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A Design and Analysis of Advanced Burner Reactor for MHR-SFR Synergy

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1. Introduction

This paper reports on the results of an advanced burner reactor core design study which is performed for an effective burning of the spent fuels from a PWR (Scenario A) or a Deep Burn-Modular Helium Reactor (DB-MHR) (Scenario B)[1]. The core configuration of the advanced burner reactor is from the ABR core design which has been designed by Rocketdyne[2]. This paper focuses on the core design performances and the some preliminary results of a simple safety analysis using the BOR (Balance of Reactivity) method[3].

2. Core descriptions

The reference core is the advanced burner core that has been proposed by Rocketdyne[2]. Fig. 1 shows its configuration. The core rates 900MW thermal power and it has a two-region homogeneous annular sodium cooled configuration. As shown in Fig. 1, the inner and middle core regions consist of 96 and 72 fuel assemblies, respectively. The reactivity control system consists of the primary and secondary ones, and they are comprised of 23 and 7 control assemblies, respectively. Table I summarizes the main design parameters of the reference core.

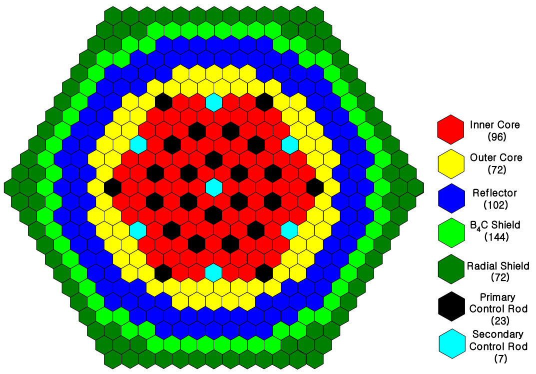

Table I Main design parameters of the reference core

Design parameters	Values
Thermal power (MWt)	900
Coolant inlet/outlet temperatures (C)	357.2/510
Core height (cm)	97.16
Fuel type	TRU-U-Zr
Fuel smear density (%TD)	75
Fuel rod outer diameter (mm)	7.493
Clad thickness (mm)	0.5588
Average linear heat rate (W/cm)	204
Number of rods/FA	271
Assembly pitch (cm)	15.96

3. Core design analysis

The previous analysis of the reference core has shown that it needs to be improved in terms of the sodium void reactivity and the neutron lifetime for better safety features of the reference core. In this work, two core design variants are suggested to improve the sodium void worth: the first core uses 12 yttrium hydride ($YH_{1.76}$) rods in each fuel assembly since it can be used in a high temperature environment (up to 1000 C) and the second core uses a reduced height of 85cm. The core analysis was done with the REBUS-3/DIF3D code system. The depletion analysis was done with the equilibrium model. The multi-group cross sections were generated based on the ENDF/B-VII nuclear data. The feed TRU composition vectors into ABR for Scenarios A and B are the ones from PWR after 50 GWD/tU burnup followed by 5-yr cooling and from DB-MHR after 57.7% burnup followed by 5-yr cooling, respectively. The Zr content of the U-TRU-Zr metallic fuel is 10% in the Scenario B core, while it is adjusted in the Scenario A core such that the TRU consumption rate should be comparable to that of Scenario B. In this paper, the following five cores are inter-compared :

1) Design-I : Original ABR Design proposed by Rocketdyne (Scenario A)
2) Design-II : Original ABR Design proposed by Rocketdyne (Scenario B)
3) Design-III : New ABR Design with 12 moderator rods per FA (Scenario B)
4) Design-IV : New ABR Design with a reduced height (Scenario B)
5) Design-V : New ABR Design with 12 moderator rods per FA (Scenario A)

Table II compares the main core performance. Four or five batch fuel management schemes are used in each core region. The cycle length and the number of fuel management batches are determined such that the peak fast neutron fluence is within $4.0x10^{23}n/cm^2$. From Table II, the comparison of Scenarios A and B shows the typical differences which were observed in the previous analysis[4] with different TRU vectors. It is clear that, for the same TRU consumption rate, the MHR TRU core has a much smaller initial excess reactivity and a smaller discharge burnup. In the new designs, the fuel volume was slightly reduced in all cases: ~4.4% in the moderated concept and 12.5% in the reduced core height case. Consequently, the TRU content in the fuel was increased in the new designs. It resulted in a greater TRU consumption rate in the modified core: 160~165 kg/GWtEFPY vs. 131 kg/GWtEFPY. In the cases of Scenario B (i.e., Design

III and IV), it is noted that fuel residence time is much longer with the moderated fuel assembly concept than with the reduced core height approach. This is because the neutron spectrum is softer in the moderated case. Table II also shows that the new ABR designs give better reactivity coefficients than the original ones. In particular, it is noted that the new ABR design with 12 moderator rods/FA (i.e., Design-III) has a comparable sodium void worth and a larger neutron life time in comparison with the original ABR design (i.e., Design-I). On the other hand, the new ABR design with a reduced height still has a higher sodium void worth and a much smaller neutron life time.

Table II Comparison of the core performances

Parameters	Design-I (Scenario A)	Design-II (Scenario B)	Design-III (Scenario B)	Design-IV (Scenario B)	Design-V (Scenario A)
Cycle length (EFPD)	440	440	420	410	420
Fuel management batches	4	4	5	4	5
Charge fuel composition(wt%)					
TRU/U/Zr	23.4/63.0/13.5	26.8/63.1/10	32.4/57.4/10	30.3/59.6/10	28.1/58.1/13.7
Burnup reactivity swing (pcm)	3080	1783	2145	2238	3478
Conversion ratio (TRU/Fissile)	0.75/0.79	0.77/0.93	0.74/0.91	0.72/0.91	0.73/0.75
Average discharge burnup (MWD/kg)	113.1	103.5	129.5	110.5	142.1
TRU wt% in HM (BOEC)					
Inner/Outer cores	24.3/29.9	29.6/34.2	32.7/39.6	30.2/37.5	29.4/35.1
TRU consumption rate (kg/GWt.EFPY)	131.1	130.5	164.5	160.2	160.0
TRU support ratio	1.28	1.28	1.61	1.57	1.57
Average linear heat rate (W/cm)	199.3	199.3	209.4	227.8	209.4
Doppler coefficient (α_D, pcm/K, 900K)	-0.36	-0.30	-0.61	-0.24	-0.76
Radial expansion coefficient (α_R, pcm/K)	-0.83	-0.81	-0.69	-0.86	-0.69
Fuel axial expansion coefficient (α_H, pcm/K)	-0.38	-0.40	-0.35	-0.38	-0.32
Sodium density coefficient (α_C, pcm/K)	0.53	0.69	0.54	0.65	0.37
Total core sodium void worth (pcm)	1630(5.0$)	2108(6.3$)	1655(5.0$)	1994(6.0$)	1139(3.5$)
Delayed neutron fraction	0.00329	0.00336	0.00333	0.00332	0.00327
Neutron life time (micro sec)	0.374	0.333	0.391	0.314	0.454

Table III Comparison of the BOR safety analysis results

Parameters	Design-I (Scenario A)	Design-II (Scenario B)	Design-III (Scenario B)	Design-V (Scenario A)
ρ_{ex}($)	0.52	0.29	0.354	0.583
A ($)	-0.335	-0.313	-0.281	-0.351
B ($)	-0.432	-0.372	-0.419	-0.488
C ($/K)	-0.00315	-0.00246	-0.00338	-0.00428
A/B	0.78	0.84	0.67	0.72
$C\Delta T_C/B$	1.11	1.01	1.23	1.34
$\rho_{ex}/\lvert B\rvert$	1.20	0.78	0.85	1.20

Table III compares the results of the BOR safety analysis to compare their safety features. In the BOR method, the reactor core is assumed to approach a new critical state asymptotically after a limited transient. The BOR analysis can be done with the reactivity coefficients and a few core design parameters given in Tables II and III. Within the framework of BOR, the self-controllability is satisfied if the following conditions are met : $A/B \leq 1$, $1 \leq C\Delta T_C/B \leq 2$, and $\rho_{ex}/|B| \leq 1$, where A, B, and C are all negative and ρ_{ex} is the externally imposed reactivity. Table III shows that the Scenario A cores do not satisfy the UTOP-related BOR condition (i.e., $\rho_{ex}/|B| \leq 1$) due to the large reactivity swing, although the sodium density coefficient is relatively small. On the other hand, the three BOR conditions are well met in the Scenario B core in spite of the relatively large positive sodium density coefficient except for the value of $C\Delta T_C/B$ for the original ABR core with Scenario B which is almost unity (i.e., lower limit). The new ABR core with 12 moderator rods/FA satisfies the condition of $C\Delta T_C/B$ much better than the original core does.

3. Conclusions

Two design variants of the ABR core proposed by Rocketdyne are introduced, and the performance analysis and a simple BOR safety analysis were done for these cores. Of these cores, the concept using 12 $YH_{1.76}$ rods/FA satisfies all of the self-controllability conditions for Scenario B. For Scenario B, there are necessities to reduce cycle length or to increase the number of control assemblies to reduce burnup swing.

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