

Methodology study for prediction of crud deposition in primary coolant circuit of PWRs

Seungjin Seo^a, Beomkyu Kim^b, Hwajeong Han^c, Dongseok Lim^b, Wook Sohn^d, Ga Hee Jeong^d,
Byunggi Park^{c*} and Sunyeol Choi^{a**}

^aSeoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, Korea

^bFNC Technology Co Ltd, 32 Fl. Heungdeok-1ro, Giheung-gu, Yongin-si, Gyeonggi-do 16954, Korea

^cSoonChunHyang University, 22, Soonchunhyang-ro, Asan-si, Chungcheongnam-do, Korea

^dKHNP Central Research Institute, 1312 Gil, 70. Yuseongdaero, Daejeon, Korea

*E-mail: byunggi@sch.ac.kr

**E-mail: choisys7@snu.ac.kr

1. Introduction

During an operation of PWR(Pressurized Water Reactor), corrosion occurs on the structure of a primary coolant circuit, and corrosion products are released and deposited on a corroded surface. This layer of corrosion product is called CRUD(corrosion-related unidentified deposition). The deposition of the CRUD layer leads to the increase of activity in the primary coolant circuit, by attaining high radioactive isotopes of nickel, iron, zirconium, and cobalt, contributing to an increase in the exposure dose of workers. In the present research, two main spots of the CRUD deposition are steam generator and reactor core, however, the CRUD deposition in the other spot of the circuit is necessary for the worker safety; such as pressurizer, hot leg, chemical and volume control system, and shutdown cooling system. To reduce safety issues from the CRUD deposition in advance, it is necessary to analyze the CRUD deposition in the entire circuit of the reactor coolant system. In this study, the methodology for modeling CRUD deposition was suggested, by referring to particulate deposition and soluble precipitation of corrosion products as well as the release of the deposited CRUD layer. Due to the lack of the measurement data for the CRUD surface in the reactor coolant system excepting reactor core and steam generator, a literature study about important parameters for the CRUD deposition, precipitation, and release was conducted.

2. Method

2.1. Model description

Corrosion products such as nickel and iron species generated from the reactor coolant system are deposited and precipitated on the surface of the circuit structure. Some portion of the CRUD is eroded by drag force generated by flow characteristics on the surface. Dinov et al. suggested the mechanism of the CRUD layer in terms of particulate, by incorporating wall boundary flow layer [1]. In this study, the wall boundary flow layer was extended for both particulate and soluble species of corrosion products, as shown in Figure 1. The scope of the research is focused on the entire

reactor coolant system except the reactor core. Detailed scope includes reactor vessel, steam generator, pressurizer, heat exchangers, and mini-flow heat exchangers for coolant pump. Corresponding systems for the heat exchangers include chemical and volume control system, shutdown cooling system, reactor component cooling system, and spent fuel storage pool.

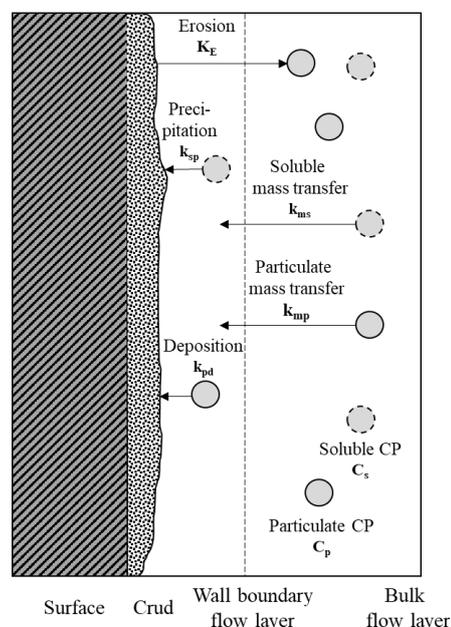


Figure 1. CRUD growth on the surface of primary coolant circuit through deposition of corrosion product particles, precipitation of soluble corrosion products, and erosion by coolant flow.

2.2. Growth equation

The net growth rate of the CRUD deposition consists of the deposition rate of particulate, precipitation rate of soluble species, and erosion rate of the crud layer, caused by a drag force, as shown in equation (1) to equation (4).

$$\dot{\delta}_{\text{net}} = \dot{\delta}_{\text{particle}} + \dot{\delta}_{\text{solute}} - \dot{\delta}_{\text{erosion}} \quad (1)$$

$$\delta_{\text{particle}} = K_P(k_{pd}, k_{mp})C_p \quad (2)$$

$$\delta_{\text{solute}} = K_S(k_{sp}, k_{mp})\{C_s - C_{eq}\} \quad (3)$$

$$\delta_{\text{erosion}} = K_E(F_{drag})m_i \quad (4)$$

δ_{net} , δ_{particle} , δ_{solute} , δ_{erosion} are mass change rate for net growth and caused by particulate deposition, soluble precipitation, and erosion. K_P and K_S are parametric functions for the net mass transfer coefficient, composed of mass transfer coefficient of soluble and particulate from bulk to deposition surface (k_{mp} , k_{ms}) and deposition/precipitation coefficient (k_{pd} , k_{sp}). K_E is erosion coefficient in terms of drag force, and the drag force is related to the flow characteristics of the coolant near the surface.

2.3. Parameters

To simulate the CRUD deposition for entire reactor coolant system, the parameters for the CRUD deposition should be estimated according to the environmental and fluid conditions; such as temperature, pH, concentration, velocity, and mass flow rate. From the Dittus-Boelter equation, Nusselt number and Prandtl number can be replaced as Sherwood number and Schmidt number according to mass transfer analogy. The mass transfer coefficient of soluble and particulate species can be calculated by using equation (5).

$$\frac{k_m d_H}{D} = 0.023 \left(\frac{\rho_f u_f d_H}{\mu_f} \right)^{0.8} \left(\frac{\mu_f}{\rho_f D} \right)^{0.4} \quad (5)$$

Naillon et al.'s calculated the net growth rate coefficient of the crystallization caused by soluble sodium and chloride ions, through a relationship between mass transfer coefficient and precipitation coefficient, as shown in equation (6) [2-3]. In this study, in the same manner, the net growth rate caused by particulates was calculated as equation (7), through the particulates deposition coefficient and mass transfer coefficient.

$$K_S = \frac{1}{\frac{1}{k_{ps}} + \frac{1}{k_{ms}}} = \frac{k_{ps} k_{ms}}{k_{ps} + k_{ms}} \quad (6)$$

$$K_P = \frac{1}{\frac{1}{k_{dp}} + \frac{1}{k_{mp}}} = \frac{k_{dp} k_{mp}}{k_{dp} + k_{mp}} \quad (7)$$

S.K. Beal's deposition model described the deposition coefficient of particulate corrosion product by using the mass transfer coefficient and sticking probability of the particles [4]. Also, Beal suggested sticking probability along with size of the particles as well as erosion coefficient along with drag force of the fluid toward surface [5]. The deposition coefficient of

the particulates and erosion coefficient can be calculated by using equations (8) and (9).

$$k_{dp} = \frac{k_{mp} S v}{k_{mp} + S v} \quad (8)$$

$$K_E = 2 \times 10^{-3} F^{0.88} \quad (9)$$

In this model, precipitation coefficients for soluble nickel and ferrite are necessary, for the precipitation reaction of Ni , NiO , Fe_3O_4 , Fe_2O_3 , and $NiFe_2O_4$. However, Naillon et al. argued that the precipitation coefficient, k_s , should be determined through the experimental approach. Due to lack of the data for the species and reactions in terms of soluble precipitation coefficient, further study about the influence of the soluble precipitation is necessary.

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