Assessment of Radiation Source Term in Reactor Coolant System during Power Operation and Overhaul for the Dose Assessment for Radiation Workers

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1. Introduction

To manage the exposure of nuclear power plant (NPP) radiation workers efficiently and safely, major NPP operating countries such as the USA, Germany, and France have developed and applied 3D model-based realistic worker's dose assessment software. Notable programs being used globally include VISIPLAN developed in Belgium, VRdose developed in Norway, and PANTHERE-RP, ADRM, and DEMplus developed in France. Recently, these programs have been used for worker's exposure management and training simulations for exposure reduction using 3D virtual reality-based ALARA planning, and research and development in this field are continuously expanding.

In line with these international trends, technology acquisition for efficient management of worker's exposure is being demanded in Korea. For NPP worker's exposure prediction, management, and training simulation, radiation field calculations for each NPP workspace are initially required, and these calculations require the input of radiation source terms. These radiation source terms include fission source terms originating from nuclear fission of nuclear fuel, radiation source term in reactor coolant system (RCS) caused by leakage of fission products, radiation source terms from activation due to the reaction of neutrons and NPP structures, and surface contamination source terms due to corrosion products.

This paper aims to study the assessment of radiation source term in RCS, which is one of the basic elemental technologies for worker's exposure prediction, management, and training simulation during power operation and overhaul. The radiation source term in RCS changes depending on the operating status of the reactor and has different values even during power operation. In this study, the method of evaluating the radiation source term in RCS and its results for the power operation and the subsequent shutdown operation are described, which can be utilized for worker's exposure prediction for all works that can be conducted at a NPPs.

2. Assessment of Radiation Source Term in RCS

In this study, Saeul NPP Unit 1 was selected as the target NPP for the assessment of the radiation source term in RCS[1]. For the assessment of the core inventory, the information of Saeul NPP Unit 1's 4th fuel cycle was used, and the core burnup days were derived from the core burnup and average core power[2]. The radiation source term in RCS was evaluated for the power operation and the subsequent overhaul of the 4th fuel cycle of Saeul NPP Unit 1.

2.1 Assessment of radiation source term in RCS during power operation

During power operation, the fission products and actinides in the RCS are generated by the escape through the gap and defect when a defect occurs in the fuel. In this study, the ORIGEN module within the SCALE computational code was used to assess the nuclide inventory during the power operation of Saeul NPP Unit 1's 4th fuel cycle with burnup[3]. Then, the RadSTAR (Radiation Source Term Analysis for Reactor Coolant System) computational code developed by KEPCO E&C was used to assess the radiation source term in the RCS generated by escape from defective fuel and creation by neutron absorption[4].

2.2 Assessment of radiation source term in RCS during shutdown operation

Seven (7) assessment points were selected for the assessment of the radiation source term in RCS during shutdown operation. When assessing the radiation source term in RCS during the shutdown operation, radioactive decay was considered, and the movement of the coolant in the system and the operation of the purification systems was considered as follows:

1) After the reactor shutdown, boron is injected through the chemical and volume control system (CVCS). Then, during the hot shutdown and cold shutdown, radioactive nuclides in the RCS are removed by the shutdown cooling system purification system.
2) The coolant is drained from the RCS to the storage tank for mid-loop operation. Then, during the mid-loop operation, radioactive nuclides are removed by the operation of the shutdown cooling system purification system.
3) To replace fuel, the coolant inside the RCS and the refueling pool is replenished from the In-containment refueling water storage tank (IRWST), and when the water level of the refueling pool

equals that of the spent fuel pool, the gate is opened to perform the fuel replacement operation.

4) During the fuel replacement operation, radioactive nuclides are removed by the spent fuel pool cooling and cleanup system, and after the fuel replacement is completed, the refueling pool and the spent fuel pool are isolated.

2.3 Results

Firstly, the results of the assessment of the core inventory during the 4th fuel cycle power operation of Saeul NPP Unit 1 are as shown in Fig. 1. For nuclides with short half-lives, the nuclide inventory increases rapidly from a small or almost non-existent state at the start of the reactor operation.

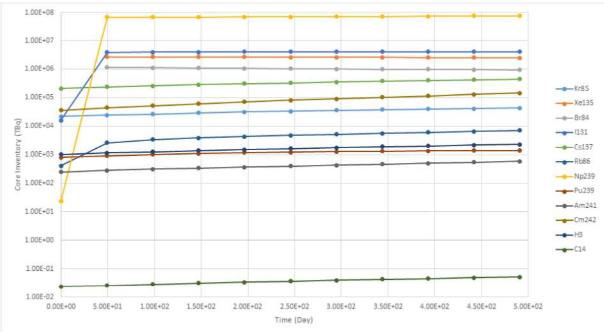

Fig. 1. Core inventory of major nuclides during the 4th cycle operation of Saeul NPP Unit 1

Subsequently, using the results of the core inventory calculation as input, the radiation source term in RCS during the power operation and shutdown operation was evaluated using the RadSTAR computational code, as shown in Fig. 2 and 3. During the power operation, the quantity of most nuclides tends to gradually increase over time. The evaluated radiation source term in RCS during the power operation was compared with the ANSI/ANS-18.1 expected radiation source term. The calculated concentration for most nuclides, as shown in Fig. 4, presents higher values than ANSI/ANS-18.1.

The results of the evaluated radiation source term during the power operation and shutdown operation will be used in the future for worker's exposure prediction, management, and training simulations during power operation and overhaul. However, the evaluated radiation source term in RCS during the power operation shows a fairly conservative value, and it is expected that the radiation source term in RCS during shutdown operation will be similar. In the future, a study on optimizing the radiation source term will be conducted using fuel cycle comparative analysis and field data.

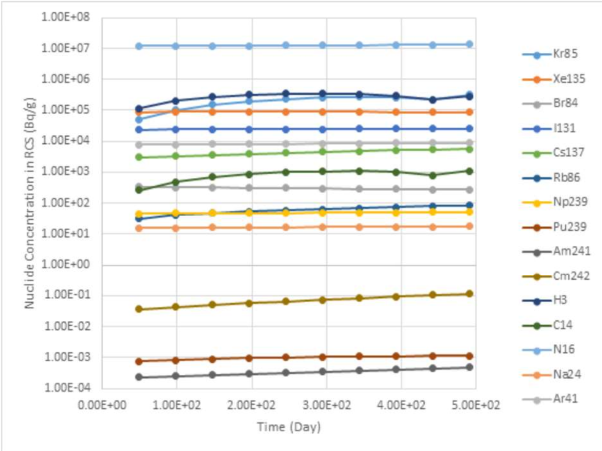

Fig. 2. Major nuclides concentration in RCS during the 4th cycle operation of Saeul NPP Unit 1

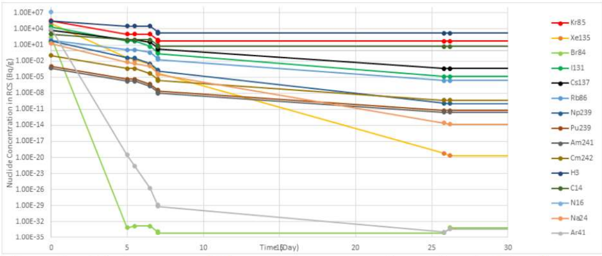

Fig. 3. Major nuclides concentration in RCS during shutdown after the 4th cycle operation of Saeul NPP Unit 1

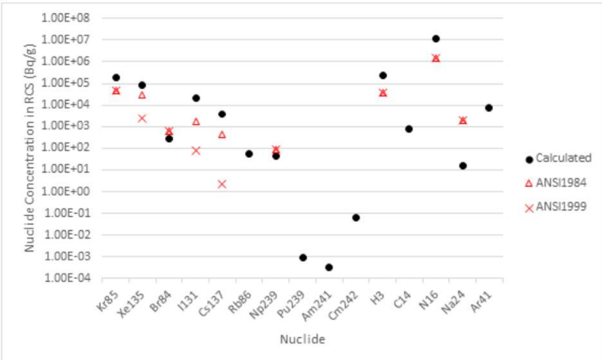

Fig. 4. Comparison of average major nuclides concentration in RCS during the 4th cycle operation of Saeul Unit 1 with ANSI/ANS-18.1

3. Conclusions

In this study, the method and application results of the assessment of the radiation source term of RCS, which is one of the basic elemental technologies for worker's exposure prediction, management, and training simulation during power operation and overhaul, were examined.

The results of this study are planned to be utilized as basic technology that can secure the safety of workers through various reactor types and work scenario-based simulations in the future. Also, the possibility of developing a data-based ALARA planning system for predicting the exposure dose of NPP workers is expected to be secured.

ACKNOWLEDGEMENT

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REFERENCES

[1] Korea Hydro & Nuclear Power Co., Ltd, Shin-Kori Unit 3,4 Final Safety Analysis Report

[2] Korea Hydro & Nuclear Power Co., Ltd, The Nuclear Design Report for Shin-Kori Nuclear Power Plant Unit 3 Cycle 4.

[3] Oak Ridge National Laboratory, Scale: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, ORNL/TM-2005/39, 2011.

[4] Korea Electric Power Corporation Engineering & Construction, Software User Manual : Radiation Source Term Analysis for Reactor Coolant System.

[5] ANSI/ANS-18.1, American National Standard Radiation Source Term for Normal Operation of Light Water Reactors, 1984.

[6] ANSI/ANS-18.1, American National Standard Radiation Source Term for Normal Operation of Light Water Reactors, 1999.