Preliminary Evaluation of Rare Earth Effect on Burnup Limit in TRU Fuel

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1. Introduction

The U-TRU-RE-Zr metal fuel is being developed in combination with the pyro-processing. Since RE (Rare Earth) will be included in the metal fuel, it is necessary to evaluate the effects of RE on burnup limit. In this paper, preliminary penetration rate model of RE to the cladding was developed based on the available data. The evaluation of burnup limits according to RE contents was carried out using the code with the developed model.

2. Preliminary penetration rate model of RE to the cladding according to the RE contents

One of the main issues that may limit burnup in metal fuel is FCCI (Fuel Cladding Chemical Interaction) due to reaction of REs with the cladding.

In order to develop the penetration rate model of RE to the cladding, the concept of penetration model developed using EBR-II DB was used [1].

In the existing model considering EBR-II DB, the coefficients such as activation energy and a diffusion coefficient were adjusted to match the penetration depths for the metal fuels with 0 wt.% RE.

In this paper, the activation energy in the model was evaluated and derived for the development of penetration rate model according to RE contents,

When RE content was 0 wt.%, the activation energy (Q) was set by applying EBR-II DB results [1].

In addition, the activation energies related to 100wt. % and 5wt. % RE were evaluated and derived using diffusion couple test data [2] and U-10Zr-5Ce HANARO irradiation data (Refer to Fig. 1) [3] .

Based on the THERMO-CALC code and the OECD DB [4], the activity of Ce-Fe was evaluated to establish the activation energies for other RE content.

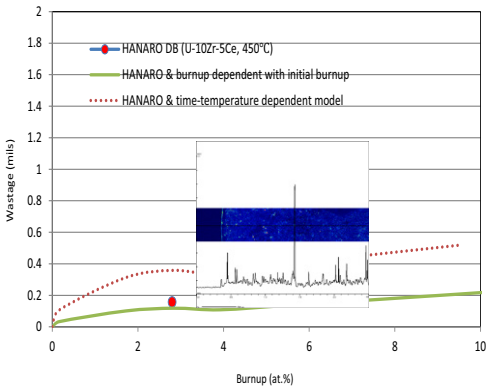

Fig. 1. Comparison of HANARO DB and calculated penetration depth.

It was analyzed that the diffusion would occur rapidly when the RE concentration reached a certain level.

The activity values for RE contents were determined considering the threshold that leads to rapid diffusion, as shown in Table 1.

Table 1. Derivation of activation energy by RE contents

RE contents (wt. %)	Activation energy, Q (kJ/mol)
0	48.227
1	47.344
3	45.616
5	43.938
100	33

The diffusion coefficient D_0 was also adjusted to be equal to the U-Pu-Zr data at 580℃ in EBR-II irradiation, because the diffusion rate of U-Pu-Zr was faster than that of U-Zr.

3. Evaluation of RE effects

3.1 Code and irradiation history for performance evaluation

In order to evaluate the bunup limit due to the RE

contents, the LIFE-METAL code [5] developed jointly with ANL (Argonne National Laboratory) was used.

Since the irradiation history for the TRU core has not yet been established, the history of the U core was applied.

Fuel rods of the U core consist of U-10Zr / FC92, and the diameter and length of the fuel slug are 5.54 mm and 900 mm, respectively. The outer diameter and thickness of the cladding are 7.4 mm and 0.5 mm respectively. The core inlet temperature of the coolant is 390℃, PICT (Peak Cladding Inner Temperature) is 650℃, and EFPD (Effective Full Power Day) of the inner / outer core is 1160 and 1450, respectively.

Fuel slug for the TRU core is assumed to be U-24TRU-RE-10Zr and the other conditions are same as the U core.

The design methodology for evaluating the burnup limits applies the specific design methodology established in the fuel rods for PGSFR.

3.2 Burnup limit evaluation according to the RE contents

In this paper, CDF (Cumulative damage fraction), which is one of fuel design criteria, was evaluated in order to evaluate the burnup limit due to the RE contents.

The burnup above the CDF limit of 0.05 were calculated. Fig.2 shows the calculated results of the burnup limit for 0, 1, 3 and 5 wt.% of RE.

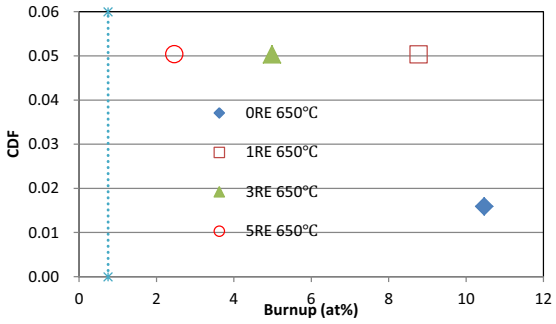

Fig. 2. Calculated results of the burnup limit for 0, 1, 3 and 5 wt.% of RE.

When the RE content was 0 wt.%, it was calculated that the CDF limit was satisfied above 11 at% of burnup.

In the case of 1, 3 and 5 wt.% of RE, however, burnup limits were calculated as 8.7, 4.9 and 2.45 at%, respectively.

Therefore, in the case of high RE contents in the metal fuel, the use of a barrier cladding is considered to be essential because a high RE earth content has a great influence on the integrity of the fuel rod.

4. Conclusion

In order to evaluate the effects of the RE content, preliminary penetration rate model was developed according to the RE contents.

Activation energies according to the RE contents were derived by considering EBR-II DB, HANARO DB, diffusion couple tests data and OECD DB.

The burnup limits according the RE contents were evaluated by applying the code and irradiation history.

It was calculated that a high RE content has a great effect on the burnup limit and the integrity of the fuel rod.

The use of a concept of barrier cladding is needed if the metal fuel has a high RE content.

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