Study on Core Characteristics for MA recycling in Fast Reactors

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Abstract

Effects of core characteristics (burnup reactivity loss, Doppler coefficient, sodium void reactivity, control rod worth, power distribution, transmutation rate, breeding ratio etc.) on MA recycling were studied in a 1000MWe - class LMFBR. Minor actinides produced by the standard PWR were used in the initial core of the MA recycling. The minor actinides that have been irradiated previously but not fissioned only introduced in this recycle system from 2nd cycle. It was found that the MA recycling in an LMFBR is feasible from neutronic and thermal-hydraulic points of view. However, the Np at the 8th recycle is significantly depleted compared to the unirradiated feed, and the fraction of Cm is greatly increased because of neutron captures in Am. The accumulation of Cm by the MA recycling may bring some design issues concerning the fuel handling and reprocessing due to increase both decay heat and neutron emission rate from ^{244}Cm.

1. Introduction

Some of the transuranium nuclides (minor actinides : MA) produced by the operation of nuclear power plants have extremely long-term radiotoxicity[1], and their management is one of the key issues for nuclear power to be accepted by the public. There are some means of reducing radiotoxicity of MA nuclides under investigation. Because of the hard neutron spectrum, LMFBRs are considered to have the potentiality of transmuting MA nuclides effectively.[2-6]

The following studies are implemented to establish MA transmutation technology by an LMFBR in PNC-Japan:

(1) Feasibility studies of MA burner core concepts and evaluation of MA material balance,
(2) Nuclear data evaluation of MA nuclides in sample irradiation experiments,
(3) Measurement and evaluation of physical and chemical properties of MA compounds,
(4) Development of fabrication technology of MA fuel,
(5) Evaluation of fuel behavior by MA fuel pin irradiation experiments.

Concerning the feasibility studies of core concepts, the following items have been carried out:

1) Optimization of loading method of MA,
2) Effect of rare earth(RE) in MA on core characteristics,
3) Influence of uncertainties of MA nuclear data,
4) Influence of MA containing fuel on reactor plant and fuel cycle,
5) Effect of MA recycling on core characteristics,
6) Evaluation of properties of MA containing fuel.

In this paper, the effect of MA recycling on core characteristics in an LMFBR is presented.

2. Calculational Method and Conditions

A 1000MWe homogeneous core with two enrichment zones was employed as a reference core. The main specifications of the reference core of MOX fuel are shown in Table 1.

The minor actinides produced by the standard PWR were used in the initial core of MA recycling as shown in Table 2. The minor actinides that have been irradiated previously but not fissioned only introduced in this recycle system from 2nd cycle after 5 years of cooling time. When adding MA in the recycled cores, these new isotopes were homogeneously distributed all over the fuel in replacement of heavy nuclides of uranium and plutonium. The fuel enrichment in PuO_2 was adjusted to get the same cycle length and overall fuel residence time and the same reactivity at the end of equilibrium core. The number of MA recycling in the core life is expected 8 times.

The nuclear characteristics of MA - recycled cores were calculated by a burnup code on two-dimensional RZ geometries. Burnup characteristics, power distribution and reactivity coefficients were obtained from the analyses. Cross sections were collapsed from JFS-3-J2 library[7] based on JENDL-2[8]. Seven-group effective cross sections were used in the calculation of burnup characteristics and power distribution. Reactivity coefficients were calculated using 18-group effective cross sections.

The core configurations of the reference core of MOX is shown in Fig. 1.

3. Results and Discussion

The effect of MA recycling on core characteristics is shown in Table 3. The effect of MA recycling on Pu and MA isotopic composition is also shown in Table 4. The results of the neuron emission rate and decay heat in irradiated fuels by the MA recycling are shown in Table 5. The main results of the study are summarized as follows.

(1) Burnup reactivity loss is ~1.6%Δk/kk' in the initial core, but the values from the 4th to the 8th recycle can keep around 0.4 % Δk/kk'. The influence of MA recycling on burnup reactivity loss is small in the equilibrium cores. The plutonium enrichment is reduced from 19.7wt% to 18.7wt% by MA recycling because of decreasing Np and increasing Cm nuclides which have large fission cross sections.

(2) Absolute value of Doppler coefficient becomes large by MA recycling, and the value of the 8th recycle is approximately 14% larger in comparison with that in the initial core. This be caused by the reduction of Pu enrichment by MA recycling, and the increase of resonance absorption of ^{238}U.

(3) Na void reactivity decreases with MA recycling, and the value of the 8th recycle is ~7% smaller than that in the initial core. It seems that the influence of MA recycling on Na void reactivity is generally small.

(4) Control rod worth is increased by ~5% in the 8th recycling. The influence of MA recycling on control rod worth is small.

(5) MA-loaded cores can transmute MA by ~10%, and there is not large difference in MA recycling. The amount of MA transmutation is approximately 4t for 30 years.

(6) Neptunium at the 8th cycle is significantly depleted compared to the unirradiated feed, and the fraction of Cm is greatly increased because of neutron captures in Am as shown in Table 4. Both the neutron emission rate and decay heat of the discharged fuels at the 8th recycle are very large in comparison with the fuels loaded in initial core as shown in Table 5. The accumulation of Cm by MA recycling will bring some problems concerning the fuel handling and reprocessing due to increase both decay heat and neutron emission rate from ^{244}Cm. If it is possible to remove Cm from the MA-loaded fuel, the decay heat value will decrease by one order, and the neutron emission rate by three orders. Since the dominant isotope, ^{244}Cm, has a relatively short half-life of 18 years, there might be another possibility of the fuel cycle, that is , partitioning of Cm and Am from MA in the reprocess and storing of Cm and Am for a period. Some study will be needed to estimate the trade-off between the plant modification and the reprocessing.

4. Concluding remarks

It was found that the MA recycling in an LMFBR is feasible from neutronic and thermal-hydraulic points of view . However, the Np at the 8th cycle is significantly depleted compared to the unirradiated feed, and the fraction of Cm is greatly increased because of neutron captures in Am. The accumulation of Cm by the MA recycling may bring some design issues concerning to the fuel handling and reprocessing due to increase both neutron emission rate and decay heat from ^{244}Cm.

REFERENCES

1. L. KOCH, Formation and Recycling of Minor Actinides in Nuclear Power Stations, Handbook on the Physics and Chemistry of the Actinides, Chapter 9, North-Holland Physics Publishing, 1986.
2. M. YAMAOKA, M. ISHIKAWA and T. WAKABAYASHI, "Characteristics of TRU Transmutation in an LMFBR", presented at Workshop on the P-T of Minor Actinides, Mito, Ibaraki, Japan, Nov. 6-8, 1990.
3. M. YAMAOKA ,M. ISHIKAWA and T. WAKABAYASHI, "Feasibility Study of TRU Transmutation by LMFBRs", Proc. Int. Conf. on Fast Reactors and Related Fuel Cycles (FR'91),Vol. IV, Oct, 28-Nov. 1 , Kyoto (1991).
4. T. WAKABAYASHI ,M. YAMAOKA , M. ISHIKAWA and K. HIRAO, "Status of Study on TRU Transmutation in LMFBRs", Trans. Am. Nucl. Soc., 64, 556 (1991).
5. T. WAKABAYASHI and M. YAMAOKA, "Characteristics of TRU Transmutation in an LMFBR", IWGFR Specialists Meeting on Use of Fast Breeder Reactors for Actinide Transmutation , September 22-24, Obninsk,Russia,1992.
6. T. WAKABAYASHI and T. IKEGAMI, "Characteristics of an LMFBR Core Loaded with Minor Actinide and Rare Earth Containing Fuels", Proc. Int. Conf. on Future Nuclear Systems : Emerging Fuel Cycles and Waste Disposal Options (GLOBAL'93),Vol. I, Sep. 12-17 , Seattle (1993).
7. T. NAKAGAWA, "Summary of JENDL-2 General Purpose File", Japan Atomic Energy Research Institute report, JAERI-M 84-103 , 1984.
8. H. TAKANO, et al., "Revision of Fast Reactor Group Constant Set JFS-3-J2", Japan Atomic Energy Research Institute report, JAERI-M 89-141 ,1989.

Table 1 Main Design Parameters of the 1000MWe Reference LMFBR

Design Parameters	Data
1. Plant Parameters	
·Reactor Thermal Power	2517 MWt
·Coolant Temperature (Reactor Outlet / Inlet)	530 / 375 °C
·Operation Cycle Length	15 Months
2. Core parameters	
·Core Concept	2-region Homogeneous
·Average Fuel Burnup	91 GWD/T
·Max. Linear Heat Rate	430 w/cm
·Core Diameter / Core Height	3.68/1.00 m
·Thickness of Axial Blanket (Upper/Lower)	0.20/0.20 m
3. Core fuel parameters	
·Fuel Composition	PuO_2-UO_2
·Pu Isotope Ratio (238/239/240/241/242)	2.4/51.1 / 26.9 / 12.0 / 7.6 (LWR Discharged)
·Pattern of Fuel Exchange	3 Dispersed Batches
4. Blanket fuel parameters	
·Fuel Composition	UO_2
·U Isotope Ratio (235 / 238)	0.3 / 99.7
·Pattern of Fuel Exchange	4 Dispersed Batches

Table 2 Composition of MA Loaded in the Initial Core

Nuclide	Data(wt%)
Np-237	49.14
Am-241	29.98
Am-242m	0.08
Am-243	15.50
Cm-242	-
Cm-243	0.05
Cm-244	4.99
Cm-245	0.26

Discharged from PWR (35GWD/T) and Cooled for 5 Years Before Reprocessing

Table 3 Effect of MA Recycling on Core Performance

Item	Initial Core	4th Recycle	8th Recycle
MA Content (wt%)	5	5	5
Pu Enrichment (Average、 wt%)	19.7	19.5	18.7
Burnup Reactivity (%Δk/kk')	1.6	0.4	0.5
Maximum Linear Power (W/cc)	383	403	410
Breeding Ratio	1.12	1.26	1.23
Doppler Coefficient	1.0	1.07*	1.15*
Na Void Reactivity	1.0	0.97*	0.93*
Control Rod Worth	1.0	1.03*	1.05*
MA Transmutation Rate(%)	10.3	10.5	10.1

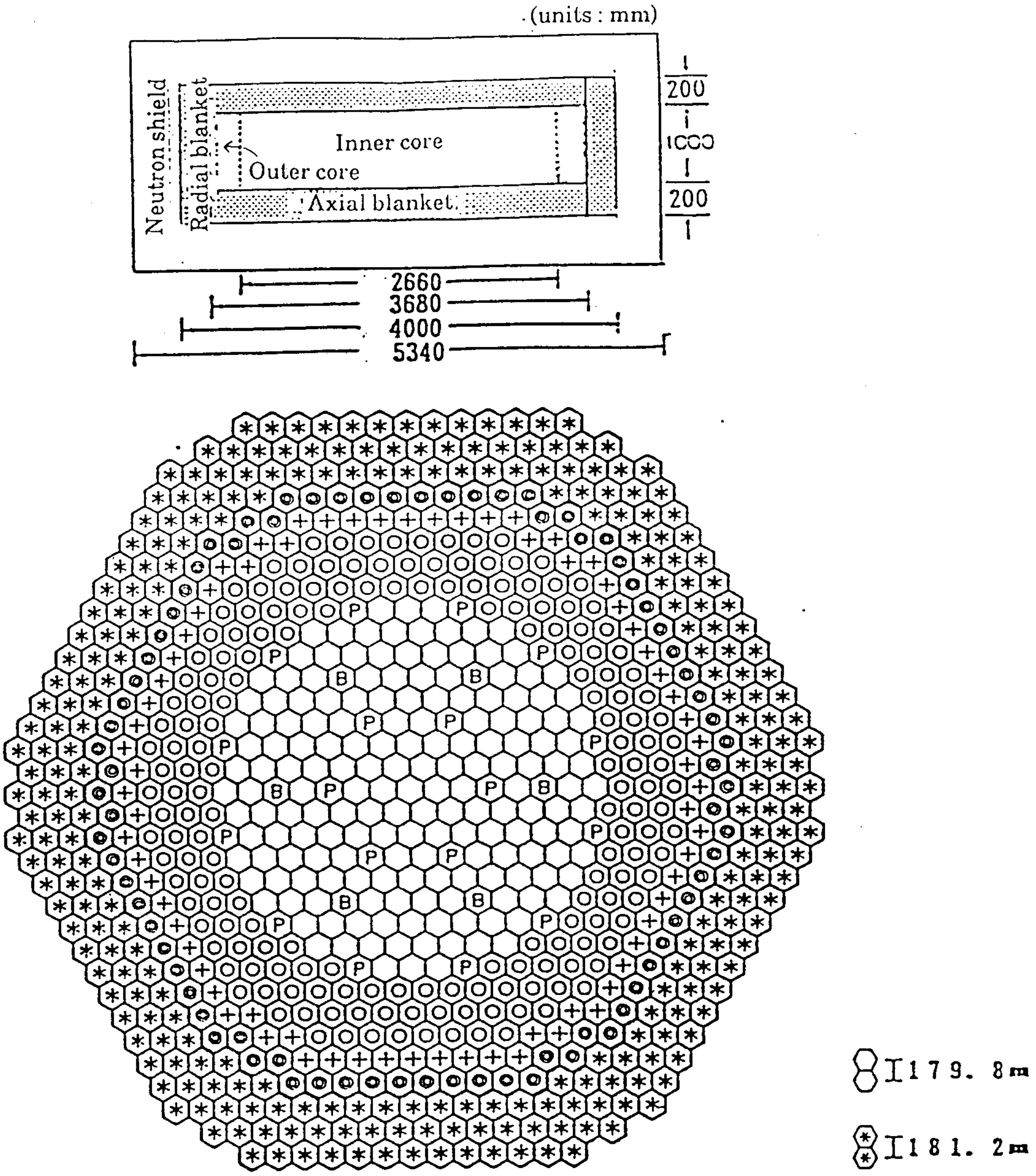
* Relative Value

Table 4 Effect of MA Recycling on Pu and MA Isotopic Composition

Item	Reference (Initial Core)	4th Recycle	8th Recycle
^{238}Pu	2.4	7.1	4.8
^{239}Pu	51.1	53.7	53.8
^{240}Pu	26.9	30.8	33.9
^{241}Pu	12.0	3.2	3.4
^{242}Pu	7.6	5.2	4.1
^{237}Np	49.1	18.9	8.8
^{241}Am	30.0	27.0	23.4
^{243}Am	15.5	28.0	28.8
^{244}Cm	5.0	16.2	20.1
^{245}Cm	0.3	5.9	8.8

Table 5 Effect of MA recycling on Neutron Emission and Decay Heat

Item	Reference (Initial Core)	4th Recycle	8th Recycle
Neutron Emission (n/sec/kg)	3.2×10^7 (1.0)	6.9×10^7 (2.2)	11.1×10^7 (3.5)
Decay Heat (W/g)	16.5 (1.0)	25.2 (1.5)	27.3 (1.6)



○	Inner core fuel	175
⊙	Outer core fuel	180
Ⓟ	Primary shutdown control rods	18
Ⓑ	Backup control rods	6
⊕	Radial blanket	72
◎	Neutron shield (Stainless Steel)	78
⊛	Neutron shield (B_4C)	277
		(total 799)

Fig. 1 Core layout of 1000MWe-class reference LMFBR