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Journal of Nuclear Materials 301 (2002) 1–7

journal of nuclear materials

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The accelerator driven system strategy in Japan

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Abstract

Recent status of study on accelerator driven system (ADS) in Japan is presented. The double-strata fuel cycle concept has been proposed by Japan Atomic Energy Research Institute (JAERI) under the 'OMEGA' program as a system for partitioning and transmutation (P&T) of long-lived radioactive nuclides. The ADS dedicated to transmutation is the key technology of the double-strata fuel cycle concept. The proposed system is a lead–bismuth cooled, nitride fuel 800 MW ADS for transmutation of minor actinides and long-lived fission products. JAERI has carried out a conceptual design study under the joint project between JAERI and KEK (High Energy Accelerator Research Organization) on high-intensity proton accelerators. In addition to a high-intensity proton accelerator complex, two experimental facilities are planned for development and demonstration of accelerator driven transmutation technology: The major objective of an ADS physics experimental facility is to obtain reactor physics data of hybrid subcritical system. The major objective of an ADS engineering experimental facility is to accumulate material data for the design of a lead–bismuth target system.

1. Introduction

The management of high-level radioactive wastes (HLW) is one of the most relevant issues in the nuclear society. In 1988, Japan Atomic Energy Commission started a long-term program for research and development on partitioning and transmutation (P&T) technology, called the 'OMEGA' program on the basis of the activities and results so far attained at Japan Atomic Energy Research Institute (JAERI), the Power Reactor and Nuclear Fuel Development Cooperation (PNC, later reformed as the Japan Nuclear Cycle Development Institute (JNC)) and the Central Research Institute of Electric Power Industry (CRIEPI). Under this OMEGA program, JAERI, JNC and CRIEPI have been developing techniques for partitioning process and transmutation system separately. JAREI has been conducting the study on P&T including accelerator driven system (ADS) under the OMEGA program. Mukaiyama et al. reviewed the total activities of R&D on ADS in Japan [1].

The accelerator driven subcritical system is proposed to burn or transmute long-lived nuclides in HLW [1–5]. This system has attracted the attention of people all over the world because it has possibility to reduce the radiotoxity and the amount of radioactive waste for future generations. From the viewpoint of safety, the concept of the ADS is also attractive because the risks of core melt-down can be avoided by a proper design and the use of heavy liquid metal coolant.

JAERI and KEK started a new joint program called the high-intensity proton accelerator project to perform the wide rage studies on life science, materials science, particle physics, nuclear physics and ADS technology [6]. In addition to the high-intensity proton accelerator, two experimental facilities are planned in the joint program to develop and demonstrate the accelerator driven transmutation technology.

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PII: S0022-3115(01)00731-0

In this paper, the strategy of ADS development in Japan is described focusing on R&D activities at JAERI under the OMEGA program, concept design of ADS and ADS experimental facilities planned in the joint program.

2. R&D at JAERI under the OMEGA program

JAERI started a basic study on P&T technology in the mid 1970s. From 1988 under the OMEGA program, JAERI has been developing technologies for a dedicated partitioning process and transmutation system, while JNC has been devoting its major efforts to an advanced fuel recycling system as a part of FBR MOX fuel cycle technology. CRIEPI has been developing pyroprocess recycling technologies for metallic fuel FBR.

In the OMEGA program, JAERI has proposed the double-strata fuel cycle concept, which consists of a power reactor fuel cycle and a P&T cycle. The characteristic of the double-strata fuel cycle is that the P&T cycle is independent of the power reactor fuel cycle. The P&T cycle treats the only elements recovered from high-level radioactive liquid waste (HLLW) of the commercial fuel cycle. Therefore, the heavy metal throughput in the cycle is less than 1/30 of that in the commercial fuel cycle.

Minor actinides (MA) (Am, Cm and Np-237) are most dominant contributors to long-term potential hazard in spent fuel. In addition, Tc-99 in HLW and I-129 from the PUREX reprocessing should be transmuted to shorter-lived or stable nuclides [1]. In Fig. 1, the effect of P&T is shown for the several cases of P&T efficiencies. The goal of technological development is 99.5% removal and transmutation of MA and some of

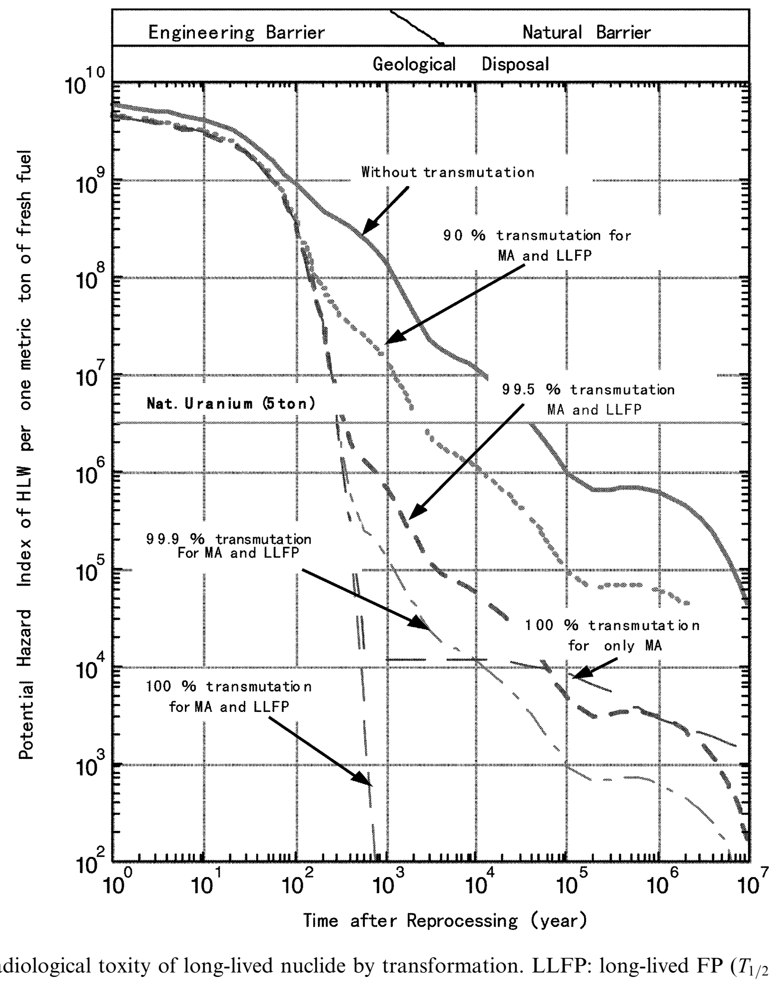

Fig. 1. Reduction of radiological toxity of long-lived nuclide by transformation. LLFP: long-lived FP ($T_{1/2} > 30$ years); MA: minor actinides.

long-lived fission products (LLFP) such as Tc-99 and I-129.

JAERI's activities in the P&T technologies cover the following areas: (a) development of the aqueous partitioning process, (b) design study of dedicated transmutation systems, (c) development of a high power proton accelerator, (d) development of nitride fuel cycle technologies and (e) basic research on nuclear data and fuel property data.

On the basis of the design study, a reference model of ADS was selected. Fig. 2 shows a concept of a dedicated transmutation system at JAERI. The components of the reference ADS are (a) a super conducting proton linac, (b) a lead–bismuth spallation target and (c) a subcritical core using nitride fuel and lead–bismuth coolant. With regard to partitioning process, the four-group partitioning process has been developed to separate the elements in HLLW into transuranium elements, Tc and Pt group metals, Sr–Cs group and others. As a modification effort of the present partitioning process, a more powerful ligand, tridentate diglycolamide has been studied to extract actinides directly from HLLW. In the development of fuel process, it was shown that nitride is suitable to the fuel material for MA transmutation from viewpoint of supporting hard neutron spectrum and high thermal conductivity. In the concept shown in Fig. 2, MA nitride fuel can be used and processed by a molten-salts electrorefining technique.

3. Concept design of ADS

It was concluded that ADS is the best option for MA transmutation from the viewpoints of avoiding use of highly enriched uranium and having the large margin for criticality accidents. JAERI has developed several concepts of ADS such as sodium cooled ADS, molten-salt ADS, molten-alloy ADS and lead–bismuth cooled ADS. Design principles of the ADS are the following: (a) System is specially designed for transmutation purpose. (b) Subcritical core is designed to achieve a hard neutron spectrum and a high neutron flux. (c) Fuel feed consists of MAs and Pu is added to the initial feed only. (d) A system supports about 10 units of large LWR. (e)

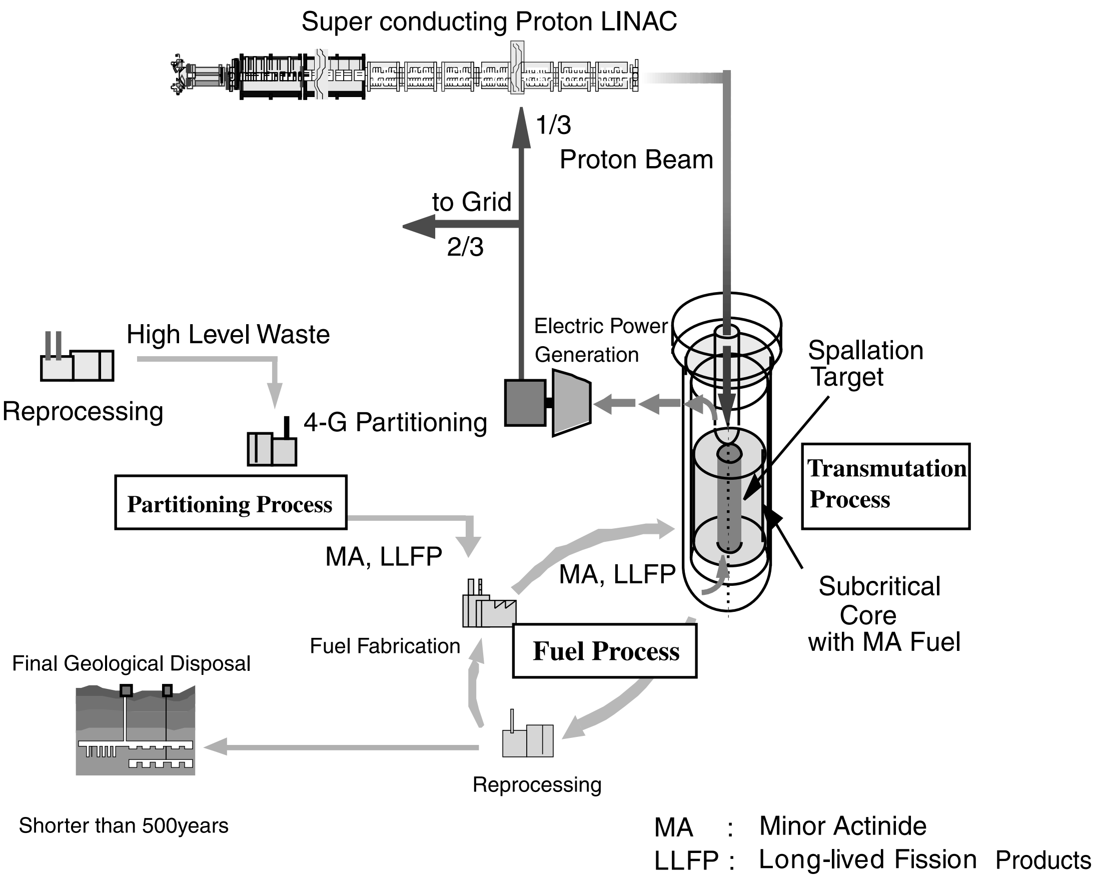

Fig. 2. Concept of a P&T system for long-lived radioactive nuclides at JAERI.

Incident proton beam energy is about 1.5 GeV and the current, few 10 mA. (g) Power generation is involved to supply electricity to operate the accelerator.

Major disadvantages of the sodium cooled ADS are treatment of chemically active sodium and the positive void reactivity [4]. In molten-salt ADS concept [7], the molten salt is used as fuel and target material. One of the disadvantages of molten-salt system is a large actinide fuel inventory [8]. In molten-alloy ADS concept [9], the molten actinide alloy is used as fuel and target material. Major disadvantages of the ADS concept using liquid fuel such as molten salt and molten alloy are the material compatibility and the safety concern of reduced defense-in depth [1].

As a result of the ADS design study, a lead–bismuth cooled ADS was employed. In the reference lead–bismuth cooled ADS model, lead–bismuth is used as both coolant and spallation target. Fig. 3 shows a concept of lead–bismuth cooled ADS. This tank-type configuration makes it possible to accommodate not only the core but also the main primary system including steam generators, main pumps and auxiliary heat exchangers within the reactor vessel. The major system parameters of the lead–bismuth cooled ADS with proton beam power of 30 MW (15 GeV, 20 mA) are shown in Table 1 [5]. The system has 800 MW subcritical core with an effective neutron multiplication factor of 0.95. The operating temperature range of the primary lead–bismuth is from 330 to 430 °C.

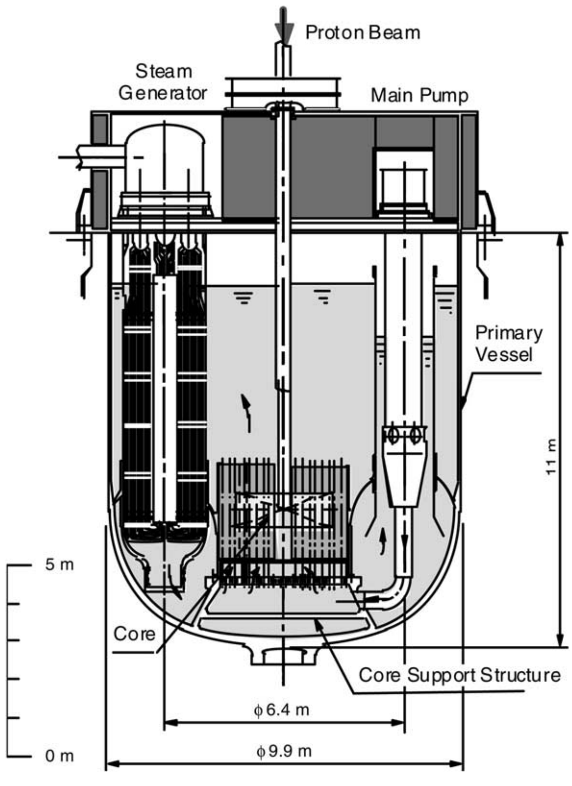

Fig. 3. Concept of lead–bismuth cooled ADS with thermal power of 800 MW.

Table 1
Core performance of a lead–bismuth cooled ADS with proton beam power of 30 MW (1.5 GeV, 20 mA)

Core	
Thermal power	800 MW
Keff	0.95
Core height/diameter (cm)	100/115
Fuel composition	60% MA + 40% Pu
Initial heavy metal loading (kg)	4000
Transmutation of MA (kg/300 days)	250

Table 2
Blanket performance of a lead–bismuth cooled ADS with proton beam power of 30 MW (1.5 GeV, 20 mA)

Blanket	Axial	Radial
Thickness (cm)	25	16
NaI/(NaI + ZrH) (%)	50	40
Initial I loading (kg)	765	839
Transmutation of I (kg/300 days)	35	22

As described in Section 2, LLFP such as Tc-99 and I-129 should be transmuted. Transmutation of MA and I-129 was studied using the reference lead–bismuth cooled ADS. Table 2 shows blanket performance of the MA and I transmutation ADS. Iodine is loaded axially and radially with the form of NaI around the fuel core. It was shown that the reference lead–bismuth cooled ADS can simultaneously transmute MA and I-129 produced from 9 units of LWR per year.

4. ADS experimental facility under the joint project for high-intensity proton accelerator of JAERI and KEK

The joint project for high-intensity proton accelerator was proposed by JAERI and KEK in 1998. The purpose of the joint project is to pursue frontier science in particle physics, nuclear physics, materials science, life science and ADS [6]. For this reason a new proton accelerator complex with the highest beam power is planned. Fig. 4 shows facilities of high-intensity proton accelerator project of JAERI and KEK. The accelerator complex consists of (a) 400 MeV normal-conducting linac, (b) 400–600 MeV super conducting linac, (c) 3 GeV synchrotron ring and (d) 50 GeV synchrotron ring. Extensive studies including condensed matter physics, materials science and structural biology would be carried out using the beam from the 3 GeV ring. Nuclear/particle physics experiments are planned using the beam from the 50 GeV ring. The current 600 MeV linac would be used for ADS experiments.

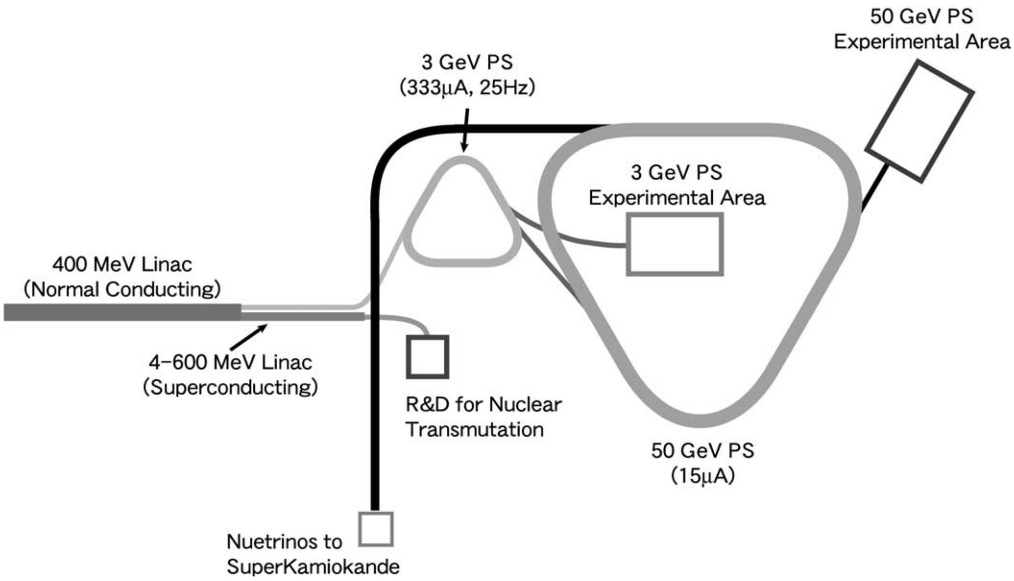

Fig. 4. Facilities planned in high-intensity proton accelerator project of JAERI and KEK.

There are several technical issues to be solved for ADS development. The major areas of the technology such as subcritical reactor physics, system operation and control, transmutation, target design, material irradiation and thermal hydraulics should be tested and demonstrated using the beam from the 600 MeV linac. For this reason two ADS experimental facilities are being designed under the high-intensity proton accelerator project [6,10]. The first one is the ADS physics experimental facility (PEF) for the study on reactor physics of a subcritical core. The second one is the ADS engineering experimental facility (EEF) for the study on material irradiation and lead–bismuth target design. The layout of the experimental facilities of PEF and EEF is shown in Fig. 5.

Table 3 shows the purposes and experimental items at the PEF. Prior to the PEF experiments, data from the fast critical assembly, FCA at JAERI will be

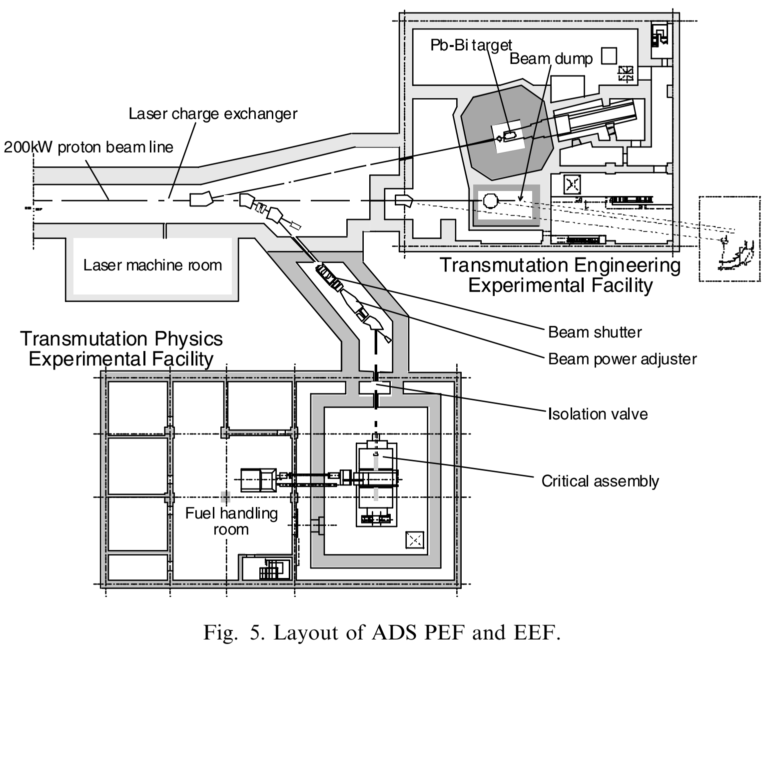

Fig. 5. Layout of ADS PEF and EEF.

Table 3
Purposes and experimental items at ADS PEF

Purposes	Experimental items
Neutronics of fast subcritical systems driven by a spallation source	Power distribution in deep subcritical systems Effective source strength and multiplication factor Effect of high energy particles
Demonstration of controllability of a hybrid system	Feedback control by beam adjustment System behavior for beam trip and restart Energy gain
Validation of transmutation rate of MA and LLFP	MA fission rate LLFP reaction rate in moderated region Reactivity worth of MA and LLFP samples

Table 4
Purposes and experimental items at ADS EEF

Purposes	Experimental items
Material irradiation and corrosion	Estimation of performance and life of beam windows Radiation effects of proton and neutron Corrosion in liquid Pb–Bi
Target design	Optimization of target structure Thermal hydraulics
System control and operation	Heat removal performance Transient response in case of beam trip or re-start

obtained using a Cf-252 neutron source and a 14 MeV D-T pulsed neutron source. These data will be used in designing the PEF facility and planning the experimental program. Neutronics data of fast subcritical systems driven by a spallation source are to be measured. The experimental items relating to system operation/control are beam-power adjustment, control scheme, beam trips. Table 4 shows the purposes and experimental items at the EEF. The major objective of the EEF is to accumulate data for the design of a spallation target system. One of the high priority issues is the estimation of degradation of structural materials in a lead–bismuth coolant at high proton and neutron fluxes. The preliminary estimate of radiation damage indicates that several tens of dpa (displacement per atom) per year can be achieved at 200 kW beam. In order to optimize the target structure the thermal-hydraulic performance of the target and beam window should be also studied.

5. Summary

The study on ADS has been carried out to contribute to the management and final disposal of HLW. The double-strata fuel cycle concept has been proposed by JAERI under the long-term program on P&T, OMEGA program. Under this OMEGA program, JAERI has performed the development of the aqueous partitioning process, design study of transmutation systems, development of a high power proton accelerator and nitride fuel technologies, and basic study on nuclear data and fuel property.

As a result of a design study of a dedicated transmutation system, JAERI decided to concentrate its efforts for transmutation study on the development of ADS. JAERI has developed several concepts of ADS such as sodium cooled ADS, molten-salt ADS, molten-alloy ADS and lead–bismuth cooled ADS. A lead–bismuth cooled 800 MW ADS was employed as a reference ADS model. It was shown that the lead–bismuth cooled ADS can simultaneously transmute MA (Am, Cm and Np-237) and I-129 produced from 9 units of LWR per year.

JAERI and KEK started a new joint program called the high-intensity proton accelerator project to perform the wide rage studies on life science, material science, particle physics, nuclear physics and ADS technology. In this program, two experimental facilities are planned to develop and demonstrate the accelerator driven transmutation technology. The major objective of an ADS physics experimental facility is to obtain reactor physics data of hybrid subcritical system. The major objective of an ADS engineering experimental facility is to accumulate material data for the design of a lead–bismuth target system.

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