Transmutation of Transuranium Waste with High Energy Proton Induced Spallation Reaction

M.Mizumoto, H.Takada, T.Nishida, I.Kanno, K.Hasegawa,
H.Yasuda, Y.Nakahara, T.Takizuka, H.Akabori, Y.Okumura,
M.Sugimoto, H.Shirakata, R.A.Jameson* and Y.Kaneko

Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

Transmutation of radioactive nuclear waste using a proton accelerator-driven transmutation (TRU) target system has been studied as a possible way to convert long-lived wastes into shorter-lived substances. The recent advances made in accelerator technology during the past decade and other considerations related to reactors and radioactive waste make it timely to re-examine this subject. Accelerators can now be provided with higher efficiency (using higher beam intensity capability, high beam loading and high efficiency RF power) and improved beam handling techniques. The proposed transmutation system and requirements to the accelerator system is described in the present paper.

Introduction

Studies of basic technologies for the nuclear wastes transmutation and nuclide partitioning have continued for the last several years, although the geological disposal techniques are also supported in the community. The Japanese Atomic Energy Commission has concluded in June 1987 that R&D efforts for these technologies should be strengthened as a national research project, where the possible use of valuable resources in the waste and improvements of safety assurance in management processes have to be evaluated. This national program called OMEGA (Options Making Extra Gains from Actinides and Fission Products) has started by aiming at promoting the research and development of the new technologies on nuclear waste partitioning and transmutation. As a part of this program, Japan Atomic Energy Research Institute (JAERI) has laid out several R&D plans for advanced partitioning technology, actinide burner fast reactor and spallation based actinide transmutation.

In this proposal, nuclear spallation reactions with high energy (say above 1 GeV) proton beams are considered as one of the effective transmutation processes. The need for the development of a high-energy high-current proton linear accelerator (linac) is stressed for that purpose. Such a high intensity proton linac is also expected to contribute to developments in other various research fields. Nuclear spallation reactions with high energy proton beams will produce intense neutron fluxes, that in turn can be utilized for the production of nuclear fuels in addition to nuclear waste incineration. Applications to material sciences, radio isotope productions and muon catalyzed fusion may be carried out using these neutron, muon and pion beams.

* Visiting from Los Alamos National Laboratory

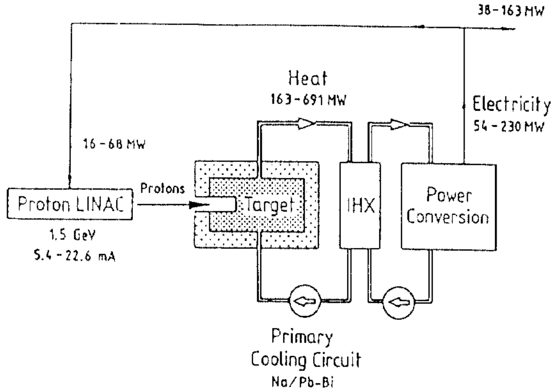

Fig. 1. Actinide transmutation system with proton accelerator.

A study of the transmutation system

The basic concept of the incineration system with proton spallation reactions has been studied at JAERI for the last several years[1]. The main goal of this program is to process the TRU of which the yearly production rate is typically 30 kg for a 1000 MWe LWR. The detailed description of a transmutation target, neutronics calculation and power dissipation calculation is given previously[2-4]. Only the essential part of the scheme will be described in this paper.

Figure 1 shows a model for an accelerator driven target system in combination with a subcritical reactor. The proton energy is initially taken to be 1.5 GeV, a value that has been estimated from the preliminary calculations to be the most efficient energy. The target and fuel assembly in the reactor proposed here are similar to that used for the common fast breeder reactor as shown in Figs. 2 and 3. The target design parameters are summarized in Table 1 with the fuel composition and dimension. Two kinds of coolant materials, Na and Pb-Bi are used in the calculations. The target is surrounded by stainless steel reflector. A harder neutron spectrum is preferable in order to make the transmutation more effective, because the fission reaction rate exceeds

Table 1. Taget design parameters.

Coolant	Na/Pb-Bi
Proton energy	1.5 GeV
Target	
Length	200 ~ 260 cm
Height	100 cm
Width	100 cm
Tungsten	
Length	60 cm
Height	100 cm
Width	10 cm
Reflector	
Composition	Stainless steel
Thickness	20 cm
Fuel	
Composition	Np-15Pu-30Zr AmCm-35Pu-10Y
Bond	Na
Clad	HT-9 steel
Fuel slug diameter	4.00 mm
Clad outside diameter	5.22 mm
Clad thickness	0.3 mm
Pin length	1000 mm

the capture rate for increasing the neutron energy.

Primary nuclear spallation reactions and the subsequent particle transport processes were simulated using the NMTC/JAERI code[5] for the neutron energy range above the cutoff energy of 15 MeV. Below this energy, a three dimensional Monte Carlo transport code was used. The keff value was taken in the range of 0.86 - 0.95 for the calculation.

Two-dimensional thermal hydraulic calculations were made for Na and Pb-Bi cooled targets. The maximum achievable thermal power was limited by a maximum allowable temperature that was set at 900 ^{o}C in the fuel and cladding. The calculated maximum thermal output powers were 405 MW and 163 MW for Na and Pb-Bi cooling, respectively. Accordingly the averaged power densities were 159 W/cc and 83 W/cc using the incident proton beam current of 18.2 mA and 5.4 mA required for these target powers.

In addition to these reference target assemblies, the tungsten loaded assemblies were also considered to make the power density flat. The maximum thermal power can be increased by about a factor of 2 by introducing the tungsten. The calculated results were summarized in Table 2. The two dimensional power distribution profile is shown in Fig. 4. The power output for Na was found to be considerably higher than that of Pb-Bi due to the effective cooling capability of sodium.

From these calculations, the spallation neutrons and the subsequent induced fission neutrons can transmute the TRU produced by 4 - 8 LWR in a Na cooled subcritical assembly. As a by-product, this system can be used to produce excess electric power of about 50 - 200 MW, a part of which can be used to operate the proton accelerator.

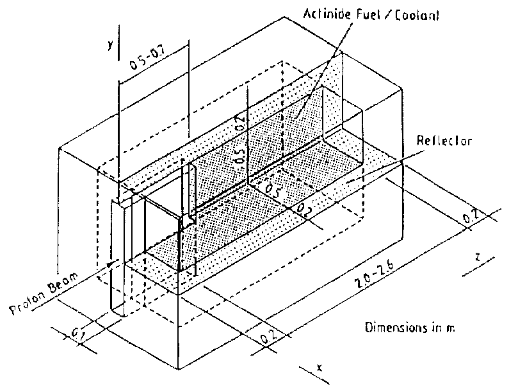

Fig. 2. Target design.

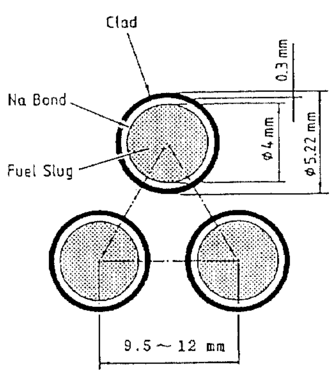

Fig. 3. Fuel pin geometry.

Accelerator development.

The conceptual design of the engineering test accelerator for actinide transmutation has been proposed by JAERI with a beam energy of 1.5 GeV and a current of 10 mA as shown in Fig. 5. This accelerator represents a large scale system when compared to the contemporary proton accelerators that are used mainly for basic nuclear physics experiments. In particular, an average proton beam current of 10 mA is nearly 10 - 50 times larger than that for existing accelerators. To obtain such high beam current, only a linac can meet the necessary requirements. Other circular accelerators such as a cyclotron or synchrotron accelerate much smaller beams with maximum currents of about 1 mA. Beam spill can not be controlled effectively in the case of circular accelerators, and will cause serious problems due to the high level activities induced in the accelerator structures.

As the first step in the development, the low energy portion of the accelerator structure will be studied, since the beam quality is determined mainly by this low energy portion. The Basic Technology Accelerator will consist of the following components; ion source, radio frequency quadruple (RFQ) and drift tube linac (DTL). The beam energy is chosen to be less than 10 MeV, below the Coulomb barrier, to avoid the proton induced reactions in the accelerator structural materials. The high energy portion of the accelerator (high beta structure) will be also studied in advance of the 2nd stage development. The feasibility study for the accelerator plant will be carried out in this initial period.

Table 2. Performance of Incineration Plant.

Target system	Tungsten-loaded		Reference	
Coolant	Na	Pb-Bi	Na	Pb-Bi
Effective multiplication factor	0.92	0.86	0.94	0.95
Pin pitch (mm)	9.5	10.5	10.5	12.0
Actinide loading (kg)	2866	2013	2682	1584
Beam current (mA)	22.6	7.5	18.2	5.4
Neutrons per proton	38.1	52.8	35.3	55.1
Average neutron flux ($\times 10^{15}$ n/cm^2·sec)	4.6	6.6	2.0	1.9
Actinide burnup (kg)	202	139	114	42
Unit of 3000 MWt LWR	7.6	5.3	4.3	1.8
Thermal Power (MWt)	691	342	405	163
Average Power Density (W/CC)	307	174	159	83
Coolant Temperature (°C) outlet	389	441	352	377
Clad Temperature (°C) max.	492	614	481	589

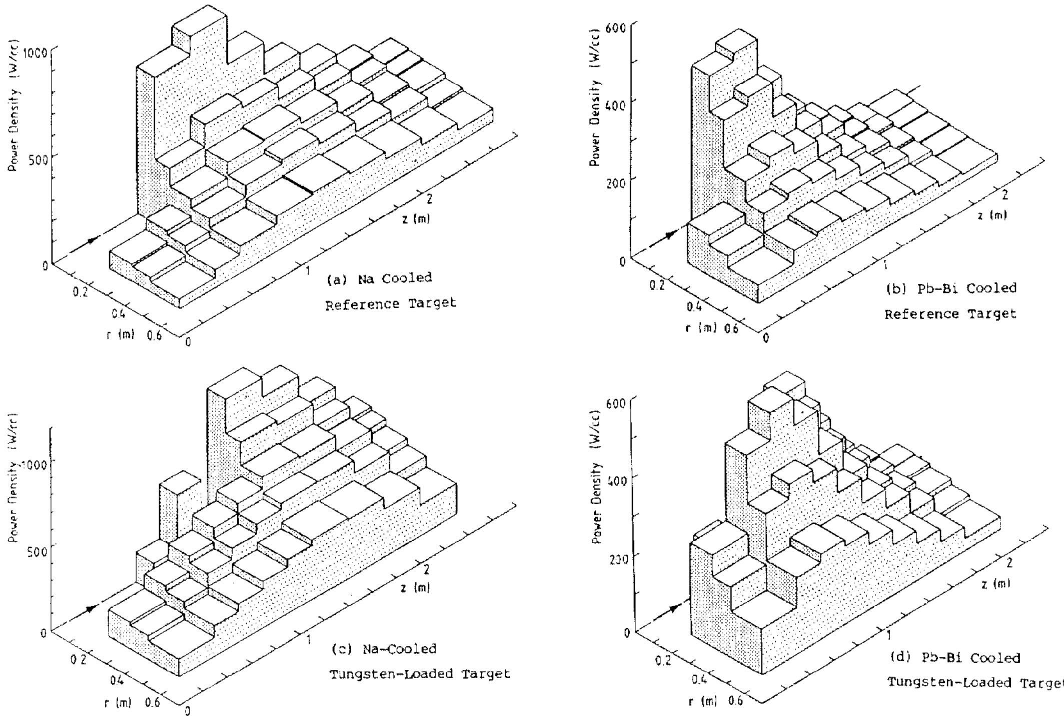

Fig. 4 Power Distribution

In the 2nd step, a proton accelerator for research purposes (engineering test accelerator) with a 10 mA current and a 1.5 GeV energy will be designed and constructed. The various engineering tests of the incineration process, including medium and large scale integral test, mock-up test and prototype experiments, will be made using this accelerator.

Finally, as the 3rd step, a commercial incineration plant utilizing intensive proton linac will be constructed after the 2nd step research has been completed.

Summary

The survey activities and preparatory design studies will be continued through 1989 and 1990. The studies for the optimization of the accelerator system and the conceptual design of accelerator structures will be started in 1990 followed by various R&D activities. The design work for research building and the utilities for the accelerator are planned for 1991.

References

[1] T. Nishida et al., "Research of TRU Transmutation System with Proton Accelerator" NEA/CRP 1989.
[2] Y. Kaneko, Proc. of The 2nd International Symp. on Advanced Nuclear Energy Research -Evolution by Accelerator- Mito (1990) p25
[3] H. Takada et al., ibid, p375
[4] T. Takizuka et al., ibid, p381
[5] Y. Nakahara et al., "NMTC/JAERI A Simulation Code System for High Energy Nuclear Reactions and Nucleon -Meson Transport Processes", JAERI-M 82-198 (1982)

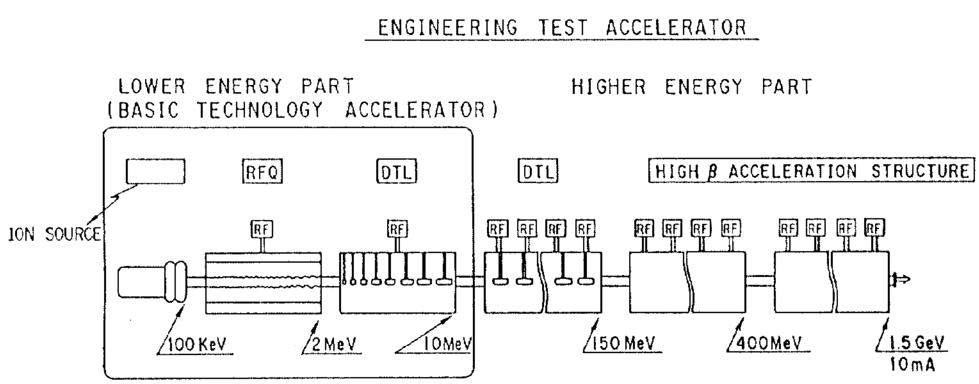

Fig. 5 Conceptual Layout of Engineering Test Accelerator