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# Radiation and Thermal Analysis of Baffle Plates in Kori Nuclear Power Plant Unit 1

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## 1. Introduction

The first commercial nuclear power plant (NPP) in Korea, Kori-1, was terminated in June 2017 after 39 years of service since 1976. Currently, preparations for safe decommissioning are in progress. Decommissioning of a NPP can give an opportunity to study the effects of long-term radiation on reactor internal materials. Precise characterization of irradiated material properties will enable us to make better decisions about operation, maintenance and inspection, which help evaluate plant lifetime extensions. To this purpose, we are performing a research program to set up a plan for investigating reactor internals of the decommissioned Kori-1. As a part of a program, we intend to characterize Kori-1 internals under the operation conditions during its commercial life. In this study, we firstly computed the neutron and gamma flux for baffle plates - one of reactor internal components. Using the neutron flux, the amount of radiation damage to the baffle was evaluated over the plant lifetime. Then, the temperature change in the baffle plate resulting from gamma heating was calculated by approximating as a 1-dimensional problem, which is still underway. This task will be a help to understand material performance under the actual radiation and temperature environments.

## 2. Methods

In estimating radiation damage and temperature changes of baffle plates, we performed the transport calculation to obtain the neutron and gamma flux for the specific locations. One of the calculation results includes heat generation rate due to gamma irradiation. The radiation damage was evaluated quantitatively using the SPECTER code [1] and then the temperature change was calculated numerically by applying a simplified 1-D heat transfer model.

### *2.1 Radiation Transport Calculation*

The transport of neutrons and gammas from the core to baffle plates was determined with 3-diemnsional transport calculation code (RAPTOR-M3G) with the BUGLE-96 cross section library [2]. The flux was calculated with the geometrical model of a reactor core in Kori-1. Fig. 1 shows the cross sectional view of a Kori-1 reactor core, in r-θ direction at z = 0. Based on this model, we computed multigroup neutron and gamma spectra at several locations of baffle plates, as well as a heat generation rate due to gamma heating. These results will be employed to evaluate the radiation damage and temperature change in baffle materials of SS304..

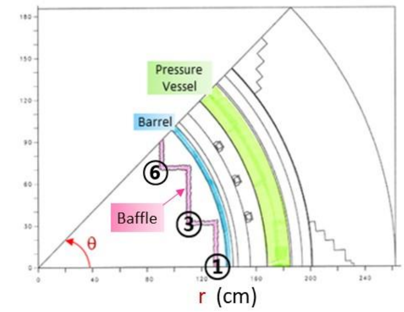


Fig. 1. Cross sectional views of Kori-1 reactor structure on r-θ plane at z = 0. (The markers of ①,③,⑥ represent the locations of interest for evaluation.)

### *2.2 Neutron Damage Evaluation*

The SPECTER code is a convenient tool to obtain damage parameters for various elements in a specified neutron spectrum [1]. The neutron spectrum is the only input to the code that the user should define. The output of the SEPCTER includes displacement damage, H/He production and spectral-averaged primary knock-on atom energy. While the parameter of *dpa* (displacement per atom) is only indicative of the total energy that is available to produce damage to the matrix – not the permanent damage, this parameter has been recognized as a successful correlation one. In addition, the production of H and He from the neutron transmutation reactions was computed from the SPECTER.

### *2.3 Temperature Change Calculation*

Thermal history of baffle plates is the result of heat transfer by convention with the coolant, conduction between solid component and gamma heating. In order to determine the temperature profile, we approximated this problem as a simple 1-D model of the baffle plate with heat generation [3]. Assuming that most parameters involving heat transfer are constant except the gamma-heat generation rate, the temperature distribution in the baffle was calculated numerically by solving a heat conduction equation with boundary conditions.

## 3. Results

Neutron spectra for baffle plates in Kori-1 are shown in Fig. 2. All spectra was evaluated at the specified locations of ①,③ and ⑥ in Fig. 1.The neutron spectrum is composed of 47-group energy ranging from 1 x $10^{-10}$ to 14.2 MeV, which represents the average neutron flux for the 16th fuel cycle of Kori-1. The gamma spectra for the baffle are displayed in Fig. 3, in which two locations of interest include θ =0 and 45 deg. at z = 0.

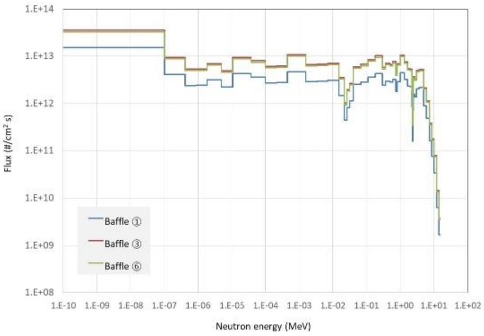


Fig. 2. Neutron spectra for baffle plates at three locations

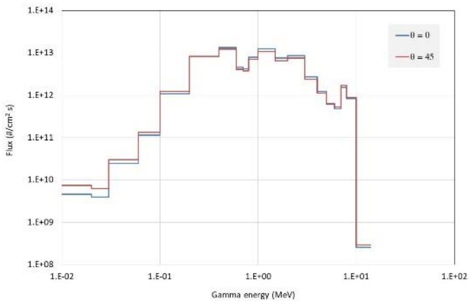


Fig. 3. Gamma spectra for baffle plates at two locations

Using the SPECTER code, the amount of neutron damage were evaluated by assuming that the baffle plates, made of SS304, were irradiated by the neutron flux (Fig. 2) without interruption for 337.6 months. The *dpa* values and H/He production for three locations of the baffle are shown in Fig. 4.

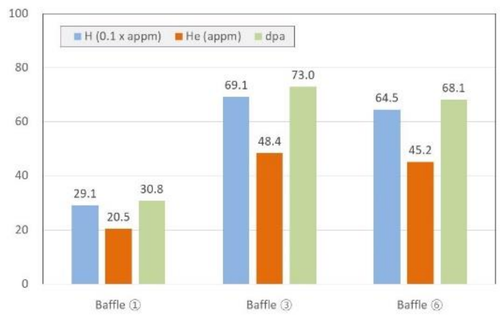


Fig. 4. Neutron damage parameters for baffle plates (H/He production in units of appm)

We estimated the thermal conditions of baffle plates, which had experienced material degradation due to irradiation during the normal operation. The absorption of gamma-ray throughout the baffle plates can be considered as heat generation within SS304. Simply, the temperature (T) variation in the baffle, resulting from gamma heating, was described by approximating as a 1-dimensional problem. For the given heat generation rate of the plates ($e_\gamma$), the steady-state heat conduction with internal heat generation can be expressed as

$$\frac{d^2T}{dx^2} + \frac{1}{k}\, e_\gamma = 0, \;\; e_\gamma(x) = q_o \cdot e^{-\mu \cdot x} \qquad (1)$$

where $k$ is thermal conductivity of SS, $q_o$ is the gamma heat generation rate at the inner surface, and μ is the gamma absorption coefficient. This coefficient is a function of gamma-energy, which was averaged over the gamma spectrum given in Fig. 3. For one-dimensional heat transfer through a plane wall of thickness L, the boundary conditions can be specified as:

$$h\,(T(x) - T_c) = k\, \frac{dT}{dx}\bigg|_{x=0} \qquad (2)$$

$$h\,(T(x) - T_c) = -k\, \frac{dT}{dx}\bigg|_{x=L} \qquad (3)$$

where $T_c$ is coolant temperature and $h$ is the convection heat transfer coefficient. To apply the equation (1) derived for gamma heat generation rate and temperature distribution, an illustrative example for a plate is selected, such as (a) in Fig. 5. The dimension, physical properties and associated nuclear data of the baffle plates are given in Table I. The temperature profiles in the baffle plate thickness due to gamma heating are solved numerically and shown in (b) in Fig. 5, where two cases of $h$ are used owing to the uncertainty [4].

TABLE I. Dimension, physical properties and associated nuclear data of the SS304 baffle plates

| Symbol | Description | Value and units |
|---|---|---|
| L | Baffle plate thickness | 0.038 m |
| $T_c$ | Coolant temperature | 578 K |
| k | Thermal conductivity (at ~330C) | 18.9 W/m/K |
| μ | Gamma energy absorption coefficient | 32 /m |
| $q_o$ | Gamma heat generation rate | 9.6 x $10^5$ W/$m^3$ |
| h | Convective heat transfer coefficient | 8x$10^3$ to 30x$10^3$ W/$m^2$/K |

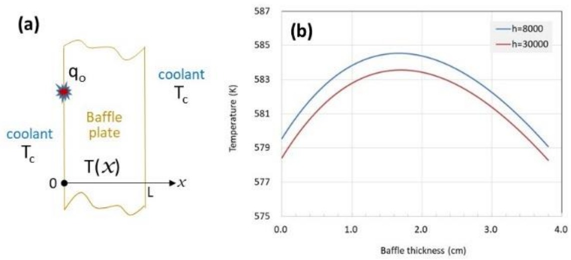


Fig. 5. (a) Schematic for heat conduction in a baffle plate with heat generation at the surface. (b) Temperature distribution of a baffle plate with two different *h*.

## 4. Conclusions

It is of importance to understand the radiation and thermal history of the reactor internals, which will be removed for an analysis. This study describes the methods for estimating the radiation damage and temperature variation of the baffle plates in Kori-1 NPP unit during the plant lifetime. Neutron damage was calculated by using the SPECTER code, which was described in terms of parameters such as *dpa* and H/He production. A difference in damage parameters was found depending on the locations of a baffle. In particular, the amount of radiation damage near the core is more than twice that of other locations. Besides, we attempted to calculate the temperature variation in the baffle resulting from gamma heating by approximating as a 1-dimensional problem. Although there is uncertainty in the heat transfer coefficient, the simple calculation shows that the change in temperature of the baffle plate due to gamma heating is not significant. Currently, more sophisticated modeling for a thermal analysis is underway.

## REFERENCES

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