The Japanese Thorium Program

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Abstract

The Japanese nuclear energy policy is based on the uranium–plutonium cycle including application of a fast breeder reactor. In 2010, the Japan Atomic Energy Commission launched a council to construct a new framework of nuclear energy policy. Although progress has been halted after the Fukushima accident caused by the Great East Japan Earthquake, the application of thorium fuel is discussed as one of the alternative options for future nuclear fuel cycles and it is recommended to precede in basic research and developments. Two research working groups related to thorium-fueled reactors and the thorium fuel cycle were set up in the Atomic Energy Society of Japan in 2013. One is the "Research Committee on Nuclear Applications of Molten Salt". The committee was established to survey molten salt technology including molten-salt-cooled reactors, molten-salt-fueled reactors, and dry reprocessing processes. The committee planned to summarize the current state of the art and issues of molten-salt-fueled systems. The other is the "Working Group for Thorium Fuel Applications in Light Water Reactors and Fast Reactors". The objective of the working group is to summarize the current status and issues for application of solid-form thorium fuel in a U–Pu fuel cycle. Through these two different approaches, it is expected that the opinion on thorium fuel applications in Japanese nuclear fuel cycle policy will be summarized from an academic point of view. This paper summarizes the outline of activities for the two groups and introduces the application of accelerator-driven systems for thorium breeding.

Introduction

The Japanese nuclear energy policy is based on the uranium–plutonium fuel cycle for application in both light water reactors (LWR) and fast breeder reactors (FBR). This was decided at an early phase of nuclear power installation in Japan and research and development (R&D) activities for nuclear power generation was based on the national policy. In 2010, the Japan Atomic Energy Commission launched a council to construct a new framework of nuclear energy policy. Although this council has been halted after the accident at Fukushima-Daiichi Nuclear Power Plant caused by the Great East Japan Earthquake, the application of the thorium fuel cycle is discussed as one of the alternative options for future nuclear fuel cycles and it is recommended to enhance basic R&D activities in Japan.

Two research working groups related to thorium-fueled reactors and the thorium fuel cycle were set up in the Atomic Energy Society of Japan in the summer, 2013. One is the "Research Committee on Nuclear Applications of Molten Salt". The committee was established to survey molten salt technology, including molten-salt-cooled reactors, molten-salt-fueled reactors, and dry reprocessing processes. The committee planned to summarize the current state of the art and issues of molten-salt-fueled systems. The other is the "Working group for Thorium Fuel Application in Light Water Reactors and Fast Reactors". The objective of the working group is to summarize the current status and issues

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for application of solid-form thorium fuel in LWR/FBR fuel cycles.

Through these two different approaches, it is expected that the opinion on thorium fuel usage in Japanese nuclear fuel cycle policy will be summarized from an academic point of view. This paper summarizes the activities of these two research working groups and gives examples for thorium utilization research using accelerator-driven systems (ADS) for nuclear transmutation as studied at Japan Atomic Energy Agency (JAEA).

Research on Thorium Utilization in Japan

Activities for Molten Salt Applications

The committee was established in 2013 to discuss current molten salt technology, including molten-salt-cooled reactors, molten-salt-fueled reactors, accelerator-driven systems, fusion reactor blankets, and dry reprocessing processes. The committee consists of about thirty members from universities, research institutes, and industrial companies. The committee planned to summarize the current state of the art and issues of molten-salt-fueled systems. The committee also discussed the handling technologies for molten salt reactors especially those in China and the United Kingdom; issues of molten salt application to fusion reactors, dry reprocessing of spent nuclear fuel, and non-nuclear applications of molten salts.

Activities for Solid Thorium Fuel Applications

The "Working Group for Thorium Fuel Application in Light Water Reactors and Fast Reactors" was started before the Fukushima accident to enhance the basic R&D for thorium-loaded fuel applications. The objective of the working group is to summarize the status and issues for application of solid-form thorium fuel in LWR/FBR fuel cycles. The working group will summarize the current status of thorium-loaded fuel research. Physical and chemical properties of thorium oxide fuel, the effect of inert materials and/or fission products, and the application of thorium–plutonium mixed oxide (MOX) fuels were discussed. The status of thorium-loaded nuclear reactors from a neutronic point of view was also discussed. Nuclear data preparation for the thorium cycle, including cross sections, burnup chain, fission product yields, and delayed neutron emission fractions, were reviewed. As a survey of international activities, the working group reviewed the reports summarized by International Atomic Energy Agency (IAEA), OECD/Nuclear Energy Agency (NEA), and the US Nuclear Regulatory Committee.

Application of ADS to Thorium Breeding

JAEA performs R&D on ADS for transmutation of long-lived radioactive nuclides to reduce the environmental impact caused by radioactive waste disposal. Although the primary candidate of the ADS is a lead–bismuth eutectic alloy (LBE) target/cooled system using minor actinide (MA) nitride solid fuel [1], JAEA has also performed studies on liquid-fueled ADS as an alternative option for a primary candidate.

Figure 1 shows the conceptual view of a chloride-based molten salt ADS [2]. In this system, the molten salt acts as a spallation target, the fuel of the subcritical core, and primary coolant. For the requirement of the higher transuranic species (TRU) solubility and a harder neutron spectrum in the subcritical core, a chloride molten salt was selected as a fluid material. The fuel composition of the molten salt is 64NaCl–5$PuCl_3$–31$MACl_3$ or 60$PbCl_2$–60(Pu + MA)Cl_3. There are no specific differences for neutronic and burnup performances caused by the difference in the fuel composition. The operation temperature of the salt is set at 650–750 °C. Molten salt circulation pumps and heat exchangers are placed in a tank-type reactor vessel to reduce the in-core fuel inventory. Thermal power of 800 MW is generated by the injection of 1.5 GeV, 25 mA protons and 250 kg of actinides can be transmuted annually. Fuel composition is continuously controlled to extract reaction products and stabilize the core subcriticality through the on-line fuel processing circuits.

To evaluate the feasibility of the JAEA-proposed molten salt ADS for thorium cycle use, neutronics studies were performed [3]. In this evaluation, the dimensions of the system were not changed and only the material composition of the chloride fuel was changed to 60NaCl–34$ThCl_4$–6$^{233}UCl_4$. When the concentration of ^{233}U was set to a higher value, the melting point changed to a lower value than that of FLiBe fuel. The trends of the subcritical core

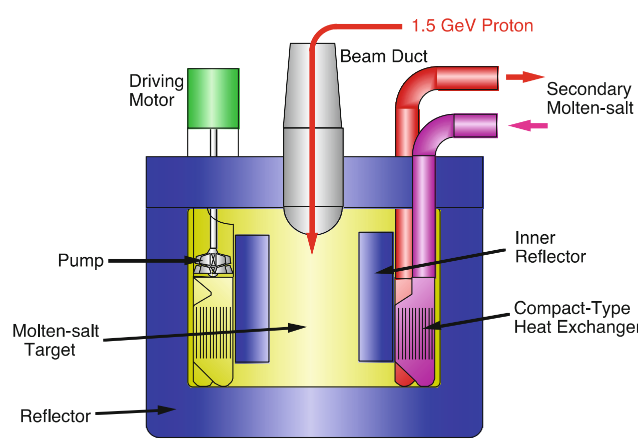

Fig. 1 Molten salt target/cooled ADS for MA transmutation

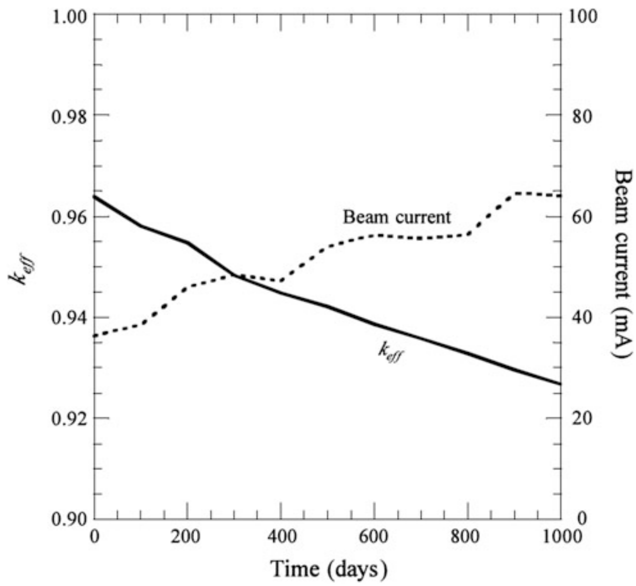

Fig. 2 Time evolution of k_{eff} and the operation beam current

multiplication factor, k_{eff}, and the required beam current for rated operation according to burnup without on-line fuel treatment are shown in Fig. 2.

Because the core of the ADS is kept in subcritical condition, this system is not sensitive to the accumulation of ^{233}Pa. The k_{eff} slightly decreases because of accumulation of fission products. The required beam current to generate 800 MW of fission power increases from 30–70 mA over 1000 days of operation. In this case, spallation neutron yields from the injection of 1.5 GeV protons are calculated to be 27 neutrons per incident proton. If a more efficient spallation target, such as liquid LBE, is used, the required beam current for rated operation can be decreased.

Design studies for a revised liquid fuel ADS with separated spallation target as shown in Fig. 3 is underway [4].

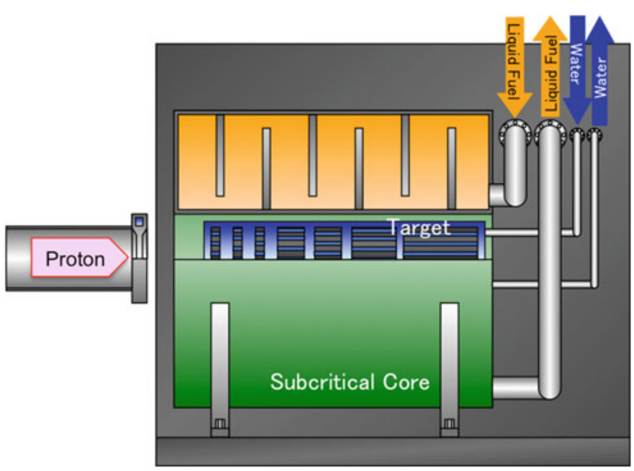

Fig. 3 Revised liquid-fueled ADS concept for MA transmutation

This system aims at extracting americium and curium from the current fuel cycle and transmute them into plutonium, which has better chemical stability and safety in MOX fuels. By adding these concepts to the current power generation cycle, fuels for power reactors can maintain a conventional fuel composition. It is useful to improve safety and cost efficiency of electric power generation. From the preliminary analysis results, there is a possibility to make the system a self-standing one to reduce the environmental impact of minor actinides. It is also found that this system, reflecting liquid-fueled ADS concepts, also gives fairly good transmutation performances. Adoption of on-line reprocessing by batch processing gives very small burnup reactivity change compared with the solid-fueled systems. The major parameters for the above-mentioned JAEA liquid-fueled ADS are summarized in Table 1.

National Review of Partitioning and Transmutation Technologies

To realize full ADS usage, there are many issues to be solved. JAEA proposes to establish a transmutation experimental facility (TEF), which is illustrated in Fig. 4, within the framework of the Japan Proton Accelerator Research Complex (J-PARC) project [5]. TEF consists of two buildings; the transmutation physics experimental facility (TEF-P) [6] and the ADS target test facility (TEF-T) [7]. The two facilities are connected by a proton beam line with a low-power beam extraction mechanism using a laser beam [8]. TEF-P is a facility with a zero-power critical assembly where a low-power proton beam is delivered to study the reactor physics and the controllability of ADS. TEF-T is planned as an irradiation test facility, which can accept a maximum 400 MeV, 250 kW proton beam into the LBE spallation target. Using these two facilities, the basic physical properties of subcritical systems and engineering tests of spallation targets will be studied.

In 2013, a national review working party for partitioning and transmutation (P-T) technologies using ADS was launched by the Ministry of Education, Culture, Sports, Science and Technology in Japan. The working party aims at reviewing the state of the art of P-T, the feasibility for construction of TEF, and a cost and benefit analysis of cooperation with European MYRRHA project. Five meetings were held during August to October 2013 and an interim report was issued in November 2013. In the interim report, the working party specified a roadmap to realize an ADS-based P-T fuel cycle. The working party also recommended to promote P-T technology as an important alternative option for future nuclear waste management and agrees that establishment of facilities to handle certain amount of MAs are required and the R&D to establish these

Table 1 Major parameters for JAEA liquid-fueled ADS

Molten salt ADS for MA transmutation	
Proton beam	1.5 GeV, 25 mA
k_{eff}	0.92
Thermal power	800 MW
Molten salt fuel	$64NaCl–5PuCl_3–31MACl_3$ or $60PbCl_2–60(Pu + MA)Cl_3$
MA loading	5000 kg
Fuel operation temperature	650 °C/750 °C
Fuel flow speed	3.6 m/s
Secondary coolant	$92NaBF_4–8NaF$
Liquid-fueled ADS for the U–Th cycle	
Proton beam	1.5 GeV, 36 mA
k_{eff}	0.964
Thermal power	1500 MW
Fuel	$60NaCl–34ThCl_4–6^{233}UCl_4$
MA loading	5000 kg
Initial ^{233}U loading	~12 t
Fuel melting temperature	370 °C
Fuel average temperature	640 °C
Revised liquid-fueled ADS for MA transmutation	
Proton beam	600 MeV, 5 MW
Initial k_{eff}	~0.98
Thermal power	320 MW
Fuel zone radius/height (cm)	18–38/~120
Fuel density (g/cm^3)	3.80
MA fraction (Am:Cm)	88:12
Fuel fraction $MACl_3$:NaCl	30:70
Target radius/height (cm)	12.0/30.0
Target material/coolant	W/water

Fig. 4 Transmutation experimental facility

facilities should be continued. As for the construction of J-PARC TEF, a step up from the current basic study stage to the next stage is noted as “suitable”. It is also noted that a detailed technical review should be held before initiating construction. As for the participation with the MYRRHA project, it is proper to begin negotiations with Belgium with comprehensive cooperation not only by JAEA but also by universities and the commercial sector. The working party continues a review works of P-T technology, including the status of the TEF project and negotiations with the MYRRHA project.

In 2014, the working party held two meetings to review the progress of R&D, particularly for the activities related to TEF construction. Various activities to realize the LBE spallation target for TEF-T, the MA-loaded core for TEF-P, and other efforts to enhance R&D activities such as international collaboration and human resource development were discussed. After the meeting, the working party summarized that, the working party approved the R&D for TEF construction as “appropriate” and that it had progressed steadily. The working party also approved enhancing activities related to the TEF construction, such as a ground survey for candidate areas for the TEF building.

Summary

There were no specifications for thorium utilization in Japanese energy policy; thus, two research working groups, the “Research Committee on Nuclear Applications of Molten Salt” and the “Working Group for Thorium Fuel Application in Light Water Reactors and Fast Reactors” were set up in the Atomic Energy Society in Japan. Through these two different approaches, it is expected that the opinions for thorium fuel usage in Japanese nuclear fuel cycle policy will be summarized from an academic point of view.

Meanwhile, JAEA performs R&D for P-T technologies using ADS. Several kinds of liquid-fueled ADS are being studied as an alternative option for ADS. The transmutation performance of these liquid-fueled ADS is comparable with primary candidate LBE target/cooled ADS.

JAEA also proposes a transmutation experimental facility within the framework of the J-PARC project. A 250 kW LBE spallation target and MA-fueled critical assembly is planned to be installed. The construction of TEF is being discussed under the national review working party launched in 2013.

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