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Evaluation of Helium Release for Am-bearing Metal Fuel up to 10 at.% burnup

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1. Introduction

A metallic fuel is being developed for SFR (sodium-cooled fast reactor) in Korea. The composition of fuel slugs are U-TRU-Zr in combination with pyroprocessing, and U-Zr for initial core. U-TRU-Zr fuel contains minor amount of Am and Np. Neutron capture by ^{241}Am produces the helium gas. This generated helium gas releases to the fission gas plenum with the fission gas, and the released helium gas adds to the total gas inventory in the fission gas plenum. So the release by the helium gas must be considered in the design of the U-TRU-Zr fuel.

In this paper, a subroutine program has been made and installed into the MACSIS code to simulate the helium release. The effect of the helium release rate was evaluated up to 10 at% burnup.

2. Methods and Results

In this section, the helium release model, the calculations of helium release, and the effect of helium release are described.

2.1 Helium release model

It is assumed that the mechanism of the helium gas release is the same as that of the fission gas release.

In the intra-granular helium gas release model, Speight's model in combination with the Booth's classical diffusion theory and Notley's idea were adopted [1].

Metallic fuels exhibit high fission-gas-induced swelling [2]. At sufficient fissile burnup, inter-granular bubbles link up and form paths for fission-gas release from the fuel.

In order to estimate the gas release and the volume change due to the accumulation of gas bubble nucleation, it is necessary to calculate the bubble size distribution formed by the gas atoms produced within the fuel particles. The procedure for calculating the bubble size distribution on grain boundary consists of dividing the bubbles into equal size ranges on a logarithmic scale and averaging their properties over the ranges as demonstrated by Li et al.

The estimated helium generation rate from ^{241}Am was about 50 ml He per gram of transmuted ^{241}Am. So helium to fission gas ratio of 6.0 was inserted into the code based on EBR-II X501, SUPERFACT-1, EFTTRA-T4 and PFR experiments[3].

It is assumed that the bubble size distribution of the helium gas on the grain boundary is smaller than that of fission gas. The bubble should easily diffuse because of smaller radius. Following conditions are inserted into the model based on above assumptions

$$r_{He,i}^2 = \frac{1}{2} r_{FG,i}^2$$
$$D_b \propto \frac{D_s}{r^4} \qquad (1)$$

where $r_{He,i}^2$ is helium gas bubble size in ith bubble size group, $r_{FG,i}^2$ is fission gas bubble size in ith bubble size group, D_b is diffusion coefficient of bubble, D_s is surface diffusion coefficient.

When the size of the helium bubble increase with increase of burnup, and reaches a threshold value, these gas bubbles will form gas tunnels on the grain boundary surfaces and edges, which reach the free space in the fuel pin.

Based on examination of the metallic fuel microstructure, the thin fuel lamina is approximated by a spherical grain with a 1 μm radius. Gas generated within the fuel lamina diffuses to the phase boundaries and is released if a network of long-range interconnected porosity has been established.

The long-range interconnected porosity starts when the swelling reaches 10% according to the irradiation experience or open pore morphology. So in order to release the He bubbles easily, it is assumed that the effective grain size is below 1 μm. Moreover, according to the Barn's theoretical consideration, the break swelling occurs when swelling reaches 33%. So in order to release the He bubbles, it is assumed that the effective grain size is below 0.1 μm.

2.2 Calculation of helium release

Fig. 1 shows the calculated helium release, the fission gas release behavior and measured release data irradiated in AFC-1 B and F up to 5at% of burnup. The helium release follows the same trend as fission gas release, but is somewhat lower. Helium release rates are 0-15% compared to 0-36% fission gas release [5].

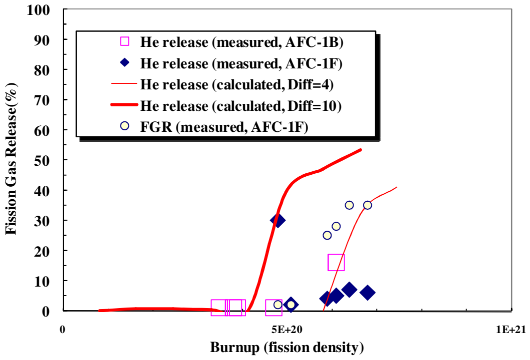

Fig. 1 Helium gas release

As shown in Fig. 1, the releases of helium gas start at 6E20 f/cm^3, which correspondent to the onset of break swelling. If it is assumed that the bubble diffusion coefficient of helium gas bubble is ten times larger than that of fission gas bubble, the releases of helium gas start at 4E20 f/cm^3.

The helium release fractions in the range of low release fractions by the developed model show a good agreement with the data measured by AFC-1.

At higher burnups, the helium release fraction is expected to be higher than fission gas. According to X-501 data, Helium release rates at 9at.% burnup are 90% compared to 75% fission gas release [6].

It was also calculated that the helium release fractions at 9at.% burnup by the developed model also showed a good agreement with the data measured by X-501.

2.3 Effect of helium release

The effect of helium release at a high burnup was calculated by using the SFR design data and the MACSIS code. The key parameters for the analysis of the helium release effect are shown in Table 1 [7].

Table 1. Key parameter

Fuel Slug Contents (wt%)	U-20TRU-10Zr
Smeared Density (%)	75
Cladding Material	HT9M
Pin Outer Diameter (mm)	7.4
Cladding Thickness (mm)	0.56
Plenum-to-fuel ratio	2.4
Fuel Slug Length (mm)	850
Coolant Outlet Temperature (°C)	545

Fig. 2 shows the fission gas plenum pressure and CDF (Cumulative Damage Fraction) according to americium contents in metal fuel.

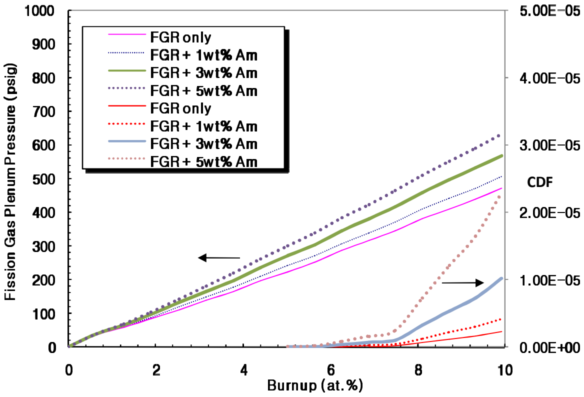

Fig. 2 Fission gas plenum pressure and CDF according to americium contents

According to the calculation, it was estimated that the fission gas plenum pressure and CDF increased considerably with Am contents.

In the case of ignoring the helium effect, the fission gas plenum pressure was about 470 psig at 10 at.% burnup. However, in the case of considering 5 wt% of Am, the fission gas plenum pressure was about 630psig.

In the case of ignoring the helium effect, the calculated CDF was about 2.4E-6 at 10 at% for the 2.4 plenum-to-fuel ratio. However, in the case of considering 5 wt% of Am, the calculated CDF was about 2.3E-5 at 10 at%.

Even though the calculated CDFs were low for both cases, but the helium release may affect on the integrity of the cladding at high burnup.

So the effects of the helium release and Am content should be considered in the fuel design, because burnup limit is affected by helium release.

3. Conclusions

U-TRU-10%Zr metallic fuel is being developed as a fuel for the SFR in combination with the pyro-processing. The model for the helium release behavior was developed to evaluate the effect of helium release by americium. The helium release rate according the burnup was calculated by the model. The helium release fractions by the developed model showed a good agreement with data measured by AFC-1 and X-501. The fission gas plenum pressure and CDF were analyzed by considering the Am contents. It was estimated that burnup limit was affected by Am contents.

Acknowledgements

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