FAST AND PERFECT TRANSMUTATION OF **ACTINIDE** WASTES USING A-BURNER

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ABSTRACT

A new transmutation concept; "two stage transmutation" of the actinide wastes is proposed. In the concept, the lower actinides such as neptunium and americium are transmuted in the high flux field with well thermalized spectrum at the first stage. The wastes are transmuted very fast owing to the high flux and the high effective cross sections. The transmutation half-life for the actinide waste discharged from the spent fuel is about 15 days in the flux of 1.0 x 10^{16} n/cm^2/sec. At the second stage, the higher actinide such as curium, which is the residual at the first stage, is transmuted in the slightly hard spectrum optimized for ^{246}Cm which slows down the transmutation speed because of the low effective cross section.

A reactor facility "A-Burner" is designed for the concept. The core of A-Burner is based on ANS currently being designed by ORNL. A-Burner consists of a small core and a large D_2O reflector. The first and second stage transmutations are performed in the reflector and the central region of the core, respectively. The core characteristics and the transmutation performance are calculated with the newest nuclear data files; JENDL-3 and ENDF/B-VI. The calculation indicates that the core with the actinide wastes could be operated for the same cycle length as ANS. The actinide wastes of 29 kg could be reduced to be 0.2 kg in one year. By re-loading the actinide residual into the central region, the wastes become finally 0.5 g by five years transmutation. A-Burner with this two stage transmutation concept allows to reduce the hazard index below that of the equivalent natural uranium and makes us free from the long-time management of the actinide wastes.

I. INTRODUCTION

The problem for the management of the high-level long-lived radioactive wastes is one of the difficult issues associated with the fission energy. The aim of the transmutation of those is to reduce the toxity and the time required for the waste management of the long-lived nuclides. Actinide, which includes many nuclides with the half-lives over a million years, is the main object of transmutation. It is the final goal for the transmutation to reduce the toxity of the actinide wastes below that of the natural uranium and make us free from the long time management. There is no stable nuclide in actinide. The short-lived actinides generate the long-lived actinides through the course of α decay chain. It is necessary for the transmutation that all the actinides disappear from the chain by fission. Although fission products also have toxity, the toxity is less severe than that of α emitter. Furthermore, the time required for the management of actinide is significantly longer than that of fission products since fission products have almost shorter lives. In this paper, we only intend to take notice of actinide

The researches for the transmutation of actinide have been performed at various research institutions. Many concepts have been proposed using the neutron-base facilities such as thermal reactors and fast reactors. The neutron fluxes of the thermal reactors are not enough to transmute the wastes in a period of time comparable to a human life. Though the fast reactors provide higher fluxes, the effective reaction cross sections are too small to transmute those practically. In the designs, huge inventory of actinide must be loaded. The huge inventory means the huge residual. It would be impossible to reduce the toxity or to shorten the time for the management based on such usual ideas.

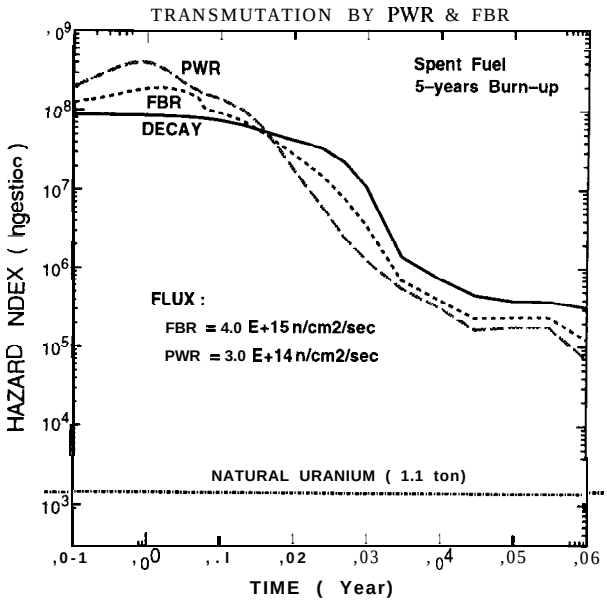

Fig. 1. Transmutation by PWR and FBR

The typical results of the transmutation by the conventional LWR and FBR are presented in Fig. 1. The LWR is the 1175 MWe PWR with the flux of 3.0 x 10^{14} n/cm^2/sec. The FBR is the fast breeder reactor of the MOX fuel with the flux of 4.0 x 10^{15} n/cm^2/sec. The actinide waste with the

composition discharged from the conventional PWR is assumed to stay for 5 years in the reactors at the constant fluxes mentioned above. The vertical scale of Fig. 1 is the hazard index by ingestion converted using "Annual Limit on Intake" taken from ICRP Pub.30. Only the actinide nuclides are considered and other nuclides such as fission products are not taken into account. The hazard indexes in this study are contributed only by the actinide nuclides. The horizontal scale is the time from the beginning of transmutation.

It is observed in Fig. 1 that the hazard indexes by the transmutations of the both reactors are inversely larger for initial 50 years than that by decay when the actinide waste was left untouched. The transmutations raise the toxity during the first 50 years. After that, the hazard indexes become below that by decay. However, the differences are small up to a million years. It is found that little effect is obtained by the transmutation on the long term management of the actinide waste. This results from the low flux or the low cross section. To make the transmutation effective, the actinide waste must be transmuted in another field with higher flux and higher effective cross section. The transmutation only in such a field leads to reduce the toxity and the time for the management within the realistic irradiation period.

The field conditions can not be met in reactors already built or planned. However, a facility to realize the both conditions has been designed by Oak Ridge National Laboratory (ORNL). The facility'), which is named "Advanced Neutron Source" (ANS), is being developed to aim the thermal flux of 1×10^{16} n/cm^2/s for the researches of condensed matter physics, material science, isotope production and fundamental physics. ANS can provide the field which satisfies the conditions mentioned above. In this paper, we first study the transmutation in the ANS field and propose a new transmutation concept. A reactor facility "A-Burner" is designed to realize the transmutation concept.

The feature of the concept is the fast transmutation rate of the lower actinides such as neptunium and americium in a well thermalized filed with high flux. The concept has another feature concerning with the problem of byproduct or residual of the transmutation. A transmutation concept using an accelerator-base neutron source has been proposed by Los Alamos National Laboratory[2,3]. The transmutation is performed in the field with the thermal flux higher than 1×10^{16} n/cm^2/s. The approach of the transmutation is same as that of the present study. The transmutation with the speed same as the A-Burner or more is expected. However, they do not mention about the higher actinides accumulated as the by-product of transmutation. The generation of the higher actinides could not be avoided in the thermal field. ^{246}Cm is mainly accumulated because of the low cross section. The nuclide produces ^{24}*Pu with the half life of 3.8×10^5 years. This is quite serious to reduce the time for the waste management.

The special prescription has been prepared for ^{246}Cm in our concept. In A-Burner, another region is designed to optimize the transmutation of the nuclide. The residual from the first transmutation stage is irradiated in that region at the second stage. Looking at the nuclear characteristics of the higher actinides, it is found that there are many nuclides with the high fission cross section or the spontaneous fission probability of 100%. It is not difficult to fission almost perfectly if burn-up advances above ^{246}Cm. Furthermore, the perfect transmutation in literal may be possible using the nuclides with the spontaneous fission probability of 100% if these nuclides accumulate as the final byproduct.

In this paper, we describe ANS briefly in Sec. 11. In Sec. III, the transmutation in the filed with the flux of 1.0×10^{16} n/cm^2/sec is discussed. A new transmutation concept is proposed in Sec. IV and V. In Sec. VI, a basic design of the reactor to realize the concept is presented with the performance of transmutation. In the last section, the possibility of the perfect transmutation is discussed.

II. ANS

ANS[1] is a new research facility to realize the thermal flux of about 8×10^{15} n/m^2/sec and the total flux of about 1×10^{16} n/cm^2/sec. The ANS core is designed to operate at thermal power of 350 MWt for 14 days. The generated neutrons work for the fundamental researches such as condensed matter physics, materials science and isotope production. The core and facility desirer have been performed by ORNL.

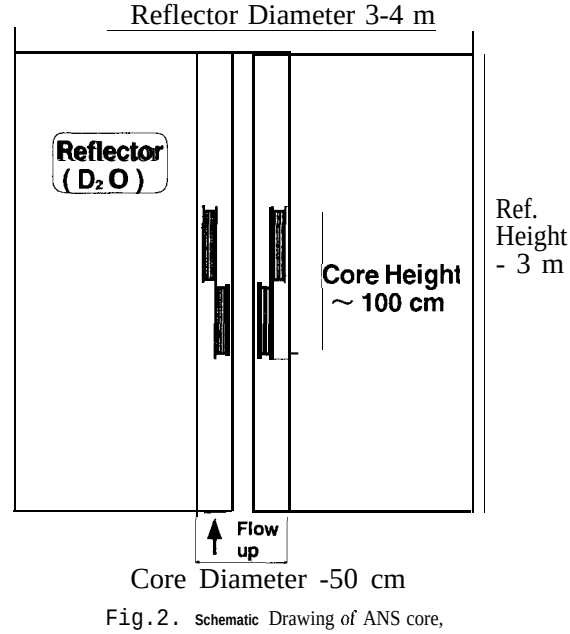

Fig.2. Schematic Drawing of ANS core,

The core consists of two hollow assemblies which are axially and radially splitted. The involute fuel with the fuel meat of highly enriched (93%-^{235}U) U_3Si_2 / Al is covered by the clad with 0.25 mm thick. Totally about 15 kg of ^{235}U is involved in the core. The ^{235}U loading in the fuel vanes continuously axially and radially to flatten the power distribution. Burnable boron poison is provided to control the excess reactivity. The plates are set with the coolant gap of 1.27 mm wide. A large surface area of fuel plates, a high flow velocity of coolant, and a short heated path are adopted to maintain the safety margin of heat removal. Heavy water is selected as the coolant that flows upward. When the coolant velocity is about 27 m/s and the inlet temperature is 49 degC, the outlet coolant temperature is kept below 100 degC.

The core is surrounded by a large D_20 reflector tank with the radius of more than 1.5 m, as shown in Fig.2. The

high flux field with the thermal spectrum appears in the reflector. Beam tubes/guides and cold neutron sources are located as close as to the position of peak thermal flux in that region. Irradiation positions for the study of materials are prepared in the central region of the core where the fast neutrons are rich. Isotope production equipments are set adjacent to the core. These equipments have influence to the neutron flux and the reactivity.

III. TRANSMUTATION IN ANS FIELD OF 1.0 x 10^{16} n/cm^2/sec

In this section, we study the transmutation in the ANS field removed all the experimental equipments mentioned above. The total flux is expected to be 1.0 x 10^{16} n/cm^2/sec in the field. The calculated results in this section are obtained by the constant flux of 1.0 x 10^{15} n/cm^2/sec. The actinide waste with the composition of the spent fuel from the conventional PWR is postulated. The composition is as follows; ^{237}Np 49.3 %, ^{241}Am 37'.6 %, ^{243}Am 10.5 %, ^{244}Cm 2.3 % and other minor nuclides. The calculation is performed by 0RIGEN2 code[4] with effective one group cross sections for actinide prepared from JENDL-3[5] and ENDF/B-VI[6]. The method adopted in the analysis will be explained in Sec. VI.

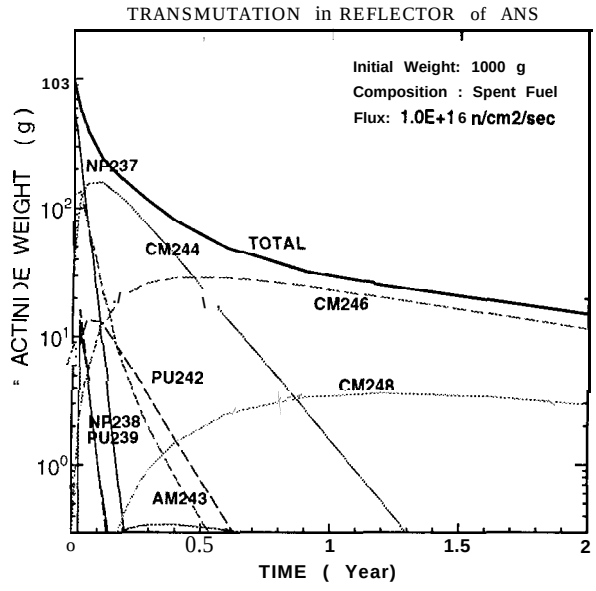

Fig.3. Actinide weight variation by transmutation in reflector of ANS.

In Fig.3, the variation of the actinide weight is shown during irradiation. The total actinide weight becomes a half of the initial weight by the irradiation of 15 days. At 120 days of the irradiation time, the total weight becomes a tenth of the initial one. The transmutation speed is very fast in comparison with those of the conventional LWR and FBR because of the increases of not only the flux but also the effective cross sections. The effective cross section of ^{237}Np and ^{239}Pu are compared in Table 1. The effective cross sections of the nuclides in the ANS reflector are 3.7 or 5.3 times larger than those for PWR and 82 or 308 times larger than those for FBR.

The variation of the hazard index by ingestion is shown in Fig.4 after the irradiation of 5 years irradiation which is

Table 1 Effective one group cross section (barn) of ^{237}Np, ^{239}Pu and ^{246}Cm

Nuclide	^{237}Np	^{239}Pu	^{246}Cm
Reaction	(n,γ)	(n,f)	Total
ANS	117.2	560.8	2.21
PWR	32.1	106.2	3.48
FBR	1.43	1.82	0.54

the same period as that of the conventional PWR and FBR presented in Fig. 1. The reduction of the hazard index by ANS is very large. At 30 years after the end of irradiation, the reduction of hazard index is about 3000 times larger or more than those of the conventional reactors. Furthermore, the hazard index becomes below that of the equivalent natural uranium at 20,000 years. The transmutation in the ANS field clearly leads to shorten the time needed for the waste management.

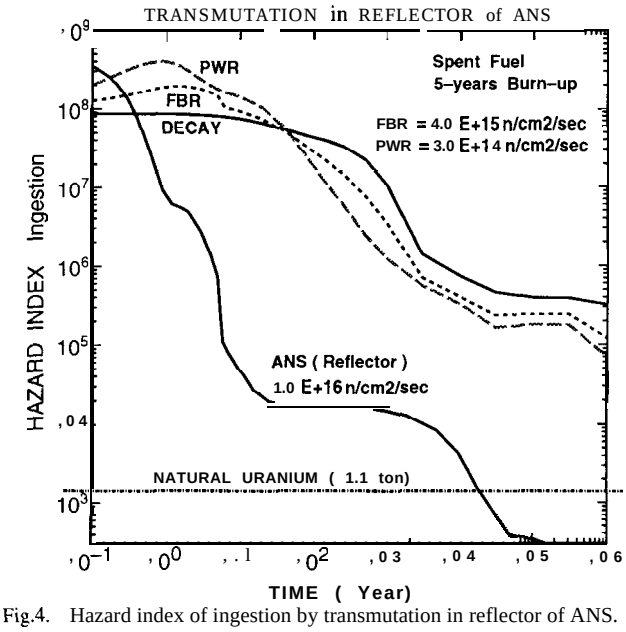

Fig.4. Hazard index of ingestion by transmutation in reflector of ANS.

IV. ACCELERATION OF TRANSMUTATION OF ^{246}Cm

As shown in Fig.3, the transmutation speed is high during first one year. However, the speed slows down after that. Except the first one year, the reduction rate is almost constant and about 1/2 per year. This situation is unfavorable, however, it can not be avoided so long as using the thermal spectrum. This slow down of the speed is caused by the accumulation of ^{246}Cm. The nuclide is one of the nuclides with the smallest effective cross sections in actinide (see Table 1). Since ^{246}Cm generates ^{242}Pu with the half life of 3.8 x 10^5 years, it disturbs to shorten the time for the management. If the acceleration of the transmutation of ^{246}Cm was

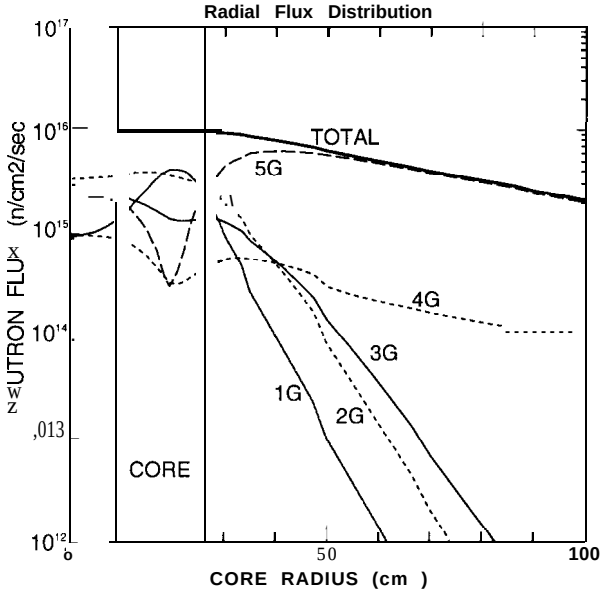

Fig.5. Radial flux distribution in ANS

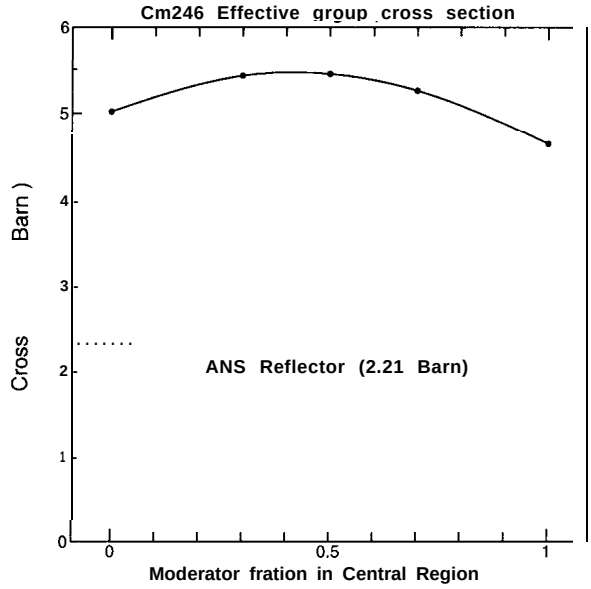

Fig.6. Effective cross section of ^{246}Cm in central region of ANS

possible, the time for the management would be reduced significantly.

The thermal cross section of ^{246}Cm is very small and only a few resonances exist in the energy region between 1 and 100 eV. To accelerate the transmutation, it is required to make the field with large flux in that eV region. In Fig.5, the flux distribution in ANS is presented when a five energy group structure is adopted. The third group corresponds to the energy region between 1 and 100 eV. The fourth and fifth groups are prepared for the thermal neutrons. As shown in Fig.5, the central region of the core has the largest flux of the third group. It is expected that the transmutation rate is faster than that in the reflector since the absolute total flux in the central region is about 1.0 x 10^{16} n/cm^2/sec.

To obtain higher speed, we studied the effect of moderator (D_2O) fraction in the central region. The central region is assumed to consist of aluminum and moderator. The moderator fraction is given by the fraction of the volume of moderator to the total volume of the central region. In the study, the fraction was varied from O to 1. In Fig.6, the effective cross section of ^{246}Cm is plotted against the fractions. The largest value of 5.5 barn is obtained when the fraction is about 0.5. The value of 5.5 barn is 2.5 times larger than that of the reflector. Considering the five years irradiation, the reduction effect is expected to be about 100 (= 2.5 ^{5}) times large. The fraction value of 0.5 is also favorable to design the definite field since the lower or the higher fractions make the installation of equipments or coolant difficult. The acceleration of the transmutation of *'"Cm should be possible.

V. TWO STAGE TRANSMUTATION CONCEPT

As mentioned above, the transmutation of the actinide wastes is very fast in the reflector region of ANS. Continuing the transmutation there, the higher actinides are accumulated, especially ^{246}Cm. Since the nuclide has the small cross section, the transmutation rate slows down. For the nuclide, the transmutation in the central region with the moderator fraction of about 0.5 is most effective. The reduction effect is expected to be 100 times larger than that in the reflector. Combining these transmutations will be very effective to make the transmutation more worthy.

We propose the two stage transmutation concept. At the first stage of the transmutation, the lower actinides such as neptunium and americium are transmuted in the well thermalized field. The transmutation advances rapidly owing to the high flux of 1.0 x 10^{16} n/cm^2/sec and the spectrum, The accumulated curium at the first stage is transmuted in the central region of the ANS in the second stage of the transmutation. Owing to the reduction by the higher isotopes with large fission cross sections and the spontaneous fission probability of 100%, it is expected that the total actinide would be transmuted almost perfectly.

The typical results by this two stage method are presented in Fig.7 and 8 for the transmutation of the actinide wastes with the actinide composition of the fuel discharged from PWR. The neutron fluxes of the two fields are assumed both to be 1.0 x 10^{16} n/cm^2/sec. The irradiation time in the reflector is 100 days. After that, 5 years irradiation in the central region is postulated. Figure 7 and 8 show the variations of the actinide weight and the hazard index, respectively. The weight of the final residuals after 5 years irradiation becomes to 10"^{5} of the initial weight. The reduction of the hazard index is 10^{-6}. The hazard index of the final residuals becomes below those of the equivalent natural uranium after five years from the end of transmutation. By this transmutation concept, the actinide wastes could be almost transmuted and the long term management would be unnecessary.

In the study, the flux is assumed to be constant of 1.0 x 10^{16} n/cm^2/sec. Although the flux level is kept in the central region, the flux in the reflector rapidly decreases along the distance from the core. Furthermore, the loading of the actinide wastes in the reflector or the central region may

influence to the flux. It is necessary to design the core for the transmutation to realize the two stage concept of transmutation and estimate the transmutation performance, considering these realistic situations.

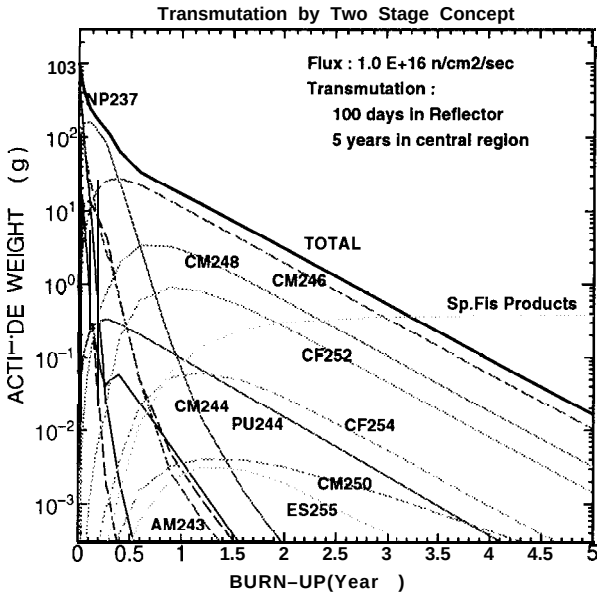

Fig.7. Transmutation by two stage concept (actinide weight).

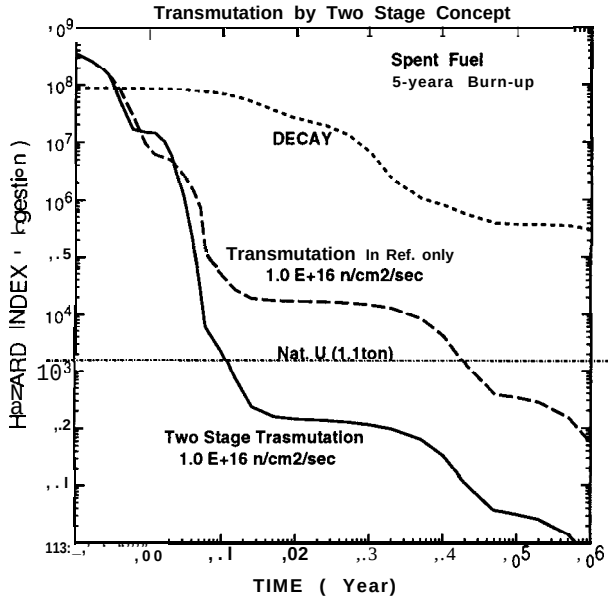

Fig.8. Transmutation by two stage concept (hazard index).

VI. A-BURNER

We have designed the facility named A-Burner to realize the two stage transmutation concept. The design of A-Burner is based on ANS except the slight modification of the core and the removal of the experimental equipments of ANS. A-Burner consists of a small hollow core (100 cm high and 50 cm in diameter) and a large D_2O reflector (400 cm high and 400 cm in diameter). The volumes of the reflector and the central region are about 50,000 and 28 liters, respectively. The core with the 93%-enriched ^{235}U also produces the thermal power of 350 MW. The unperturbed total flux becomes 1 x 10^{16} n/m^2/sec. Although the ANS core consists of two core-assemblies, three core-assemblies of the A-Burner are arranged in barrel shape in order to yield higher epithermal flux in the larger volume in the central region. The fuels have the similar dimensions to the ANS fuels.

It is postulated here that the actinide wastes are directly diluted into D_2O reflector of A-Burner with the concentration of about 1 g/1 except the outer region of A-Burner. The 20,000 liters of volume is available for loading the actinide wastes. The concentration is same order as the liquid wastes from the reprocessing plant. Because of the loading in the form of solution, no fabrication process is needed. It is unnecessary to take care of the radiation damage of the moderator. The transmutation is performed in unit of an operation cycle. Although the continuous reprocessing would be possible in the operation, the solution in the reflector is reprocessed at the end of each cycle in this study. Plutonium and fission products are removed from the solution of the reflector. Since the inventory of A-Burner is about 20 kg, the reprocessing plant could be small. Adding the actinide wastes into the reflector, the first stage transmutation is continued to next cycle.

After the first stage transmutation, the portioning and the fabrication of the curium wastes are required for the second stage transmutation. The curium wastes are fabricated into pins and loaded in the central region. Since the amount of curium wastes generated in the reflector is small (2 - 3 kg/year), the partitioning and fabrication could be handled by laboratory scale equipments. The irradiation of the pins in the central region is performed in unit of a year. After one year, the pins are discharged and reprocessed. The residual curium (0.2 kg/year) is reloaded to the central region mixing with the curium wastes from the reflector.

The flow of the analysis is given in Fig.9 for calculating the core characteristics and the performance of transmutation. The nuclear data for the nuclides appeared in the bum-up chain were prepared by combining JENDL-3 and ENDF/B-VI. RESEND-D and CRECTJ codes were used to prepare the 107 group cross sections of 42 nuclides above ^{235}U up to ^{255}Fm. The one dimensional cell calculation by SRAC[7] produced the 107 energy group spectrum and the 5 group library for CITATION*). The 5 group cross section for each nuclide was collapsed from the 107 group cross section using the 107 group spectrum. The two dimensional core calculation was performed by CITATION. The one group cross section for ORIGEN-2 was obtained based on the 5 group cross section and the 5 group spectrum from CITATION for each subregion in the reflector of A-Burner.

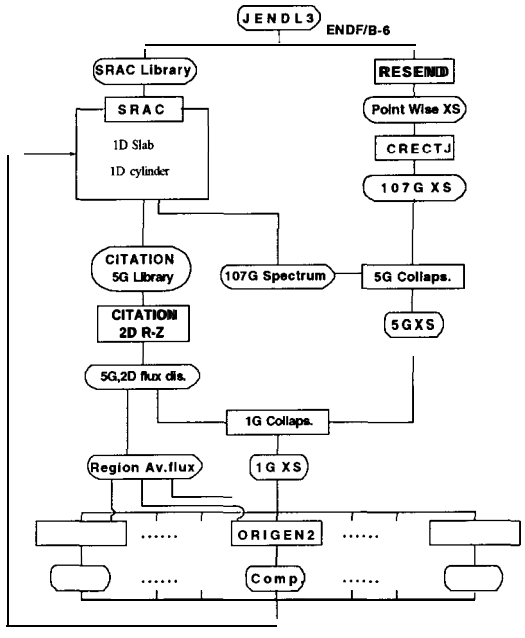

Fig.9. Analysis flow of A-Burner.

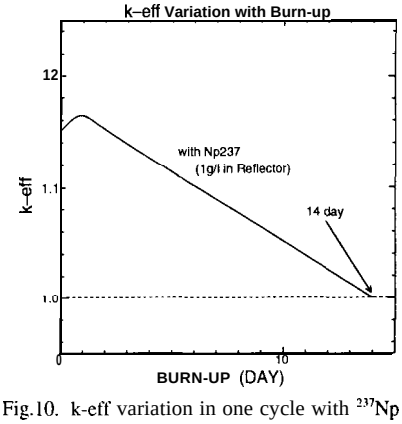

Fig.10. k-eff variation in one cycle with ^{237}Np in reflector at concentration of I g/1.

The characteristics of the core are calculated for the various actinide concentrations in the reflector. The typical k-eff variation of the ANS core is presented in Fig.10 for the case that only ^{237}Np with the concentration of 1 g/1 is initially loaded in the reflector. The cycle length is maintained to 14 days. The actinide of about 20 kg can be loaded in the reflector at 1 g/1 of concentration.

Figure 11 shows the flux distribution with and without $^{23}{}'Np$ of 20 kg. A-Burner has the total flux of about 1.0 x 10^{16} n/cm^2/s in the reflector adjacent to the core and the central region. To estimate the transmutation performance in the reflector, we divide the reflector to 8 subregions depending on the flux and the effective cross section. The flux decreases along the core radius, while the effective cross section vanes with the spectrum change of each region. The

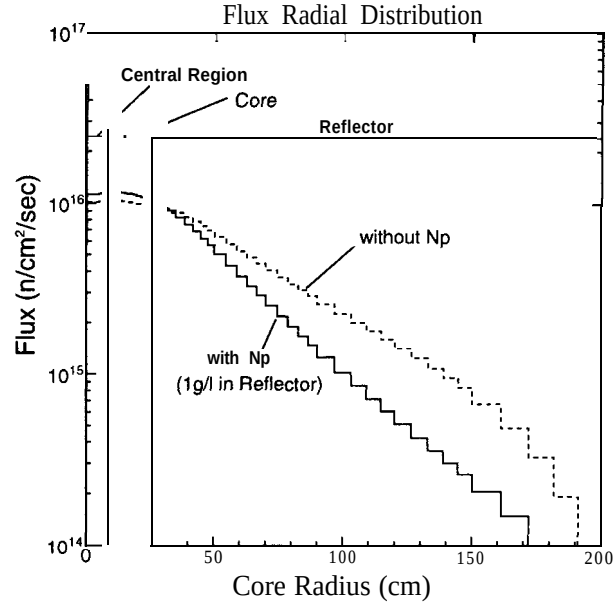

Fig.11. Total flux distribution without & with ^{237}Np in reflector of A-Burner.

spectrum near the core is hard. Only the thermal neutrons exist deep in the reflector. In Table 2, the volume, the average flux and the effective cross section of ^{237}Np are presented. For each subregion of the reflector, the calculation of transmutation by 0RIGEN2 is performed individually.

Table 2 Region volume, average flux and effective cross section of ^{237}Np in A-Burner for estimating the performance of transmutation

Reg.#	vol.*	Av.Flux**	Eff.XS***
1	38.4	0.902	68.4
2	122.	0.724	96.9
3	254.	0.635	116
4	672.	0.382	123
5	1838.	0.206	124
6	4320.	0.084	125
7	7700.	0.034	125
8	5592.	0.014	125

* liter ** 10^{16} n/cm^2/sec *** ^{237}Np Capture XS (barn)

Summarizing the transmutation of each subregion, the transmuted weight is the total reflector is about 650 g per cycle and 14 kg per year. The weight of plutonium generated is about 550 g per cycle and 12 kg per year. Since the plutonium is removed at each end of cycle, the total weight removed from the reflector is about 26 kg per year. The curium residual by this method becomes almost ^{244}Cm because

of the short period of irradiation.

In the second stage of the transmutation, it is assumed that the accumulated curium is to be loaded in the aluminum pin with the inner and outer thicknesses of 4 mm and 8 mm (the clad thickness of 2 mm). When the pins are arranged in the hexagonal geometry with the pitch of 10 - 12 mm, the volume fraction of moderator becomes about 0.5. About 3.0 kg of curium is available to be loaded when the density is assumed to be 1 g/cm^3. The effect on the flux by the curium waste is estimated using the method explained in Fig.9. The average flux in the central region with curium of 2.4 kg becomes about 0.83 x 10^{16} $n/cm^2/sec$. The flux depression is small. This resulted from the low absorption cross section of ^{244}Cm. On the other hand, the effect on k-eff is about -0.08 dk at the beginning of irradiation. This is significant. However, when the nuclide absorbs one neutron, it produces ^{245}Cm which has the large fission cross section of about 280 barn. This nuclide provides the positive effect on k-eff. At the equilibrium condition of ^{244}Cm and ^{245}Cm, the net effect on k-eff by the curium waste is positive. This situation is held even if the negative effect on k-eff by fission products is considered. As the result, the large effect does not exist on the flux and k-eff by the curium 'waste,

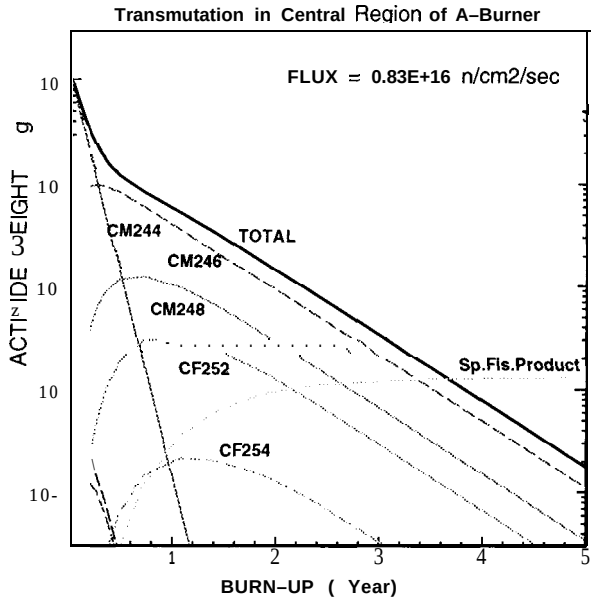

Fig.12. Transmutation of curium in central region in A-Burner

The transmutation rate of the curium is also estimated by 0RIGEN2. The result is presented in Fig. 12 when the ^{244}Cm of 1000 g is loaded. After one year irradiation, the waste weight is reduced to about 1/16. Considering the 5 years irradiation, the amount of final residual is about 2 x 10" ^{4} of the initial amount. The reduction rate is about 1/4 per year from second year.

In A-Burner, neutrons for the transmutation are produced by fission in the core. We must consider the generation of actinide. Initially, ^{235}U and ^{238}U loaded in the core are about 15 kg and 1.1 kg, respectively. To estimate the generation of the actinide wastes, 0RIGEN2 code is also employed using the effective cross sections prepared for the core by SRAC.

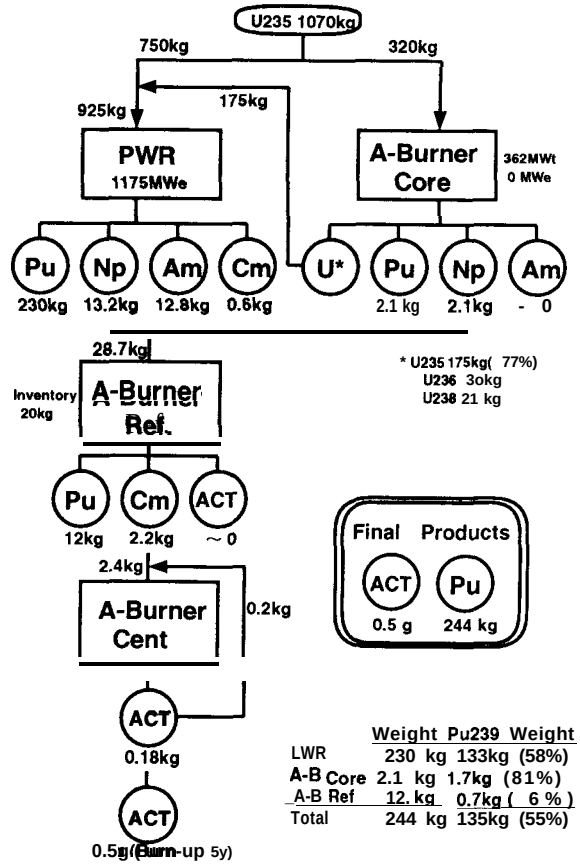

Fig. 13. Transmutation Scheme of A-Burner

Since the core of A-Burner has very hard spectrum, the effective absorption cross sections are small. Then, the produced weight is not large. After one cycle of operation, generated neptunium and plutonium are both about 0.1 kg per cycle and 2.1 kg per year. No americium is generated. The amount is small comparing to those transmuted in the reflector. Neptunium from the A-Burner core is mixed with the actinide wastes from the LWR and is transmuted in the reflector and the central region.

The mass flow in the two stage transmutation is summarized in Fig. 13. The actinide wastes of 27 kg (13.2 kg of neptunium, 12.8 kg of americium and 0.6 kg of curium) are produced from one PWR after one year of operation. Neptunium of 2.1 kg is produced in one A-Burner. The total 29 kg of actinide wastes are loaded into the reflector and are transmuted. After one year of transmutation, 2.2 kg of curium wastes is produced. The curium waste loaded to the central region is reduced to 0.2 kg by one year irradiation. The residual from the central region is re-loaded to the central region. After five years irradiation, the final byproduct becomes about 0.5 g. One A-Burner can transmute the wastes from one conventional 1175 MWe PWR. To operate an A-Bumer, additionally 145 kg of ^{235}U is needed. This amount is about 15 % of ^{235}U required to the conventional PWR operation.

VII. PERFECT TRANSMUTATION

As mentioned earlier, four nuclides have the spontaneous fission probability of 100 % ; *^{50}Cm, ^{254}Cf, ^{256}Cf and ^{256}Fm. If these nuclides were accumulated as final byproduct, the perfect transmutation is possible in literal. Especially, since ^{254}Cf has the half-life of decay of 60 days, this nuclide is very attractive for the transmutation of actinide. Furthermore, ^{254}Cf may be accumulated since the capture cross section is small (1.0 barn) in the central region. Observing the result of the transmutation in Fig.7, it is found that ^{254}Cf is accumulated. Since the amount of the nuclide is not enough, another way must be studied to accumulate as the primary byproduct.

The generating amounts of the nuclides above ^{246}Cm presented in Fig.7 is governed by the small cross section of ^{246}Cm. If the transmutation was started from the nuclide above ^{246}Cm, another situation would appear. We calculated the transmutation of ^{249}Bk in the central region of A-Burner. By the calculation, it is observed that large amount of ^{254}Cf is accumulated during the irradiation in comparison with that in Fig.7. However, the amount is below that of ^{252}Cf. Although ^{250}Cm is accumulated as the primary byproduct at the longer irradiation time. the accumulation does not lead to the reduction of time for the waste management since the nuclide has the half-life of about 10,000 years.

The situation strongly depends on the nuclear data of actinides. The nuclear data are remarkably improved for actinides recently. However, the accuracy of the cross section data is not sufficient. For example, no resonance data exist for ^{253}Cf even in ENDF/B-VI. Considering the situation of the nuclear data, we checked the sensitivity of cross sections of ^{252}cf, ^{253}Cf and ^{254}Cf for the accumulation amount of ^{254}Cf, considering the uncertainty up to 500 %. Although the amount of ^{254}Cf increases, it is limited to 90 % of the total actinide weight. The 90% of accumulation does not have large effect for the perfect transmutation since 10 % of residuals (mainly "*Cm) have the long half-lives. It is judged that the perfect transmutation through the accumulation of ^{254}Cf is difficult.

VIII. SUMMARY

The transmutations by conventional reactors or transmutation methods are studied. The transmutations by those are not effective to reduce the hazard index of the actinide wastes and the time required for the waste management since the flux or the effective cross section are too small. Considering the situation, we proposed the two stage transmutation concept. In the concept, the lower actinides such as neptunium and americium are transmuted in the well thermalized field with the high flux of 1.0 x 10^{16} n/cm^2/sec. The accumulation of higher actinide with low cross section could not be avoided by such transmutation. Then, the accumulated curium at the first stage is transmuted in the field with the slightly hard spectrum which has the large component in the energy region between 1 and 100 eV.

The transmutation speed in the first stage is very fast because of not only high flux but also large effective cross sections. Owing to the higher isotopes with large fission cross sections and the spontaneous fission probability of 100%, the waste is transmuted almost perfectly in the second stage. After the transmutation, the weight and the hazard index of the actinide waste are reduced to be 10^{5} and 10^{-6}, respectively. The hazard index becomes below that of the equivalent natural uranium after 5 years from the end of irradiation.

A new core, which is named '"A-Burner", was designed to realize the two stage concept. The core is almost same as ANS except for change of the core alignment to get larger volume with the high epithermal component within the central region. The core characteristics and the transmutation performance of A-Burner are calculated by SRAC, CITATION and ORIGEN2 codes with the newest nuclear data files; JENDL-3 and ENDF/B-VI. The calculation shows that the core could be operated for 14 days, which is same as ANS, with the actinide waste at the concentration of 1 g/l in the reflector. Furthermore, it is found that the loading of curium into the central region does not have significant effect on the flux and k-eff. Using A-Burner, 29 kg of the actinide waste could be reduced to be 0.5 g finally. One A-Burner can transmute the wastes from one conventional" PWR. The A-Burner could transmute the actinide wastes almost perfectly. By the two stage transmutation concept, little actinide waste is left and no long term management is required.

Our transmutation concept is an available option to shorten clearly the time required for the management of the long-lived actinide. The concept is a realistic solution to solve the problem of actinide wastes within our generation since the since ANS is going to be realized.

REFERENCE

1. J. M. Rsykamp et.al.,"Reactor Design of Advanced Neutron Source", Nuclear Technology, 3 (1991) 330-349
2. E. D. Arthur,"A New Concept for Accelerator Driven Transmutation of Nuclear Wastes ", Fusion Technology, 20 (1991) 641-647
3. C. D. Bowman et. al.,"Nuclear Energy Generation and Waste Transmutation using An Accelerator Driven Intense Thermal Neutron Source",, Nuclear Instruments and Methods, A320 (1992) 336-367
4. K. Schibata et al.,"Japanese Evaluated Nuclear Data Library, Version-3", JAERI-1319 (1990)
5. P. Rose and C. Dunford,''Data Formats and Procedures for the Evaluated Nuclear Data file ENDF/B-VI", ENDF-102, BNL (1991)
6. A. G. Croff, "ORIGEN-2 - A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code", ORNL-5621,ORNL (1980)
7. K. Tuchihashi et.al.,''Revised SRAC Code System", JAERI- 1302 (1986)
8. T. B. Fowler,"Nuclear Reactor Core Analysis Code: CITATION", 0RNL-TM-2496,Rev.2 (1971)