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Improvement of a calculation procedure of neutron-flux distribution for radioactivity inventory estimation for decommissioning of nuclear power plants

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ABSTRACT

We improved a calculation procedure of neutron-flux distribution in the Primary Containment Vessel (PCV) to get reliable estimation of radioactivity inventory, which is crucial for specification of a decommissioning plan of nuclear power plants. We calculated two-dimensional (2D) distribution of neutron-flux in cylindrical coordinate (r–z) with a 2D discrete ordinate (Sn) code DORT by utilizing knowledge of the characteristics of neutron-flux distribution in the PCV of Tsuruga Nuclear Power Plant unit 1 (TS-1). The knowledge was obtained from measurements and three-dimensional (3D) calculation of neutron-flux distribution in cylindrical coordinate (r–θ–z) with a 3D Sn code TORT. The measurements were performed by using activation foils at 30 locations where the distribution characteristics could be observed in the PCV. The 3D calculation provided us better qualitative understandings about the characteristics of neutron-flux distribution in the PCV. An improved model of 2D calculation of neutron-flux distribution was generated by utilizing the knowledge from the measurements and the 3D calculation in the PCV. The reliability of 2D calculation was confirmed by comparing calculated fluxes with measured ones at locations where measurements were performed. The comparison between them showed that neutron-flux distribution calculated by the improved 2D model has met our criteria of the reliability. Therefore, the improved procedure provided a reliable 2D distribution of neutron-flux.

1. Introduction

1.1. Preparatory tasks for decommissioning

Preparatory tasks for decommissioning of a nuclear power plant start with a radioactivity characterization of the plant. Information about radioactivity inventory from this task is referred to by other preparatory tasks such as decommissioning scenario design, radiowaste disposal planning, estimation of decommissioning cost, assessment of potential risks (safety assessment) and application to regulator (IAEA, 1998; NEA, 2013). Reliable information of radioactivity inventory can be used to optimize these tasks. The radiological characterization, thus, plays an important role in the preparatory tasks for decommissioning.

The radiological characterization comprises three sub-tasks. These are 1) an evaluation of neutron-induced radioactivity, 2) an evaluation of contaminated materials and 3) an estimation of amount of waste materials. Neutron-induced radioactivity is calculated with calculation codes and its validity should be verified with measurements. Contaminated materials, which are contaminated by radioactive releases from fuel and/or activation products of corrosion and erosion, were evaluated by assessing in situ measurements, sampling and analysis. Amount of metal such as piping, pumps and other equipment and amount of concrete is estimated by referencing to design diagrams and to design charts. Data from these three sub-tasks are stored in database system in order to be accessed by the other tasks easily. We have started improving the reliability of radiological characterization in order to optimize the other tasks by a betterment of the evaluation procedure of neutron-induced radioactivity.

The evaluation procedure of neutron-induced radioactivity consists of two calculation steps. The first step is a calculation of neutron-flux distribution and the second step is an activation

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Fig. 1. Tsuruga Nuclear Power Station unit 1. Turbine Building: the square building in the right. Reactor Building: Cylindrical building in the back-left side.

calculation, which uses the distribution of neutron-flux as input data and outputs radioactivity distribution. Only the reliable distribution of neutron-flux can provide reliable radioactivity distribution.

In this study, we have improved a procedure for calculation of neutron-flux distribution (Tanaka et al., 2007a, b; Tanaka et al., 2010; Tanaka et al., 2011). Our goal of this improvement was to establish a procedure for a reliable 2D calculation of neutron-flux distribution in the Primary Containment Vessel (PCV) of the Tsuruga Nuclear Power Plant unit 1 (TS-1).

1.2. Outline of Tsuruga nuclear power plant unit 1

Tsuruga nuclear power plant unit 1 (TS-1) (See Fig. 1) went under construction in April 1966 as the Japanese first Boiling Water Reactor (BWR) nuclear power plant for commercial use, and the plant entered commercial service in March 1970. The Japan Atomic Power Company (JAPC) has already started preparatory tasks for decommissioning of TS-1. Plant major specifications of TS-1 are shown in Table 1.

2. Calculation procedure of neutron-flux distribution

2.1. Over view of calculation procedure

A work-flow diagram of our improved procedure is shown in Fig. 2. The procedure consists of two works. One is “works for measurement and 3D calculation” and the other is “works for 2D calculation”. In “works for measurement and 3D calculation”, measurements and 3D calculation of neutron-flux distribution were performed. The purpose of measurement is to obtain quantitative knowledge about neutron-flux distribution and to be used for the validation of 2D distribution. The other hand, the purpose of 3D calculation of neutron-flux distribution is to obtain the qualitative knowledge about neutron-flux distribution and to be used for the modification of 2D model of calculation. In “works for 2D calculation”, 2D calculations started with a simple model and we repeated model modifications by referencing to the knowledge until reliability is achieved. Better understanding of the characteristics of neutron-flux distribution in the PCV can make the 2D calculation reliable. Accessing the knowledge, we generated and modified the models of 2D calculation. The reliability of calculated fluxes was confirmed comparing them with measured ones. The purpose of 2D calculation is that we obtain the reliable 2D distribution of neutron-flux distribution to be used for radioactivity calculation to evaluate neutron-induced radioactivity in the PCV.

2.2. Works for measurement and 3D calculation

In “works for measurement and 3D calculation”, we performed measurements and three-dimensional (3D) calculation of neutron-flux distribution. We measured neutron-fluxes by using activation foils at 30 locations where the distribution characteristics such as streaming, leakage, shielding and others are observed in the PCV. We also performed 3D calculation of neutron-flux distribution with 3D discrete ordinate method (Sn) calculation code TORT (ORNL, 1998; Tsukiyama et al., August 2002) in the range where such characteristics can be observed. Both assessing the measurements and observing the 3D distribution of neutron-flux provided knowledge of the distribution characteristics of neutron-flux in the PCV. The measured fluxes at each location would be also used for confirming the reliability of 2D distribution of neutron-flux.

2.3. Works for 2D calculation

We calculated the two-dimensional (2D) distribution of neutron-flux with 2D Sn code DORT (ORNL, 1998; Sukegawa et al., 1993; Wall et al., April 1996; White, April 1996) in “works for 2D calculation”. In order to perform the reliable 2D calculation of neutron-flux distribution, we must generate the 2D model that simulates neutron transport phenomena well in the PCV and set optimized calculation conditions. At the onset, we generated a simple model, and causes of difference between calculated and measured fluxes were investigated. Then, we modified the 2D models by utilizing the knowledge obtained from “works for measurement and 3D calculation”. The 2D models were modified repeatedly until a reliable result is provided. We judged 2D distribution calculation “Reliable”, when C/M (ratio between Calculated value and Measured value) is within one through ten ($1.0 < C/M < 10.0$) (IAEA, 1989). This criterion was determined by considering as follows. That C/M should be less than ten is required without excessive overestimation of neutron-induced radioactivity to plan rational decommissioning. And that C/M should be more than one is required without underestimation to keep that the tasks in decommissioning using the radioactivity are always safe side.

We generated the 2D model to simulate the phenomena, which were observed in the 3D distribution of neutron-flux. Here, to simulate the phenomena meant that we generated the 2D model so

Table 1
Major specifications of Tsuruga Power Plant Unit 1.

Type of Reactor	BWR (Boiling Water Reactor)	**Reactor Pressure Vessel (RPV)**	
		Inner Radius	2.35 m
Thermal Power	1070 MWt	Height	10.5 m
Electric Output	357 Mwe	Thickness	14 cm
Core Assembly		**Primarily Containment Vessel (PCV) & Biological Shielding Wall (BSW)**	
Core Equivalent Radius	151 cm		
Core Height	366 cm	BSW Thickness	2 ~ 4 m
Numbers of Fuel Assembly	308	PCV Inner Radius (Upper Part)	2.5 m
		PCV Inner Radius (Lower Part)	8.5 m