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Evaluation of the in-pile performance of boron containing fuel pellets

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1. Introduction

The world rare earth resource are heavily concentrated in certain area and if these natural resources are weaponized by a country, we may confront serious difficulty because rare earth element gadolinium(Gd) is used as burnable poison material in some nuclear power plants (NPP) in Korea. Gd is used as a neutron absorbing material in Gd_2O_3 form and mixed with UO_2 in fuel pellets. The burnable poison mixed in the fuel pellets is called integral burnable absorber (BA) design which differentiates it from the old separate BA design. In the old separate BA design, boron(B) was used in borosilicate glass (PYREX) form and placed in guide tubes. With the development of the concern over the availability of rare earth material Gd, B is considered as a candidate material replacing Gd for the case when the rare earth material is weaponized. However the idea for new boron BA design is integral type because the integral type BA design has several benefits over the separate BA design, such as reduction of radioactive waste, more positions for BA location, etc.

When boron is used as burnable poison in nuclear fuel, ^{10}B absorbs a neutron and produces helium by the following reaction:

$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He$$

The helium produced by the nuclear reaction may cause the increase of rod internal pressure and change the gap conductivity if the significant amount of helium gas is released to the gap between the pellet and the cladding. Thus, it is necessary to investigate the in-pile behaviors of B containing pellet.

However, few experiment have been carried out so far on the behavior of in-pile produced helium in UO_2 fuel pellets, especially for the cases boron compound is mixed with UO_2 fuel.

In this paper, we will evaluate the production and the release of helium depending on ^{10}B concentration in the fuel.

2. Methods

In this section, for evaluation of the in-pile performance of boron containing pellet, it is described how to collect, analyze, and assess data related to it.

2.1 Helium production in the pellet

The effect of burnable poison in a typical Westinghouse PWR core, including ^{10}B as a form of ZrB_2 coating, was investigated by *Grossbeck, Renier, and Bigelow using* MCNP4. The amount of alpha-He production was obtained, depending on ^{10}B concentration [1]. Although the He production in the ZrB_2 coating layer is essentially out of the pellet in the Integrated Fuel Burnable Absorber (IFBA) fuel rod, the concentration and amount of He produced in the fuel pellet which contains boron absorber mixed with UO_2 powder if the burnout of ^{10}B in both fuel are the same. The amount of He produced by the burnout of ^{10}B in the boron containing fuel pellet is calculated using MCNP5 code and is compared with the Grossbeck's results.

2.2 Diffusion and release of helium

C.Ronchi and J.P. Hiernaut [2] measured the He diffusivity during the annealing of UO_2, PuO_2 and MOX fuel in a Knudsen cell provided by a mass spectrometer. In this experiment, He was produced by the alpha decay of Pu or laboratory infused at high temperature and high pressure.

The helium diffusion coefficient in solid has the expression:

$$D = 8\times10^{-7}\ \exp(-46\ \text{kcal mol}^{-1}/RT)\ m^2s^{-1} \quad (1)$$

Booth [3] evaluated the release of fission gases from UO_2 as a diffusion process of equivalent spheres to the surface. The solution of the fractional release during irradiation (f) can be obtained as follows:

$$f = 4\cdot\left(\frac{D\cdot t}{\pi\cdot a^2}\right)^{0.5} - \frac{3}{2}\cdot\frac{D\cdot t}{a^2} \qquad \left(f < 0.57, \frac{D\cdot t}{a^2} < \pi^{-2}\right) \quad (2)$$

$$f = 1 - \frac{0.0662}{D\cdot t}\left\{1 - 0.93\exp\left(-\pi^2\cdot\frac{D\cdot t}{a^2}\right)\right\}, (f > 0.57) \quad (3)$$

where D (m^2s^{-1}) is the diffusion coefficient of fission gas from (1) at a given temperature, t(s) is time, and a(m) is grain size. The grain size is assumed to be theoretical value from other researches. In effective temperature range of these equations, it is possible to predict how much helium is released into the gap based on equation (2) and (3).

The influence of He, which is produced by the burnout of ^{10}B and released to the gap, on rod internal pressure and gap conductance are evaluated using the fuel rod performance core FRAPCON.

4. Conclusion

Expected performance of the boron BA containing pellet under reactor irradiation is evaluated.

- The helium production by the neutron absorption of ^{10}B was calculated using MCNP5 code and compared with the results of Grossbeck, Renier, and Bigelow.
- Helium release was evaluated using the data reported by C.Ronchi and J.P. Hiernaut applying Booth model.
- The influence of released helium to fuel performance was evaluated using FRAPCON code.

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