Development of a RELAP5 R/T Model for the APR1400

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1. Introduction

Korea Electric Power Research Institute (KEPRI) is developing the APR1400 Simulator which is used to verify and validate the Human Factor Engineering (HFE) of Man-Machine Interface (MMI) [1]. A RELAP5 R/T model has been developed to simulate the NSSS thermal hydraulics and the core neutronics for the APR1400 Simulator. The RELAP5 R/T code is a real-time version of RELAP5 Mod3.2 provided by Data System & Solutions (DS&S) [2]. The primary feature of this code is the three-dimensional neutronics model of the reactor core.

The APR1400 RELAP5 Mod3.2 input deck was used to develop the APR1400 RELAP5 R/T model. One-dimensional models of the reactor pressure vessel and its internals have been replaced with their three-dimensional models. More details of the APR1400 RELAP5 R/T models are described in this paper. The paper also describes the results of steady state validation using the APR1400 nominal design steady state data.

2. Model Description

The APR1400 RELAP5 Mod3.2 model was developed to analyze the Large Break LOCA which is presented at the SKN 3&4 PSAR Chapter 15 [3]. The significant modifications between the RELAP5 R/T models and the RELAP5 Mod3.2 models are finer nodalization in the reactor vessel, and the replacement of point kinetics input to nodal kinetics input.

2.1 Thermal-hydraulics Model

The basic model nodalization for the Reactor Coolant System (RCS) is patterned after the RELAP5 model used for the LBLOCA analyses. Figure 1 shows the RCS model nodalization scheme. Changes have been made to the LBLOCA model to support a real-time simulation capability. The following are the principal differences between the LBLOCA RCS model and the Simulator RCS model:

- Set time step to 83.3333 milli-seconds (12 Hz) for simulator operation. The control variable input was modified to support the expanded format 205CCCCN. The trip input was modified to support the expanded format 206NTTT0. This format requires that logical trips are between 1000 and 1999.
- Modified the core hydraulic and heat structure nodalization from 20 levels in the active fuel to 12. Also, input five flow paths to replace the existing average core and hot channel paths. Heat structures were also added for each flow path. Components 210 and 250 were modified to support the additional junctions, and the junction flow areas were adjusted to correspond to the number of fuel assemblies in each flow path.

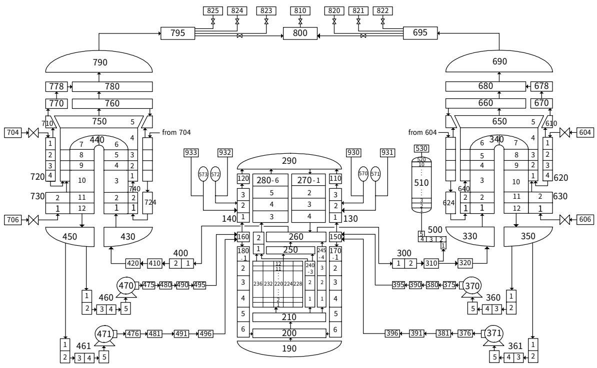

Figure 1. RELAP5 R/T nodalization for the APR1400

2.2 Core Neutronics Model

The RELAP5 R/T neutronics package, Nodal Neutron Kinetics Module (NNKM), is based on the fundamental equations of space and time dependent diffusion theory. The model is a true two-energy group code and computes the neutron flux and power for each node at every time step. NNKM provides this output by performing nodal diffusion calculations while assuming constant thermal-hydraulic conditions over the duration of the time step.

The neutronics model within RELAP5 R/T consists of three different types of nodalizations as follows:

- Neutronics (kinetics solution mesh)
  Assignment of cross section compositions to the kinetics solution mesh
- Thermal-hydraulic zones
  Assignment of volumes and heat structures to thermal-hydraulic zones, and thermal-hydraulic zones to the kinetics solution mesh
- Control Rods
  Assignment of unique identifiers to collections of control rods (Control Rod Identifiers), individual rods (normal for simulator applications), banks or groups of rods (normal operational mode), and assign control rod identifiers to the kinetics solution mesh

The core neutronics model consists of 241 fuel assemblies surrounded by radial reflector nodes. The fuel assemblies are lumped into thermal-hydraulic zones as shown in figure 2 for the interface with the RELAP5 R/T thermal-hydraulics solution. In figure 2, the new volumes are 220 (central, 37 assemblies), 224 (lower right, 51 assemblies), 228 (upper right, 51 assemblies), 232 (lower left, 51 assemblies), and 236 (upper left, 51 assemblies).

The point kinetics input was removed and the nodal kinetics input was incorporated into the model. To develop three-dimensional core neutronics model, the following data are required at each of the burnup and branch calculations from the DIT calculations:

- fast and thermal diffusion coefficients
- fast and thermal macroscopic absorption cross sections (without xe135 and sm149)
- fast and thermal macroscopic fission cross sections
- fast and thermal neutrons per fission
- macroscopic scatter cross section from fast to thermal
- fast and thermal Xe-135 microscopic cross sections
- fast and thermal Sm-149 microscopic cross sections
- fission yields for I-135, Xe-135, and Pm-149
- six group delayed neutron data
- fast and thermal neutron velocities

Also, ROCS edits are required at each statepoint. These edits should include assembly-wise three-dimensional data for relative power fractions, burnups, and Sm-149 concentrations (if available). These files should be provided at BOC (0 MWd/T), BOC (150 MWd/T, equilibrium xenon), MOC, EOC, and EOC (ARO Coastdown).

To facilitate development of the RELAP5 R/T input data, a cross section processing utility was developed to process the large quantity of information into the form needed by NNKM [4]. This utility performs specific functions. First, it takes the cross section data at each burnup and generates a set of cross sections and feedback coefficients for each lattice type. A lattice type is defined by the ^{235}U and burnable poison. Second, the assignment of fuel compositions to kinetics model nodes is performed.

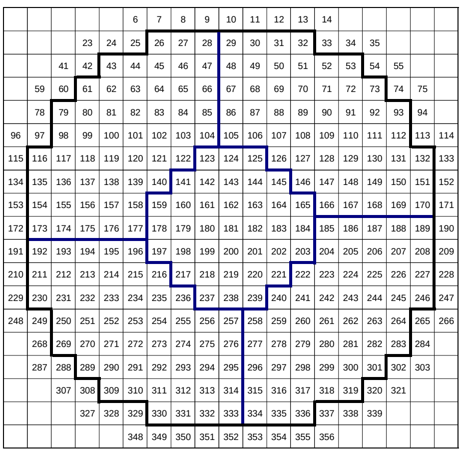

Figure 2. Radial nodalization for the APR1400 core model

3. Validation Results

As source data for steady state validation of the RELAP5 R/T model, the APR1400 nominal design data were used. The main parameters are shown in table 1. As shown in table 1, the calculated parameters are in a good agreement with design ones. However, the results are not final ones as the RELAP5 R/T model undergoes successive revisions.

Table 1. Comparison of steady state parameters

Parameter	Units	APR1400 Design data	R5 R/T Calc. data
Loop flow	Kg/s	10495.57	10496.00
T hot	K	597.04	598.60
T cold	K	563.71	565.80
PZR P	Pa	15513075.0	15513800.
PZR level	m	7.78	7.63
Steam flow	Kg/s	1131.46	1109.7
Steam P	Pa	6891942.12	6658000.0
Delta P at Vessel	Pa	399892.6	409500.0
Delta P at SG	Pa	246761.31	243800.0

4. Conclusion

A RELAP5 R/T model has been developed to simulate the NSSS thermal hydraulics and the core neutronics for the APR1400 Simulator. The primary feature of this model is the three-dimensional neutronics model of the reactor core. The validation of steady state input model was performed using the APR1400 nominal design steady state data. The calculated parameters were in a good agreement with design ones. A transient validation of the RELAP5 R/T model including mid-loop and cold shutdown operation is in progress. By bringing RELAP5 into the real-time simulator environment, the flexibility to analyze a full range of transient plant conditions and predict accurate results under all modes of plant operation will be provided.

ACKNOWLEDGMENT

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