situation, the Council on FR Development [5] was established to discuss future approaches of the FR development at a meeting of the Inter-Ministerial Council for Nuclear Power (Inter-Ministerial Council) held in September 2016. The new policy for FR development in Japan [6] and the policy on the Monju [7] were decided in the meeting of the Inter-Ministerial Council held in December 2016.

This paper describes Japan's energy and nuclear policies related to an FR cycle issued since 2013, current status and future view of the FR cycle technology development in Japan

2. Japan's overall energy policies and nuclear policies related to an FR cycle

The following are excerpts from Japanese Government's decisions on the overall energy policies and nuclear policies related to an FR cycle issued in 2013 or later are described in chronological order.

The instruction of the Prime Minister at the Headquarters for Japan's Economic Revitalization based on the discussion at the first meeting of the Industrial Competitiveness Council (Jan 25, 2013)

The Prime Minister's instruction to the Minister of Ministry of Economy, Trade and Industry (METI) is to review from scratch "Innovative Strategy for Energy and the Environment" decided by the former administration and establish a robust and responsible energy policy from various perspectives, including stable supply of energy and reduction of energy cost.

Monju Research Plan (September 2013) [8]

In September 2013, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) adopted Monju Research Plan, which summarizes expected outcomes by conducting R&D using Monju and how long does it take to obtain such outcomes from the technical point of view (technological priority and level of importance), based on the current status in Japan and abroad. The plan presented the three main pillars of Monju R&D that aims for the

following: 1) Compilation of outcomes of FR development, 2) Reduction of the amount and toxic level of radioactive waste, and 3) Safety enhancement of FR.

4th Strategic Energy Plan of Japan (April 2014) [4]

In April 2014, the Cabinet approved the 4th Strategic Energy Plan, which indicates Japan's new direction of energy policy for the next 20 years or so. The plan describes below.

- Nuclear power is an important base-load power source as a low carbon and quasi-domestic energy source, contributing to stability of energy supply-demand structure.
- Dependency on nuclear power generation will be lowered to the extent possible and the volume of electricity to be secured by nuclear power generation will be carefully examined.
- In case that the Nuclear Regulation Authority (NRA) confirms the conformity of nuclear power plants with the new regulatory requirements, the Government will proceed with the restart of the nuclear power plants.
- The Government will steadily promote a nuclear fuel cycle.
- The Government will promote FR R&D through international cooperation with the US and France, etc. and promote development of technologies for reducing the volume and harmfulness of radioactive waste using FRs and accelerators in order to secure a wide range of options in the future.
- The Government will position Monju as an international research center for technological development, such as reducing the amount and toxic level of radioactive waste and technologies related to nuclear nonproliferation.

Long-term Energy Supply and Demand Outlook (July 2015) [9]

The agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry (METI) approved the "Long-term Energy Supply and Demand Outlook" (Long-term Outlook) in July 2015, based on the Strategic Energy Plan approved by the Cabinet in April 2014. In the Long-term Outlook for 2030, Japan is supposed to achieve an improvement in energy self-sufficiency to around 25% and the reduction of energy costs, as well as greenhouse gas (GHG) reduction with a target in line with those of Europe and the United States by promoting energy conservation, introducing renewable energy as much as possible and improving efficiency in thermal power generation, etc. Specifically, the government intends to reduce the GHG emissions by 26% from the FY2013 level, by achieving a share of 20 to 22% of nuclear energy and 22 to 24% of renewables in the electricity generation mix.

NRA's recommendation on Monju (November 2015) [10]

The NRA issued the Minister of MEXT a recommendation that states a qualified management body other than Japan Atomic Energy Agency (JAEA) should be identified to operate Monju safely or review of the status and future of Monju should be conducted.

Report of the MEXT's Panel for Discussion on the Status and Future of Monju (May 2016) [11]

MEXT set up the Panel for Discussion on the Status and Future of Monju (Chair: Mr. Akito Arima) to discuss revolving around Monju in responding to the NRA recommendation. The panel held hearings with related parties and conducted on-site inspections with the main aim of extracting those requirements that a prospective operator of Monju should be able to meet after examining and summarizing problems regarding Monju, and issued a report.

The new policy for FR development in Japan and policy on the Monju (December 2016) [6], [7]

After the NRA recommendation concerning Monju to the Minister of MEXT issued in November 2015, the Inter-Ministerial Council in September 2016 decided to establish the Council on FR Development (Council) consisting of the Minister of METI (Chair), the Minister of MEXT, JAEA and private entities (electric utilities and core manufacturers) concerned with FR development, which aims at fundamentally reviewing the Monju project including its decommissioning and discussing future approaches of the FR development in Japan. In response to the discussion of the Council, the Inter-Ministerial Council decided in December 2016 the new policy for FR development (refer to Chapter 4) and the policy on the Monju.

The policy on the Monju describes that various technological outcomes and knowledge at Monju have been accumulated and basic technologies for establishing a system of power-generating plant have been acquired as a prototype reactor; however, it was decided that Monju should not resume operation but decommissioned as well as take a new role in the future FR development for the following reasons.

- Expected increase of time and cost for the restart of Monju by the adoption of the new regulatory requirements (it will take at least 8 years to resume operation and cost more than 540 billion yen until the end of operation if it is supposed to operate for eight years (five cycle) including performance tests.)
- There was no alternative Monju operator who accommodates the NRA recommendation.
- After the restart of Monju it will be expected that useful data for the realization of a demonstration reactor, particularly a loop-type demonstration reactor, are obtained. However, knowledge expected to be gained after the restart of Monju can be obtained through such alternative measures as the utilization of domestic test facilities and international cooperation, and R&D in the next demonstration reactor stage.

3. The Status of FR cycle technology development in Japan

The progress of FR cycle technology development in Japan after FR13 (held in March 2013) is as follows.

3.1. R&D aiming at safety enhancement of FRs with the use of international cooperation

In terms of the safety of FRs, it is important to establish safety standards common throughout the world. In order to achieve high safety goals of Generation IV (Gen-IV) reactors including the Sodium-cooled FR (SFR), the Generation IV International Forum (GIF) is engaged in developing Safety Design Criteria (SDC) that embodies the goals and then Safety Design Guidelines (SDG) to deploy the SDC in design [12]. Japan has actively contributed to developing the SDC and SDG as follows. Japan proposed a draft SDC which consolidated international safety requirements for the design of SFRs in light of lessons learned from the 1F accident, and then the draft SDC was examined by the Atomic Energy Society of Japan, followed by the provision to discussion in the GIF. The SDC has been already discussed in the GIF-SDC task force and then approved by the Policy Group of GIF and is undergoing reviews by regulatory bodies in GIF member countries and international institutions. The development of the SDG for SFRs is following the same procedures.

In light of lessons learned from the 1F accident, a set of new regulatory requirements in consideration of severe accidents for Japanese power reactor facilities in the R&D stage such as the SFR Monju was enacted in July 2013. Since these new regulatory requirements are due to be revised after taking public comments, etc. into consideration before conducting safety

inspections, JAEA set up "Monju Safety Peer Review Committee" consisting of FR experts and drew up the report "Safety Requirements Expected to Prototype Fast Breeder Reactor Monju" [13] taking into account the SFR specific safety characteristics. JAEA submitted this report to the NRA in July 2014 and then asked leading international experts to review with the purpose of validating the content. Incorporating the summary of the results of international review, the report was released in September 2015 [14].

Japan has been engaged in the cooperation with France on the Advanced Sodium Technological Reactor for Industrial Demonstration (ASTRID) project since 2014 while seeking the possibility of FR development utilizing international cooperation. There are many common SFR technologies in the ASTRID although it is a pool type which is different configuration of the reactor and the primary coolant system from a loop-type reactor like Monju that Japan has developed so far.

Joyo has conducted operation for 71,000 hours in total and irradiation of around 100 test assemblies so far since it reached first criticality in 1977 [15]. However, Joyo has been shut down since June 2007 because part of the fuel handling function was damaged due to the interference between a small rotating-plug for refueling and the Material Testing Rig with Temperature Control (MARICO-2). JAEA completed the replacement of the damaged Upper Core Structure (UCS) and the retrieval of the bent MARICO-2 sub-assembly in 2014. Then it restored the surroundings of the reactor vessel to a normal state by loading a new UCS on the rotating-plug in November 2014 [16], and completed re-installation work of the retrieved equipment on the rotating-plug in June 2015. JAEA applied for change of reactor installation license for restart in around 2020 under the new regulatory requirements in the end of March 2017 and is currently examining safety enhancement measures. In addition, it will discuss the operation plan for Joyo including the utilization of international cooperation to meet requirements in Japan and abroad such as the U.S. and France.

3.2. R&D for reducing volume and harmfulness of high-level radioactive waste by the use of FR cycle

In order to realize the recycling with FRs using minor actinides (MAs), it is necessary to separate and recover MAs from spent fuels, fabricate MA bearing fuels using the recovered MAs and irradiate them to verify that MAs can be burned as expected. JAEA has conducted Small Amount of Reused fuel Test (SmART) project with small amount of MAs using its R&D facilities at Tokai and Oarai sites and has extracted Np together with U and Pu from 4 spent fuel pins irradiated at Joyo so far [17]. It will recover Am and Cm from high-level liquid waste (raffinate) and fabricate MA bearing MOX fuel using more than 1 gram of the extracted MAs followed by the irradiation at Joyo for a post irradiation experiment.

Meanwhile JAEA has fabricated 301 fuel assemblies for Joyo and 366 fuel assemblies for Monju at its Plutonium Fuel Production Facility [18], where it is preparing for the application for restart under the new regulatory requirements to supply fuel for Joyo.

4. New policy for FR development in Japan

The Council on FR Development (Council) was established based on the decision "Future Approaches to Developing FRs" at the meeting of the Inter-Ministerial Council held on September 21, 2016. Based on the discussion at the Council, the new policy for FR development was decided as a guide for parties involved in the FR development at the meeting of the Inter-Ministerial Council on December 21, 2016 [6]. The policy states that Japan should maintain and develop technical infrastructures at a world-class level and develop and commercialize FRs with high level of safety and economics, and thereby aim to play a

leading role towards the realization of international standards. Based on this policy, Japan will integrally carry out the formulation of strategy and establishment of research systems for the realization of FRs in future.

Therefore, it was decided that a practical-level strategy working group made up of "International Cooperation" team, "Joyo" team, "Monju" team, "Domestic Facility" team and "Administration" team, which controls the other teams, will be established under the Council to develop "Strategy Roadmap" (tentative name) that identifies developmental work for the coming 10 years in line with basic concepts as follows (Fig 1).

4.1. Basic approach

As Japan has accumulated reasonable intellectual assets, it is possible to set to work again on developmental work for the design stage of a demonstration reactor utilizing these assets. Knowledge expected to be gained from the future operation of Monju will instead be obtained by new measures. In the demonstration reactor development with the development goals clarified, it aims to 1) develop individual technologies that can be implemented in the FR plant (element-technology development), 2) to clearly articulate targets of what kind of plants it aims for and a concept of the plant that meet the targets (specifications including reactor type and scale) and identify the appropriate combination of technologies to realize the plant concept (the determination of the plant concept, 3) build an integrated plant system that includes peripheral equipment (integrated system design).

For the time being, it will devote resources in the decision of the plant design, make best use of domestic knowledge and facilities and carry out developmental work by the use of optimal facilities in the international network and the collaboration with appropriate institutions while conducting basic and fundamental research.

5. Conclusion

Japan has been carrying out the FR development for the early commercialization of the FR cycle through the stages of the construction and operation of experimental FR Joyo and prototype FBR Monju, and the R&D of a demonstration reactor as a national policy from the initial stage of nuclear energy development. Although it was decided in December 2016 that Monju will not resume operation as a reactor, but set to be decommissioned, Japan intends to firmly maintain the basic policy to promote the nuclear fuel cycle and work on the FR development, and it is determined to develop and materialize the Strategy Roadmap incorporating the active utilization of international cooperation toward the early realization of the FR cycle.

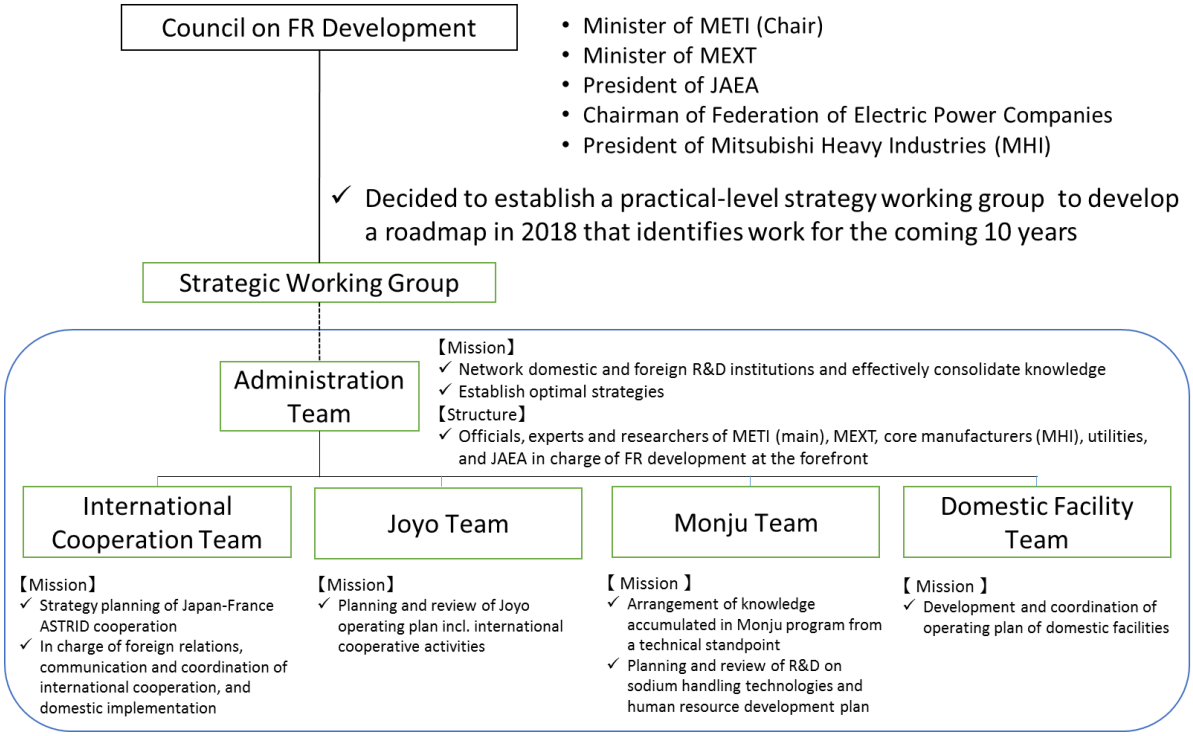

FIG. 1 Organization Structure for Strategy Roadmap (tentative name) on FR Development

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