Consequence analysis of postulated criticality in SFP using the randomized model of fuel debris

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A postulated criticality event has been studied that occurred in fuel debris produced after the loss of cooling function in a spent fuel pool. The $1/f^{\beta}$ spectrum model was applied to deal with the random distribution composition of fuel debris. The results showed that the number of fissions per volume varying from 4.05×10^{18} to 1.6×10^{19}.

Keywords: criticality accident, fuel debris, randomized model, number of fissions, Nordheim-Fuchs model.

1. Introduction

Loss of cooling function is supposed to initiate a severe accident of Spent Fuel Pool, SFP, and it indicates a possibility that fuel meltdown occurs without any accident management[1]. Melted fuels could drop on the floor of SFP and penetrate into concrete to make fuel debris by molten corium concrete interaction. In this study, criticality of such fuel debris was investigated. A simplified model of fuel debris, which consisted of a fuel and concrete as a moderator was introduced to calculate k_{eff}. An effective approach is necessary due to the difficulties to predict the spatial distribution of concrete and fuel in fuel debris. The $1/f^{\beta}$ spectrum model was applied to deal with the random distribution[2]. This study investigated effect of randomness of the randomized model of fuel debris on the number of fissions at the first peak power in a criticality incident.

2. Calculation Method

SWAT[3] code and JENDL-4.0 were used for burnup calculation to obtain the nuclide density at several burnup conditions. The calculation was performed based on the BWR STEP3 model[4]. The cooling time was set as 5 years. Thereafter, the MVP code was used to generate two-energy group cross section. There are three types of macroscopic cross section (Σ) that produced using MVP code, Σ_{UO2}, $\Sigma_{UO2\text{ with concrete}}$, and $\Sigma_{concrete}$ as reflector.

As it is mentioned about the difficulties to predict the spatial distribution of fuel debris. Therefore, the $1/f^{\beta}$ spectrum model was applied to deal with the random distribution. The $1/f^{\beta}$ model generates random media based on Randomized Weierstrass function (RWF)[4]. Simplified geometry as shown in Fig.1 was used to generate k_{eff} under the $1/f^{\beta}$ spectrum model. The macroscopic cross section of burned UO_2 and concrete were applied in the RWF model to calculate the k_{eff}. In this study, 100 replicas were considered to understand the fluctuation of k_{eff} and temperature coefficient under the random distribution of fuel debris. Each replica has different k_{eff} value and temperature coefficient.

Afterwards, the Nordheim-Fuchs (N-F) model that is based on the one-point kinetics as presented in Eq. 1, where only prompt neutron is considered, was introduced to estimate the magnitude of fission numbers in the first peak power in a criticality event. In this study, an initial excess reactivity of 2$ was assumed due to a scenario that the reactivity increases gradually and the peak power appears after the excess reactivity more than 1$. Energy production was calculated for each of the 100 replicas using Eq. 2, which was converted into number of fissions. The number of fissions were calculated for each replica.

$$\frac{dn}{dt} = \frac{\rho - \beta}{\ell} n \qquad (1)$$

$$E = \frac{2(\rho_0 - \beta)}{\alpha K} \qquad (2)$$

ρ_0 initial excess reactivity ($)

β delayed neutron fraction

α temperature coefficient (1/K)

K reciprocal heat capacity (K/J)

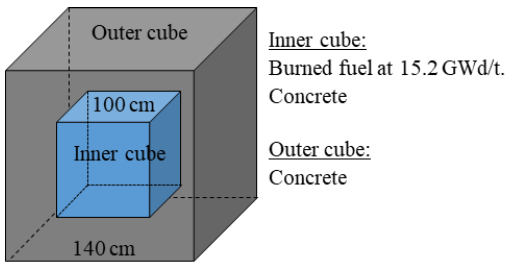

Fig. 1. Simplified geometry for k_{eff} calculation under the $1/f^{\beta}$ spectrum model

3. Results・Conclusion

In this study, the burned fuel at 15.2 GWd/t showed the possibility of re-criticality under the randomized model of fuel debris, and the results for both 5.2 GWd/t and 33.3 GWd/t showed that k_{eff}<1. The number of fissions of the first peak was calculated for burned fuel at 15.2 GWd/t. By implementing the randomized model, the number of fissions per volume fluctuating from 4.05×10^{18} to 1.6×10^{19} as shown in Fig.2. It shows that there is a variation of number of fissions depending on the variation of temperature coefficients.

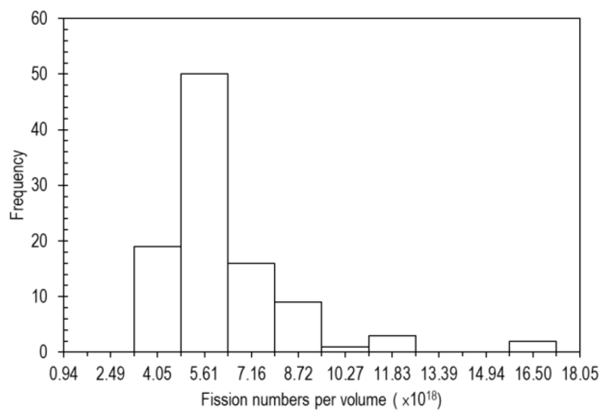

Fig.2. Histogram of fission numbers per volume using randomized model for burned fuel at 15.2 GWd/t.

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