Review of Modeling Codes for Radioactive Corrosion Product of PWR Primary Coolant System

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1. Introduction

CRUD (Chalk River Unidentified Deposit) is created by a stable element of corrosion products moving in the PWR primary coolant of primary system and depositing in a nuclear fuel cladding then becoming radioactive. The radioactive corrosion products circulate the primary system with the surroundings of high temperature and high pressure, whose flow mechanism is shown in Fig. 1.

The accumulation or deposition of corrosion products is determined according to a change in solubility due to changes in temperature of primary coolant. These radioactive corrosion products are come to be deposited in pipe surfaces or curved tubes, circulating within the system. The deposited radioactive corrosion product is also very important consideration for planning of nuclear power plant decommissioning.

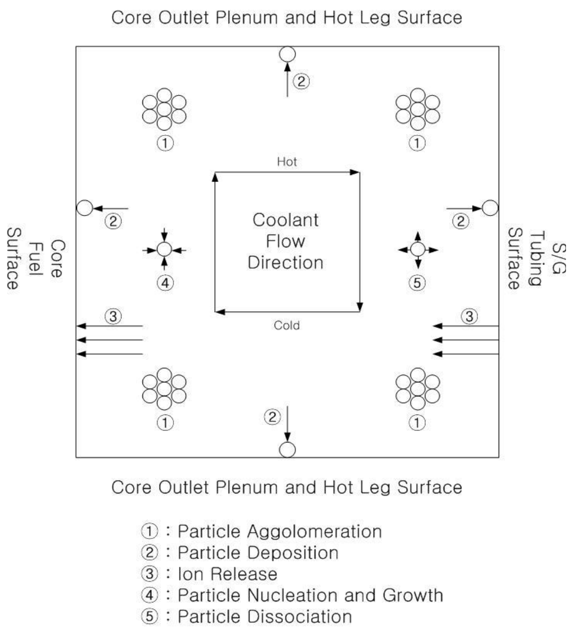

Fig. 1. Flow Mechanism of Corrosion Product in Primary System

2. Various Codes for Modeling Corrosion Products

This study introduced a variety of codes which allow the generation and behavior of radioactive corrosion products to be modeled.

2.1 PACTOLE Model

PACTOLE is a program that EDF and AREVA NP of France co-developed and it is a model which can be comprehensively applied in the PWR primary coolant system. PACTOLE Code has been studied and developed for almost 20 years, which considers the corrosion products to be Fe, Ni, Cr and Co. The main mechanism of PACTOLE is shown in Fig. 2.

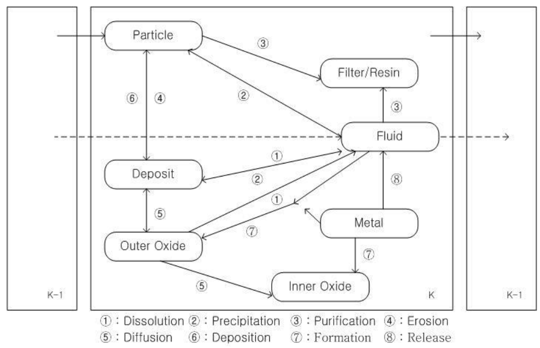

Fig. 2. PACTOLE: Code Process Diagram.

2.2 CRUDTRAN Model

CRUDTRAN was developed by Korea Atomic Energy Research Institute from the previous CRUDSIM/MIT Code and it is a model to analyze and predict the correlation between the spread of corrosion products in the primary coolant system and the radioactivity.

As for the characteristics of CRUDTRAN, it has a relatively simple mechanism compared to other codes, but it shows a high accuracy of the modeling result value when compared to that of other codes with complex mechanism. The nuclides under consideration of CRUDTRAN are Co-58 and Co-60, which can be modeled in three parts (S/G, core and coolant) of the primary system. The mechanism is shown in Fig. 3.

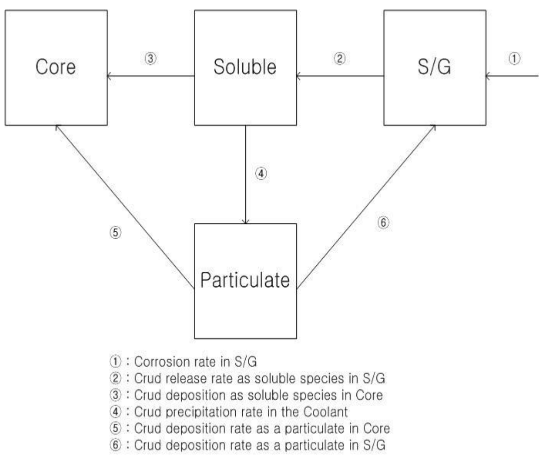

Fig. 3. CRUDTRAN: Four Node Model for CRUD Transport

2.3 ACE-ⅡModel

ACE-II was developed by Japan's MITSUBISHI and it is a model which applied experimental variables based on the existing CRSEC Code and actual values of PWR. ACE-II model considered that the size of particles that are deposited on unanchored CRUD applies 3 ㎛ in case of 0.68㎛ external layer of oxide. As shown in Fig. 4, the primary system of ACE-II model is divided into the core and other parts. The oxide film is divided by external and internal oxide film and the behavior of the corrosion products is modeled for the external and internal oxide film, respectively.

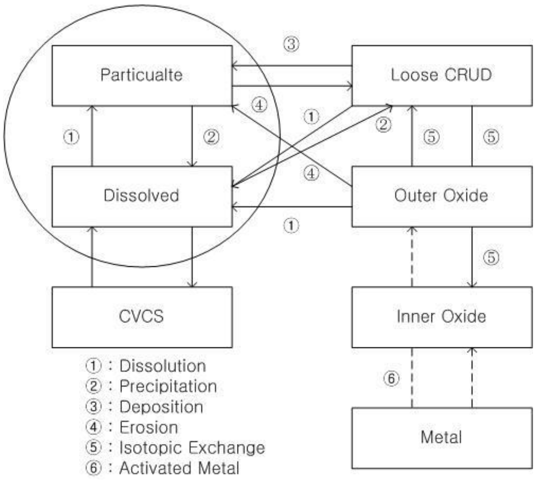

Fig. 4. ACE-II: Transport Process (Activity)

2.4 MIGA Model

MIGA was developed in Bulgaria in order to simulate the Co-58 and Co-60 corrosion product in the primary coolant of WWER. MIGA Code considered particulates and soluble matters by dividing the reactor into five parts.

As for the characteristics of MIGA Code, deposition is determined by the mass transfer rate of the particles in the flow and boundary layer.

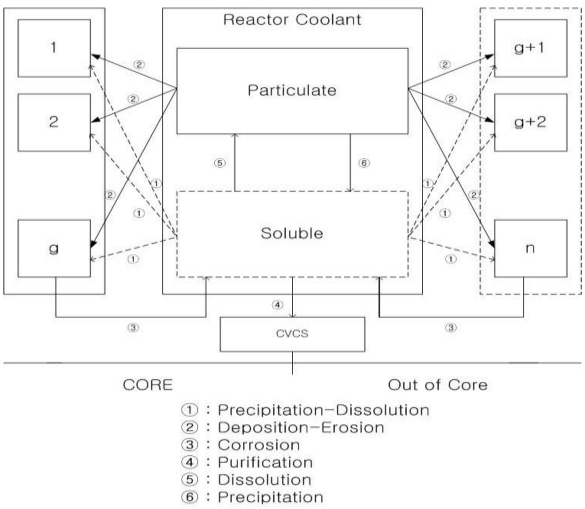

Fig. 5. MIGA: Modeling Region

2.5 CORA Model

CORA was developed by Westinghouse in order to predict the generation and behavior of corrosion products. It separates the entire system into 10 Nodes and it is known to be a comprehensive model for the behavior of corrosion products in the primary coolant system of PWR.

CORA model can predict the behavior of corrosion products as a function of design parameters and operating parameters of power plants. And as for its characteristic, it divided the reactor core into Out-of and In Flux System and used the solubility of magnetite. The main mechanism of CORA is shown in Fig. 6.

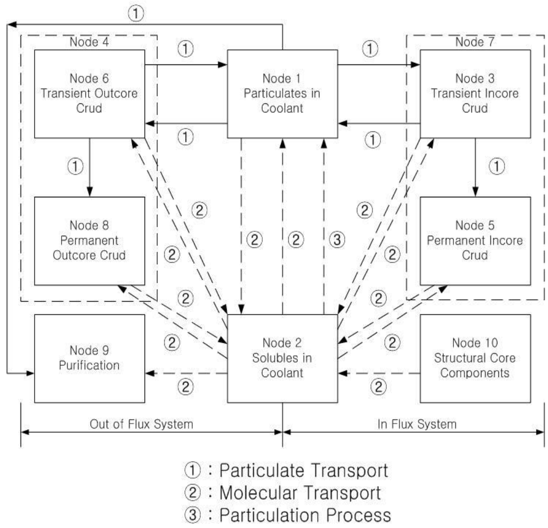

Fig. 6. CORA: Diagram of Nodes for PWR Primary Coolant System

2.6 Comparison of the Codes

Looking briefly the characteristic of each code mentioned above, PACTOLE has a high accuracy in predicting PWR operation as the one depicted in greater detail than the other codes. CORA induces exact calculation values such as volume of transportation and deposition of corrosion product by departmentalizing computational domain within the primary system. On the other hand, even if CRUDTRAN is modeled as simple mechanism, it shows high accuracy on the result value with it when compared to the CORA. The advantage of ACE-II lies in being modeled reflecting the corrosion rate of the Alloy 690 by using EPRI`s erosion test data, but using the input value based on the experimental data is known as limitation. Table I shows characteristics of each code.

Table I: Characteristics of the Codes

	PACTOLE	CRUD TRAN	ACE-II	MIGA	CORA
Developer	EDF & AREVA	KAERI	MITU BISHI	Bulgaria	Westing house
Consideration Nuclide	Fe Ni Cr Co	Co	Fe Ni Co	Co	Fe Ni Co
Advantage	Detailed & high accuracy	Simple process but high accuracy	Predict alloy 690 base	Predict VVER either	Detailed & high accuracy
Limitation	Only used in France	Based on experimental data	Based on experimental data	Only used in north Europe	Based on experimental data

3. Conclusions

In this study, typical codes used in each country or organization for modeling the radioactive corrosion product of PWR primary coolant system were analyzed. Although there are a number of codes other than the models mentioned above, most of the codes mentioned herein consider the behavior of particles, and calculate it by considering these particles and products to be deposited and accumulated in a specific part within the primary coolant system. Most of the codes are using the empirical values for variables, so that they have a limitation of not being able to interpret all the complex results of commercial reactor. And as for modeling, they have predicted the deposition and behavior of corrosion products according to the changes of chemical states considering only the normal operation of reactor or experimental reactor.

According to the comparison of various codes, PWR`s accurate prediction to operation by detailed description of PACTOLE code and CRUDTRAN mechanism of high accuracy rate are proved to be advantages. Such codes showed exact calculation results using the given variables. However, the codes which will be developed in the future need development and improvement that can enable them to make a prediction and calculation, considering the abnormal states of a reactor (accidents and failures), the availability of various old types' modeling and even the material quality of equipment which will be developed in the future.

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