Estimation of Fission Product Release from the TRISO Fuel

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1. Introduction

To analyze severe accidents in high temperature gas-cooled reactors (HTGR), the radioactivity in fuel elements is basically provided. The fundamental information is how many fuel elements lose their protection barrier and how much radioactivity is released without the barrier. As for one fuel element, a tri-isotropic coated fuel particle (TRISO), which is used in HTGR, above values are investigated here.

The stem procedure suggested here is as follows. First, with what percent of probability, TRISO fracture is considered at given condition. Next, when TRISO is failure, it is needed to calculate the activity from broken TRISO. Coupling two methods is to be the final.

In this study, the purpose is to calculate the radioactive release from the core during the accident by coupling the probability of TRISO fracture and the source radioactivity of the core.

2. Fracture probability

TRISO fracture is usually perceived as a SiC layer, the physical barrier, fracture. There are two types of the SiC layer fracture mechanism. Mechanical pressure vessel failure is caused by inner gas pressure increase from fission gases (FGs)/CO and irradiation-induced PyC layer crack formation. Because another fracture mechanism, which is chemical manner damage like influences kernel migration, corrosion and decomposition of SiC layer, is prevail at temperature over 2000℃, this mechanism will not be considered.

To calculate the fracture probability, the process is like this. Temperature profile and inner pressure build-up were obtained according to temperature and burn-up.

$$r^2 \frac{\partial^2 \sigma_{rad}}{\partial r^2} + 4r \frac{\partial \sigma_{rad}}{\partial r} = -\frac{2(\dot{\varepsilon}_{irr,\tan} - \dot{\varepsilon}_{irr,rad})}{c(1-\nu_c)} = \Delta\varepsilon$$

By solving fundamental strain equation, the stress with temperature and burn-up was provided in Figure 1. (The detail process including explanation about parameters used was omitted here, but referred [1].)

Table 1. Initial condition for assessment of TRISO integrity

Property	Value
Fuel temperature [℃]	1300
Max. fast fluence [10^{25}n/㎡]	1.5
Time [day]	660
SiC Median fracture strength [㎫]	702 (=834-88 x 1.5)
Weibull modulus	8
TRISO-type	HTTR

Last, with given condition summarized in Table 1, the probability of TRISO fracture is shown in Figure 2. Weibull distribution is used for this calculation.

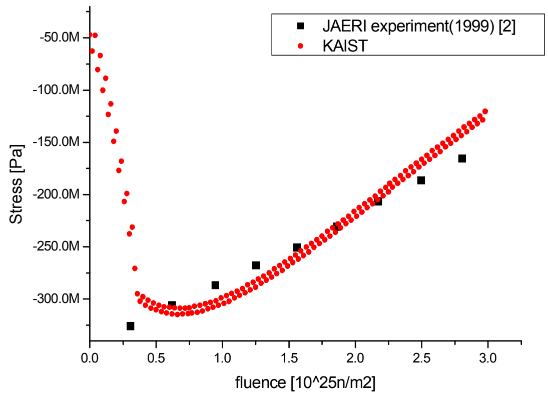


Figure 1. Stress distribution comparison with JAERI's experiment [2]

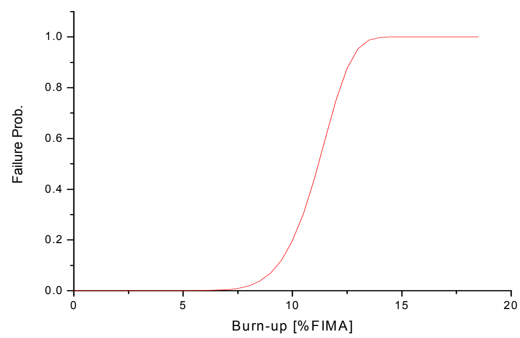


Figure 2. SiC fracture probability versus burn-up

3. Fission products activity

The criteria to select the index Fission Products (FPs) is following next; the manner in which the radioactive nuclides can affect human health varies with the half life, the quantity of material released, the type of emitted radiation, the mechanisms of transport to humans, and the chemical reactions within the human body. [3] Based on the criteria, noble gases, iodine and cesium isotopes, others (Rb, Sr, Ba, Ce) were chose. These FPs produced many different types of gaseous form: Xe, Kr, Ba, BaO, Sr, SrO, Ce, CeO, CeO_2, Te, Te_2, TeO_2, I, I_2, Cs, Cs_2, CsI, Cs_2I_2, Rb, Rb_2. [4]

To calculate the activity of FPs, the following assumptions were used. First, FP inventory can be obtained without the information of neutron energy. Production of FPs from our interest regions, the two peaks, is almost independent on neutron energy. Second, FPs decay with time, not with neutron capture after fission occurred. Third, index gaseous fission products were only regarded and the activity was calculated from the inventory of those index FPs. Finally, combined FPs will be perceived as detached individual elements. (e.g. CsI→Cs and I)

There the goal is to calculate the activity from designated FP inventory when FPs are released at any burn-up ratio. There are two requirements:
① Weight fraction according to burn-up
② Activity at certain burn-up

In fact this method cannot predict the actual behavior in TRISO. To use previous work on this study, following two assumptions should be regarded. The order of magnitude for FPs in any TRISO fuel burned differently is similar, and weight fraction or activity data of FPs may be similar to those of general FPs in HTGR even though the environment around fuel is not alike.
The inventory of FPs from the ref. [4] is illustrated in Figure 3 and this is for requirement ①.

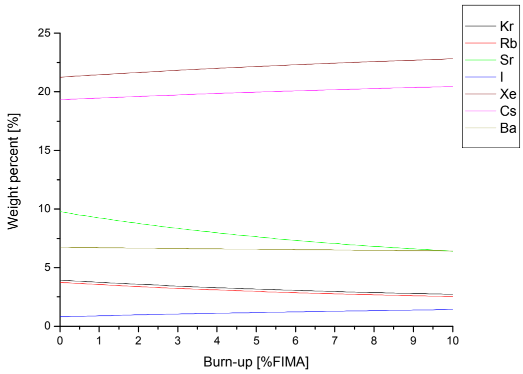


Figure 3. FP weight percent in TRISO with burn-up

Although the activity in 8.4%FIMA is only known [5], the activity with general burn-up can be derived by using Figure 4; normalized with 8.4%FIMA. This is for the requirement ②.

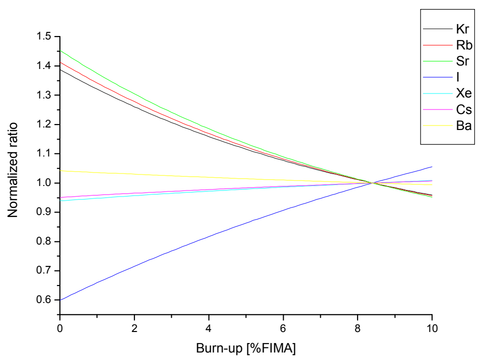
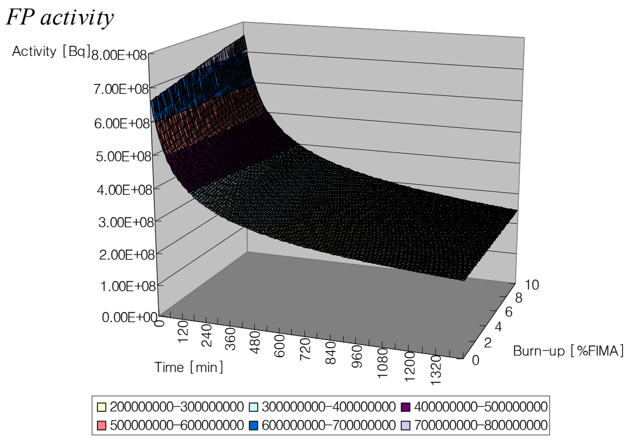


Figure 4. Normalized FP activity according to 8.4%FIMA

By regression analysis of above two curves in Figure3 and 4, the initial activity of specific FP in given any burn-up condition can be obtained as below, Figure 5.



4. Conclusion

Through this study, by the combination of information of fracture and pre-contained activities, the probability and magnitude of radioactive release outside of TRISO can be estimated. This study gives the basic information of radioactivity release during postulated severe accident in the gas cooled reactor.

This study suggests simple modeling to calculate the fracture probability and the activity. However, there are some errors due to uncertainty from ignoring detailed reactor environment. It is needed to address the uncertainties under the systematic approach presented in this paper.

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