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Modeling of Radionuclide Transport for NPP Simulator Using RELAP5 R/T

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1. Introduction

KEPRI (Korea Electric Power Research Institute) adopted RELAP5 R/T to simulate the NSSS thermal hydraulic phenomena in nuclear power plant (NPP) simulator. The RELAP5 R/T based on a RELAP5 Mod3.2 has an option to perform radionuclide transport within the hydrodynamics. This new version of RELAP5 includes a module to solve transport equation for radionuclide specie which is either radioactive (decays with a half-life) or fertile (absorbs neutrons to create another specie).

This paper describes the radionuclide transport model for NPP simulator using RELAP5 R/T. Three major species of the Iodine-131, Xenon-133, and Nitrogen-16 have been modeled. This paper also represents the result of steam generator tube rupture (SGTR) test as the accident could show the characteristics of radiation release.

2. Method

This section describes the basic conservation equation to be used for each different radionuclide, the input format, and the details of radionuclide transport models.

2.1 Conservation Equation

The basic mass conservation equation is given below:

$$\frac{\partial M}{\partial t} = F_{in} - F_{out} + D_p - D + S \tag{1}$$

where:

$\frac{\partial M}{\partial t}$ is the rate of change in mass in a control volume
F_{in} is the mass flow in to the volume
F_{out} is the mass flow out of the volume
D_p is the mass produced by the decay or activation of a parent
D is the mass lost by the decay or neutron absorption of this radionuclide
S is a user specified source term

The existing upwind differencing scheme used for the boron transport was used for the numerics with the appropriate changes to support the decay, source, and sink terms. This yields the equation below:

$$M^{n+1} = M^n + \Delta t F_j^n - \Delta t F_{j+1}^n + \Delta t \lambda_p^* M_p^n - \Delta t \lambda^* M^n + \Delta t S^n - \Delta t L^n \tag{2}$$

where:

Δt is the time step in seconds
n denotes the old time value
n+1 denotes the new time value
λ^* is an effective value of the decay constant that works on mass and not number density

A fertile specie will absorb neutrons to create a new specie which may be either fertile or radioactive. The flux-volume integral is calculated over the kinetics nodes that are assigned to the thermal-hydraulic zone. The concentration of a specie is constant within each volume in a thermal hydraulic zone. This activation rate is included in the D_p term of as a source for the daughter specie and in the D term as a loss for the parent specie. The activation rate is calculated using the equation below:

$$A = \sum_{1}^{NG} \int \phi N \sigma \partial V \tag{3}$$

where:

ϕ is the neutron flux in neutrons/m^2-sec
N is the concentration of the specie in particles/m^3
σ is the activation cross section for the daughter specie in barns
dV is to integrate of the volume of the thermal-hydraulic zone in m^3

2.2 Input Description

The radionuclide transport option is activated with the 50000000-59999999 series of cards.
Card 50000000 Number of species
Card 500NNN00 Basic data for each specie
Card 500NNN01 through 500NNN99 Source and sink data for each specie

The character string N16 is a reserved identifier for the N^{16} radionuclide. If this identifier is input, separate logic is activated to identify those volumes associated with the reactor core and activation calculations are performed based on the average neutron flux and water density in the volume. N16 is not permitted to have a parent nuclide and specification of a parent is a fatal error. Also, if N16 is specified, either the point or nodal kinetics models must be present. The details are described in reference [3].

2.3 Modeling of Radionuclide Transport

The radionuclide transport model is composed of three parts as radionuclide species modeling, source and sink modeling, and calculation of activities for output to the simulator. Three species of the Iodine-131, Xenon-133, and Nitrogen-16 have been modeled. The decay constant, energy released in decay, and molecular weight of specie have been modeled for the first two ones. In addition, the weight factor for use in the production calculation and production cross sections have been modeled for the Nitrogen-16. 10 Volumes such as reactor core, 4 RCP seal injections, charging, and 4 feed water injections have been used for the sources of the Iodine-131 and Xenon-133. The local activities in the model have been calculated in micro-Curie/cc, and the activity flow rates for LOCAs and leaks in Curies/sec.

3. Test Results

Transient tests such as LOCAs and leaks could show the phenomena of radiation release. In this paper, the result of SGTR test is presented as the accident could show the release of all kinds of radionuclide species modeled in this study.

Figure 1 to 3 show the activity flow rates in main steam line (mSv/hr), the leak flow rates calculated by Nitrogen-16 activities (l/hr), and the activities in SG blow down sides (Bq/cc). As the SGTR happens in SG 1, the activity flow rates in main steam line are sharply increased, and the leak flow rates calculated by Nitrogen-16 activities are increased as time goes on. Also, the activity in SG 1 blow down side shows the increased local activity. These radioactivities are monitored at simulation environment which was developed using 3KeyMaster.

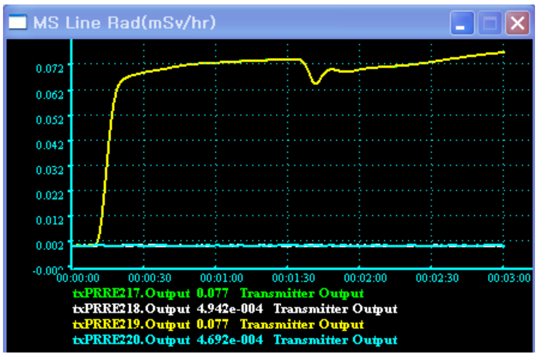

Fig. 1. Activity flow rate in main steam line (mSv/hr)

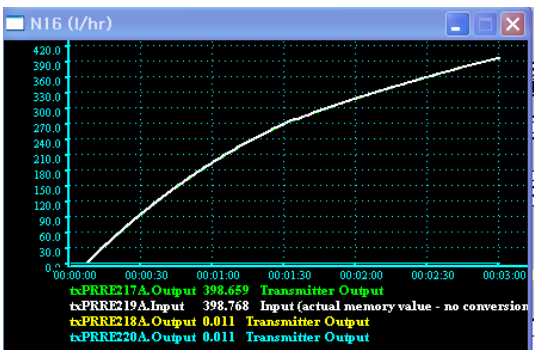

Fig. 2. Leak flow rates calculated by Nitrogen-16 activities (l/hr)

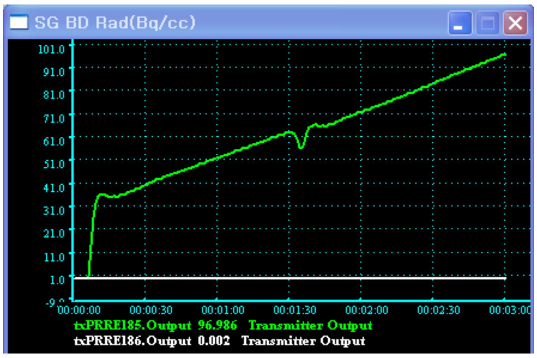

Fig. 3. Activities in SG blow down sides (Bq/cc)

4. Conclusions

The radionuclide transport models for NPP simulator have been developed using RELAP5 R/T. Three species of the Iodine-131, Xenon-133, and Nitrogen-16 have been modeled. The result of SGTR test showed a reasonable behavior of the radiation release. By including the radionuclide transport model within the hydrodynamics using RELAP5 R/T, the farther fidelity of the NPP simulator radiation models could be achieved.

REFERENCES

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[4] "American National Standard for Nuclear Power Plant Simulators for Use in Operator Training and License Examination", ANSI/ANS 3.5, ANS, 1998.