MINOR ACTINIDE TRANSMUTATION IN FISSION REACTORS

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ABSTRACT

Reactor core performance for the existing and/or advanced thermal and/or fast reactors is investigated from the view point of fuel-recycle. When transuranium nuclides are mixed homogeneously to recycling fuels, initial excess reactivity and burnup reactivity swing become remarkably small, and high conversion ratio is obtained. Because Long-lived radioactive minor-actinides(MA) such as ^{237}Np, Am and Cm make instead of burnable poison at the initial state, and they are gradually transmuted to fissile materials with burnup. By recycling fuels, it is shown that the MA-nuclides are not waste, but incinerated usefully as poison- and burnning-fuels. However, it should be noted that coolant void coefficient depends significantly on plutonium and MA enrichments. Therefore,the suitable reactors for the MA-transmutation are proposed for LWR and FBR under the safety consideration that the coolant void coefficient becomes negative.

INTRODUCTION

In the present atomic energy development, safety, reliability, fuel-utilization and economics are required, and in addition, processing and management for radioactive waste are required strictly from the point of view for public acceptance. In order to close the fuel cycle backend, nuclear transmutation of long-lived radioactive minor-actinides(MA) to stable or short-lived nuclides by exposure to neutron fluxhas been studied to reduce the necessary confinement period of high-level radioactive waste(HLW) from some hundred of thousound years to a about 1000 years[1-5]. For this purpose, it is expected that the most suitable reactor for these required items is designed from the view point of fuel cycles. As a starting point, in the present study, reactor core performance for the existing and/or advanced thermal and/or fast reactors is investigated, when transuranium and fission product nuclides are contained in the fuel recycled with reprocessing and refabrications. Hence, at first, in the present study, it is investigated that the MA nuclides of ^{237}Np, Am and Cm generated with reprocessing and Portioning process are transmuted by mixing homogeneously into fuel for the existing and/or advanced light water and fast breeder reactors. As light water reactors (LWRs),uranium-fuel PWR (U-PWR),MOX-fuel PWR (MOX-PWR), high-conversion tight lattice PWR (HCPWR)[6] and very high burnup MOX-fuel PWR (VHBPWR)[7] are considered. As fast reactors (FBRs), the MOX-fueled(MOX-FBR) and metallic alloy fuel (M-FBR)[8,9] assemblies are considered.

Secondly, the suitable reactors for the MA-transmutation are proposed for LWR and FBR under the safety consideration that the coolant void coefficient becomes negative.

Finally, a low-decontamination reprocessing process simplified for MA confinement/transmutation fuel cycles in fission reactors is proposed from a view point of advanced reactor LWR and FBR developments.

CHARACTERISTICS OF MA NUCLIDES

As long-lived radioactive MA nuclides, in the present study, Np, Am and Cm are considered. Half-life and buildup-decay chain scheme are shown in Fig. 1. The ^{237}Np is one of the most important MA nuclides from the point of view for very long half-life and large hazard index. It should be noticed that ^{241}Am becomes ^{237}Np by alpha-decay of half-Life 458 years. The half-lives for curium nuclides are small.

Table 1 shows the comparison of cross sections for MA-nuclides, ^{238}U, ^{238}Pu and ^{239}Pu. Figure 2 shows the comparison among neutron spectra for UO_2-PWR, MOX fuel high conversion tight lattice PWR and a typical fast breeder reactor. From these table and figure, several kind of transmutation process are considered as follows: The ^{237}Np has large capture thermal cross section

Table 1 Comparison of cross sections for MA-nuclides

	2200m/s		R.I.		F.A.	
	capture	fission	capture	fission	capture	fission
^{237}Np	181	*0.02*	*663*	6.3	0.2	1.3
^{238}PU	549	17	156	32	0.3	2.0
^{241}Am	600	3	1300	15	0.3	1.5
^{242}Am	1342	6620	207	1528	0.1	1.9
^{243}Am	79	0.2	1818	11	0.2	1.3
^{242}Cm	16	5.0	116	11	0.1	1.8
^{244}Cm	14	1.2	594	18	0.1	1.6
^{245}Cm	346	2001	108	800	0.05	1.9
^{238}U	2.7	0.0	279	2.1	0.1	0.3
^{239}Pu	270	741	195	302	0.1	1.8

R.I. is the resonance integral and F.A. is the averaged cross sections over fission spectrum.

and resonance integral, and can be tranmuted to ^{238}Pu by neutron capture reaction. The ^{238}Pu has also large capture cross section, and can be transmuted to ^{239}Pu with large fission cross section. In thermal reactors, ^{237}Np can are incinerated by these capture and fission process. Americium 241 is transmuted to ^{242}Am and can be fissioned by large fission reaction. On the other hand, in fast reactors, direct fission reactions for MA-nuclides may be expected in addition to the capture and fission process reactions.

FUEL RECYCLING METHOD

The present fuel recycle is based on the assumptions as follows: Spent fuels are reprocessed and refabricated with cooling times of three years after burnnig in reactor core. The reprocessed fuels are adjusted for ^{235}U or plutonium enrichment so as to reach the burnup rate obtained by initial fuel compositions in each reactor. The following three cases are considered for this fuel recycl. 1) MA-recycle: Only the MA-nuclides of ^{237}Np, Am and Cm are recycled. 2) (U, Pu and MA)-recycle: Uranium, plutonium and MA isotopes are recycled, 3) (U, Pu, MA, Fps)-recycle: Uranium, plutonium, MA and fission product nuclides(Fps) are recycled. In these recycle, decontamination factors (DF) of FPs for reprocessing system are assumed as shown in Table 2. In the present study, DFs of NP, Am and Cm are treated as .0 by consider ng portioning process.

Table 2 Decontamination factors assumed for fission products

for U-PWR, MOX-PWR, MOX-FBR[10]		for metallic-FBR[11]	
Uranium-fuel			
Ru	10^6	Ce	250
Zr	$10'$	Y	1000
Tc	10^2	Nd	1500
Plutonium-fuel		other RE	1000
Ru	10^4	Cs, Rb, Na	1500
Zr	10^4	Ba	1500
Tc	1	Sr	2000
		Zr	1000
		noble metal	1000

x RE is the rare earth materials.

CORE CHARACTERISTICS OF THERMAL and FAST REACTORS

In thermal reactors, the existing PWR with uranium-fuel and MOX-fuel, and advanced PWRS of high conversion tight lattice[6] and very high burnup design cores[7] are considered. In fast reactors, MOX-fuel and metallic fuel assemblies are considered. These core characteristics are shown in Table 3.

Table 3 Core characteristics

	Thermal reactor				Fast reactor	
	U-PWR	MOX-PWR	HCPWR	VHBPWR	MOX-FBR	MFBR
Power (MWt)	3410	3410	3410	3300	2600	1720
Burnup(GWd/t)	33	33	50	100	90	50
Fuel enrichment ^{235}U(w/%)	3,2					
Pu-fissile(w/%)		3.3	8.0	15.0	11.8	8.5
V_m/V_f	1.8	1.8	0.8	2.2	0.73	0.64

x V_m/V_f is the volume-ratio of moderator to fuel.

CALCULATIONAL METHOD

Burnup calculations were performed with the SRAC-FPGS code which consists of the neutron spectrum calculation code SRAC and the burnup calculation code FPGS-3. SRAC calculates the spectrum for heterogeneous cell geometry with the use of collision probability method. In thermal reactor calculations, zero buckling was assumed, and in fast reactos, geometrical buckling was used. Furthermore, the FPGS-3 code calculates the buildup and decay for about 1200 nuclides on the basis of the DCHAIN code. In FPGS-3, fission product yields are mainly based on the data ofJENDL-3.

The SRACLIB-JENDL3 cross section library based on the nuclear data file of JENDL-3 were used in the present calculations, In the library, the 70-group structure for fast energy region has 1/4 lethargy width for the 1.855 eV to 10 MeV range and 1/8 lethargy for 0.683 to 1.855 eV. The thermal region is devided by 37 energy groups with equal velocity width. The self-shielding effect for all of the nucl ides is calculated by the table-look-up method using the self-shielding factors tabulated as a function of background cross sectionsand temperatures. Moreover, resonance shielding effects for important heavy nucl ides are calculated accurately with the ultra-fine group method in resonance energy region below 275 eV.

THE EFFECT OF MA-RECYCLING ON CORE PERFORMANCE

Burnup calculations for three different fuel cycles were performed and ^{235}U or plutonium enrichment was adjusted so as to reach the reference burnup rate in Table 3. Here, the obtained nuclear characteristics such as fuel enrichment, burnup reactivity swing, coolant void coeffient and conversion ratio are discussed. The adjusted enrichments are shown in Table 4.

Table 4 ^{235}U and Pu-fissile enrichments adjusted in each cycle.

	Cycle No.								
	0	1	2	3	4	5	6	7	8
MA-recycle									
U-PWR	3.2	3.3	3,3	3.3	3.3	3.3	3.3	3.3	3.3
MOX-PWR	3.3	3.4	3,4	3.4	3.4	3.3	3.3	3.3	3.3
HCPWR	8.0	8.2	8.2	8.1	8.0	7.9	7.8	7.8	7.8
VHBPWR	15.0	15.4	15.2	14.9	14.8	14,7	14.6	14.6	14.6
MOX-FBR	11.8	11.8	11.7	11.6	11.5	11.5	11.5		
MFBR	8.5	8.5	8.4	8.4	8.4	8.4	8.4		
(U,Pu,MA)-recycle									
U-PWR	3.2	2.8	2,8	2.9	3.0	3.1	3.2	3.3	3.3
MOX-PWR	3.3	4.3	4.8	5.2	5.5	5.7	5.8	5.9	6.0
HCPWR	8.0	8.5	8,7	8.7	8.7	8.6	8.5	8.5	8.5
VHBPWR	15.0	15.1	15.6	16.4	16.6	16.5	16.4	16.3	16.2
MOX-FBR	11.8	11.5	11.1	10,9	10.8	10.7	10.7	10.6	10.6
MFBR	8,5	8.4	8.4	8.4					
(U,Pu,MA,FPs)-recycle									
U-PWR	3.2	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.3
MOX-PWR	3.3	4.3	5.1	5.5	5.9	6.2	6.4	6.6	6.8
MOX-FBR	11.8	11.6	11.4	11.3	11.2	11.2	11.2		
MFBR	8.5	8.5	8.4	8.4					

In MA-recycle, the change of enrichment is very small in each reactor. This shows that the amount of MA-nucl ides generated and transmuted in each recycle is almost same. This is observed from Figs. 3 - 5 in which the MA-quantities remained at the end of each cycle are shown for U-PWR, MOX-PWR and HCPWR, respectively. Considerable quantities of "'Am, ^{243}Am and *"Cm are generated for HCPWR, because of high enrichments of plutonium.

In (U, Pu, MA)-recycle, the plutonium-enrichments of MOX-fuel thermal

reactors increase with fuel-recycles. The enrichment of 8-cycle in MOX-PWR is about two times of the initial one. This is due to the increase of ^{242}Pu as seen in Fig. 6. Figure 7 shows the atomic number density of plutonium isotopes in HCPWR. The change of ^{242}Pu in HCPWR is gentler than that of MOX-PWR.

In (U, Pu, MA, FPs)-recycle, the decontamination factors (DF) of fission products in reprocessing are given in Table 2. The low DF for Tc is assumed in purex processing. This low DF value of Tc in MOX-PWR causes gradually increasing of plutonium-enrichment in comparing it in (U, Pu, MA)-recycle.

In the fast reactors of MOX-FBR and MFBR, the plutonium enrichment is reduced slightly by fuel-recycle, because of harder neutron spectrum.

BURNUP REACTIVITY SWING

Burnup reactivity changes are shown in Figs. 8 - 13 for the case of MA-recycle and in Figs. 14 -19 for (U, Pu, MA)-recycle. The excess reactivity is reduced with recycling numbers in each reactor, The reduction is remarkable forU-PWR,MOX-PWR and VHBPWR. The reduced reactivities are 14 % for MA-8-cycle and 20 % for (U, Pu, MA)-8-cycle of U-PWR, and 10 % for (U, Pu,MA)-8-cycle of MOX-PWR. As the result, the burnup reactivity swing becomes very small.This shows that the MA-nucl ides behave as it were burnable poisons at the initial burnup stage, and gradually are transmuted to positive reactivity worth materials such as ^{239}Pu. This tendency is observed for all thermal reactors and MOX-FBR, but burnup swing for MFBR becomes positively after 4 cycles, because of harder neutron spectrum in metallic fuel core. The small burnup reactivity swing reduces remarkably to the burnable poison quantity and boron-concentration in water, and it is advantageous for safety control and neutron economy,

CONVERSION RATIO

It was shown that excess reactivity and burnup reactivity swing became small in each reactor. This means that conversion ratio increases more than that of the initial cycle core. The conversion ratio (CR) is defined as follows:

$$CR = \frac{\text{total capture rate of } ^{23*}\text{U, } ^{238}\text{Pu, } ^{240}\text{Pu, } ^{241}\text{Am and } ^{244}\text{Cm}}{\text{total absorption rate of } ^{235}\text{U, } ^{239}\text{Pu, } ^{241}\text{Pu, } ^{242m}\text{Am and } ^{245}\text{Cm}},$$

where the capture rate of ^{241}Am is reduced by branching ratio to ^{242m}Am. The average conversion ratio is obtained by integrating over burnup time:

$$ACR = \int CR(t)dt / \int dt.$$

Furthermore, as advantageous indicator, the fissile-material remaining ratio is defined as follows:

$$FRR = \frac{\text{total amoumt of } {}^{235}U, {}^{238}Pu, {}^{241}Pu, {}^{242m}Am \text{ and } {}^{245}Cm \text{ at EOL}}{\text{total amoumt of } {}^{235}U, {}^{239}Pu, {}^{241}Pu, {}^{242m}Am \text{ and } {}^{245}Cm \text{ at BOL}}$$

Table 5 Conversion ratio

	ACR	FRR		ACR	FRR
U-PWR: Initial	0.61	0.49	VHBPWR: Initial	0.57	0.58
MA 8-cycle	0.61	0.50	MA 8-cycle	0.59	0.60
(U, Pu, MA) 8-cycle	0.67	0.71	(U, Pu, MA) 8-cycle	0.68	0.72
(U, Pu, MA, FPs) 8-cycle	0.67	0.71			
MOX-PWR: Initial	0.75	0.67	MOX-FBR: Initial	0.89	0.89
MA 8-cycle	0.77	0.70	MA 6-cycle	0.90	0.90
(U, Pu, MA) 8-cycle	0.82	0.85	(U, Pu, MA) 6-cycle	0.99	0.97
(U, Pu, MA, FPs) 8-cycle	0.80	0.85	(U, Pu, MA, FPs) 6-cycle	0.95	0.95
HCPWR: Initial	0.77	0.78	MFBR: Initial	0.94	0.96
MA 8-cycle	0.79	0.81	MA 6-cycle	0.95	0.95
(U, Pu, MA) 8-cycle	0.86	0.87	(U, Pu, MA) 3-cycle	1.04	1.01
			(U, Pu, MA, FPs) 3-cycle	1.04	1.01

x ACR is the average conversion ratio and FRR is the fissile-material remain ratio. In MOX-FBR and MFBR, no blanket is considered.

The ACR and FRR values calculated for initial and recycle fuel cores are shown in Table 5. The recycle fuels produce higher conversion ratios than the initial fuels. It should be noted that ACR and FRR of (U, Pu, MA)-8-cycle in MOX-PWR are larger than those of initial cycle in HCPWR. This causes the small reactivity swing of MOX-PWR recycle as shown in Fig. 15.

In the (U, Pu, MA)-recycle of MFBR, the ACR becomes larger than unity, that is, the fissile fuels are breeded even in the core without blanket. The burnup reactivity swing becomes almost zero as observed from Fig. 19.

COOLANT VOID REACTIVITY

It is necessary on a view point of reactor safety that the effects of the recycle-fuels mixed with plutonium and MA to coolant void reactivity are investigated. Table 6 shows the coolant void reactivities calculated for various fuel cycles in thermal and fast reactors, Generally, the plutonium and MA contribute positively to the void coefficients. In U-PWR and MOX-PWR, the void coefficient is negative for three cases of different fuel cycles, though it becomes smaller than that of initial fuel. However, it becomes positive for (U, Pu, MA) 8-cycle in HCPWR and for MA 8-cycle of VHBPWR. Hence, the increase of V_m/V_f in HCPWR and the reduction of plutonium enrichment in VHBPWR must be considered to avoid positive void coefficient in the fuel recycles. The proper parameters will be found between MOX-PWR, HCPWR and VHBPWR. Therefore, a new-advanced MOX-PWR optimized for high burnup, high conversion ratio and void coefficient should be designed, when the fuel-recycling is considered.

In MOX-FBR and MFBR, the recycling of plutonium and MA makes significantly positive void coefficient.

Table 6 Coolant void reactivity (%dk/k)

	U-PWR	MOX-PWR	HCPWR	VHBPWR	MOX-FBR	MFBR
Initial	-52	-39	-8	-2	2.6	2.9
MA 8-cycle	-51	-37	-4	7	2.7	3.1
(U,Pu,MA) 8-cycle	-31	-lo	8	25	3.4	3.7
(U,Pu,MA,FPs) 8-cycle	-31	- 6			3.4	3.9

PROPOSAL OF MINOR ACTINIDE TRANMUTATION REACTORS

LIGHT WATER REACTOR FOR MA-TRANSMUTATION

In design study for MA-transmutation reactor, it should be noticed that coolant void reactivity coefficient in the existing LWR or high-conversion LWR may become positive by including a large mount of MA-nucl ides, as shown in Table 6. Furthermore, the reactor core with high burnup as possible should be designed to reduce the number of MA-recyclings. For these purposes, we propose the MA-tranmutation light water reactor with well-moderated core in which the volume ratio of moderator to fuel (Vm/Vf) is 3.

High enrichment for ^{235}U or fissile plutonium are required to obtain high burnup with the use of fuels including a large amount of MA-nuclides. The high enrichment and a large quantities of MA make inferior void coefficient. The well-moderated core improves the inferior void coefficient. However, the well-moderated core produces very high excess reactivity. Fortunately, this high excess reactivity is reduced significantly by mixing the MA-nuclides. The LWR suitable for the MA-transmutation should be selected by considering three parameters for the enrichment, MA-quantity and moderator to fuel volume ratio (Vm/Vf). The core performance for the MA-transmutation reactors obtained by parameter studies are shown in Table 7.

Table 7 Core characteristics and transmutation efficiency of the MA-transmutation reactors designed with negative coolant void reactivity

	Np-PWR(U)	MA-PWR(U)	Np-PWR(MOX)	MA-PWR(MOX)	MA-MFBR
Power (MWt)	3410	3410	3410	3410	1800
Vm/Vf	3.0	3.0	3.0	3.0	0.64
Enrichment (%)	7.6EU	7.6EU	9.0Puf	9.0Puf	10.0Puf
Cycle length (EFPD)	1500	1300	1690	1610	600
Burnup (GWd/t)	58	51	65	62	80
MA transmutation rate (kg)					
Loading	2700	2700	2756	2756	2500
Transmuted	1484	1335	1435	1370	615
Generated	74	70	650	640	40
Net transmuted	1410	1265	785	730	575
Per 300 days	282	292	139	136	288
Per 1GWt·300 days	83	86	41	40	160

In Table 7, Np-PWR(U) shows the PWR with UO_2-fuel assembly that ^{237}Np of 3 w/% are homogeneously mixed in the fuels, and in MA-PWR(U),MA(Np, Am and Cm) of 3 w/% are mixed in the UO_2 fuels. In Np-PWR(MOX) or MA-PWR(MOX), ^{237}Np or MA of 3 w/% are homogeneously mixed in the MOX-fuels. The transmuted net quantities for ^{237}Np or MA in PWR(U) are larger than those in PWR(MOX). Because, the generated MA quantities in UO_2-fuels are smaller than those in MOX-fuels.

Table 8 Minor actinide composition generated per 300 days from a U02-PWR(3410MWt), burnup 33GWd/t and 3 years cooling before reprocessing.

MA-nuclide	weight (kg)	fraction (%)
^{237}Np	13.7	59.3
241AM	6.51	28.2
^{242m}Am	0.02	0.09
^{243}Am	2.28	9.9
^{243}Cm	0.006	0.03
^{244}Cm	0.57	2.5
^{245}Cm	0.033	0,14
Total	23.1	100.0

In the existing UO_2-fuel LWRS with burnup of 33 GWd/t, the MA-quantities generated per 300 days are 23 kg as shown in Table 8, Thus, MA-PWR(U) or MA-PWR(MOX) can transmute the MA-quantities generated from about 13 or 6 existing LWRS, respectively. When we tranmute $^{2,7}Np$ only by using Np-PWR(U) or Np-PWR(MOX), ^{237}Np-quantities generated from 20 or 10 LWRS can be tranmuted per 300 days, because ^{237}Np generated per 300 days from a typical LWR is 14 kg,

FAST BREEDER REACTOR FOR MA-TRANSMUTATION

When a large amount of MA-nucl ides are mixed in the fuels, the positive sodium void coefficient in fast breeder reactors for both the MOX and metallic fuel assemblies become more larger as shown in Table 6.

In design study of fast breeder reactor, reduction for positive sodium void reactivity coefficient is noticed as one of the most essential problems in the view point of inherent safety, especially, after the Chernobyl accident. To reduce the positive void reactivity, several ideas have been considered: flattening pan-cake core models utilizing neutron leakage, heterogeneous core models with axial depleted uranium blanket as low importance region, etc. To design the core with nearly zero void reactiv ty by using these reduction methods, there are needed very flat core or large nner blanket which are not realistic models. Furthermore, there are passiv$_e$s$_i$fety fast reactors such as LMR developed by ANL.In these reactors, negative reactivity effects such as flowering expansion of core supporting plate and/or extension of control rods which are caused by temperature rising are considered to overcome the positive void reactivity. However, these are

significant time-delayed effect in comparison with instantaneous Doppler effect. Moreover, inherent safety fast reactors with nearly zero void reactivity coefficient are also considered. These have very small cores without blanket region to make neutron leaky. Therefore, neutron economy is very bad and breeding ratio becomes smaller than unity.

Table 9 Core performance of MFBR

Parameter	Th/Pu core
Reactor power (MWt)	1800
Core height(cm)	100
radius(cm)	164
Inner core radius(cm)	83
Axial blanket	30
Average linear heat rating(w/cm)	348
Cycle length(EFPD)	600
Fuel	
Inner core(IC)	Th-^{233}U-10%Zr
Outer core(OC)	DU-Pu-10%Zr
Enrichment(w/o)	
IC1/IC2/OC	9,0/7.5/20.4
Moderator	graphite
Breeding ratio	1.5
Average burnup(GWd/t)	
IC1/IC2/OC	105/132/80
Burnup swing(%dk/k)	0.56
β_{eff}(%dk/k)	0.41
Na-void reactivity in IC(%dk/k)	-0.08
Instantaneous temperature reactivity in IC (%dk/k)	-0.21

A concept of advanced fast breeder reactor with instantaneous negative temperature coefficient has been proposed [12] recently in which the sodium void reactivity and/or the summation in the void and Doppler reactivities becomes negative. This advanced reactor consists of two-region core as follows: The central core region has negative void reactivity and/or instantaneous negative temperature reactivity, and outer core region becomes high breeding

composition with positive void reactivity. Moreover, important condition is that linear heat rating in the central region is more larger than that in the outer core region. This reactor can make shutdown before sodium void propagate to the whole core range. Because, when sodium flow is reduced by pump trip accident, at first, the sodium are voided from the central core region with higher linear heat rating, and the effective multiplication factor (keff) is reduced instantaneously by the negative temperature reactivity.

This advanced metallic fuel FBR (MFBR) can be used as the MA-transmutation reactor to avoid positive void coefficient by including MA-nuclides, The core performance of MFBR is shown in Table 9. The transmutation rate for MA is shown in Table 7, when MA-quantities of 5 w/% are homogeneously mixed for the fuel of DU-Pu-Zr in the outer core assemblies. The transmutation rate of MA-MFBR per 1GWt·300 days is about 4 times better than that of MA-PWR(MOX).

PROPOSAL OF LOW DECONTAMINATION FUEL CYCLE

Table 10 shows the comparison of MA-quantities transmuted and generated per cycle calculated for each reactor. It is observed from this table that the

Table 10 Comparison of MA-transmutation and build-up quantities per 1000MWt and 300 burnup days

Reactor	MA-quantity(w/%)	Build-up(kg)	Transmute(kg)
U-PWR	0.2	6	10
MOX-PWR	1.0	23	36
HCPWR	1.0	33	34
MOX-FBR	1.0	11	12
MFBR	1.0	11	16

generated MA can be transmuted by recycling in each reactor. From this result, "MA-confinement/transmutation fuel cycle" may be considered. The MOX-fuel and metallic-fuel cycles are distinguished clearly by the different reprocessing systems. The reprocessed fuels can contain ^{237}Np and Tc nuclides in recycling Therefore, a simple and economical reprocessing cycle may be considered for this fuel cycles. In the present fuel reprocessing, Np and Tc are extracted in the 2nd and 3rd processing cycles as shown in Fig.20. In the MA-transmutation fuel cycle, a simplified reprocessing system may be considered without extracting Np and Tc, that is a low decontamination reprocessing process.

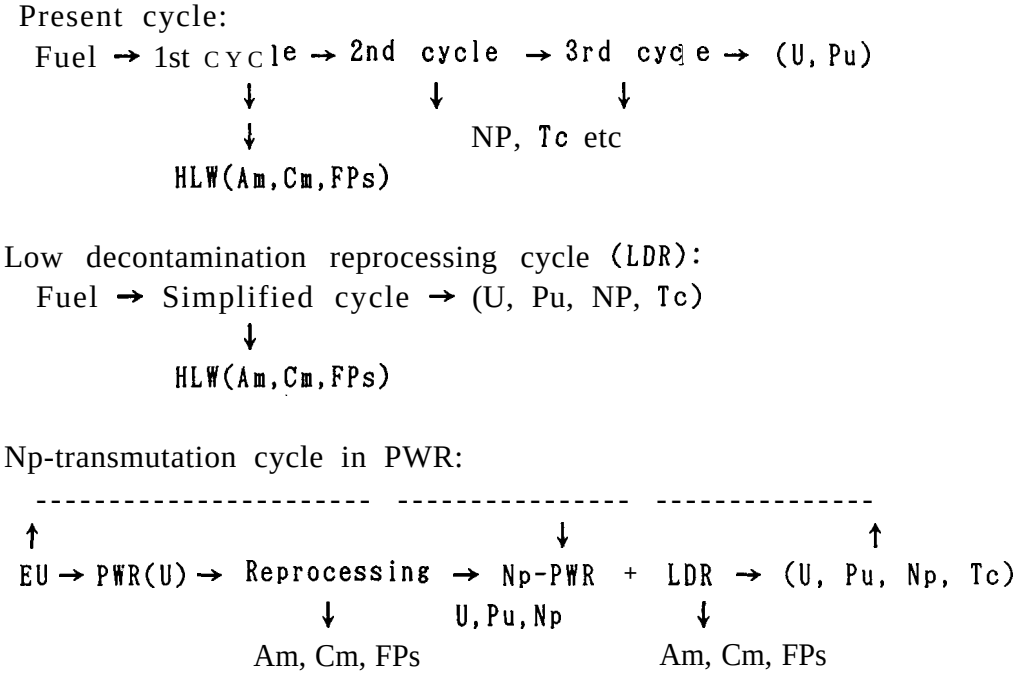

Fig.20 Low decontamination reprocessing fuel cycle

A metallic fuel cycle with pyrochemical processing is more better than purex processing cycle from the view point of MA confinement/transmutation. The MA remained finally in the LWR fuel cycles should be transmuted by MFBRs, in future.

CONCLUDING REMARKS

Reactor core performance for the existing and/or advanced thermal and/or fast reactors has been investigated from the view point of MA-recycle. When transuranium nuclides were mixed homogeneously to recycling fuels, initial excess reactivity and burnup reactivity swing were reduced remarkably, and higher conversion ratio was obtained. Because long-lived radioactive nuclides (MA) such as ^{237}Np, Am and Cm make instead of burnable poison at the initial state, and they are gradually transmuted to fissile materials with burnup. By recycling fuels, the MA-nuclides are not waste, but incinerated usefully as poison- and burnning-fuels. However, it should be noted that coolant void coefficient is dependent on plutonium and MA enrichments.

By considering the negative void coefficient and high burnup, MA-transmutation reactors have berm proposed for both LWR and FBR. In LWR, there were considered the Np-PWR(U) for ^{237}Np transmutation only which the quantities

generated from 20 existing UO_2-LWRs per 300 days are transmuted, and the MA-PWR(MOX) for MA-transmutation which the quantities generated from 6 UO_2-LWRs can be transmuted per 300 days, In FBR, the metallic fuel fast breeder reactor with negative void reactivity in central core region was considered for MA-transmutation. This reactor can transmute about 4 times MA-quantities than MA-PWR(MOX) per 1GWt·300 days.

In future works, a feasibility study of the low decontamination fuel cycle for MA-transmutation should be done from a view point of fuel-reprocessing, -refablication and –transportation systems.

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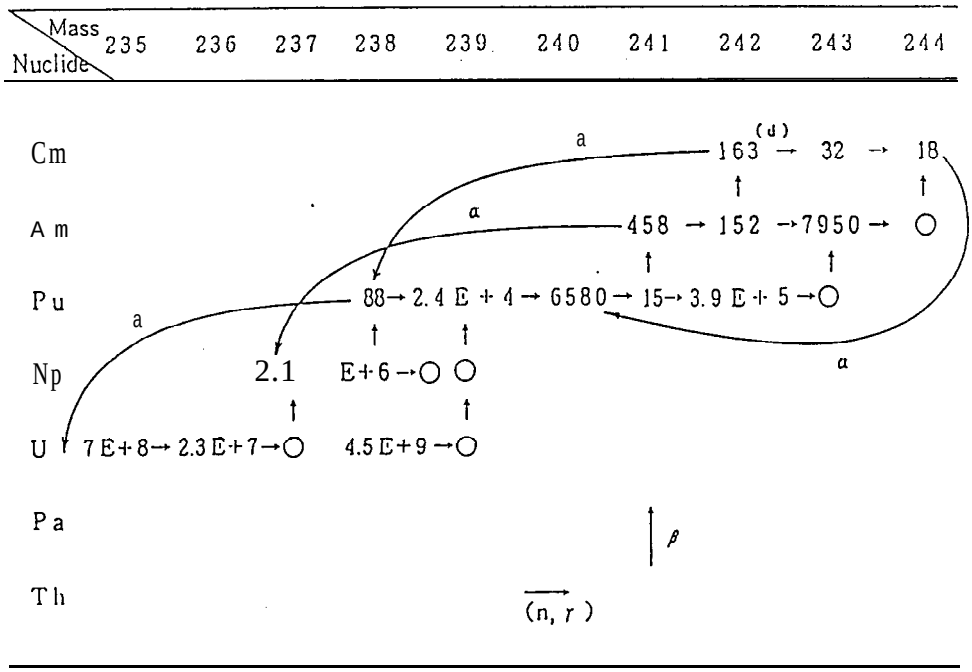

Fig.1 Half-life (year) and buildup-decay chain scheme for MA-nuclides.

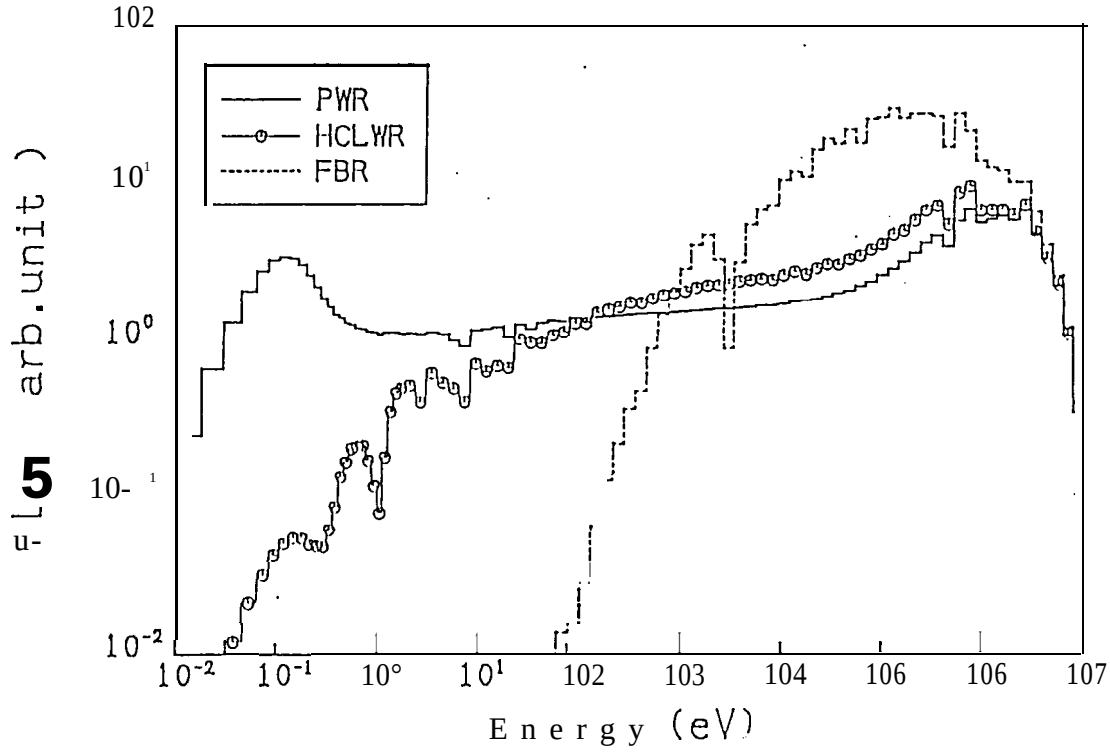

Fig.2 Comparison of neutron spectra among UO_2-PWR, MOX-HCPWR and MOX-FBR.

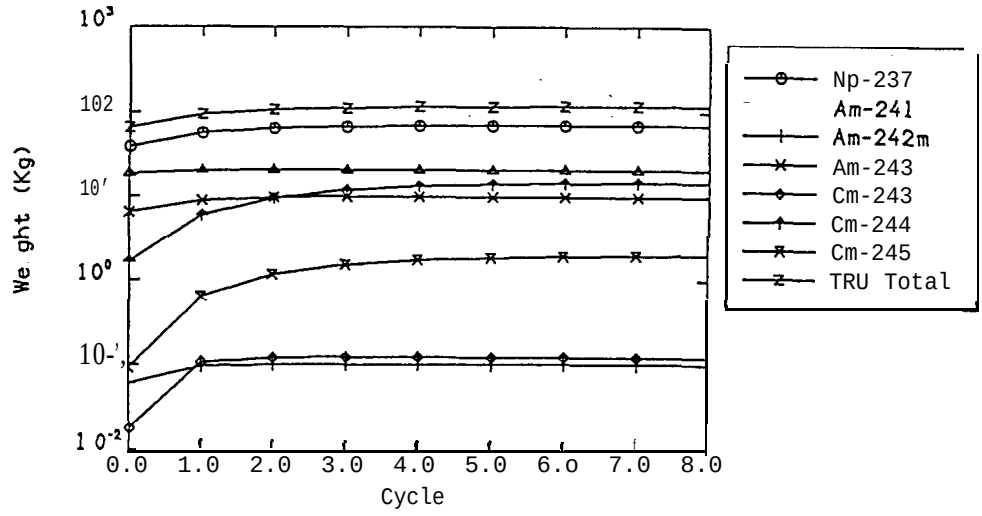

Fig.3 MA-nuclide change for U-PWR in MA-recycle.

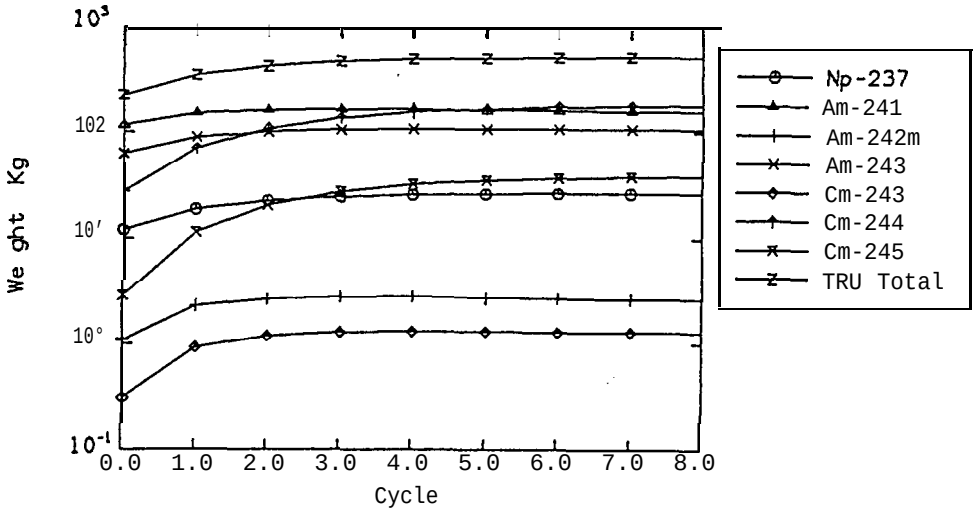

Fig.4 MA-nuclide change for MOX-PWR in MA-recycle.

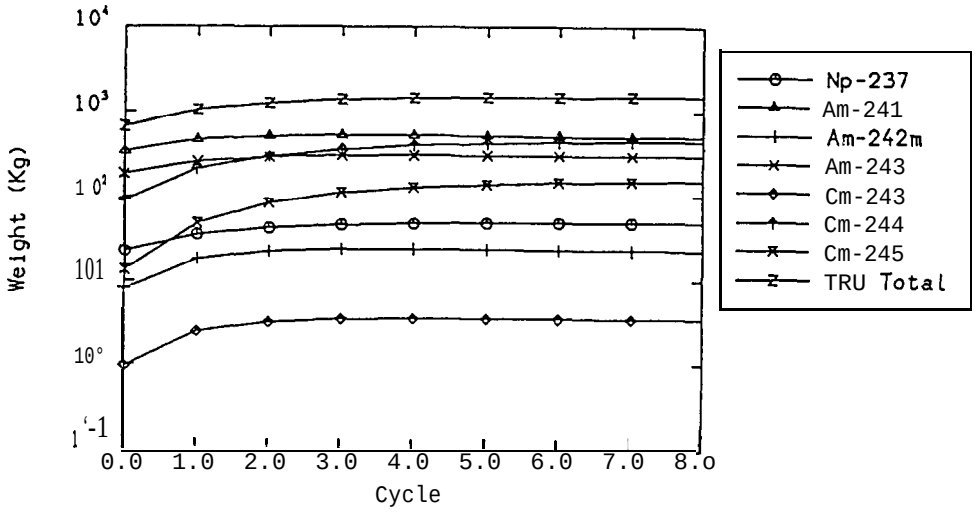

Fig.5 MA-nuclide change for HCPWR in HA-recycle.

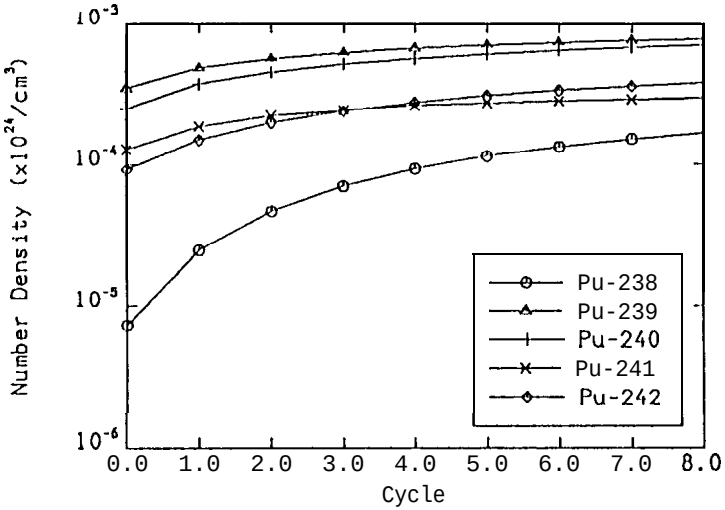

Fig.6 MA-nuclide change for MOX-PWR in (U, Pu, MA) -recycle.

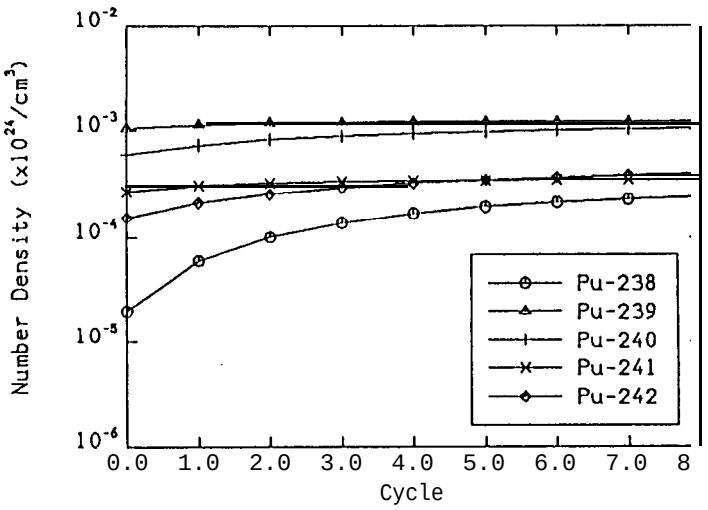

Fig.7 MA-nuclide change for HCPWR in (U, Pu, MA) -recycle.

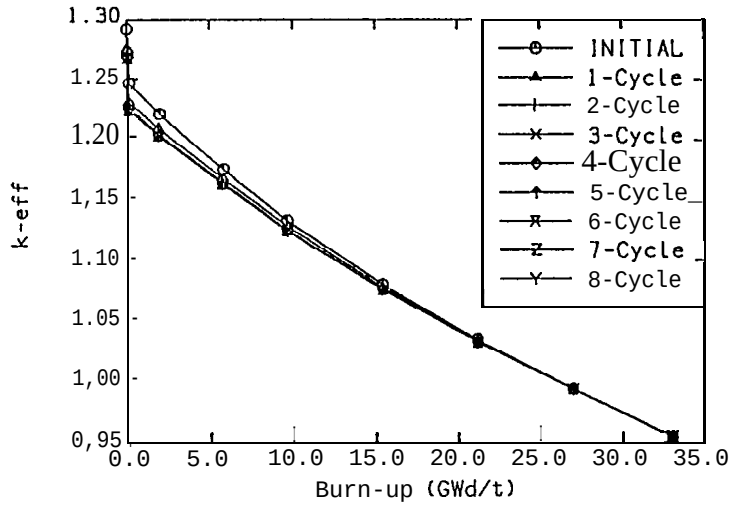

Fig.8 Burnup reactivity swing of U-PWR in MA-recycle

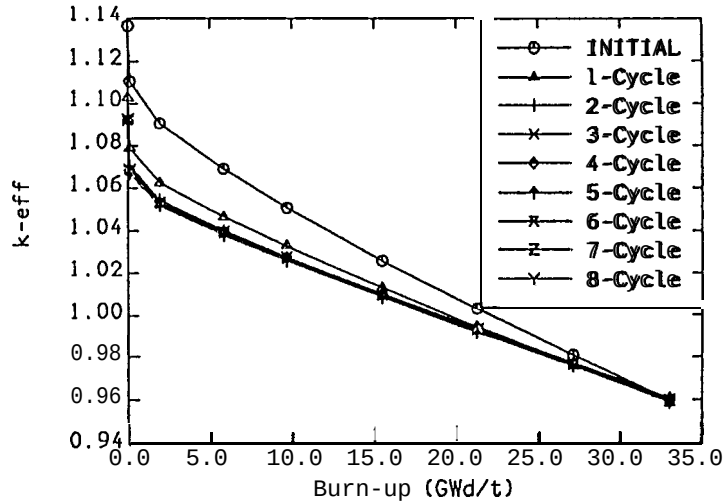

Fig.9 Burnup reactivity swing of MOX-PWR in MA-recycle

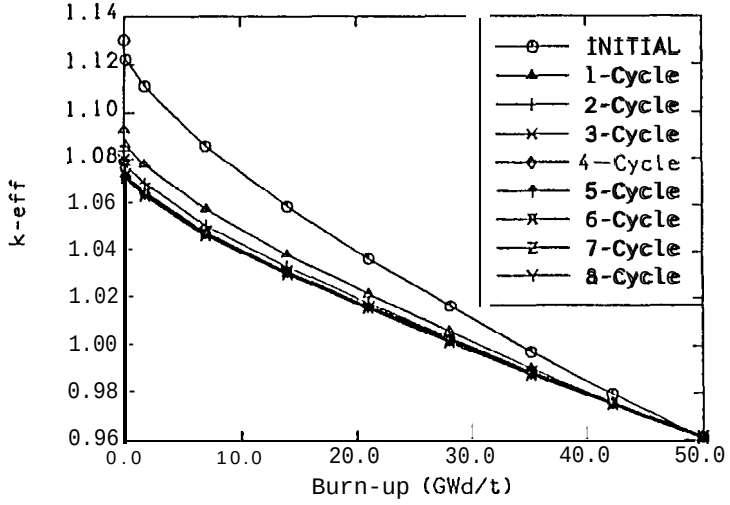

Fig.10 Burnup reactivity swing of HCPWR in MA-recycle

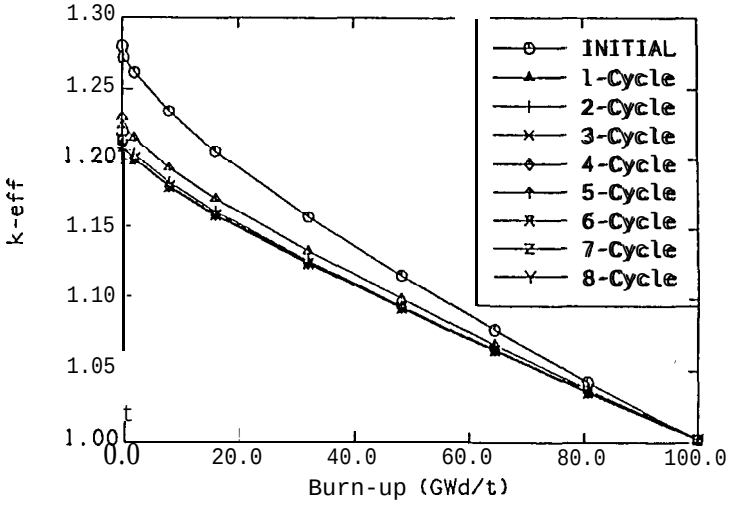

Fig.11 Burnup reactivity swing of VHBPWR in MA-recycle

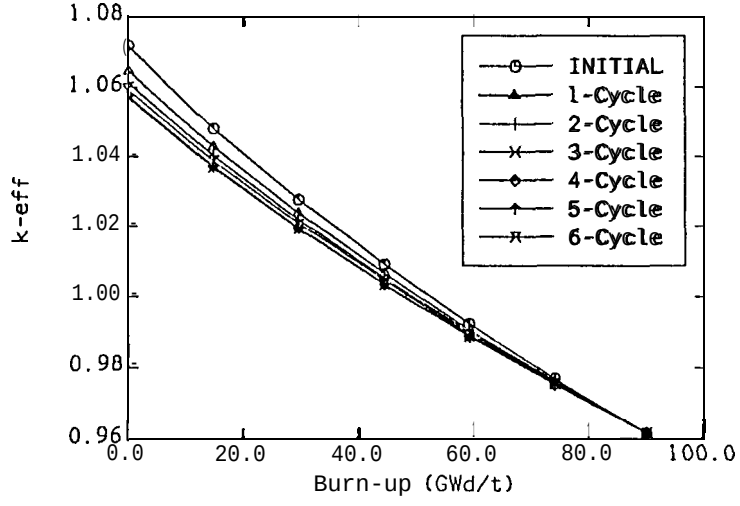

Fig.12 Burnup reactivity swing of MOX-FBR in MA-recycle

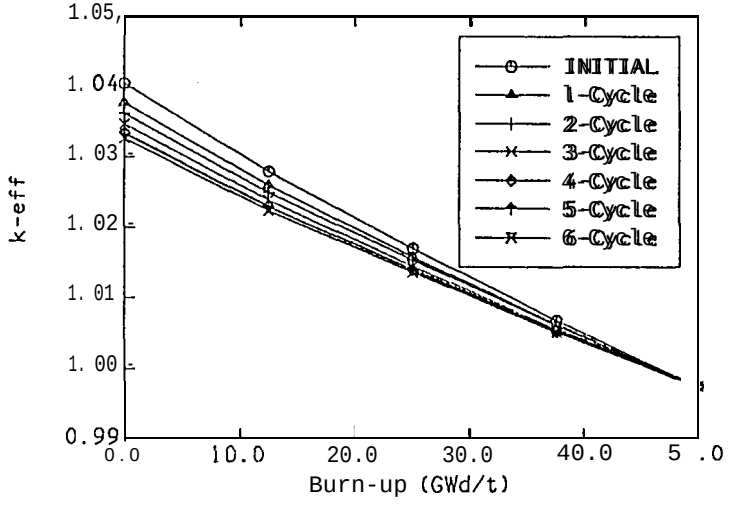

Fig.13 Burnup reactivity swing of MFBR in tlA-recycle

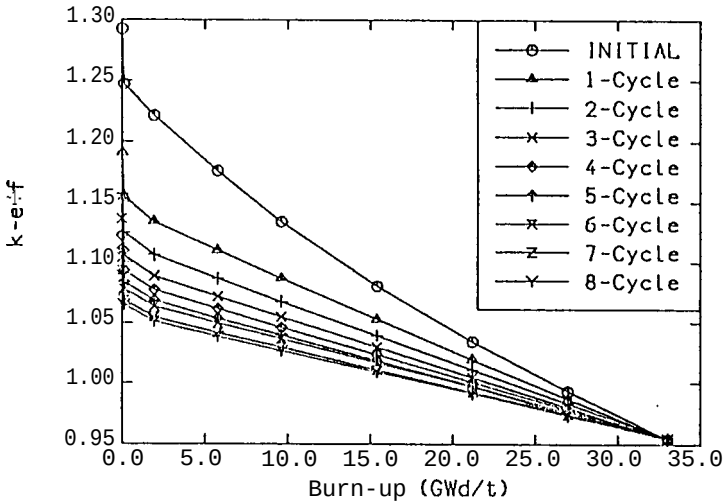

Fig.14 Burnup reactivity swing of U-PWR in (U,Pu,MA)-recycle

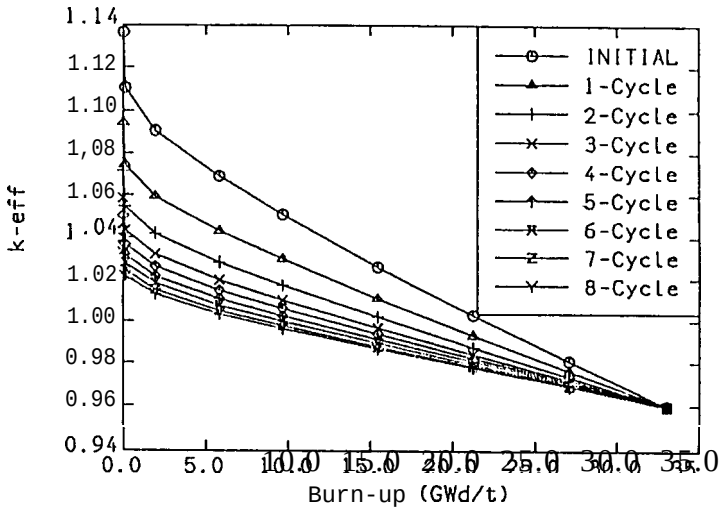

Fig.15 Burnup reactivity swing of MOX-PWR in (U, Pu,MA)-recycle

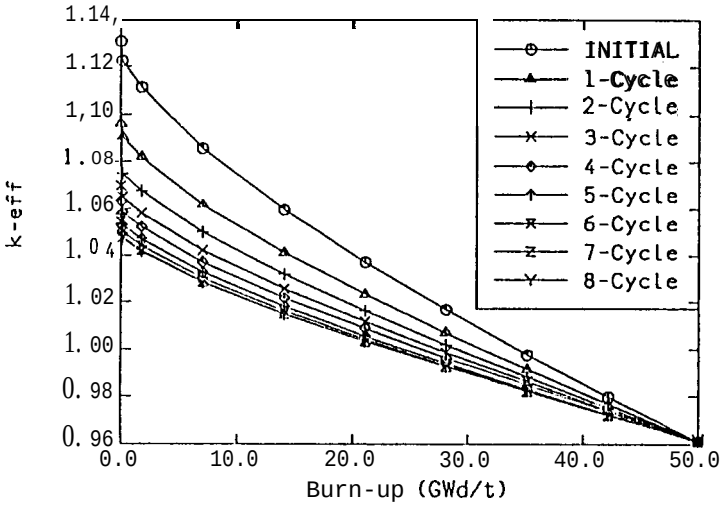

Fig.16 Burnup reactivity swing of HCPWR in (U, Pu,MA) -recycle

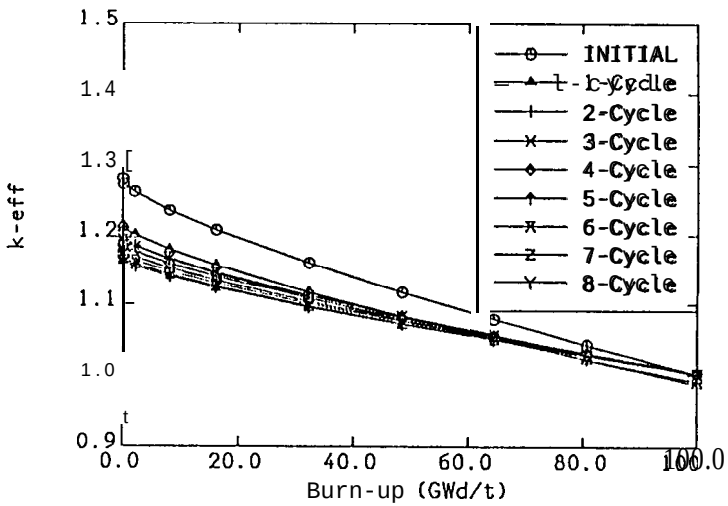

Fig.17 Burnup reactivity swing of VHBPWR in (U,Pu,MA) -recycle

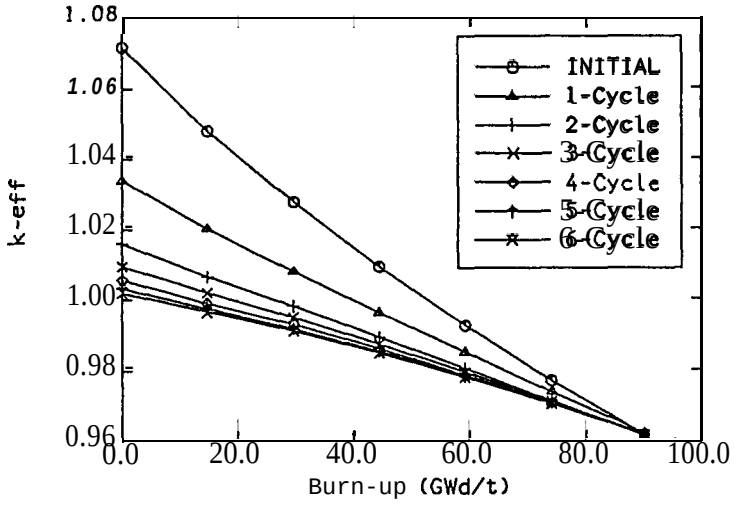

Fig.18 Burnup reactivity swing of MOX-FBR in (U,Pu,MA)-recycle

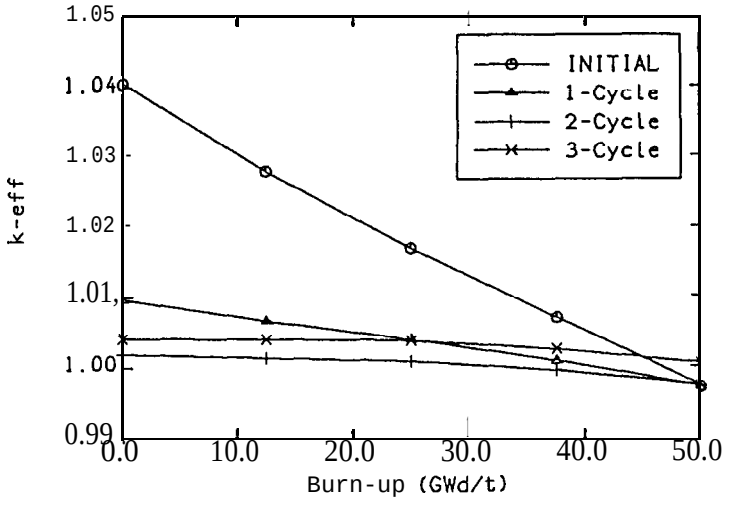

Fig.19 Burnup reactivity swing of MFBR in (U,Pu,MA)-recycle