Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

Evaluation of Radiation Damage to Reactor Components in Kori Nuclear Power Plant Unit 1

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1. Introduction

Neutron irradiation displaces atoms from lattice positions and creates point defects. Although most point defects are annihilated by recombination, residual defects form various microstructures such as cavities, precipitates and dislocations. The defects and precipitates from irradiation act as obstacles to dislocation motion and result in embrittlement of materials. Radiation embrittlement of reactor structural materials is normally associated with reactor pressure vessel and reactor internals. In order to investigate the amount of radiation embrittlement, we measure the mechanical properties of irradiated materials, which include fracture toughness and/or tensile properties.

Since the operating license for Kori-1, the first commercial nuclear power plant (NPP) in Korea, was terminated in June 2017, preparations have been made for decommissioning. Decommissioning of NPP can give an opportunity to study the effects of long-term radiation on reactor materials. Precise characterization of irradiated material properties will enable us to make better decisions about operations, maintenance and inspection, which can help evaluate plant lifetime extensions. To this purpose, we are planning the Kori-1 primary components research program. As a part of project, it is necessary to determine the conditions of structural material based on the operating history. In this study, we firstly computed the neutron flux for internal components over time, including baffle, barrel and pressure vessel. Then, the amount of radiation damage to each component was evaluated. This task will be a help to understand material performance under high-radiation environments.

2. Methods

In estimating radiation damage to reactor components, we performed the neutron transport calculation to define the neutron flux for the specific locations of components. Subsequently, the amount of radiation damage should be evaluated quantitatively using the previous results.

2.1 Neutron Transport Calculation

The transport of neutrons from the core to locations of interest was determined with 3-diemnsional transport calculation code (RAPTOR-M3G) with the BUGLE-96 cross section library [1]. As detailed material input data should be assigned, the neutron flux was calculated with the geometrical model of a reactor core in Kori-1. Figs. 1 (a) and (b) show the geometrical structures of a Kori-1 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 and pressure vessel, which will be applied to the next evaluation of radiation damage.

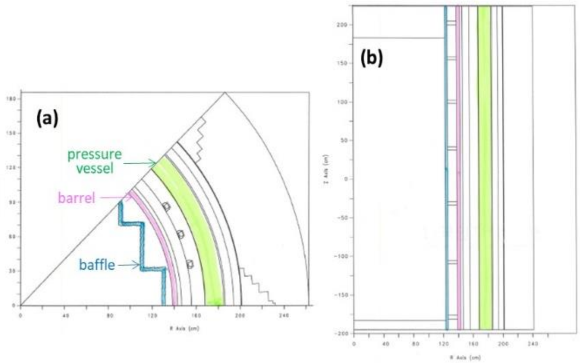

Fig. 1. Cross sectional views of Kori-1 reactor structure (a) on r-θ plane, (b) on r-z plane.

2.2 Radiation Damage Evaluation

The SPECTER code is a convenient tool to obtain damage parameters for various elements in a specified neutron spectrum [2]. The neutron spectrum is the only input to the code that the user needs to specify. The code integrates over the cross section libraries to give the spectral-averaged results. The output of SEPCTER includes displacement, helium/hydrogen production (appm) and spectral-averaged PKA energy. One advantage of SPECTER is that since the basic neutron reaction calculations have been done to create the SPECTER libraries, the user does not need access to ENDF libraries. The evaluation of dpa is only indicative of the 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 which in turn is largely proportional to the final lattice defects in materials [3].

3. Results

Neutron spectra for reactor internal components in Kori-1 Unit, including baffle, barrel and pressure vessel, are shown in Fig. 2. All spectra was evaluated at θ = 0 degree and z = 0, which are designated in Figs 1. The spectrum is composed of 47-group neutron energy ranging from 1 x 10^{-10} to 14.2 MeV, which represents the average neutron flux for the 29th fuel cycle.

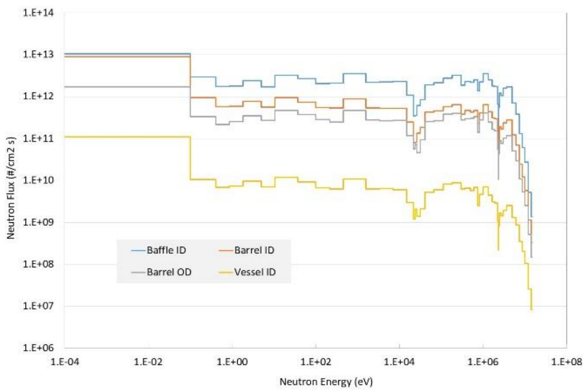

Fig. 2. Neutron spectra for baffle ID, barrel ID/OD and pressure vessel ID in Kori-1 Unit (ID: Inner Diameter, OD: Outer Diameter)

We calculated damage parameters by using the SPECTER code and neutron spectra. It was assumed that the reactor internals were irradiated by the given neutron flux continuously without interruption for 337.6 months. Barrel and baffle are made of SS304 and pressure vessel is SA508 [4]. The chemical compositions of two alloys are listed in Table 1. The dpa value, helium and hydrogen production for reactor internals are displayed in Figs. 3-5, respectively.

Table I: Chemical compositions of SA508 and SS304 (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

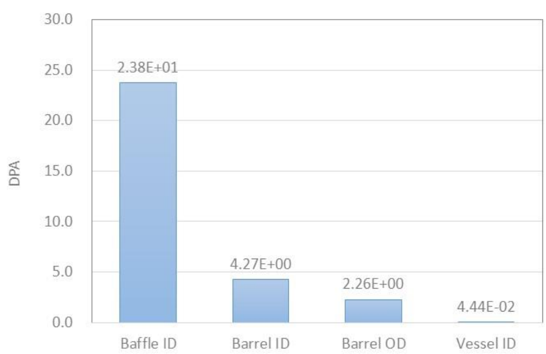

Fig. 3. dpa values for baffle, barrel and pressure vessel

4. Discussion

We quantitatively evaluated radiation damage to reactor material for Kori-1, which was described in terms

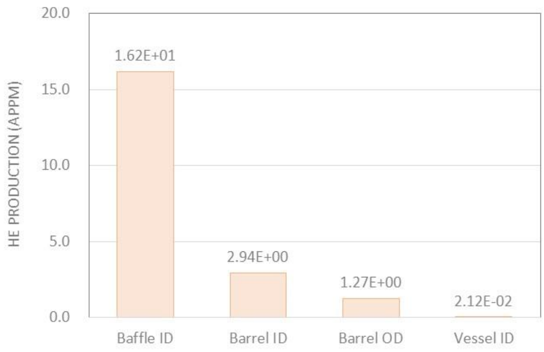

Fig. 4. He production for baffle, barrel and pressure vessel

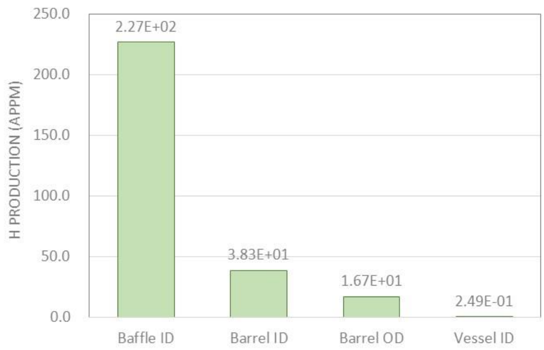

Fig. 5. H production for baffle, barrel and pressure vessel

of dpa and He/H production. Baffle, which was made of SS304, shows the highest damage for all parameters among components of interest since it is located close to the fuel assemblies. It is expected that baffle would demonstrate the higher neutron-activation. Currently, in order to investigate the effect of long-term irradiation of materials from Kori-1, a national program is underway. As a preliminary step, we are evaluating the radiation dose and activation level of materials that will be harvested from the reactor, as well as securing the equipment that can treat radioactive materials. The analysis of radiation damage to reactor components will be applicable to harvesting the most suitable materials for testing.

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