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Estimation of Neutron Damage to Reactor Vessel Internals for OPR-1000 and APR-1400

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1. Introduction

Neutron irradiation to materials displaces atoms from lattice positions and creates point defects. Most of defects are annihilated by recombination and residual defects form various microstructures such as cavities, precipitates and dislocations. These defects evolved from irradiation act as obstacles to dislocation motion and lead to embrittlement of materials. The amount of radiation damage is proportional to defect production, which is usually described as *dpa* (displacement per atom) and transmutation gas production. These parameters are closely related to the mechanical property changes in irradiated materials, including fracture toughness and/or tensile properties.

Currently there are several types of pressurized water reactors (PWRs) operating domestically. Two types of representative PWRs are OPR-1000 and APR-1400, which were designed by our technology and have been operating safely. As a reactor operating time increases, the degradation of structural materials advances due to neutron irradiation. Precise estimation of material property changes will enable to make better decisions about operations, maintenance and inspection, which can help predict a plant lifetime. To this purpose, we estimate quantitatively the radiation damage to materials of reactor vessel internals near the end of plant lifetime in the future. First, we computed the neutron flux for internal components, which include baffle, barrel, core shroud ring (CSR) and pressure vessel (PV). Then, the amount of radiation damage to each component was evaluated using a computer code.

2. Methods

In estimating neutron damage to reactor components, we performed the neutron transport calculation to obtain the neutron flux for the specific locations of components. Subsequently, the amount of neutron damage was calculated using a SPECTER computer code [1].

2.1 Neutron Spectrum Calculation

The transport of neutrons from the core to locations of interest was computed using 3-diemnsional neutron transport code (RAPTOR-M3G) with the BUGLE-96 cross section library [2]. For a given material input data, a neutron flux was estimated with the geometrical model of a reactor core in Hanbit Unit 5, which is one type of OPR-1000 PWRs. Figs. 1 (a) and (b) show the geometrical structures of OPR-1000 reactor core, in r-θ and r-z direction, respectively. Based on this model, we computed absolute multigroup neutron flux at several locations of baffle, barrel, CSR and PV. For APR-1400 PWR, Shin Kori Unit 3 was chosen as a reference one. The difference in the configuration of internal components was considered in computing the neutron spectrum for APR-1400.

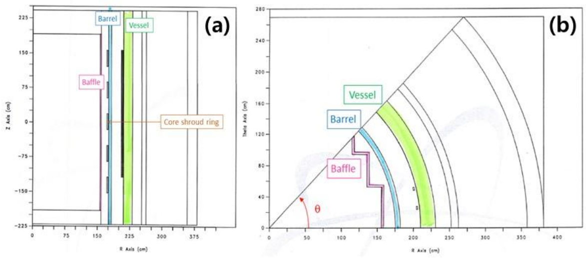

Fig. 1. Cross sectional views of Hanbit Unit 5 (OPR-1000) reactor structure (a) on r-z plane, (b) on r-θ plane.

2.2 Neutron Damage Evaluation

We use the SPECTER code to obtain neutron damage parameters of various elements for a given neutron spectrum. The neutron spectrum is the only input to the code that the user needs to define. The code integrates over the cross section libraries to give the spectral-averaged results. The output of the SPECTER includes displacement, He/H production (appm) and spectral-averaged primary knock-on atom spectrum. The advantage of the SPECTER is that the user does not need access to ENDF libraries because the basic neutron reaction calculations had been performed to create the cross section libraries. The parameter of dpa indicates total initial energy that is available to produce damage to the matrix – not the final, permanent damage. The dpa parameter, however, has been recognized as a successful correlation one since dpa is proportional to the total energy available for producing defects [3].

3. Results

Depending on the locations of the core components, the neutron flux changes significantly, as well as operating conditions. In order to estimate the maximum possible damage, we select the position where the maximum neutron flux occurs. Maximum neutron spectra for reactor internal components in OPR-1000 are shown in Fig. 2. The spectrum is composed of 47-group neutron energy ranging from 1 x 10^{-10} to 14.2 MeV. Fig. 3 displays the maximum neutron flux for internal components in APR-1400. It is seen that fast neutron flux near baffle is about one order of magnitude higher for APR-1400 than for OPR-1000.

Fig.2. Maximum neutron spectra for baffle, barrel, CSR and PV in Hanbit Unit 5 (OPR-1000).

Fig.3. Maximum neutron spectra for baffle, barrel, CSR and PV in Shin Kori Unit 3 (APR-1400).

Damage parameters were calculated by inputting the neutron flux to the SPECTER code. It was assumed that the reactor components were irradiated with the flux, given in Figs. 2 and 3, continuously without interruption for the 80% of plant design lifetime. That corresponds to 32 EFPY (Effective Full Power Year) for OPR-1000 and 48 EFPY for APR-1400, respectively. Barrel, baffle and CSR are made of SS304, and pressure vessel is SA508. The chemical composition of two alloys is listed in Table I. The damage parameters of dpa value and He/H production (appm) for each component are summarized in Table II.

Table I: Chemical composition of SS304 & SA508 (unit: w/o)

	Fe	Mn	P	S	Si	Ni	Mo	Cr	Cu	Co	V	Nb	C
SA508	97.1	0.63	0.01	0.01	0.26	0.73	0.57	0.32	0.07	0.01	0.01	0.01	0.22
SS304	68.9	2.0	0.05	0.03	1.0	9.0		19					0.08

Table II: Summary of evaluated damage parameters forOPR-1000 and APR-1400

		OPR-1000	APR-1400	OPR/APR
총 운전시간 (EFPY)		32	48	0.67
fast neutron flux (#/cm^2 s)	Baffle	3.318 x 10^{12}	5.008 x 10^{13}	0.07
	CSR	2.313 x 10^{12}	3.841 x 10^{12}	0.60
	Barrel	1.375 x 10^{12}	2.428 x 10^{12}	0.57
	PV	1.555 x 10^{10}	1.826 x 10^{10}	0.85
displacemet damage (dpa)	Baffle	5.37	115.17	0.05
	CSR	3.66	9.52	0.38
	Barrel	2.16	6.15	0.35
	PV	0.02	0.05	0.40
He production (appm)	Baffle	4.31	74.41	0.06
	CSR	2.65	4.91	0.54
	Barrel	1.76	2.96	0.59
	PV	0.020	0.023	0.87
H production (appm)	Baffle	54.63	1076.3	0.05
	CSR	21.61	68.87	0.31
	Barrel	34.16	40.86	0.84
	PV	0.2	0.32	0.63

4. Discussion

Neutron damage to reactor internal materials was evaluated for OPR-1000 and APR-1400 PWRs, which was described in terms of dpa and He/H production. Baffle, which was made of SS304, shows the highest damage for all damage parameters since it is located close to the fuel assemblies. The overall neutron damage to baffle in APR-1400 is very high even with the operation time, which is caused by a harder neutron spectrum. It is also expected that baffle would be susceptible to a microstructural evolution in extreme conditions due to the high production of transmutation gas. Although the dpa parameter does not represent the final, permanent damage, it is proportional to the final defects that remain in the material. Therefore, the estimation of the dpa parameter is the first step toward radiation damage study.

REFERENCES

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