PRESENT STATUS OF ACCELERATOR BASED TRANSMUTATION STUDY AT JAERI

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The overview of the Japanese long-term research and development program on nuclide partitioning and transmutation, called "OMEGA," is presented. Under this national program, major R&D activities are being carried out at JAERI, PNC, and CRIEPI. Transmutation study at JAERI is focused on dedicated transmutors and directed toward two approaches; actinide burner fast reactor and proton accelerator-based transmutation system. The conceptual design study of an accelerator-based transmutation system with a spallation target and a subcritical actinide-loaded core is discussed. JAERI is proposing the development of a high-intensity proton linear accelerator ETA with 1.5 GeV-10 mA beam to perform engineering tests for accelerator-based transmutation. Achievements in the accelerator development are described.

1. OMEGA PROGRAM

National policy of managing high-level radioactive waste (HLW) in Japan is based on disposal into a deep geological formation after solidification into a stable form and cooling for 30-50 years. In addition, to widen options of future waste management and to explore the possibility to utilize HLW as useful resources, Japan Atomic Energy Commission submitted in 1988 a report entitled "Long-Term Program for Research and Development on Nuclide Partitioning and Transmutation Technology." The report plots a course for technological development up to the year 2000. This program is called "OMEGA," which is the acronym derived from Options Making Extra Gains from Actinides and fission products.

The R&D programs were jointly stimulated by the collaborative efforts of the Japan Atomic Energy Research Institute (JAERI) and the Power Reactor and Nuclear Fuel Development Corporation (PNC). In the public sector, the Central Research Institute of Electric Power Industry (CRIEPI) also has been carrying out R&D on this subject.

The program is conceived as a research effort to pursue benefits for future generations through the long-term basic R&D, and is not to seek a short-term alternative for established or planned fuel cycle back-end policies. The program is expected to serve to revitalize the nuclear option into the 21st century in a healthy state. In addition, advancement of technologies such as accelerator technology, as advocated in this program, will provide potential spin-offs for other fields of science and technology.

The program is to be proceeded in two steps: the phase-I and H. The phase-I covers a period up to about 1996, and the phase-II covers a period from about 1997 to about 2000. In general, the basic studies and testings are to be conducted in the phase-I to evaluate various concepts and to develop required technologies. In the phase-II, engineering tests of technologies or demonstration of concepts are planned. After 2000, pilot facilities will be constructed to demonstrate the partitioning and transmutation (P-T) technology.

Within the framework of the OMEGA program, following R&D activities are underway at JAERI, PNC, and CRIEPI.

JAERI : Four-group partitioning process
Actinide burner fast reactor

Proton accelerator-based transmutation system

PNC : TRUEX -based partitioning process
Transmutation with oxide fuel fast breeder power reactor
Transmutation of Sr-90, Cs-137 by electron accelerator

CRIEPI : Pyrometallurgical process
Transmutation with metallic fuel fast breeder power reactor

2. TRANSMUTATION STUDIES AT JAERI

A dedicated transmutor with a very hard neutron energy spectrum and high neutron flux would be very efficient and effective for minor actinide (MA) transmutation if it is technically feasible. In this context, JAERI has been pursuing the concepts of actinide burner fast reactor and accelerator-based transmutation system, rather than the transmutation schemes using commercial power reactor.

With the dedicated transmutor, the troublesome MA from the waste management view point could be confined in a P-T fuel cycle for transmutation, which is separated from the commercial one for power generation. The concept of double-stratum fuel cycle will offer several advantages over the recycling of MA to the commercial power reactor. These are higher transmutation rate, effective confinement of MAs, and no impact on the power reactor operation. There will be no additional shielding and cooling requirements to the conventional fuel cycle.

3. ACTINIDE BURNER FAST REACTOR [1)]

Two types of reactor concept are proposed, one is the metallic fuel and sodium cooled type, called M-ABR, another is the nitride coated particle fuel and helium cooled type, named P-ABR.

M-ABR is a modular plant consisting of six 170-MWt reactors. The core is separated into two regions; an inner core composed of Np-Pu-Zr fuel and an outer core composed of (Am, Cm)-Pu -Y fuel. The mean neutron energy in the core is about 800 keV. Hard neutron spectrum is achieved to transmute actinides effectively by fast fission reaction. One plant can transmute 300 kg/y of actinides.

P-ABR has fuel elements of particle bed formed in the annular space of concentric porous tits. Fuel particles are dire ctly cooled with helium gas. Very high power density is obtained since a large heat transfer surface per volume is very effective for heat removal. A fuel particle consists of actinide nitride microsphere and thin TiN coating layers. P -ABR has a thermal power of 1200-MW and can transmute 360 kg of actinides annually.

4. R&D ACTIVITIES ON ACCELERATOR-BASED TRANSMUTATION

JAERI R&D includes the conceptual design study of accelerator-based transmutation plant, the development of spallation simulation code system, and the spallation integral experiments.

In the design study of transmutation plant, two types of system concepts are being investigated; solid system and molten-salt system. In either system, an MA-loaded subcritical core is driven by a high-intensity proton accelerator and uses fast neutron to bum MAs efficiently.

A computer code system has been developed for the design of accelerator-based transmutation system 2) The High Energy Nuclear Reactions and Nucleon-Meson Transport code NMTC/JAERI 3) simulates the proton-induced nuclear spallation, subsequent internuclear transport process for energies above 15 MeV. It also calculates high energy fission reaction as a competing process with evaporation. Neutronic calculation below 15 MeV is carried out using transport codes, TWOTRAN, MORSE, and MCNP. The time evolution process of transmutation products is calculated by SPCHAIN code and by ORIGEN-2 code for energies above and below 15 MeV, respectively. The code system has been upgraded and improved by incorporating current models and methods.

Spallation integral experiments 4) have been carried out to obtain data on the neutron and spallation product yields and to evaluate the validity of the simulation code system. The 500 MeV booster proton synchrotrons facility at the National Laboratory for High Energy Physics (KEK) is used for the experiments. A lead/tungsten target was installed in the center of a lead assembly with a diameter of 600 mm and a length of 1000 mm. The activation samples of Al, Fe, Ni and Cu *were* inserted in the holes drilled through the assembly along the beam axis at various radial positions. The number of induced activities in the sample was obtained by measuring y-rays with 100 cc Ge -detector. Experimental results agreed fairly well with prediction by NMTC/JAERI.

5. ACCELERATOR-BASED TRANSMUTATION SYSTEM CONCEPTS

5.1 Solid Target/Core System 5)

A conceptual design study has been made on an accelerator-based MA transmutation plant with a sodium-cooled solid target/core (Fig. 1). A 1.5 GeV proton beam is injected through beam window into the tungsten target located at the center of MA-loaded subcritical core. Spallation neutrons from the target induce fission reactions in the MA fuel. Heat generated in the target/core is removed by primary sodium, then transported through secondary loop to the power conversion system.

The fuel compositions are Np-15Pu-30Zr and AmCm-35Pu-10Y. These alloy systems are proposed for a sodium-cooled actinide burner reactor (M-ABR). In the fuel subassembly design, measures are incorporated to ensure adequate fuel cooling during out-of-core handling operation. The target subassembly, composed of tungsten disks, is designed to maximize the number of emitted neutrons and to flatten the axial distribution of neutron flux.

The fuel and target subassemblies are cooled by forced upward flow of sodium. The beam window is cooled by a sodium flow from the target. The whole target/core including reflectors is contained within a steel reactor vessel.

Heat transport and power conversion systems are based on the current design practice for a sodium-cooled fast breeder reactor plant. A primary reactor auxiliary system with NaK loops is provided as an independent means of removing target/core decay heat.

With a 1.5 GeV-39 mA proton beam, the target/core having an effective neutron multiplication factor 0.89 produces 820-MW thermal power. Assuming a load factor of 80%, the MA burnup (fission) is approximately 250 kg/y, or 8 %/y. The result shows that the system can support about 10 units of 1000-MWe light water reactor (LWR). An electric output of 246 MW is obtained at a plant thermal efficiency of 30%. The power required to operate the 1.5 GeV-39 mA accelerator is 146 MWe, assuming a 40% efficiency. This means that the system is more than self-sufficient in terms of its own energy balance.

5.2 Molten-Salt Target/Core System [6)]

A conceptual design study is being performed on an 800-M Wt molten-salt core target/system as an advanced option for an accelerator-based nuclear waste transmutation system. Chloride salt with a composition of $64NaCl\text{-}5PuCl_3\text{-}31\,MACl_3$ is chosen for the molten-salt system based on the consideration mainly about actinide volubility. The molten-salt acts both as fuel and as target material, and at the same time it also serves as coolant in the molten-salt system. This significantly simplifies the core/target system configuration, as schematically shown in Fig. 2.

High energy proton beam at 1.5 GeV is injected into the central core/target region through the beam window. The core/target region is surrounded by an internal reflector. Intermediate heat exchangers and salt pumps are installed in the annular region around the internal reflector. This in-vessel heat exchanger design minimizes the total actinide inventory in the system.

The molten-salt target/core has an effective neutron multiplication factor of 0.92, and produces 800-MW thermal power with a 1.5 GeV-25 mA proton beam.

The molten state of fuel salt offers several attractive features for the design of transmutation system. The main advantage over the solid system is the capability of the continuous on-line processing. The fuel composition can be continuously controlled and fission and spallation products can be continuously removed from the fuel.

6. PROTON ACCELERATOR DEVELOPMENT [7]

The construction of a high-intensity proton linear accelerator called the Engineering Test Accelerator (ETA, 1.5 GeV-10 mA) has been proposed by JAERI for the purpose of performing various tests for accelerator-based transmutation and other possible nuclear engineering applications. The conceptual layout of ETA is shown in Fig. 3.

In the case of high-intensity accelerator, it is particularly important to minimize beam losses to avoid resultant damage and activation on the accelerator structures. The beam quality and maximum current are mainly determined in the low energy portion of the accelerator. As a first step toward the construction of ETA, the Basic Technology Accelerator (BTA, 10 MeV-10 mA) is designed for the mockup test of the low energy potion. Because of the high beam current and high duty factor (10%), heat removal from the accelerator structure is an important issue for the mechanical design. Temperature distribution, thermal stresses and displacements were carefully studied with the 3-dimensional modeling codes. The main accelerator components, ion source, radio-frequency quadruple (RFQ), and radio-frequency (RF) sources, for BTA have been developed and beam tests are successfully performed.

The conceptual studies for ETA are underway in collaboration with the Los Alamos National Laboratory (LANL). These studies include design optimization for the operating frequency, the energy configuration, and the high β structure based on beam dynamics and mechanical engineering considerations, aiming at ensuring low beam loss, hands-on maintenance and reduced construction cost .

7. SUMMARY

The background of the OMEGA Program and its R&D areas were overviewed. The program pursues benefits for future generations through the long-term basic R&D.

The R&D activities at JAERI include the development of four-group partitioning process, the design study of MA burner fast reactor sand accelerator-based transmutation systems, the development of a high-intensity proton accelerator, and the related data measurement.

A conceptual design study of an accelerator-based transmutation plant with a sodium-cooled solid target/core has been carried out. The proposed plant *transmutes* about 250 kg of MA per year with a 1.5 GeV-39 mA proton beam and generates enough electricity to drive its own accelerator. The molten-salt system of chloride MA has been also examined as an another option with a capability of continuous on-line chemical processing. Simulation code development and spallation integral experiments have been made to improve the method and data for the design of accelerator-based transmutation systems.

The R&D works for prototype accelerator components (ion source, RFQ, DTL, and RF source) for high-power test are in progress. The detailed design of the BTA is followed in the next stage based on the results of the R&D work.

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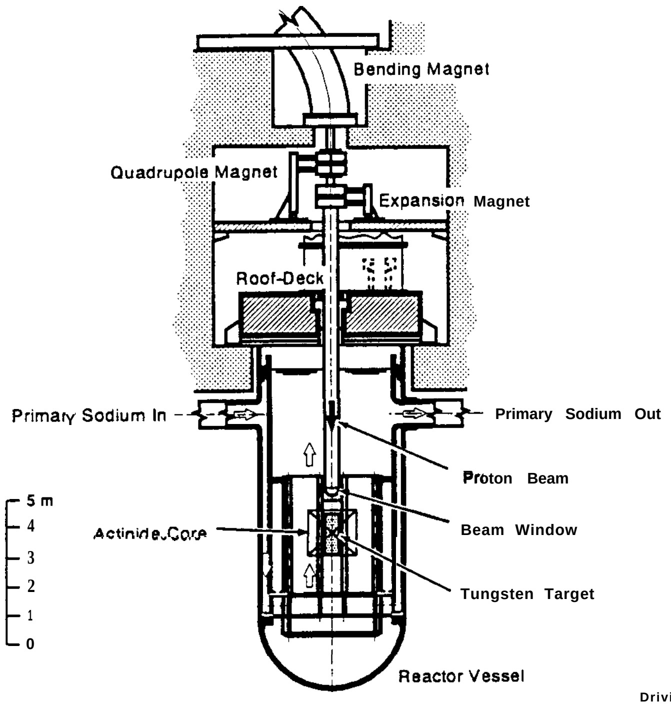

Fig. 1 Solid Target/Core System

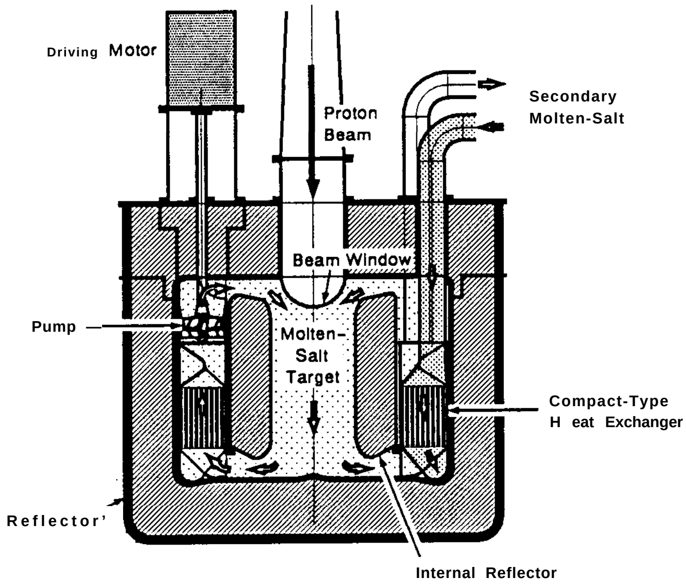

Fig. 2 Concept of Molten-Salt Target/Core System

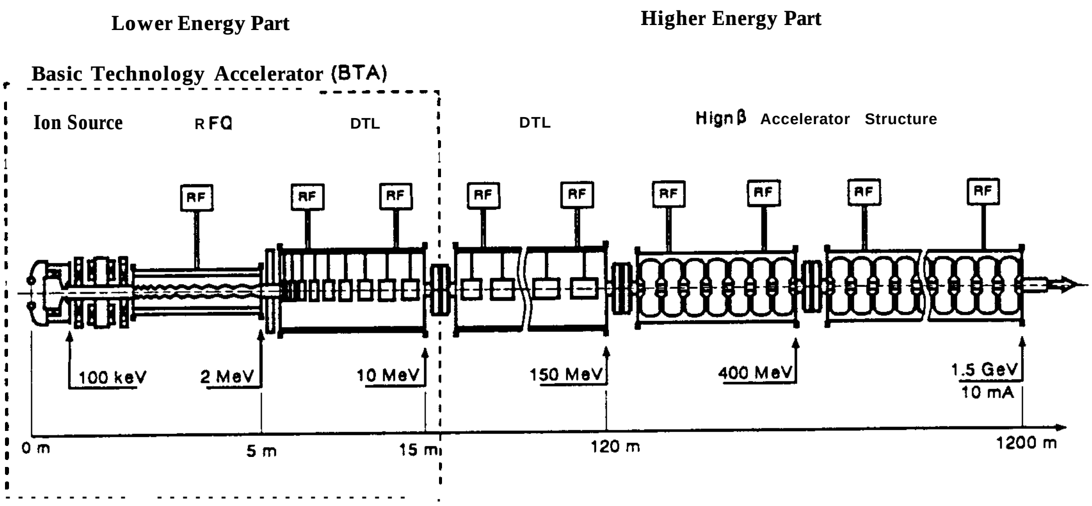

Fig. 3 Conceptual Layout of Engineering Test Accelerator (ETA)