R & D STATUS ON TRANSMUTATION OF MINOR ACTINIDES AND FISSION PRODUCTS IN JAERI

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ABSTRACT

According to OMEGA program JAERI has carried out the R & D on the transmutation of long-lived radioactive nuclides such as minor actinides and fission products. To transmute the nuclides design studies of actinide burner reactors and accelerator driven transmutation system have been conducted in parallel with R & D efforts on acquisition of nuclear data, fuel property data, development of compute code, and so on. R & D to construct the Engineering Test Accelerator (ETA) for the transmutation has also been carried out.

INTRODUCTION

The national policy of management of high level radioactive waste in JAPAN is to solidify in a stable form and to dispose of ultimately into deep geological formations after 30 to 50 years of storage for cooling. Toward this goal, guidelines for research and development were adopted in 1980 by the Advisory Committee on Radioactive Waste Management to the Atomic Energy Commission. This has been further endorsed in the last revision of the long-term Program for Development and Utilization of Nuclear Energy by the Atomic Energy Commission in 1987.

At the same time, the long-term program called OMEGA program, has adopted to promote the following two R and D items from the standpoint of conversion of high-level radioactive waste into useful resource and of their disposal efficiency (1):

1. Separation of nuclides contained in reprocessing HLW according to their half-lives and potential usefulness.
2. transmutation of long-lived radioactive nuclides into short-lived nuclides or non-radioactive nuclides.

Along with the OMEGA program, R & D are being carried out in a systematic way by the collaborative efforts of the Japan Atomic Energy Research Institute (JAERI), the Power Reactor and Nuclear Fuel Development Corporation (PNC), and the Central Research Institute of Electric Power Industry (CRIEPI), MOX-fueled FBR (PNC), intense proton accelerator (JAERI), and electron accelerator (PNC) have been studied. R & D status on the transmutation of MA and FP in JAERI is reported.

TRU TRANSMUTATION BY ACTINIDE BURNER REACTORS (2)

Conceptual design study has been carried out on 'Actinide Burner Reactor (ABR)' which is a kind of fast neutron reactor specially designed for efficient burning of TRU elements or minor actinides (MA). Since most MA have a fission threshold at neutron energy above 700 MeV, a very hard neutron spectrum has to be achieved throughout the core in order to burn them effectively. Two types of reactor design have been evolved. The first design concept is a sodium-cooled ABR with metallic MA fuel (M-ABR). The advantages of the M-ABR are its very hard neutron spectrum and the compactness of the accompanying fuel cycle facility where spent fuel is recycled by a pyrometallurgical process. The second concept is a helium-cooled ABR with MA-nitride particle fuel (P-ABR). In this reactor a very high power density is achievable because the heat removal of the core is excellent thanks to large heat transfer surface of the particle per unit volume. Coated fuel consists of actinide nitride microspheres and thin TiN coating. Major design parameters for both types of ABRs are shown in Table I. One unit of a modular reactor which consist of 6 modules of M-ABR (1020 MWt) or one unit of 1200 MWt of P-ABR can transmute about 290 kg of TRU in a year which is the amount of TRU generated in 11 units of 1000 MWe PWR per year. Based on the ABR design, a concept of 'double strata nuclear fuel cycle' has been developed as shown in Fig. 1.

To support these design activities, several R & D efforts are in progress. One of such efforts is the phase diagram and thermodynamic studies on MA alloys which are being carried out under the cooperation with the Oak Ridge National Laboratory (ORNL). The integral experiment has also been

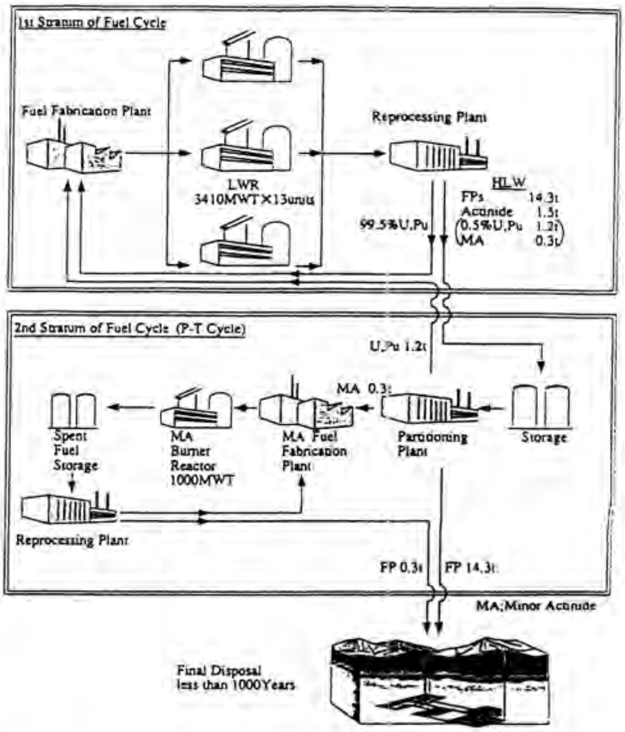

Fig. 1. Flow of high-level radioactive waste per year through double strata fuel cycle combined with partitioning and transmutation (MA burner reactor) cycle.

TABLE I
Major Design Parameters of Actinide Burner Reactors

	M-ABR[1]	P-ABR[2]
Fuel Concept	IC[3]: Np-22Pu-20Zr OC[3]: AM-CM-35Pu-5Y	Coated Particle $(66NpAmCm\text{-}34\ Pu)_{1.0}N_{1.0}$
MA initial loading[4] kg	666	2065
Np/Am,Cm/Pu	255/199/212	765/598/702
Reactor power, MWth	170	1200
Coolant material	Sodium	Helium
velocity, m/s	8	total flow 1088kg/s inlet pressure 10MPa pressure drop 13kPa
inlet temperature °C	300	127
outlet temperature °C	IC:484, OC:440	340
Fuel temp., max[5] °C	IC:834, OC:809	722
Clad temp., max[6] °C	IC:517, OC:484	Frit temp., max. 560
Neutron flux, 10^{15} n/cm^{2}s	IC:4.1, OC:3.4	8.4
Neutron fluence (E > 0.1MeV), 10^{23} n/cm^2	IC:2.2, OC:1.7	2.2
Core averaged mean neutron energy, keV	IC:766, OC:785	743
Reactivity (%Δk/k)		
Na-void reactivity/core	2.52	-
Doppler reactivity/core (Δt = 300°C)	-0.01	-0.01
Kinetic Parmeters		
βeff	1.55×10^{-3}	1.72×10^{-3}
Lp,sec	6.84×10^{-8}	10.8×10^{-8}
Cycle length, full-power days[7]	730	300
MA transmutation, %cycle	26.0	25.3
MA burnup, %cycle	17.8	17.3

1. M-ABR: MA metallic fuel burner reactor
2. P-ABR: MA particle fuel burner reactor
3. IC: Innere Core, OC: Outer core
4. After 1st cycle, only Np, Am, Cm are added
5. Predicted melting point of fuel 900°C for M-ABR
   Max allowable temp. of fuel 727°C(1/3 of M.P. 3000K) for P-ABR
6. Max. allowable temp. of cladding/frit (HT-9) 650°C

conducted in the fast critical facility (FCA) of JAERI to evaluate and refine cross sections for MA.

TRANSMUTATION WITH PROTON ACCELERATORS

Development of Simulation Codes for a Spallation Process (3)

The simulation code NMTC of ORNL for high energy nuclear reaction process in the energy range from 15 MeV to 3 GeV was modified as NMTC/JAERI to calculate high energy fission reaction above 15 MeV and spallation reaction of minor actinides. The simulation code 'NUCLEUS' for spallation reaction of one nucleus was developed to evaluate a computational model for spallation reaction and analyze the date measured in thin foil experiments. these codes will be improved to include pre-equilibrium neutron emission and fragmentation process in spallation reaction. The intercomparision of the routines for high energy fission calculation of NMTC/JAERI and HETC/KFA is planned. The code SPCHAIN has been developed by combining NMTC/JAERI with the neutron transport codes, one with MORSE-DD and the other with TWOTRAN-II.

Experiments from Spallation in a Heavy Metal Bulky Target (4)

The integral experiment with a lead bulky target and 500 MeV protons from the booster facility at the Institute of High Energy Physics (KEK) was started in 1990 to evaluate the reliability of the code NMTC/JAERI. The neutron energy spectrum, spatial distribution and the yields of spallation products were measured.

Design Study of Transmutation System with Solid Target (5)

A conceptual design study on the accelerator-driven transmutation system which consist of a sodium-cooled subcritical core with actinide fuels and a tungsten target has been conducted. Neutronics and thermal hydraulics calculations were performed to estimate the performance of the system. In the design, the core generates the thermal power of 820 MW within the maximum allowable temperature limits of the actinides alloy and ODS cladding. The core, with the effective neutron multiplication factor of about 0.89, is driven by a 1.5GeV-39 mA proton accelerator. The present system transmute about 250 kg of actinide annually, which corresponds to the actinides production rate in about 10 units of 3000 MWt LWR. the system generates electricity of 246 MW(820 MWt) with a conventional steam turbine, and supplies sufficient electricity to power the accelerator. The major design parameters and conceptual flow diagram for the accelerator transmutation system with solid target are shown in Table II and Fig. 2, respectively.

Design Study of MA Transmutation System with Molten Salt Target (6)

A preliminary design study on the transmutation system for MA and FP was studied. Molten chloride salt of NaC1 - (Pu,MA) $C1_3$ system has been adopted for the target salt of MA transmutation. the advantages of use of molten chloride salts instead of the fluoride salts as the target will be as follows:

1. to establish a fast neutron spectrum system,
2. to expect large solubility of actinide in the chloride salt, and high transmutation rate, eventually,
3. possibility to establish a continuous transmutation system with on-line separation facilities for the elements transmuted by spallation and fission reactions.

In the design, the molten salt target with the effective multiplication factor of about 0.92 is driven by a 1.5GeV-25mA proton beam. the present system transmute about 250 kg of actinide annually. The system generate thermal output of about 800 MW (corresponding to about 300 MWe). the major design parameters are shown in Table II, comparing with those of the solid target system design.

The transmuted elements in the chloride salt target can be classified into 3 groups based on the chloride formation energy. First group is composed on inert gases and volatile chloride, 2nd group noble metals and transition metals, and 3rd group alkaline earth metals, lanthanide and yttrium chlorides. The Hepurge method and Cd-metal extraction method for on-line separation will be applicable to 1st and 2nd group, respectively. the cold trapping method may be applicable to 3rd group. the continuous transmutation system may be realized by adopting these on-line separation methods. the schematic images of molten salt target system and the on-line separation system are shown in Fig. 3.

Design Study of FP Transmutation System with Bi-Pb Liquid Target (6)

For the FP transmutation Bi-Pb fluid target system with heavy water blanket is studied. Tc-99 may be contained in the water as a slurry of TcO_2 and I-129 solved as ion from solution of $A1I_3$. In this concept neutrons produced by the spallation reaction with Bi-Pb target transmute Tc-99 to Ru and I-129 to Xe of stable nuclides. To obtain the effective transmutation velocity neutron flux of around 10^{15} n/cm^2s is required. The radiation damage and corrosion to the wall of the Bi-Pb vessel are serious problems. The austenitic stainless steel, however, may be applicable if the temperature of the wall can be

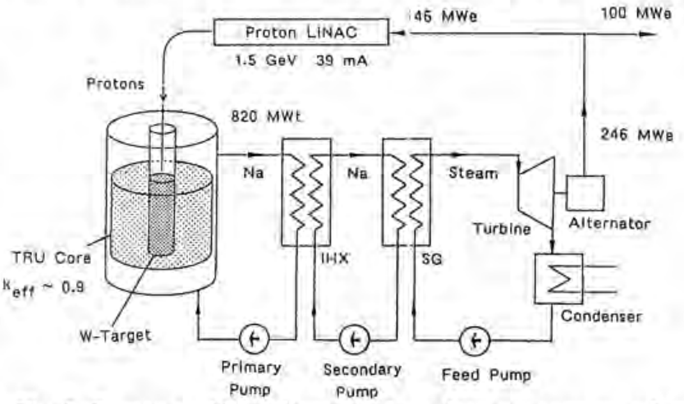

Fig. 2. Conceptual flow diagram of accelerator transmutation system with solid target.

TABLE II

Major Design Parameters of Accelerator Transmutation System of Solid and Molten Salt Targets

	Solid System	Molten-Salt System
Fuel	Np-15Pu-30Zr AMCm-35Pu-10Y	64NaC1-5PuCl3-31MAC13 (MA:Np,AmCm)
Inventory	3160kg	5430kg
Multiplication Factor	0.89	0.92
Spallation Neutrons	40n/p	38n/p
Proton Beam	1.5GeV-39mA	1.5GeV-25mA
Thermal Power	820MW	800MW
Burnup	250kg/y	250kg/y
Power Density		
maximum	930MW/m^3	1660MW/m^3
average	400MW/m^3	310MW/m^3
Temperature		
core inlet	330°C	550°C
core outlet	430°C	650°C
Maximum Velocity	8m/s	3.6m/s

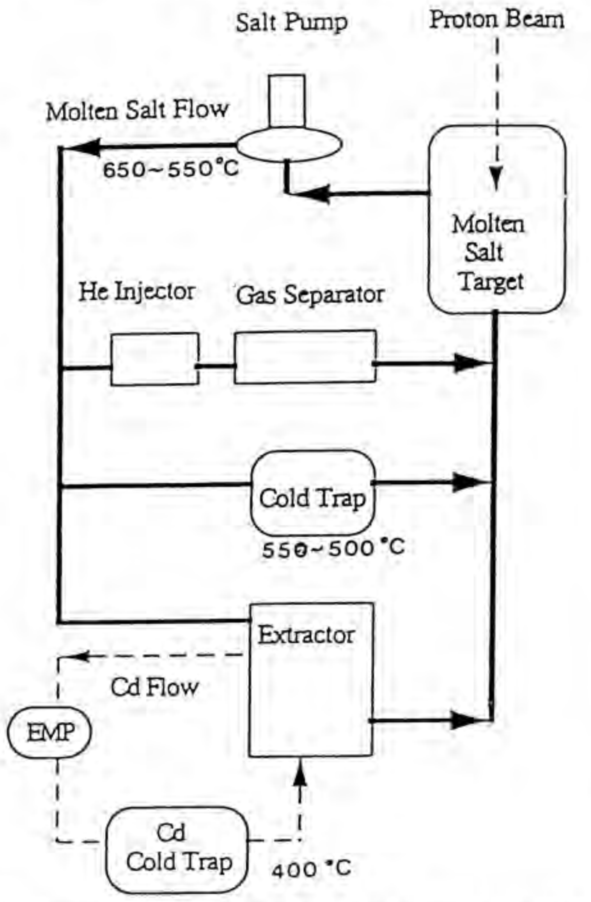

Fig. 3. Conceptual flow diagram of accelerator transmutation system with molten salt target.

controlled under 300°C. The schematic image of the FP transmutation system is shown in Fig. 4.

DEVELOPMENT OF AN INTENSE PROTON ACCELERATOR (7)

The construction of Engineering Test Accelerator (ETA) with a proton energy of 1.5 GeV and a current of 10 mA is planned. Various engineering test will be performed using this accelerator for an accelerator-driven transmutation system. ETA is a significantly large system. In particular, an average proton current of 10 mA is 10 to 50 times larger than that of existing accelerators used for nuclear physics experiments. As a first step, Basic Technology Accelerator (BTA) with proton energy of 10MeV and a current of 10mA is to be built to study a low energy portion of the accelerator. A study of high energy portion of the accelerator (high β structure) is also planned. The schematic layout of the ETA is shown in Fig. 5. As a hot *model* test, a RF power source will be built and the electric and magnetic characteristics of ETA will be measured. Various computer design codes are to be checked for their reliability. The conceptual design study for the performance parameters of ETA is being carried out.

CONCLUSION

Various R & D activities related to the partitioning and transmutation are in progress in parallel at JAERI, PNC and CRIEPI under the OMEGA program in Japan. In the transmutation research at JAERI the actinide burner reactors and

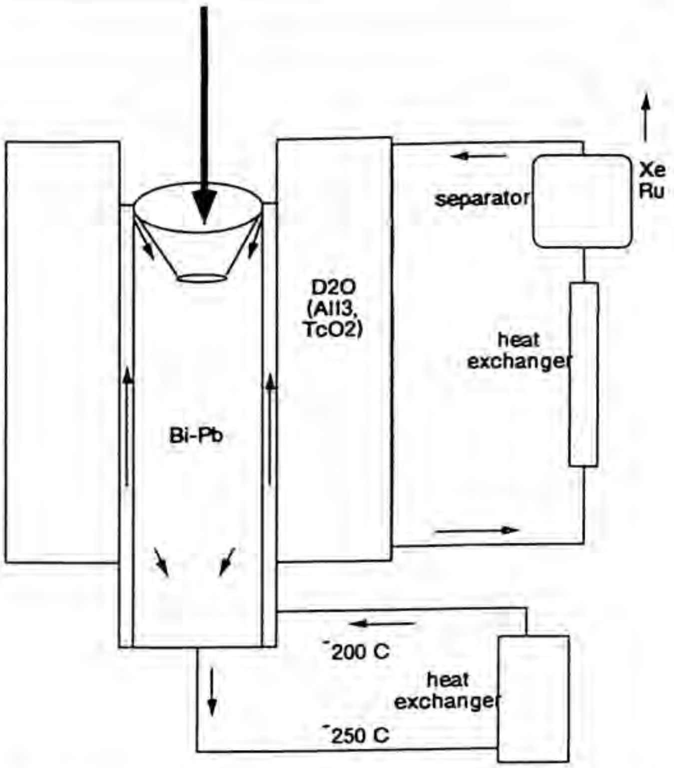

Fig. 4. Schematic image of accelerator transmutation system for FP transmutation.

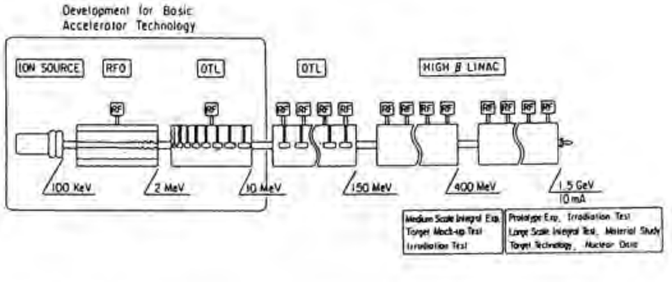

Fig. 5. Schematic layout of Engineering Test Accelerator (ETA)

accelerator transmutation systems are concurrently studied obtaining the fundamental data such as nuclear data, physical chemical data on actinide fuels, irradiation data on fuels and materials, thermal hydraulic data, beam dynamics of intense accelerator, and so on. In the design study, M-ABR and P-ABR of about 1000MWt can transmute about 290 kg of TRU in a year, and the accelerator transmutation system with solid or molten salt target can transmute about 250 kg TRU in a year by the introduction of the proton beam of about 1.5GeV-39 to 25 mA.

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