A New Method of Hydride Loading into Fast Reactor for its Multipurpose Uses

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ABSTRACT

A new method, "Core Character Control Pin (CCP)" is proposed to load hydride into a Fast Reactor (FR) aiming at a multipurpose FR. By using this method and a new hydride (CaH_2), it is possible that one FR works for transmuting HLWs, burning weapon grade plutonium (WG-Pu) and realizing a safer reactor. The FR using a special assembly designed for transmutation can transmute about 750 [kg] of MAs which corresponds to the amount discharged from 8 LWRs through three years operation. The FR with a special assembly designed for burning WG-Pu can convert about 210[kg] of WG-Pu to the LWR grade plutonium by the three years burnup.

1. INTRODUCTION

In atomic energy utilization, there are many problems which are very difficult to be solved by conventional thermal reactors. The problem of HLWs (High Level Wastes) such as MAs (Minor Actinides) and LLFPs (Long-Lived Fission Products) is very important for the development of atomic energy in future. It will be possible to ease this problem if these long-lived nuclides discharged from nuclear reactors are transmuted to stable nuclides or short-lived nuclides by any nuclear reaction. There is another difficult problem to deal with the weapon grade plutonium (WG-Pu) discharged from nuclear weapons from the viewpoints of nuclear nonproliferation. Any method for WG-Pu should be made using a reactor.

In order to solve these problems by a FR more efficiently, loading a material with hydrogen into a FR has been studied aiming at efficient transmutation by softening neutron spectrum. The FR with hydrogen is effective to enhance the efficient burnup of WG-Pu by the same reason. Almost in such studies, a homogeneous fuel model with a hydride and a fuel material (or HLWs) has been adopted. But, the homogeneous fuel method has little flexibility in core design. If there is a new flexible method to load hydrides into a FR, a FR will serve as a multipurpose FR. We propose a new method to load a hydride into a FR aiming at a multipurpose FR. By applying the new method to a FR, we show that one FR will be available for: (1) transmuting HLWs, (2) burning WG-Pu and (3) improving reactivity coefficients of a FR.

2. NEW METHOD OF HYDRIDE LOADING

In this paper, we propose "Core Character Control Pin (CCP)" as a new method to load a hydride into a FR. The CCP is the pin which only contains hydride. The size and the form of the CCP are set to be the same as those of a normal fuel pin. Therefore, it is easy to replace the fuel pin with the CCP (Figure1). Since we can easily change the amount of hydrogen in the core by using CCPs, it will be available to make any spectrum in one FR. Owing to this flexible design concept, the CCP method is effective for realizing a multipurpose FR. Technical and economical problems in the process of nuclear fuel recycle and other facilities will reduce by the CCP model in which MAs and hydrides separately load.

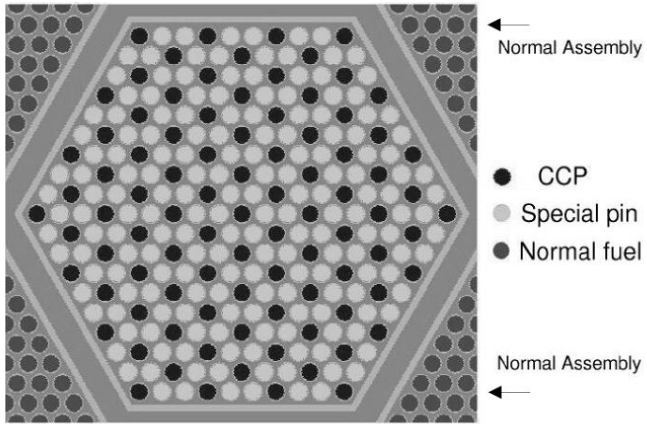


Figure 1. CCP model

CaH_2 was adopted as the hydride as the CCP hydride. Although ZrH has been considered as the hydride in many studies, this material has been pointed out that it dissociates hydrogen in a Na cooled FR core [1]. It is anticipated that positive reactivity is introduced into a FR core by dissociating hydrogen from ZrH and the transient behavior becomes worse by the positive reactivity insertion. Table 1 shows the summary of new hydride material investigation described in Ref. [2]. As shown in Table 1, it is found that CaH_2 never dissociate hydrogen in a Na cooled FR core and the moderation performance of CaH_2 is almost the same as that of ZrH. From these reasons, CaH_2 was selected as the new hydride for the CCP.

Table 1 Summary of new hydride materials (from Ref. [2])

	$ZrH_{1.6}$	CaH_2	$ZrV_2H_{4.8}$	$PrH_{2.8}$	$LaH_{2.76}$	SrH_2
Dissociation Temp.*1 [℃]	800	1000	1200	1149	1124	1040
Melting Temp. [℃]	1854	1000	1250	940	826	770
Neutron capture cross section*2	reference	OO	OO	X	X	OO
Probability to produce long-lived nuclides*3	reference	O	O	OO	O	O
Transmutation amount of MAs*4 [kg]	585	575	545	604	596	541

*1: Sodium boiling temperature is 940℃ at normal operation pressure of a typical FR.
*2: OO: Cross section is lower than Zr. O: Roughly the same as Zr. X: Larger than Zr.
*3: OO: No production of long-lived nuclides. O: Long-lived nuclides are produced, but the probability is smaller than Zr.
*4: The calculation results in 1000MWe class FR with three years operation (initial amount of MAs was about 1100[kg]).

3. CALCULATION METHOD

3.1 Reference core for applications of CCP method

We have adapted the FR core proposed by SANDA et al. [3] as a reference of the present study. The core is a 1000MWe-class Na cooled fast reactor core using mixed oxide fuel. Figure 2 shows the

Table 2 Core parameter

Reactor electric power	1000MW
Reactor thermal power	2600MW
Core fuel element	PuO_2+UO_2
Coolant material	Sodium
Core diameter/Height	3.0/1.0[m]
Pu enrichment (IC/OC)	13.0/17.0 [wt%]
Assemblies (IC/OC/Special)	187/156/36

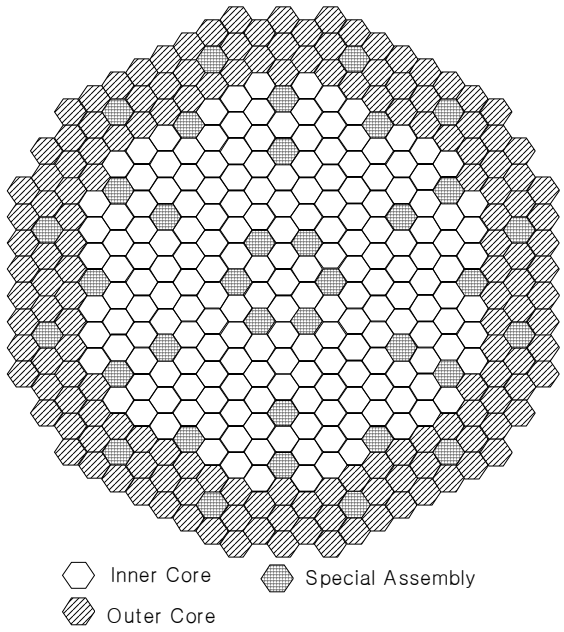


Figure 2. Core layout

core layout and Table 2 shows main parameters of the core. The core consists of the inner core region (IC), the outer core region (OC) and 36 special assemblies. The core is convenient to check the CCP method since it employs target assembly.

In this study, the position and the number of special assemblies were kept and the numbers of CCPs and special pins in special assemblies were changed. The special pin is the pin except the CCPs in the special assembly and its content was selected according to the purposes.

The calculations were performed by a Monte-Carlo continuous energy code, MVP, and burnup calculation code, MVP-BURN, developed at JAERI (Japan Atomic Energy Research Institute). JENDL-3.2 was employed as the nuclear data library. The burnup calculations for transmutation and burn of WG-Pu were performed by MVP-BURN and reactivity coefficients were calculated by MVP.

3.2 Special assemblies with CCP

We supposed 4 special assemblies which have the different numbers of CCPs (Table 3). HVF means the hydrogen volume fraction in the special assembly and this parameter also means CCPs fraction in the special assembly.

Although the effective multiplication factor was slightly changed by adding hydrides, the adjustments of the plutonium enrichment were not carried out because it was the most important purpose to confirm the effectiveness of each special assembly in this study.

Table 3 Special assemblies we designed

HVF [%]	CCPs	Special pins
0	0	271
34	91	180
45	121	150
55	150	121
66	180	91

3.3 Transmutation

3.3.1 Transmutation of MAs

The transmutation performance calculations for MAs were made by MVP-BURN and MA pins included only MA oxide (MAO_2) were employed as the special pin. The isotopic vector of MAs was ^{237}Np/ ^{241}Am/ ^{243}Am = 77.4/5.0/17.6 which corresponds to those of discharged LWR UO_2 fuel after 45 GWd/t irradiation. The transmutation performance was compared using the following parameters:

$$M_{trans} = M_{ini} - M_{end} \quad (1)$$

$$TR = \left(M_{trans} / M_{ini}\right) \times 100 \quad (2)$$

where M_{trans}[kg] is the transmutation amount, TR[%] is the transmutation rate, M_{ini}[kg] is the initial amount of MAs and M_{end}[kg] is the residual amount at the end of all cycle. In the calculation, it was assumed that the cycle length was one year (300 days for operation and 65 days for refueling), the loading batch was 3.

MAs only existed in special assemblies region, so there were no MAs in the inner and outer core regions before operation. But MAs were also produced in the inner and outer core regions after operation. To consider this point, the amount of MAs in all core regions was calculated for MAs transmutation.

3.3.2 Transmutation of LLFPs

In this study, we supposed ^{99}Tc and ^{129}I as LLFPs. ^{99}Tc was loaded as metal and ^{129}I as NaI [4]. The LLFPs pins were employed as the special pin.

MVP-BURN, however, did not have ^{99}Tc and ^{129}I in the burnup chain model. So, we calculated the capture reaction rate by MVP to check the transmutation performance of LLFPs.

To verify the transmutation amount of LLFPs, another calculation was made by ABC-SC code [5] developed at JAERI. Although this code is not available to calculate the heterogeneous fuel model, the burnup calculation is available for the two LLFPs. In this calculation, the same calculation conditions were taken as that in the MVP-BURN calculation assuming the R-Z model core, which consists of the homogeneous inner core region, the homogeneous outer core region and the homogeneous special assembly region.

3.4 Burn of weapon grade plutonium

In the calculation of WG-Pu burnup, MOX fuel pins which included 20[wt%] WG-Pu were used as the special pin. To deal with WG-Pu has been very difficult since the fraction of ^{239}Pu is very large (^{239}Pu/^{240}Pu = 93/6.5 [wt%]). From this viewpoint, we aimed at reducing the fraction of ^{239}Pu until LWR grade (i.e. ^{239}Pu/^{240}Pu = 58/24 [wt%]). We also estimated the fraction of ^{240}Pu from the viewpoint that the plutonium with higher fraction of ^{240}Pu would be unable to be used for military. The burnup calculations were performed by MVP-BURN. The cycle length was the same as that of MAs transmutation. The core arrangement were adjusted since the effective multiplication factor significantly increases accompanied with loading WG-Pu.

3.5 Improvement of reactivity coefficients

The improvement of reactivity coefficients is also estimated for realizing a safer FR. The calculations were performed by MVP to estimate the coefficient of the Doppler reactivity and the sodium void reactivity. The reactivities were calculated assuming that the fuel temperature increases of 200 [K] in the calculation of the Doppler reactivity and that the void fraction of 100% in the core region in the calculation of the sodium void reactivity. Normal fuel pins were placed as the special pin.

3.6 Comparison between CCP and homogeneous fuel model

The moderation effect of the heterogeneous model such as the CCP will be less than that of the homogeneous fuel model. To consider the CCP method, it is very important to check quantitatively the difference between the homogeneous fuel model and the CCP model.

We carried out the calculations and compared the CCP model with the homogeneous fuel model for this point. Calculation methods were the same as mentioned above (see section 3.1 – 3.5).

4. CALCULATION RESULTS AND DISSCUSION

4.1 Transmutation performance

4.1.1 Transmutation of MAs

Figure 3 shows the calculation results for the transmutation of MAs. From the results, it is found that the performance of the MAs transmutation becomes better than that of the reference case. The transmutation amount became largest by using the special assembly with 91 CCPs (HVF=34%). In this case, the transmutation amount was about 100 [kg] more than the reference case. As HVF increases more, the transmutation amount decreases and the transmutation rate increases, since the initial mount of MAs decreases.

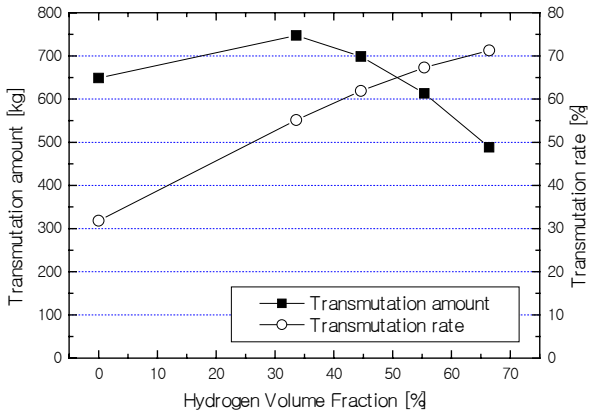
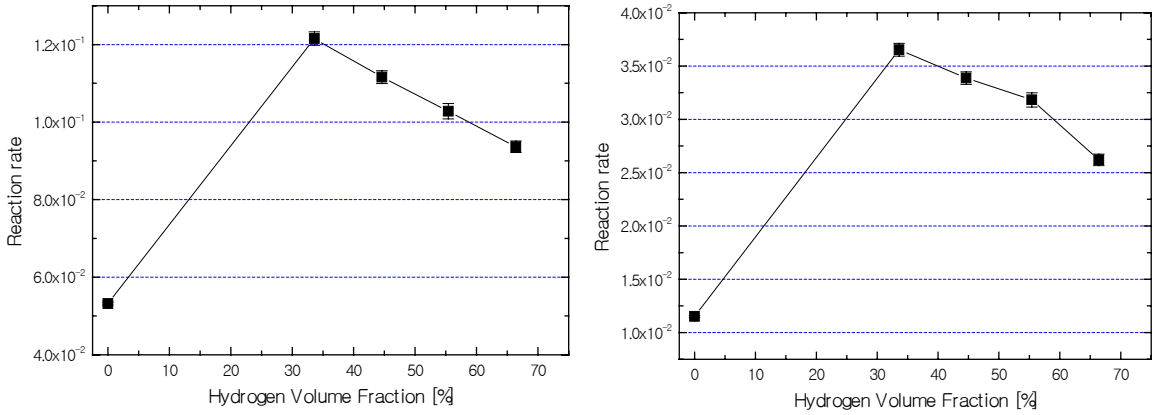


Figure 3. Transmutation amount of MAs

About 30 [kg] MAs are discharged from 3000MWt class LWR through one year operation [6], i.e. about 90 [kg] MAs are discharged from the LWR through three years operation. The transmutation amount of MAs was about 750 [kg] by using the special assembly with 91 CCPs (HVF=34%). By using this special assembly, it will be possible to transmute MAs corresponded to the amount discharged from 8 LWRs through three years operation..

4.1.2 Transmutation of LLFPs

Figure 4 shows the calculation results for the capture reaction rate of LLFPs. It is observed that the capture reaction rate of the LLFPs becomes better than that of the reference case. Both capture reaction rates were largest by using the special assembly with 91 CCPs (HVF=34%). The capture reaction rate of ^{99}Tc was about 2.3 times larger than the reference case, and that of ^{129}I was about 3.2 times larger than the reference. By using the special assemblies, the efficient transmutation of LLFPs will be achieved.



(a) ^{99}Tc (b) ^{129}I

Figure 4. Capture reaction rate of LLFPs

The transmutation amount of ^{99}Tc increased about 260[kg] and that of ^{129}I increased about 125[kg] by using hydride (HVF=60%) in ABC-SC homogeneous calculations. Although the transmutation amount by ABC-SC slightly underestimates compared with that by MVP-BURN, the difference is very small compared with the transmutation amount of ^{99}Tc and ^{129}I in the present study.

About 24[kg] ^{99}Tc and 5 [kg] ^{129}I are discharged from 1000MWe class LWR through one year operation [7]. The increase of each transmutation amount by using special assemblies corresponded to the amount discharged from about 4 LWRs and 8 LWRs through three years operation. For the transmutation of LLFPs, it is also considered the special assemblies using the CCP method are useful.

4.2 Burn of weapon grade plutonium

Figure 5 shows the fraction of ^{239}Pu. In the reference case (HVF=0%), the fraction of ^{239}Pu was reduced about 14%. On the other hand, the fraction of ^{239}Pu was reduced about 40% by using the special assembly with 180 CCPs (HVF=66%). In this case, the fraction of ^{239}Pu was lower than the value of LWRs grade (^{239}Pu=58%).

The special assembly with 91 CCPs (HVF=34%) was also hopeful from the viewpoints of the fraction of ^{240}Pu (Figure 6). In this case, ^{239}Pu/^{240}Pu composition was 70.0/22.8. It is the composition that this plutonium will be unable to be used for military.

If we employed the special assembly with 180 CCPs for burn of WG-Pu, we could burn about 210 [kg] WG-Pu through three years operation. In the United States, 38.2[t] WG-Pu remained at 1995 [8]. It will be available to burn 38.2[t] WG-Pu by 20 cycles, which one cycle is three years, if there are 10 FRs considered here. In the case of the special assembly with 91 CCPs, we could burn about 420 [kg] WG-Pu, so it will be available to burn 38.2[t] WG-Pu by 9 cycles, if there are 10 FRs.

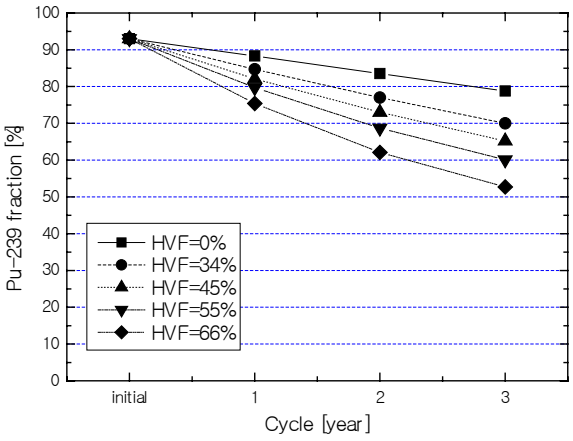


Figure 5. The fraction of ^{239}Pu in each cycle

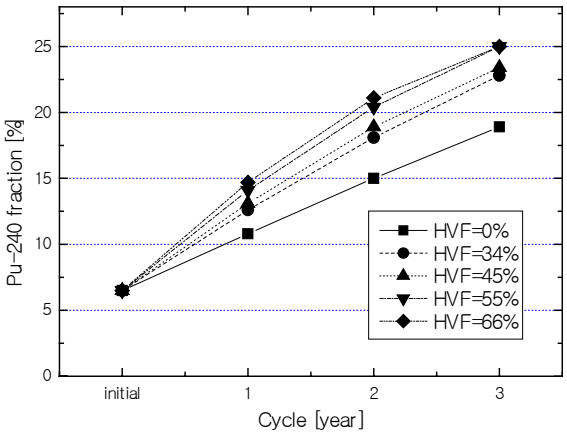


Figure 6. The fraction of ^{240}Pu in each cycle

4.3 Improvement of reactivity coefficients

Figure 7 and 8 shows the calculation results for the improvement of reactivity coefficients. It was confirmed that both reactivity changes are improved by using the special assembly with CCPs. The special assembly with 180 CCPs (HVF = 66%) showed the best improvement. The coefficient of Doppler reactivity was about 3.3 times better than the reference case. The sodium void reactivity was about 44% better than the reference case.

The sodium void reactivity is one of the major issues of the FR safety. The sodium void reactivities we calculated were \$7.05 in the reference case and \$3.96 in the case using the special

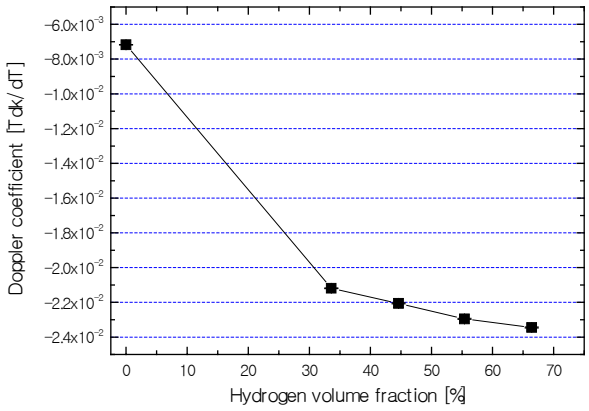


Figure 7. The Doppler reactivity coefficients

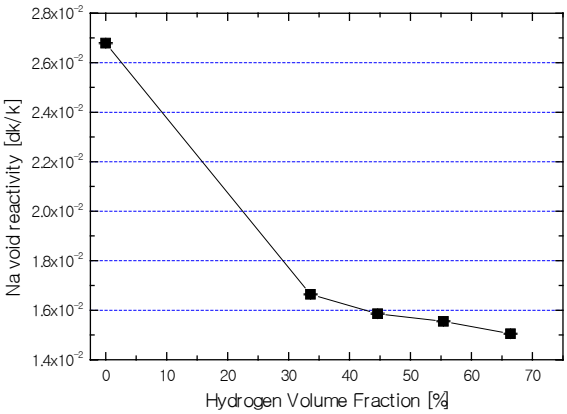


Figure 8. The sodium void reactivity

assembly with 180 CCPs (effective delayed neutron fraction is 0.0038 in this core). It is supposed that the reactivity coefficients of FRs will be improved greatly by using a special assembly with CCPs.

4.4 Comparison between CCP and homogeneous fuel model

Table 4 shows the comparison between the CCP model and the homogeneous fuel model for all purpose considered here. The differences between the CCP model and the homogeneous fuel model were very small although the homogenous fuel model was better than the CCP model. It is confirmed that the decrease of moderation effect is small and almost the same moderation effect as homogeneous fuel model will be achieved by slightly changing the hydride treating in the CCP.

It should be remarked that for the burnup amount of WG-Pu, the CCP model had better result than the homogeneous fuel model. It is caused by that in the homogeneous fuel model, the production of ^{239}Pu produced from ^{238}U is larger than the CCP model. Therefore, the burnup amount of WG-Pu by using the CCP model was better than the homogeneous fuel model relatively.

Table 4 Comparison between the CCP model and the homogeneous fuel model

	CCP model	Homogeneous
Transmutation amount of MAs (HVF=34%) [kg]	747	765
Reaction rate of ^{99}Tc (HVF=55%) [x10^{-2}]	10.3	11.4
Reaction rate of ^{129}I (HVF=55%) [x10^{-2}]	3.2	4.2
Burnup amount of weapon grade Pu* (HVF=34%) [kg]	144	134
Coefficient of the Doppler reactivity (HVF=34%) [x10^{-3} Tdk/dT]	-21.2	-21.5
Sodium void reactivity (HVF=34%) [%dk/k]	1.66	1.63

*: (Burnup amount of weapon grade Pu) = (initial amount of weapon grade Pu) - (residual amount of weapon grade Pu at the end of cycle), for special assembly region.

CONCLUSIONS

In this study, we proposed the CCP method as a new method to load hydride into a FR. Using CaH_2 as hydride we performed the calculation for the transmutation performance, the burnup of WG-Pu and the improvement of reactivity coefficients. The transmutation amount of MAs was about 750 [kg] by using the special assembly for MAs. This amount corresponded to the amount discharged from 8 LWRs through three years operation. By using special assembly for LLFPs, the reaction rates of LLFPs became better than the reference case (HVF=0%). The composition of WG-Pu was converted to that of LWR grade plutonium by using special assembly through the three years burnup. The reactivity coefficients were also improved greatly by using special assemblies designed here. These calculation results showed that special assemblies based on the present method and the hydride are useful to improve each problem. The comparisons between the CCP model and the homogeneous fuel model were also performed to confirm the difference of the moderation effect. It is confirmed that the decrease of moderation effect by the heterogeneous (CCP) model is small compared with the moderation effect of homogeneous fuel model. By employing the CCP method to a FR, one FR will be available for multipurpose and contribute to solve the problems accompanied with atomic energy utilization.

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