MINOR ACTINIDE BURNING LMFBR CORE SYSTEM TO ENHANCE SAFETY CHARACTERISTICS

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ABSTRACT

A minor actinides (MAs)-burning core system is proposed for future LMFBRs. It provides high-burnup, a long cycle length and enhanced safety characteristics. MAs are transmuted in two steps. MAs are mixed into the blanket fuel only. Pu, reprocessed from discharged blanket fuel, is mixed into the core fuel of an axially heterogeneous core (AHC). Advantages of this MA-burning system include reduction of sodium void reactivity by not mixing MA into the core fuel, introduction of an above-core-sodium-tilled-gap (ACSG) region into the AHC and introduction of a solid moderator into the internal blanket and thin layer region between the ACSG and the upper axial blanket. Evaluation of the equilibrium cycle core performance shows the feasibility of a cycle length of 24 months, a high burnup of 200GWd/t and a breeding ratio of over 1.2.

1. INTRODUCTION

Research on separation and transmutation of minor actinides is attracting much attention. Minor actinides (MAs) are transuranium elements, excluding plutonium, many of which have long half-lives, e.g. 2.14 X 10^6 years for ^{237}Np. Transmutation methods using nuclear power reactors are considered to be promising because their technology has reached a practical use level, and extensive experimental data are available. Aiming at use of liquid metal fast breeder reactors (LMFBRs) as the main electric power generation plants in the future, we have studied some attractive core concepts. We found that another merit of LMFBRs is that of actinide burners whose core performance can be greatly improved by using MAs as a burnable absorber and high-conversion fertile fuel [1-3]. On the other hand, as the MA enrichment increases, the neutron energy spectrum gets harder and the fast fission rate increases. Therefore, the value of the sodium void reactivity coefficient moves to the plus side and the absolute value of the Doppler coefficient decreases. In this study, we propose an MA-burning LMFBR core system which not only transmutes MA efficiently and improves core performance, but also provides enhanced safety characteristics.

II. DESIGN CONSIDERATION

A. Design Goal

A high-performance LMFBR core system is proposed for future LMFBRs which provides economic and safe operation. In assessing the core performance characteristics, several figures-of-merit are considered which include operation length, discharge burnup, burnup reactivity swing, efficiency of MA transmutation and sodium void reactivity. The present core design effort focuses particularly on the reduction of positive sodium void reactivity.

The key design parameters and design goal were decided in line with the following considerations.

1) 1,000-MWe class cores, and a mixed oxide (MOX) fuel are adopted. MOX fuel is chosen because of the advanced state of its research and development and the extensive amount of experimental data available.

2) High burnup and a long operation cycle reduce LMFBR fuel cycle costs(FCC). It was pointed out that increasing a discharge fuel burnup from 100GWd/t to 200GWd/t can reduce FCC by about 1/2. But reducing FCC effect shows a tendency to be saturated with a further increase in burnup[4]. Therefore, a discharge fuel burnup of over 200GWd/t is chosen as a design goal.

3) Burnup reactivity less than that of an MOX fuel core is chosen as a design goal for an operation cycle length of over 24 months.

4) Previously, we proposed' an MA-burning LMFBR core whose core performance can be greatly improved by mixing 10% MAs into its core fuel and which can transmute MAs produced by about 10LWRS every year. In this study, MAs produced by over 10 LWRS are chosen to be transmuted every year in order to close them in a nuclear fuel cycle.

Core design parameters and goals are listed in Table 1.

B. Effects of MA Enrichment on Reactivity Coefficients

Utilization of MA-mixed MOX fuel and high burnup (over 200GWd/t) have a significant impact on reactivity coefficients as in the following.

1. Effect of MA enriched fuel. The dependency of sodium void reactivity (SVR) on the MA enrichment of core fuel in the MOX fuelled Axially Heterogeneous Core (AHC) is shown in Fig. 1. Average discharge fuel burnup is 90 GWd/t and the ratio of the internal blanket (IB) volume accounts for 10% of the whole core volume. SVR increases due to the increase of its non-leakage component in accordance with the MA enrichment. The loss of sodium from the core makes the neutron spectrum harder, decreasing neutron capture reaction rate and increasing fission reaction rate. That is why the positive reactivity effect increases with the MA enrichment. Figure 1 shows a 10% MA enrichment increases the SVR by 3.6$.

2. Effect of high-burnup. Figure 2 shows the dependence of sodium void reactivity on exposure in the 1000-MWe AHC's with the above-core-axial-sodium-filled-gap (ACSG). The ACSG consists of 90% sodium and 107o steel (i.e., wrapper tube). Core fuel is 10% MA-mixed MOX (mixed oxide). The SVR without ACSG is also shown for comparison. The dashed line is the non-leakage component of SVR without ACSG (spectrum component is dominant). The net SVR increases with bumup due to increased non-leakage component. This is because the loss of sodium from the core makes the neutron spectrum harder, decreasing the neutron capture reaction rate of FPs (fission products), which accumulate by high burnup operation, increasing positive reactivity effects. The SVR-reducing effect of ACSG (difference in SVR with ACSG from that without it) decreases with burnup. This is because the Pu accumulation in the IB weakens the fast flux peak near the core top, decreasing the neutron axial leakage effect upon voiding. The difference is about 1$ between the fresh core (0GWd/t) and the end of equilibrium cycle core (average 133GWd/t). We have clarified 3. that optimization of the IB in the AHC had a significant effect for reducing SVR. An additional technique to further reduce SVR was developed as shown in Fig.3: i) an IB configuration, which is thicker in the inner region than in the outer region and is extended to the core edge fuel assemblies, can accentuate neutron leakage upon voiding through the ACSG region within the outer radial region while maintaining radial power flattening; ii) optimization of IB volume fraction to 30% can greatly reduce SVR, attaining the minimum burnup reactivity.

Other demerits are also pointed out, that is, use of MA-enriched fuel may reduce thermal conductivity, melting point and the absolute value of the Doppler coefficient of the core.

III. CORE DESIGN AND NEUTRONICS PERFORMANCE

In this setion, the core design effort is focused on to further reduce SVR less than that of a 1000-MWe class MOX fuel LMFBR (5$) so as to enhance the inherent safety chracteristics, while attaining the design goals mentioned in II-A.

Table 1 Core design parameters and goats

Item		Soccification
Electric power	(MWe)	1000
Core inlet /outlet temperature	(℃)	355/510
Fuel composition · ^{239}Pu /^{240}Pu /^{241}Pu /^{242}Pu · ^{235}U /^{238}U .239 ND /^{240}Am /^{241}Am /^{242}Cm /^{244}Cm		 58/24/14/4(*) 0.3 / 99.7 80.4 / 5.7/ 9.9/ 0.6/ 3.4 (*)
Fuel material, Core / Blanket		PuO_2-UO_2 / MAOZ - U02
Structural material		Improved ferritic steel
Coolant material		Sodium
Core fuel weight	(t)	28.4
Core volume fraction Fuel / Structure / Coolant	(%)	42/22/36
MLHGR	(W/cm)	≦430
Cycle length	(Months)	≧ 24
Discharge burnup	(GWd/t)	≧200
Burnup reactivity	(% A k/kk')	≦ 4
MA transmutation amount	(LWR/vear)	≧ 10
Sodium void reactivity	($) I	≦ 5

(*) Valiable as described in Section-III.

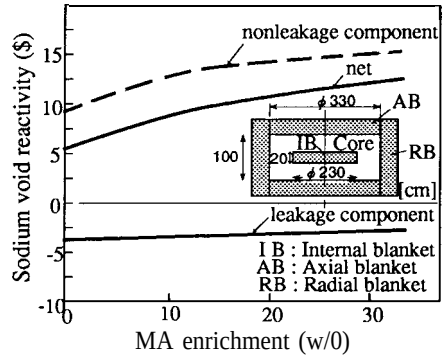


Fig. 1 Dependency of sodium void reactivity on"MA enrichment

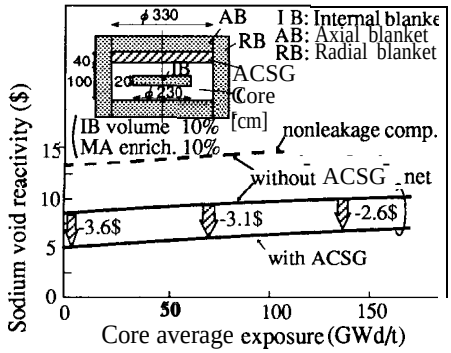


Fig. 2 Dependency of sodium void reactivity on exposure

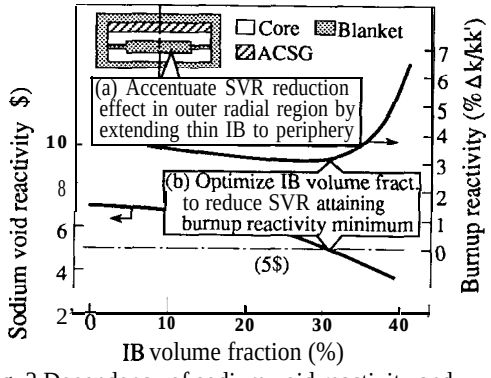


Fig. 3 Dependency of sodium void reactivity and burnup reactivity on the IB volume fraction

A. Calculation Methods

Core neutronics analysis is performed for the equilibrium cycle. Three-dimensional flux and burnup calculations are performed with the multigroup diffusion/depletion code HICOM[7] and two-dimensional calculations are performed with CITATION[8]. The calculational accuracy of HICOM was previously verified by analysis of AHC mockup experiments[9,10] on the Fast Critical Assembly (FCA) of the Japan Atomic Energy Research Institute. Sodium void reactivity is calculated by direct keff calculations at the end of cycle. Transport effects are evaluated with the two-dimensional multigroup transport code TWOTRAN[11]. In the voided configuration, the flowing sodium within the wrapper tube is removed from the core, internal blanket and their upper regions, excluding the upper axial shielding,

Cross-section sets are processed from the Japanese Evaluated Nuclear Data Library-2 (JENDL-2)[12]. The newest Japanese Nuclear Data Library JENDL-3[13] is also used for comparison. They are generated in the following way. The TIM-I and PROF-GROUGH-G codes" are used to generate a 70-group cross section set from the JENDL-2. This set is then collapsed to an 18-group effective cross-section set using neutron spectra in a cylindrical core geometry. To calculate sodium void reactivity, individual 18-group cross-section sets are created for voided and non-voided core conditions.

B. MA-mixing into Blanket Fuel

In this study, an alternative transmutation method of MAs in spent fuel is demonstrated in which MAs are mixed into the blanket fuel only.

1. Survey on MA loading method. Figure 4 shows the AHC with a 40-cm ACSG used in the parametric survey. The ACSG consists of 90% sodium and 10% steel (i.e., wrapper tube). MA transmutation characteristics are surveyed by using MA enrichments in internal blanket (IB), radial blanket (RB) and axial blanket (AB) fuels as parameters. A high-burmtp of average discharge fuel 200GWd/t is simulated by 10% MA enrichment in the core fuel. The MA compaction is assumed to be that of a 1000-MWe LWR spent fuel, 3 months after discharge from the core (Table 1).

Figures 5 and 6 show the dependency of MA transmutation efficiency and amount on its loading position. MA transmutation amount is the difference between loaded and surviving MAs. MA transmutation efficiency is the ratio of the MA transmutation amount to its loaded amount. The solid lines are values of core fuel. MA transmutation efficiency does not have strong correlation with MA enrichment. Total MA transmutation amount in the 20% MA- enriched blanket fuel is almost the same as that of 10% MA- enriched core fuel, attaining the design goal. Therefore, we chose the MA enrichment of 20% in the blanket for the following design study.

Table 2 shows the Ptr and MA compositions in loaded and discharged blanket fuel in each operation cycle. The operation cycle length is 2 years and the refueling batch factor is three. It is found that the amount of ^{238}Pu in the discharged blanket fuel is almost the same as that of ^{239}Pu. The isotopic fractions of MAs are almost constant throughout the burnup period. This is because MA nuclides have similar nuclear characteristics.

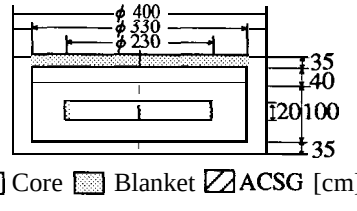
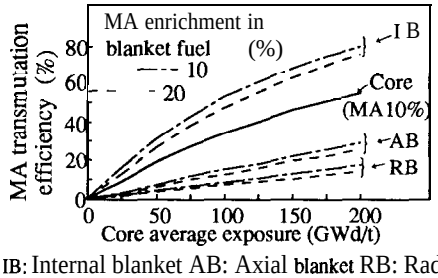


Fig. 4 Core configuration for MA loading method survey (Vertical section)



IB: Internal blanket AB: Axial blanket RB: Radiat blanket

Fig.5 Dependency of MA transmutation efficiency on its loading position

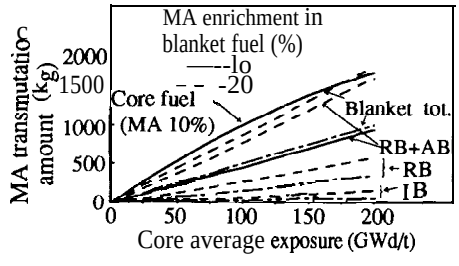


Fig.6 Dependency of MA transmutation amount on its loading position

2. Nuclear characteristics of Ptr recycled from blanket.

Nuclear characteristics of ^{238}Pu and its feasibility for providing high performance through a recycled Pu enriched core are researched. Figure 7 shows dependency of the a value of the main transuranic nuclides (including ^{238}Pu) on the core region and MA enrichment. The a value is the ratio of microscopic neutron capture cross section (σ c) to fission cross section (σ f), and a fissile species is defined as a nuclide with a value less than one and a fertile species is defined as a nuclide with a value larger than or equal to one. ^{238}Pu which is fertile in the blanket fuel can be taken as fissile in the core fuel. On the other hand, the η value, defined as the ratio of the neutron production cross section ($\nu\sigma$f) to the neutron absorption cross section (σ a), is 1.8 for ^{238}Pu. It is much smaller than 2.3, the value of ^{239}Pu. Therefore, the core which includes a large amount of ^{238}Pu may reduce excess reactivity at the beginning of cycle and attain high burnup on account of ^{239}Pu buildup due to neutron capture by ^{238}Pu.

3. Evaluation of equilibrium cycle core performance.

Feasibility of a high-performance core is studied on the basis of evaluation of the equilibrium cycle core under a fuel cycle concept using an MA-burning LMFBR. Figure 8 illustrates the fuel cycle concept. The configuration of the MA-burning LMFBR core is the same as that shown in Fig. 4. It is a 1000-MWe AHC with an ACSG.

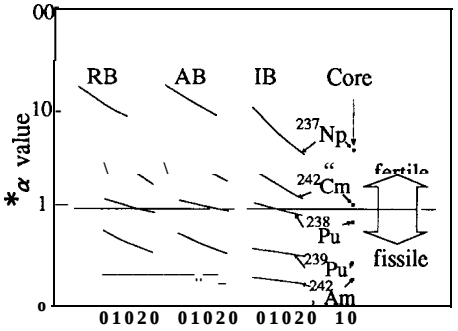
We assume MAs which are separated and reprocessed from LWR spent fuel are mixed into the blanket fuel only. Pu reprocessed from discharged fuel of the core and blankets is reloaded into the core fuel for the succeeding cycles. As mentioned above, discharge fuel of blanket includes much= Pu. As 20% of MAs in the blanket fuel are transmuted, MAs reprocessed from LWR spent fuel are supplemented in the succeeding cycles.

Some Pu and MA nuclides have relatively short half-lives. Therefore, collapse of these nuclides during cooling time and time between separating and reprocessing processes should be considered. This effect is surveyed using the cooling time and period between separating and reprocessing processes as parameters. The MA compositions are compared in Table 3 for two cases. Case A corresponds to a passage of 3 months after discharge from the core. The same composition was used in the previous study. In Case B, cooling time is 3 years and these are 5 years between separation and reprocessing (total 8years)[15]. The same loss time is used to calculate Pu isotopic composition. Recovering loss of Pu and MAs in the process of separation and reprocessing is neglected because it has a large uncertainty at the present time.

Figure 9 shows burnup reactivity and ^{238}Pu isotopic fraction (^{238}Pu/Pu total) for each cycle. In each case, operation cycle length of the initial core (the first cycle) is 12 months. In the succeeding cycles, operation cycle length is lengthened in accordance with the reduced effect of burnup reactivity swing due to increase ^{238}Pu inventory within the design goal (≦4% A k/kk'). Average discharge fuel burnup is also increased in accordance with the increased cycle length.

Table 2 Pu and MA composition in loaded and discharged blanket fuel (Cooling 3 months, MA enrichment 20w/o)

Nuclides		loaded fuel		discha :d fuel	
		weight (kg)	fraction (%)	veight (kg)	raction (%)
Pu	^{238}Pu	o	0	450.0	47.1
	^{239}Pu	o	0	465.4	48.7
	^{24a}Pu	o	0	36.3	3.8
	^{241}Pu	o	0	2.7	0.3
	^{242}Pn	o	0	0.3	0.0
	Total	o	100.0	954.6	100.0
MA	^{237}Np	3004.1	80.4	2347.1	79.2
	^{241}Am	213.0	5.7	161.6	5.5
	^{243}Am	369.9	9.9	292.6	9.9
	^{242}Cm	22.4	0.6	3.6	0.1
	^{244}Cm	127.1	3.4	143.6	4.8
	residual	0.0	0.0	13.7	0.5
	Total	3736.5	100.0	2962.2	100.0



$$*\alpha \text{ value} = \frac{\text{U. (neutron capture cross section)}}{\sigma\text{f (fission cross section)}}$$

Fig. 7 Dependency of α value of main nuclides on core region and MA enrichment

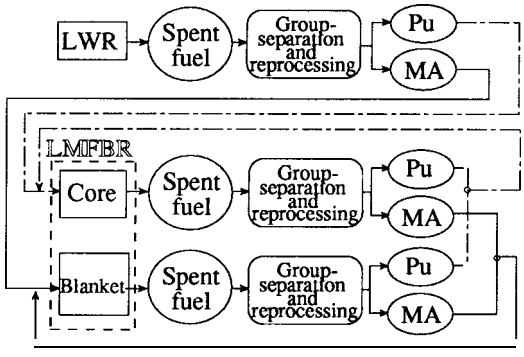


Fig. 8 Fuel cycle concept including MA-burning LMFBR

Table 3 Dependency(*) of MA composition on cooling time and time between separation and reprocessing

Time	Case A	Case B
Cooling	3 months	3 years
Between separation and reprocessing	0	5 years
^{237}Np	80.4	56.2
?.41 Am	5.7	26.4
^{243}Am	9.9	12.0
^{242}Cm	0.6	0.03
^{244}Cm	3.4	5.11
^{245}Cm	0.0	0.28
Total	100.0	100.0

(*) Based on a 1000-MWe LWR with discharge burnup of 33GWd/t.

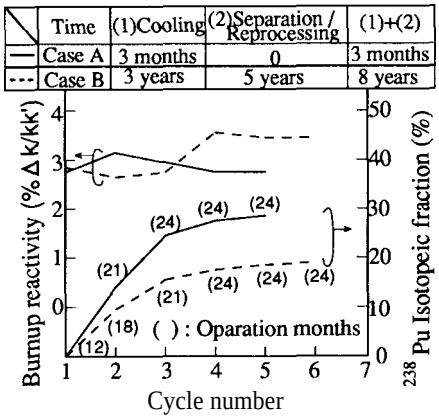


Fig. 9 Reactivity and 238 Pu isotopic fraction for each cycle

A cycle core whose burnup reactivity and fuel composition are almost equal to those of the previous cycle is taken as an equilibrium cycle core. The fifth and sixth cycles are taken as equilibrium cores of Cases A and B, respectively. Main core performance values are shown in Table 4 and Pu composition change is shown in Table 5, for the equilibrium cycle core of each case. The design goals for operation length, discharge fuel burnup and burnup reactivity are attained in both cases. But SVR does not meet the design goal.

In the next section, we develop a technique to reduce sodium void reactivity in the equilibrium cycle of Case B which is more realistic because Pu and MAs are considered to be transmuted during cooling and in the processes of separation and reprocessing.

C. Technique to Reduce Sodium Void Reactivity

1. Introducing neutron moderator into IB fuel. In section II, we pointed out that SVR reducing effect of ACSG decreases with burnup in the AHC with the ACSG. This was because Pu accumulation in IB mitigates the axial neutron leakage effect upon voiding. In this study, we adopt an additional technique to keep the SVR reducing effect of the IB throughout the burnup period.

Table 4 Nucler core performance of equilibrium cycle (IB volume fraction 10%)

Item	Case A	Case B
Cycle length (months)	'24(*)	24(*)
Pu enrich. (^{239}Pu/Pu) (%)	23.4 (28.6)	24.3 (19.0)
MA enrich., core/blanket (%)	0 / 20	0 / 20
Burnup reactivity (% A k/kk')	2.8	3.5
MLHGR (W/cm)	≦ 430	≦ 430
Discharge burnup (GWd/t)	200	200
Sodium void reactivity ($)	7.5	7.0
MA transmutation (LWR/year)	15.1	14.4

(*) Load factor 90%

Table 5 Pu change of equilibrium cycle core through burnup period

(a) Case A (Cooling 3 months, MA enrichment 20 w/o)

Nuclides		loaded fuel		discharged fuel	
		weight (kg)	fraction ('%0)	weight (kg)	fraction (%)
PO	^{238}Pu	553.6	28.6	158.1	10.8
	^{239}Pu	1011.9	52.3	820.5	56.2
	^{240}Pu	303.9	15.7	398.5	27.3
	^{24}, PO	41.8	2.2	57.3	3.9
	^{242}PO	22.8	1.2	26.9	1.8
	Total	1934.1	100.0	1461.2	100.0

(b) Case B (Cooling 3 years, MA enrichment 20 w/o)

Nuclides		loaded fuel		discharged fuel	
		weight (kg)	fraction (%)	weight (kg)	fraction (%)
PO	^{238}Pu	381.7	19.0	109.1	7.3
	^{239}Pu	1125.1	55.9	819.6	54.6
	^{240}Pu	435.5	21.6	469.1	31.2
	^{24}, Pu	38.9	1.9	69.8	4.6
	^{242}PO	31.2	1.5	34.4	2.3
	Total	2012.4	100.0	1502.0	100.0

Previously", it was found that introducing a moderator into tire IB fuel of the AHC is effective to reduce SVR because this mitigates neutron spectrum hardening upon voiding. This technique also has a potential to reduce burnup reactivity swing because it softens the IB neutron energy spectrum, increasing capture reaction rate of ^{238}U. In this study, combined effects of introducing a moderator into the IB fuel and the ACSG on SVR are evaluated

First, the SVR reducing effect is evaluated by employing hydrogen in the IB region of the equilibrium cycle core in Case B, without changing fuel inventory. The core configuration is the same as that of Fig. 4. The volume fraction of the IB (=IB/(Core+IB)) is 10%. The results of calculations are plotted

in Fig. 10. It illustrates the dependency of sodium void and burnup reactivities on the hydrogen density in the IB fuel. SVR decreases with the increase of hydrogen density and it goes down below 2$ when the hydrogen density is 5 X 10^{21} atom/cm'. On the other hand, burnup reactivity increases a little.

In this study, we choose calcium hydride (Cd-b") which is stable at high temperature. Its dissociation temperature can be increased by clothing in a pressurized clad. Its hydrogen density is 5.4 Xl& atom/cm³. Replacing 22% of the internal blanket fuel with CaH_2 realizes a hydrogen density of 5 X 10^{21} atom/cm'. On the other hand, it reduces the subassembly power. An IB configuration which is thicker in the inner region than in the outer region and is extended to the core edge fuel assemblies is found to be effective to flatten the radial power distribution. As a result, the IB volume fraction is increased to 15%. The core configuration is shown in Fig. 11 (a). Replacing part of an IB fuel with CaH_2 also increases the burnup reactivity to 5% A k/kk' ,which is beyond the design goal.

2. Introducing solid moderator layer. Recently, it was found" that introducing a thin zirconium-hydride layer between seed and blanket fuels is effective to reduce void reactivity in a steam-cooled fast reactor or LMFBR whose H (core height)/ D (diameter) ratio is close to unity. In this study, the SVR reducing effect of a CaH_2 layer in the AHC with ACSG is surveyed. Figure 11 illustrates the core configurations for the CaH_2 layer survey. The SVR reducing effect in comparison with the reference case (a) is 0.5$ for (b), 0.7$ for (c) and 0.9$ for (d). In the case (d), many of the axial leaked neutrons through the ACSG upon voiding are moderated by the CaH_2 layer and absorbed by structrual materials in the ACSG and ^{238}U in the upper axial blanket (UAB) in the range of epithermal neutron energy. On the other hand, thermalized neutrons through the moderator causes a power spike in the core fuel. Therefore, we introduce the CaH2 layer between the UAB and the ACSG in the following study.

D. Core Performance

It follows from the above survey that the effects of the above-core-axial-sodium-filled-gap in the AHC on the sodium void reactivity reduction are enhanced when combined with the introduction of a moderator into the IB and a thin layer between the UAB and ACSG. On the other hand, burnup reactivity is 5% A k/kk' which is still beyond the design goal. Therefore, a core is designed to reduce burnup reactivity swing to meet the design goal by optimizing the IB volume fraction to 20% while meeting MLHGR(Maximum Linear Heat Generation Rate) its design goal.

1. Core configurations. Three core configurations, HOC, AHC-I and AHC-II are designed here and the core performances are compared. Discharge burnup of HOC is 90GWd/t, while that of AHC-I and AHC-II are 200GWd/t. A vertical section of each core is shown in Figs. 12 (a)-(c). The

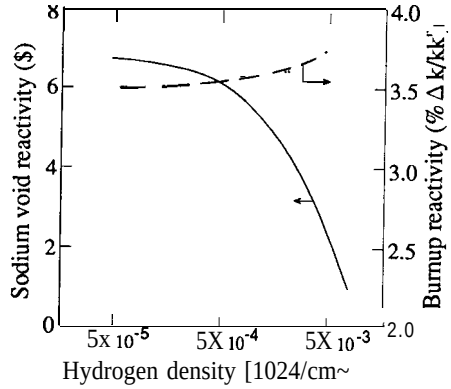


Fig. 10 Dependency of sodium void reactivity and burnup reactivity on the hydrogen density in the IB fuel

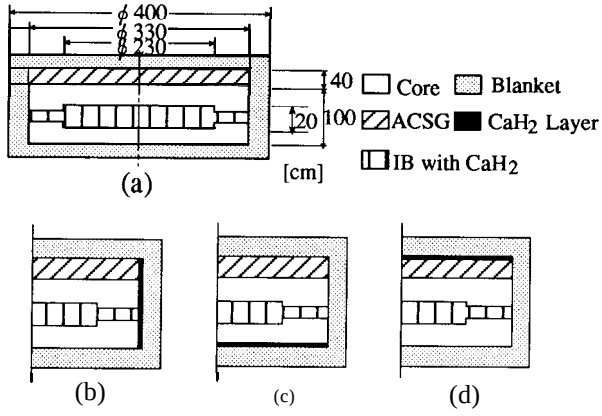


Fig. 11 Core configurations for moderator layer survey (Vertical section)

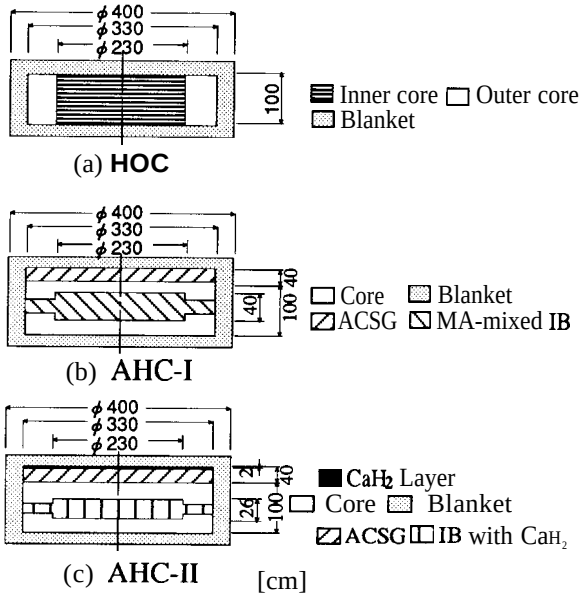


Fig. 12 Core configurations (vertical section)

HOC is the homogeneous core without ACSG. It is based on a 1000-MWe-class LMFBR core design study' in Japan. The AHC-I is an MA-burner with the ACSG which was proposed in our previous study'. It has an IB which is thicker in the radial central core region than in the peripheral core region; a thinner IB is extended to the core edge fuel assemblies. The 10% MA-mixed MOX fuel is employed in the core and 20% MA-mixed UO_2 fuel is employed in the IB. The IB volume fraction is optimized to 30% while meeting MLHGR its design goal by using the effect of power flattening of MA-mixed to core fuel. By contrast, the AHC-II is an MA-burner based on the advanced design and characterized by the moderator material, CaH_2, which replaces 22% of the IB fuel and is introduced into the thin layer between the UAB and ACSG. MAs are mixed into the blanket fuels (IB, RB and AB).

2. Neutronics performance. Core performance values, based on detailed neutronic calculations, are summarized in Table 6 for the three configurations. The MA enrichment of the blanket fuel is 20% and the Pu enrichment of the core fuel of the AHC-II is 33%. The isotopic fraction of ^{238}Pu is 19%.

Key core performance characteristics of the AHC-II are the following.

1) A long operation cycle length of 24 months, a high-burnup of 200GWd/t and a small burnup reactivity swing of 3.5% A k/kk' can be attained. Both the cycle length and discharge fuel burnup are doubled as compared with those of the HOC.

2) MAs produced in 10 LWRS can be transmuted every year.

3) Sodium void reactivity can be reduced to 3$, which is much smaller than that of HOC and AHC-I. A preliminary calculation with JENDL-3 shows SVR is reduced by about 0.5$.

4) The absolute value of the Doppler coefficient is increased by over 50% as compared with AHC-I because MAs are only mixed into the blanket fuel where neutron importance is relatively smaller than in the core fuel.

Figure 14 shows the history of the radial assembly power distribution. The assembly power changes about 5% at most during burnup.

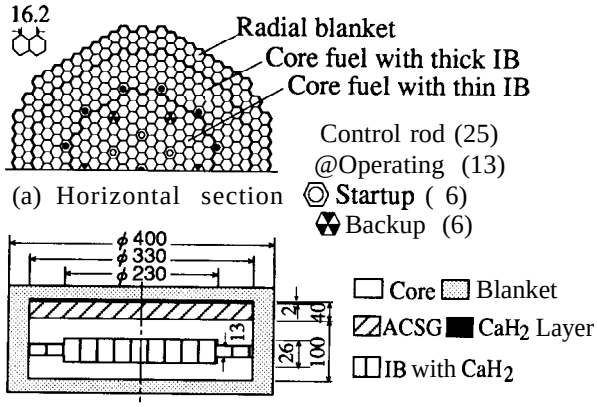


Fig. 13 Core configuration for AHC-II

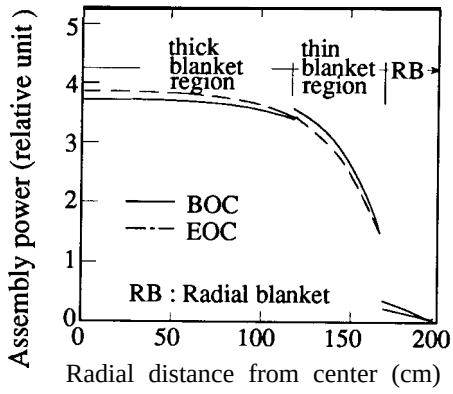


Fig. 14 Radial power distribution at BOC and EOC

Table 6 Nuclear core performance

Title	Reference	AHC-I	AHC-II
Configuration	HOC	with ACSG	with ACSG, CaH_2 to IB & ACSG
Core fuel weight (t)	28	28	27
Cycle length (months)	12[1)]	25[1)]	24[1)]
Volume fraction, core / IB (%)	42 / -	42 / 42	42 / 32[2)]
IB volume fraction (%)	0	30	20
Pu enrich. (^{238}Pu / Pu) (%)	18 (0)	30 (0)	33 (19)
MA enrich., core / Blanket (%)	0.0 / -	10 / 20[3)]	0 / 20[4)]
Burnup reativity (% Δ k/kk')	3.4	3.0	3.5
MLHGR (W/cm)	≦430	≦430	≦430
Discharge burnup (GWd/t)	90	200	200
Neutron fluence[5)] 10^{23} (n/cm^2)	2.8	5.2	5.0
Sodium void reactivity[6)] ($)	5.0	5.0	3.0
Doppler coef.[7)] 10^{-2} (Tdk/dt)	-1.0	-0.3	-0.5
Breeding ratio[8)]	1.2	1.3	1.2
MA transmutation (LWR/year)	-1	11	10

1) load factor 90%, 2) replace 22% IB fuel to CaH_2, 3) IB, 4) IB+RB+AB,
5) neutron energy> O. 1MeV, 6) EOC, 7) BOC, 8) includes ^{238}Pu

IV. CONCLUSION

An MA-burning core system was proposed for future LMFBRs. MAs are transmuted in two steps i) MAs are mixed into the blanket fuel, ii) Pu reprocessed from the discharged blanket fuel is loaded into the core fuel of the axially heterogeneous core (AHC) with the above-axe-sodium-filled-gap (ACSG).

The combination of employing a CaH_2 moderator in the internal blanket (IB) and a thin layer between the upper axial blanket and the ACSG had a significant SVR reduction effect without causing large penalties on other core performances.

According to detailed neutronic calculations, this system has a feasibility to provide a high-burnup of 200GWd/t, a long cycle length of 24 months and enhanced safety characteristics by reducing sodium void reactivity to 3$, which is much smaller than that of the reference HOC. The MAs produced by 10 LWRS can be transmuted every year.

Because MAs are only *mixed into the* blanket fuel with lower power density and neutron importance, the above MA-burning system has less severe thermal restraints, making it easy to cope with uncertainty factors such as caused by a decrease in thermal conductivity due to MA-mixed fuel.

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