

Assessment on Transport of Radioactive Species from Nuclear Facilities-17079

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Introduction

It is generally recognized that radioactive nuclides are most hazardous fission products that could be released in the event of reactor accidents. The reactor coolant system of a pressurized water reactor (PWR) nuclear plant exhibits radioactivity from various sources. These radiation sources consist of the fission products from fuel element and activated products from corrosion products.[1,2,3] The complex infrastructure of the processes does not allow detailed measurement of activity until after the reactor is shutdown. All of the components that require dismantling will be radioactive which was caused by neutron activation during operation, contamination by corrosion products, contamination by damaged by fuel rods and leaks by equipment.

Due mainly to the various operation modes and their aging, there are the increasing needs to carry out repair works that are not sufficiently provided for by the original design. Many difficulties are involved in these tasks, namely, high radiation doses, cramped areas, hard to reach components, coupled with stringent quality conditions. The need to simulate the behavior of corrosion products in a nuclear power plant environment has attracted many researchers' attention. It has performed the in-depth reviews of the various theories and physics associated with the corrosion products transportation, the laboratory loop testing, and the field measurements in operating plants. Before we start the decommissioning of nuclear power plants, workers, the public and the environment shall be properly protected from radiation hazards. For this purpose, a safety assessment should be carried out relating to the potential hazards that may occur during the decommissioning. The radiological hazards involved in the decommissioning activities also should be identified, and be taken into account in the safety assessment.

The radiation conditions of the primary circuit are determined by the activity of corrosion and fission products that have accumulated on the internal surfaces of the components. Therefore the estimation of contamination on the components is very important and, may be the first step in the reactor operation and decommissioning of components. The predominant radionuclide in the PWR primary coolant is Co-60, although Co-58 contributes significantly to radioactivity level at the early stage of a reactor operation. Since Co-60 is produced from the in-core Co-58, which is the source of cobalt in a reactor coolant system, many researchers have investigated its transmutation in the core, its transport around the system, and its subsequent deposition on surfaces. The major parameter influencing the behavior of radioactivity, such as Co-60 in the coolant, is the corrosion product oxides [4,5].

The objective of this work is to analyze the corrosion product activity transported in the primary circuit by using a multi-region model. This model, which is incorporated with the mass and activity transport between the dissolved corrosion products in the coolant and the surface, describes the specific activity of corrosion products in coolant and on the surfaces according to the operation modes as well as decommissioning stage.

Modeling of Activity Transport

A multi-region modeling is developed to calculate the corrosion products activity in primary circuits of the nuclear power plants. Since there are too many unknowns to predict the activity and radiation level accurately, a simplified model is formulated for this program. This model is aimed at evaluating the corrosion products concentrations in coolant and on the surface of major components in the reactor coolant system. This model includes the mass transfer between the various locations of the plant and also accounts for the various reactor plant operation modes.

The radioactive mass transport within the primary circuit is described by the multi-region model through the path of fluid of reactor coolant system. This model is aimed at an evaluation of the corrosion products concentrations in coolant and on the surfaces of the major components in the reactor coolant system. This numerical simulation model includes the mass transfer from the various locations of the plant and also take accounts for reactor plant operation modes as well as decommissioning stages.

For the simple calculation we divided the reactor coolant circuit into nine control volumes shown in **Figure 1**. Between the control volume and its associated surfaces, the radioactive nuclei are transported by the sedimentation, washing-out, and release of corrosion products. The coolant between the control volumes transports the nuclei, too. Dividing the reactor coolant system into several regions requires more differential equations to be solved and takes a longer computation time.

During the each operation stage from startup to end of fuel cycle, it is assumed that the mass transfer coefficients are equal for the active and inert corrosion products and that the concentrations of the parent nuclides and activation products in the reactor coolant are in equilibrium. The uptakes of cobalt are calculated under the consideration of the production rate and removal rate. The parent nuclides are produced by the corrosion of the surface materials consisting of primary circuit and are transported by coolant into reactor core region. The parent nuclides are removed by neutron induced activation in the reactor core region, by deposition on surface of the primary circuit components, such as steam generator, main coolant pumps. After permanent shutdown of reactor we have to secure precise knowledge of the radiological condition of nuclear power plant for the decommissioning.

An integral type pressurized water reactor(330 MWt) is designed to contain all of the major primary system components, such as steam generators, pressurizer and reactor coolant pump in a single reactor pressure vessel. With this integral arrangement, there are no large size pipe connections and thus no possibilities of large break loss of coolant accidents. The primary coolant flows up through the core and then through the RCP's to enter the shell side of the SG from the top. On the secondary side, a subcooled feedwater enters the tube side of the SG tubes from the bottom and a superheated steam exits the SG's. A large volume at the top part of the reactor pressure vessel constitutes the pressurizer. These pressures vary with the total primary coolant volume that is changing according to the temperature distribution within the RPV and the reactor power.

With an appropriate control of the average primary coolant temperature and pressurizer design features, the pressurizer can self-regulate the system pressure within a desired range without any active control[6,7].

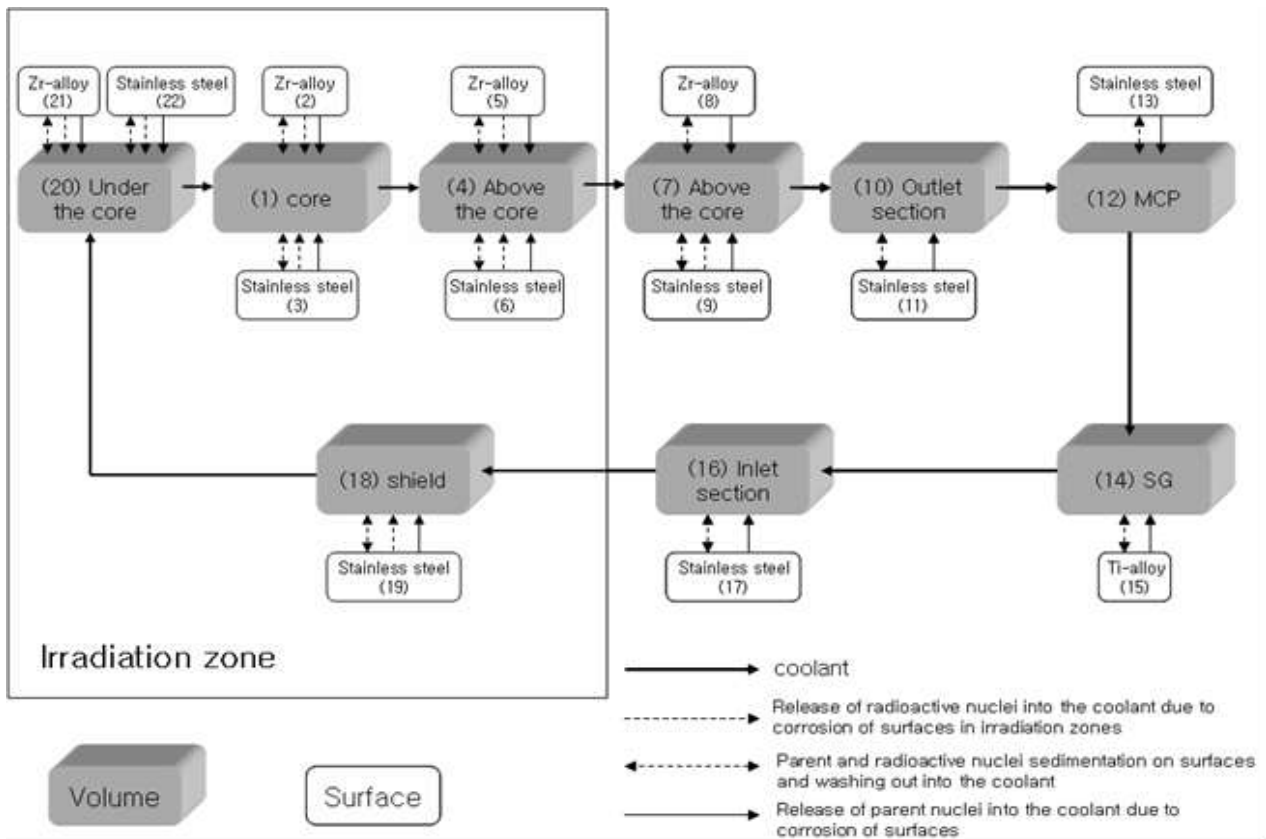


Figure 1. Breakdown reactor coolant system of nuclear power plant

Results and Discussion

The behavior of various radioactive corrosion products is simulated for an integral type reactor. The calculation was done for one fuel cycle of 15,000 hours but the release of the corrosion products into water was calculated for the time of a metal exposure in water for 24,000 hours. The calculated specific activities of the various species on the surface of the core and steam generator during the effective full power hours, 15,000 hours, are shown in **Figure 2** and **Figure 3**, respectively. On the reactor core surface, the final specific activities of Cr-51, Mn-54, Fe-59, Co-60 and Co-58 are estimated to be 18.3, 5.01, 4.36, 3.41 and 26.5 $\mu\text{Ci}/\text{cm}^2$, respectively. On the steam generator surface, the final specific activities are also estimated to be 0.251, 0.259, 0.0882, 0.209 and 0.769 $\mu\text{Ci}/\text{cm}^2$, respectively. It means that the greater part of the generated corrosion product in the reactor is deposited on core surface. These values are less than that of KSNP such as Yonggwang Units 5&6, Ulchin Units 5&6 given in final safety analysis report (FSAR). The biggest difference is shown at Cr-51 and Co-58. The specific activities of Cr-51 of Yonggwang Units 5&6 and Ulchin Units 5&6 are about 2.2×10^5 $\mu\text{Ci}/\text{g}$ and 1.35×10^5 $\mu\text{Ci}/\text{g}$, respectively. In integral type reactor, it is estimated as 4.05×10^3 $\mu\text{Ci}/\text{g}$, which is 1/50, 1/30 less than that of Yonggwang Units 5&6 and Ulchin Units 5&6, respectively. In the case of Co-58, specific activities in KSNP

are $8.38 \times 10^4 \mu\text{Ci/g}$, $6.76 \times 10^4 \mu\text{Ci/g}$, respectively. These are 13 and 10 times greater than that of a simulated reactor as $6.39 \times 10^3 \mu\text{Ci/g}$. The higher values of specific activities of Cr-51 and Co-58 in KSNP are due to the higher release rate of inconel, which has the high nickel and chromium content. The specific activities of others are shown similarly, but that of integral type reactor is the lowest value.

The above the result is explained by the difference of the structural materials and the water chemistry between a simulated reactor and KSNP. In this simulated reactor, the titanium alloy is applied to the steam generator tube material which is known as a weight gain material while inconel is used in KSNP as weight loss material. It means that the layer of protective oxide which is formed on the surface would increase, to disturb the diffusion of the oxygen ion through the oxide layer, resulting in a decrease of corrosion rate as the corrosion reaction proceeded.

The water chemistry in KSNP is the $\text{H}_3\text{BO}_3\text{-LiOH}$ chemistry. The lithium hydroxide alkali, which is injected for a reaction control in the primary coolant circuit of KSNP to compensate for the acid properties of boric acid, brings about the stress corrosion cracking of steam generator tube and the corrosion of zirconium alloy for a fuel cladding. Furthermore in this simulated reactor, hydrogen, which is used to remove the dissolved oxygen in the coolant, is not added to the primary coolant. The hydrogen concentration is maintained by ammonia dosing in the primary coolant where hydrogen and nitrogen are generated by ammonia subsequent radiolytical and thermal decomposition[8,9].

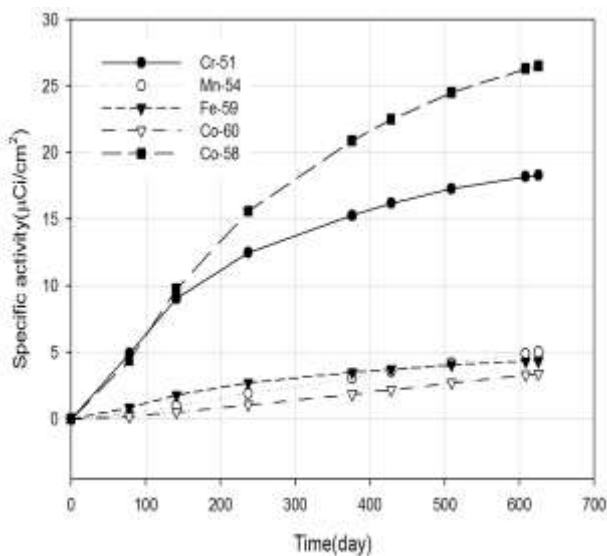


Figure 2. Behavior of specific activity according to time (day) in core surface

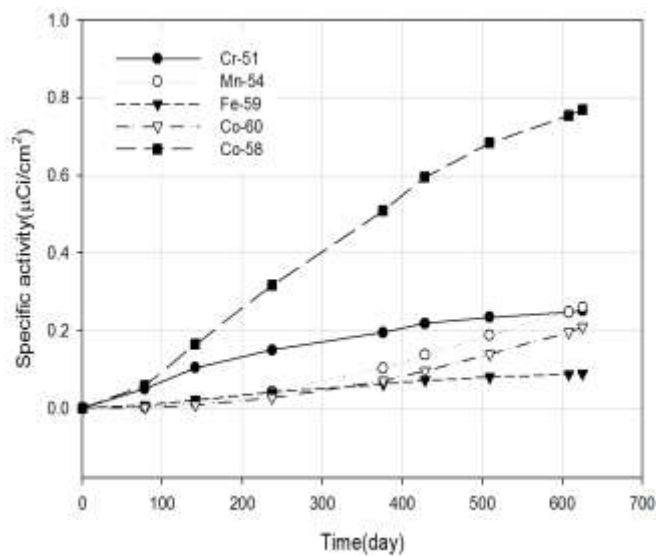


Figure 3. Behavior of specific activity according to time (day) in steam generator surface

Conclusion

In order to evaluate the analysis of the corrosion products in an integral type reactor, a multi-region mass balance model is applied. The specific activities of the various species on the surface of core and steam generator throughout the effective full power hours, 15,000 hours, are simulated for the various modes of operations. As a result, the specific activities of corrosion products from the surface of primary circuit were shown as very low compared to those of other commercial nuclear power plants.

In this simulated reactor, a significant reduction of specific activities from the activated corrosion products is obtained due to the introduction of titanium alloy to the steam generator tube and the avoidance of boric acid induced corrosion. From this result we conclude that we are able to predict the level of radioactive nuclides generated by corrosion products in a primary circuit according to the various modes of operations by using multi-region model. In this point of view it is concluded that this multi-region model can be used as an engineering tool for analysis of the corrosion products within the primary coolant for the nuclear power plants. It is also considered that it is possible to extend to a calculation tool for estimating the radiological hazards involved in the decommissioning activities in terms of safety assessment.

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