IMPROVEMENT OF REACTIVITY COEFFICIENTS OF METALLIC FUEL LMFBR

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ABSTRACT

A new concept to improve the Doppler coefficient of metallic fuel liquid metal fast breeder reactor (LMFBR) is proposed. This is accomplished by adding a moderating material to a metallic fuel assembly, so that the neutron spectrum becomes softer and the negative temperature coefficients are improved. The effects to the typical core parameters, such as the Doppler coefficient, the sodium void reactivity and the reactor breeding ratio are investigated. The results show this concept improves temperature coefficients similar to those of the mixed oxide (MOX) core of same size without much sacrificing the breeding ratio.

Introduction

The liquid metal fast breeder reactor (LMFBR) using metallic fuel has several merits compared with mixed oxide fuel (MOX) LMFBR. The metallic fuel offers substantial advantages such as high fuel density and thermal conductivity, therefore, high breeding ratio and reduced cost for fuel cycle are expected. At the same time, a metallic fuel reactor has disadvantage in safety standpoint, such as poorer Doppler coefficient and larger sodium void worth than a MOX LMFBR has. It is said that these disadvantages could be compensated by the radial core expansion and extension of control rods because of high thermal conductivity of metallic fuel. However, these effects suffer from time delay, and if it is possible to make prompt negative Doppler feedback larger, a metallic fuel LMFBR would simultaneously satisfy safety and economy requirement.

In order to improve the Doppler effect, the addition of moderating material to a metallic fuel is considered. This makes the neutron spectrum softer, so that instantaneous negative Doppler coefficient becomes larger. This also restrain the spectrum hardening when coolant sodium were voided and makes positive sodium void worth smaller. However, at the same time it is inevitable the breeding ratio will decrease to some extent. Therefore, the principal purpose of this study is to investigate the core concept without much sacrificing the breeding ratio. The effects of moderating material to the typical LMFBR core parameters, such as the Doppler coefficient, the sodium void reactivity and reactor breeding ratio are parametrically surveyed. This was already demonstrated for berylia (BeO) [1, 2] , however, the possibility of the use of other moderating material has not been pursued.

Core Parameter

A homogeneous 1000-MW(electric) metallic fuel LMFBR was chosen as a base case for the investigation of this study. The typical parameters for the fuel and the blanket are shown in Table.I. For the fuel, the use of standard metallic fuel, U-15%Pu-10%Zr alloy which has the smear density of 75% of theoretical one was assumed. The isotopic ratio of the plutonium in the fuel was assumed to be 0.58, 0.24, 0.14 and 0.04 for ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu, respectively. This composition corresponds to the discharged fuel from typical LWR after about 33GWD/ton of burnup without fuel recycling.

Table.I Reference lattice parameter for driver and blanket

	Fuel	Blanket
Fuel Material	U-15%-10%Zr	U-10%Mo
Number of Pins per Assembly	271	169
Smear Density (%TD)	75	90
Theoretical Density (g/cm^3)	15.8	16.7
Pin Diameter (mm)	7.5	10.375
Cladding Thickness (mm)	0.4	0.4
Pitch / Diameter Ratio	1.2	1.096
Ducts Outside Flat-to-Flat (mm)	150.8	150.8
Duct Wall Thickness (mm)	4.0	4.0
Gap between Ducts (mm)	6.0	6.0

As the moderating material, the zirconium-hydride ($ZrH_{1.7}$) was chosen. As a method to introduce ZrH into the LMFBR core, we first considered the TRIGA type fuel, namely a mixture of U-Pu and zirconium-hydride. However, in this case the hydrogen would dissociate at high temperature in a transient, and then the positive reactivity might be inserted. Therefore, we considered the concept to replace some of the fuel pins in a subassembly by the pin containing only ZrH. The size of this ZrH pin was assumed to be same as the fuel pins. This allows that the heat travels to ZrH pin must come through the coolant sodium, and the dissociation of hydrogen is out of consideration not only under the normal operation but also at the transient since the dissociation is insignificant up to the sodium voiding temperature. The parametric survey was made by changing the fraction of ZrH pins, and the effects to the typical core parameters, such as the Doppler coefficient, the sodium void reactivity and reactor breeding ratio, were investigated in comparison with conventional MOX LMFBR.

Computation

The cell averaged cross sections were derived with SLAROM code [3] using 70 group cross section set JFS3-J2[4] based on Japanese Evaluated Nuclear Data Library, version 2 (JENDL-2) library. Then, after the cell calculation, the two dimensional r-z diffusion calculation for the entire core was performed using the homogenized cross section for each region by CITATION-FBR code [5]. This code is based on CITATION code [6] and makes it possible to use anisotropic diffusion coefficient defined by Benoist [7].

In the cell calculation, to simulate the fuel assembly heterogeneously containing several ZrH pins, three cell models were considered. In the first model, a fuel pin in a subassembly was assumed to be composed of a mixture of fuel and ZrH. The atomic number density for this single pin was determined averaging that of each pin weighted by the number of each pin in a subassembly. In the second and third model, a hexagonal cell model in which a ZrH pin is placed at the center of the hexagonal arrangement of fuel pins is used. The fraction of ZrH pin in the fuel pins is adjusted by the number of fuel pins surrounding the central ZrH pin. This fraction is ranged from about 1.1% (ratio of the ZrH pin to the fuel pin, 1/90) to about 5.3% (1/18). Prior to this cell calculation, group constants for each fuel pin and ZrH pin are prepared using the isolated pin model. The difference between the two models is the treatment of fuel pins next to the ZrH pin. In the third model, the preliminary calculation was performed for these fuel pins taking account of the effect by the existence of ZrH pin, while isolated pin model was used in the second model. By comparing the results of these different three models, the third model was concluded to be most suitable.

As mentioned above, parametric calculation for the Doppler coefficient, the sodium void reactivity and the breeding ratio was performed as a function of ZrH pin fraction. In the calculation of Doppler coefficient, we assumed that the temperature would change only in the fuel region except for ZrH pin, and calculated the effective multiplication factor at 600, 900 and 1200K. For the calculation of sodium void reactivity, we assumed that the coolant sodium and bond sodium would be voided perfectly in the fuel region. The core breeding ratio was obtained using flux for each region calculated in the two dimensional diffusion calculation and the effective cross section averaged over the cell.

Results of Parametric Survey

Doppler coefficient is strongly affected by the shape of neutron spectrum. Hence, cell averaged neutron spectra for various cells are shown in Fig.1, before refers to the results of parametric survey. In this figure, solid line indicates that of the reference case, metallic fuel including ZrH pins with fraction of about 3%, the dotted line and dashed line indicate base case (pure metallic fuel) and MOX fuel, respectively. These spectra are normalized to unity. By introducing ZrH to the metallic fuel core which has harder spectrum than that of MOX, relative fraction in low energy region (about 10^2 ~10^4eV) increases because of the strong moderating effect of hydrogen. However, since the ZrH pin is heterogeneously inserted to a subassembly, the moderating effect is limited to the neighboring rods, and the spectrum is intermediate between that of metallic fuel core and MOX fuel core.

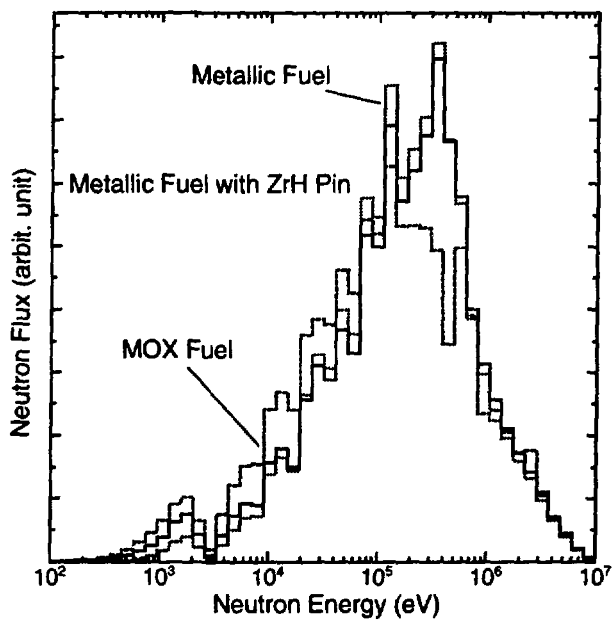

Fig.1 Neutron spectra for metallic fuel core with ZrH pin (the fraction is 1:36) compared with metallic fuel and MOX fuel core

The results for the Doppler coefficient and the sodium void reactivity are shown in Fig.2. In Fig.2, the points denoted as MOX and Metal fuel correspond to those of LMFBR with same reactor power using MOX fuel and metal fuel respectively. As shown in Fig.2, the Doppler coefficient for the metallic fuel is much smaller than that of the MOX fuel. However, the addition of ZrH pin of about 2.7% (number ratio of ZrH pin to other fuel pins is 1:36) brings the Doppler coefficient to almost the same as that of MOX fuel. Although in Fig.1, the spectrum component in low energy region for the reference case is less than that for MOX, introducing about 5.3% of ZrH pin (V_{ZrH}/V_{fuel} is 1/18), the Doppler coefficient becomes about 50% larger than that of MOX case and about five times as large as that of base case. The sodium void reactivity for the metallic fuel, which is originally larger than that for the MOX fuel, becomes smaller than that of MOX fuel by the addition of only a small amount of ZrH pin. Therefore, the addition of ZrH pin of more than 2.7% leads to the improvement of the reactivity coefficients of the metallic fuel LMFBR superior to those of conventional MOX LMFBR.

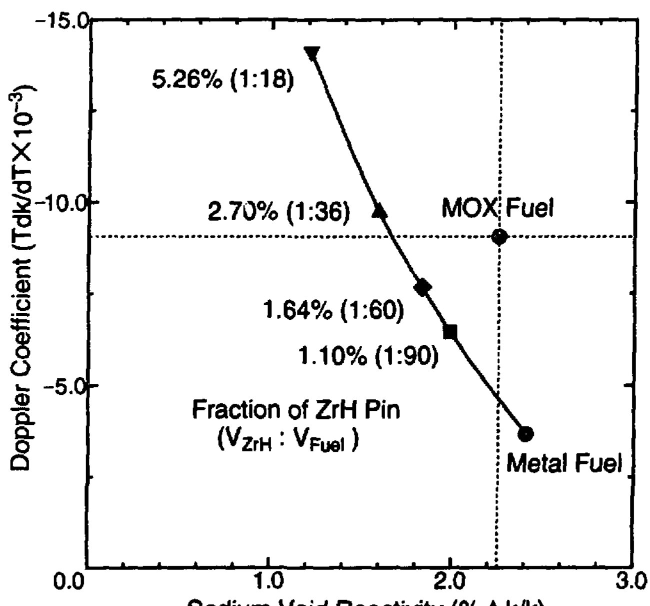

Fig.2 The result of parametric survey for Doppler coefficient and sodium void reactivity as a function of fraction of ZrH pin

The spectrum softening by the addition of moderating material gives negative effect to the breeding ratio. The results for the core breeding ratio of MOX and those of metallic fuel as a function of fraction of ZrH pin are indicated in Fig.3. The breeding ratio was calculated as the ratio of production and consumption of fissile fuel shown in the following equation.

$$BR = \frac{P(^{239}Pu) + P(^{241}Pu)}{A(^{239}Pu) + A(^{241}Pu)}$$

Here, P and A represent the production and the consumption rate respectively. As shown in Fig.3, the introduction of ZrH affects the breeding ratio. However, even the addition of about 5.3% of ZrH makes the breeding ratio still almost the same as that of the MOX core.

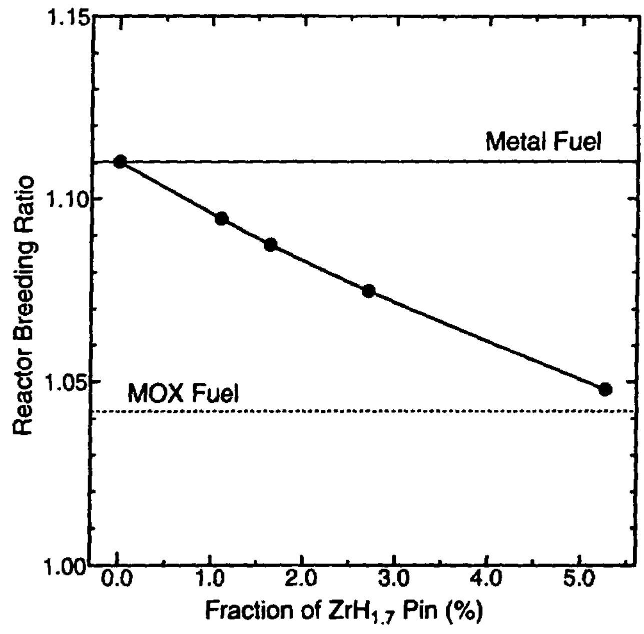

Fig.3 The result of parametric survey for Doppler coefficient and sodium void reactivity as a function of fraction of ZrH pin

Summary

Although a metallic fuel LMFBR has good characteristics in economy compared with MOX LMFBR, it has disadvantage that Doppler coefficient is much smaller than MOX LMFBR. For better safety, emphasis is placed on the improvement of Doppler coefficient. Since the Doppler coefficient depends on the shape of neutron spectrum, the spectrum softening has strong effect for it. Thus, the introduction of ZrH as moderating material to a metallic fuel core is proposed. Also, the moderator restrains the spectrum hardening when coolant sodium were voided and decreases the positive sodium void reactivity.

For the addition of moderating material, some fuel pins in a fuel subassembly were changed by the pins containing only ZrH. The Doppler coefficient, sodium void reactivity and the breeding ratio were studied as a function of fraction of ZrH pin. The results are summarized in Table.II. As shown in Table.II, the addition of ZrH pin in the metallic fuel LMFBR from 3% to 5% will improve the reactivity coefficients. For Doppler coefficient, especially, these cases provide as large as three to four times that of base case, and even larger than that for MOX fuel without much sacrificing the breeding ratio. Also, for the sodium void reactivity they give about half that of MOX and base case.

The results of this study have shown the addition of ZrH pin in metallic LMFBR is useful in improving reactivity coefficient. However, more detailed study such as power distribution in the subassembly will be necessary in adopted this concept.

Table.II The results of parametric survey in comparison with MOX fuel and metallic fuel

Fraction of ZrH Pin	Breeding Ratio	Doppler Coefficient ($T\Delta k/\Delta T$)	Sodium Void Reactivity ($\%\Delta k/k$)
2.7% (1:38)	1.11	-0.0090	1.79
5.3% (1:18)	1.08	-0.0134	1.40
Metallic Fuel	1.15	-0.0029	2.60
MOX Fuel	1.06	-0.0081	2.35

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