Calculation of DPA in the Reactor Internal Structural Materials of Nuclear Power Plant

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1. Introduction

This study focuses on evaluating the neutron irradiation damage of the internal structural materials in a nuclear reactor. One of the life-limiting factors of a nuclear power plant is the embrittlement of reactor pressure vessel and internal structural materials. The embrittlement is mainly caused by atomic displacement damage due to irradiations with neutrons, especially fast neutrons [1]. The integrity of the reactor internal structural materials has to be ensured over the reactor life time, threatened by the irradiation induced displacement damage. Accurate modeling and prediction of the displacement damage is a first step to evaluate the integrity of the reactor internal structural materials. Traditional approaches for analyzing the displacement damage of the materials have relied on tradition model, developed initially for simple metals, Kinchin and Pease (K&P) [2], and the standard formulation of it by Norgett et al. [3], often referred to as the ′NRT′ model. An alternative and complementary strategy for calculating the displacement damage is to use MCNP code. MCNP uses detailed physics and continuous-energy cross-section data in its simulations.

In this paper, we have performed the evaluation of the displacement damage of the reactor internal structural materials in Kori NPP unit 1 using detailed Monte Carlo modeling and compared with predictions results of displacement damage using the classical NRT model.

2. MCNP Modeling

2.1 Reactor Internal Structural Modeling

A detailed MCNP[4] modeling has been done based on design of the Kori NPP unit 1, especially focused on the reactor internals such as fuel assembly, baffle, barrel and baffle former shown in Figure 1. The one eighth of the core was modeled in the x-y coordinate plane and full size height of the fuel assembly and internal structure was modeled in the z-coordinate axis. The seven baffle formers are connected between baffle plate and barrel, and core lower plate is located in the bottom of the fuel assembly. The geometric specifications of the reactor internals are summarized in Table 1.

2.2 Source Term & Irradiation Cycle Modeling

The source term was modeled to evaluate the integrated fissile materials according to the reactor cycle nuclear design reports. For the irradiation cycle modeling, the loading patterns were verified at each cycle. It turned out that three kinds of loading patterns have been used for the Kori NPP unit 1. The EFPD, EFPY and loading pattern are summarized in table 2.

Table 1. Summary of specifications of the reactor internals

	Length [cm]	Thickness [cm]	Material
Baffle Plate	402.59	2.8575	SUS 304
Baffle Former	-	5.08	SUS 304
Barrel	495.24	4.445	SUS 304
Thermal Shield	459.53	8.89	SUS 304L

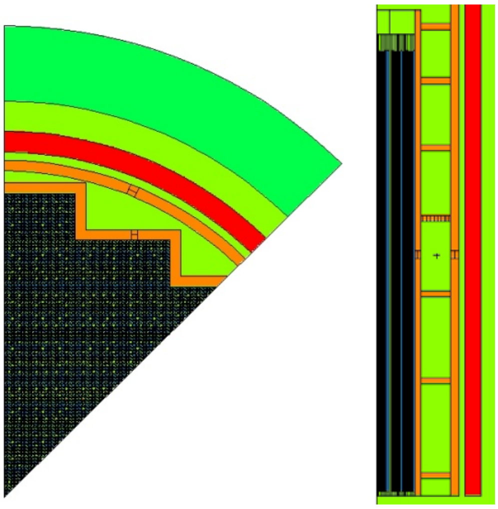

Figure 1. Schematic diagram of the MCNP modeling of reactor core and internal structures

Table 2. The loading patterns, EFPD and EFPY associated with reactor cycles in Kori NPP unit 1

	Cycle	EFPD	EFPY
Out/In	1-12	3872.4	10.6
Low Leakage	13 -28	5698.2	15.6
Equilibrium	29 -50	8060	22.9

2.3 NRT Model

In this study, the classical DPA calculation model, NRT model was used to compare the results from MCNP detailed modeling calculations. The detailed model is described in the bellows. The damage rate in a material, i.e. the rate of DPA production during an irradiation, is obtained by multiplying the total neutron flux in the irradiation environment by the spectrally averaged DPA cross section.

$$\sigma_d(E_n) = \int_{E_d}^{\Lambda E_n} \sigma_n(E_n, E)\nu(E)dE$$

$\sigma_d(E_n)$: *displacement cross section* $[b]$
Λ : $4m/(m+1)^2$, m: *atom mass of matter*
E_d : *displacement energy* $[eV]$
E_n : *incident neutron energy* $[eV]$
E : *Primary Knockon Atom energy* $[eV]$
$\nu(E)$: *number of displacement*

$$DPA/s = \int_{E_d/\Lambda}^{\infty} \sigma_d(E_n)\emptyset(E_n)dE_n$$

$\emptyset(E_n)$: *Neutron Flux* $[n/cm^2 \cdot sec]$

3. Results

Table 3 shows the summary of the displacement damage calculation results using MCNP from 4, 18 and 29 cycle irradiations respectively. The value of the DPA rate was the highest value at the BOC of each cycle. Figure 2 to 4 show the DPA rate distributions within the reactor internal at each cycle. The maximum value of the DPA rate was occurred at the baffle side of the reactor internal where the node has the maximum neutron flux.

Table 3. Summary of displacement damage for each cycle

		4 cyc	18 cyc	29 cyc
Displacement Damage [DPA/s]	BOC	4.42E-12 ~ 1.12E-7	4.59E-12 ~ 9.46E-8	5.62E-12 ~ 9.40E-8
	MOC	4.77E-12 ~ 1.07E-7	4.14E-12 ~ 8.80E-8	4.67E-12 ~ 9.03E-8
	EOC	1.15E-12 ~ 6.93E-8 *	4.59E-12~ 8.56E-8	4.61E-12 ~ 8.89E-8

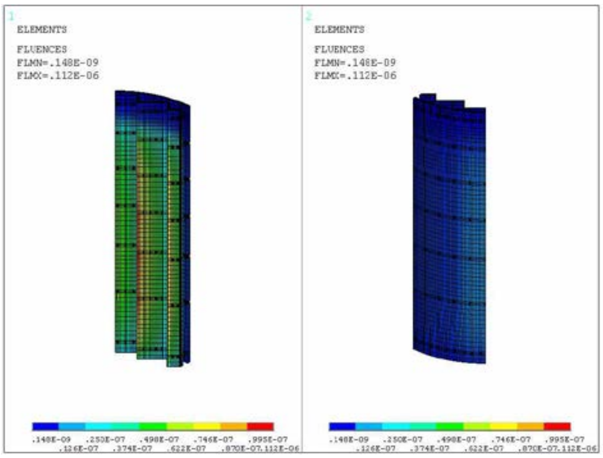

Figure 2. DPA rate distribution within the reactor internal at BOC in cycle 4

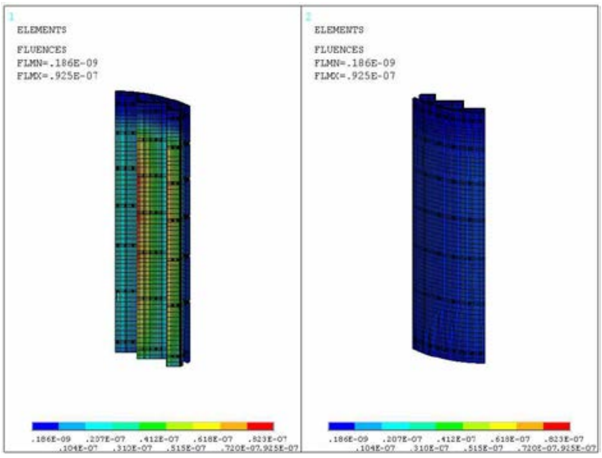

Figure 3. DPA rate distribution within the reactor internal at BOC in cycle 18

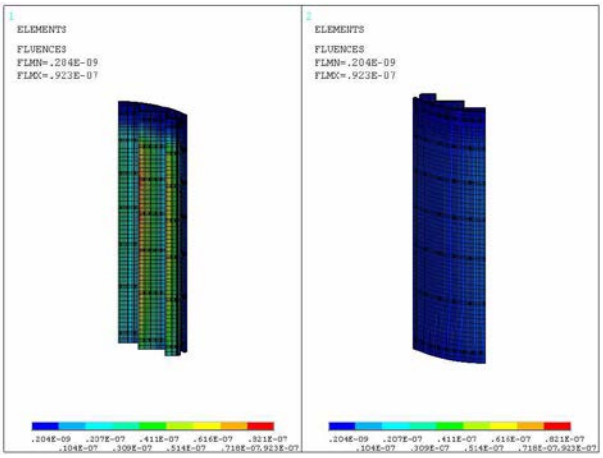

Figure 4. DPA rate distribution within the reactor internal at BOC in cycle 29

4. Summary and Future Works

The evaluation of the displacement damage of the reactor internal structural materials in Kori NPP unit 1 using detailed Monte Carlo modeling has been performed. The maximum value of the DPA rate was occurred at the baffle side of the reactor internal where the node has the maximum neutron flux. These displacement damage calculation results are supposed to use for further thermal and mechanical functional analysis.

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