

## Modeling of Activity Transport and Uptake of Cobalt in the Primary Circuit

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### 1. Introduction

The predominant radionuclide in the PWR primary coolant is Co-60, although Co-58 contributes significantly to radioactivity 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 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 [1~4]. The oxide originates from the circuit materials in contact with the coolant of the primary circuit, these materials are mainly a zirconium alloy for the core, a titanium alloy for tubing in the steam generator, and a stainless steel for the reactor vessel internals. The material and water chemistry are selected carefully to control the corrosion products.

The objective of this work is to analyze the corrosion product activity in the primary circuit 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.

### 2. Modeling of Activity Transport

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 equipments in the reactor coolant system. This model includes the mass transfer between the various locations of the plant and also accounts for reactor plant operation modes.

The primary circuit is divided into nine control volumes. 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 primary circuit into several regions needs more differential equations to be solved and takes a longer computation time.

During the normal operation, 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 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 reactor core region, by deposition on surface of primary circuit components, such as steam generator, main coolant pumps.

### 3. Results and Discussion

The behavior of the various radioactive corrosion products is simulated for integral type reactor. The calculation was done for the 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 of 24,000 hours. The calculated specific activities of the various species on the surface of core and steam generator during the effective full power hours, 15,000 hours, are shown in **Figure 1** and **Figure 2**, 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  $2.2 \times 10^3 \mu\text{Ci}/\text{g}$  and  $1.35 \times 10^5 \mu\text{Ci}/\text{g}$ , respectively. In integral type reactor, it is estimated as  $4.05 \times 10^3 \mu\text{Ci}/\text{g}$ , 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  $8.38 \times 10^4 \mu\text{Ci}/\text{g}$ ,  $6.76 \times 10^4 \mu\text{Ci}/\text{g}$ , respectively. These are 13 and 10 times greater than that of integral type reactor as  $6.39 \times 10^3 \mu\text{Ci}/\text{g}$ . 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 structural materials and the water chemistry between

integral type reactor and KSPN. In integral type 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 a layer of protective titanium oxide which is formed on the surface would increase to disturb the diffusion of the oxygen ion through the oxide layer, giving a decrease of corrosion rate as the corrosion reaction proceeded.

The water chemistry in KSNP is the  $H_3BO_3$ -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 integral type 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 an ammonia subsequent radiolytical and thermal decomposition [5,6].

#### 4. Conclusion

In order to evaluate the analysis of corrosion products in 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 integral type reactor.

As a result, the specific activities of corrosion products of integral type reactor were shown as very low compared to those of KSNP such as Yonggwang Units 5&6, Ulchin Units 5&6. In integral type reactor, a significant reduction of specific activities from the activated corrosion products is obtained due to the introduction of the titanium alloy to the steam generator tube and the avoidance of boric acid induced corrosion. From this result we conclude that the design features of integral type reactor can prevent and reduce the generation of corrosion products in the primary circuit.

#### REFERENCES

- [1] P. Millet *et al.*, "PWR Primary Water Chemistry Guidelines : Revision 4," EPRI Report *TR-105714-V1R4*, (1999).
- [2] F.H. Sweeton *et al.*, "The solubility of magnetite and hydrolysis of ferrous iron in aqueous solutions at elevated temperature," *J. Chem. Thermodynamics*, vol. 2, (1970).
- [3] J.W. Barton *et al.*, "Experience with Ferritic and Austenitic Steel PWR Circuit," *IAEA-264/10*, International Atomic Energy Agency, Vienna (1982).
- [4] R. Bordoni *et al.*, "Corrosion Behavior and Deposition of CRUD on Zr-alloys," *IAEA-TECDOC-1128*, International Atomic Energy Agency, Czech (1999).
- [4] K.A. Burrill, "A Possible Mechanism for Corrosion Product Transport and Radiation Field Growth in a

Pressurized Water Reactor Primary Circuit," *Nuclear Technology*, Vol. 29, (1997).

[5] B.S.Choi, *et al.*, "Characteristics of water chemistry for the integral reactor, SMART," *Proceedings of Korean Nuclear Society Spring Meeting*, (1998).

[6] B.S.Choi, *et al.*, "Design Features of the SMART Water Chemistry," *Proceedings of ICAPP '04*, Pittsburgh, PA USA, June 13-17, (2004).

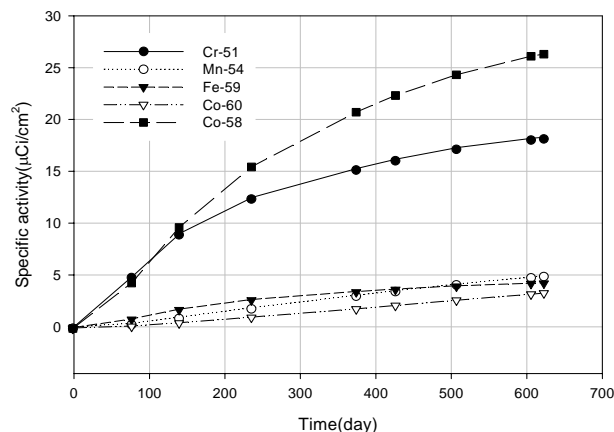


Figure 1. Behavior of specific activity according to time (day) in core surface

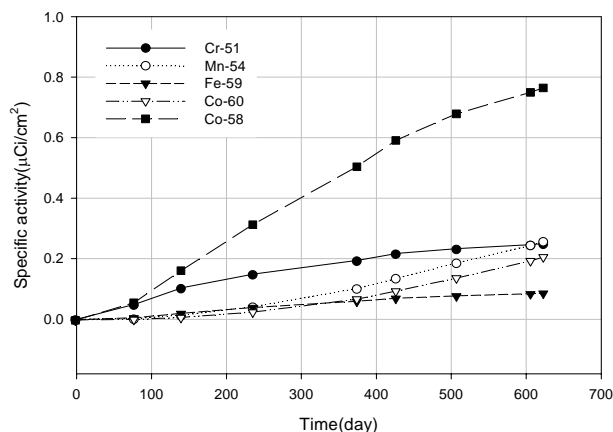


Figure 2. Behavior of specific activity according to time (day) in steam generator surface