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Non-Integrated Standalone Tests of APR1400 Simulator

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1. Introduction

APR1400 being developed for the construction of New Kori 3&4 Units has improved safety and more economical efficiency compared with previous PWR [1]. The ESF(Engineered Safety Features) newly introduced to enhance safety are as follows:

- DVI (Direct Vessel Injection)
- Fluidic Device
- IRWST (In-containment Refueling Water Storage Tank)

So the transient pattern of anticipated accidents will show different characteristics from previous PWR. There are multidimensional flow phenomena like as emergency core cooling coolant bypass discharge in the downcomer, downcomer boiling, and different safety injection characteristics due to fluidic device during LBLOCA. Also there is the phenomenon of critical flow due to the open of pressurizer POSRV (Pilot Operated Safety Relief valve) connected to IRWST and safety depressurization system and the prediction of discharge flow is very important.

KEPRI is developing APR1400 simulator using RELAP-RT [2]. RELAP-RT was developed by DS&S (Data systems & Solutions) based on RELAP5/MOD3.2. The improved features of RELAP-RT to function as a simulator are as follows:

- Add simulator functionality
  - Control by simulator executive
  - IC snap and reset capability
  - Back-track snap and reset capability
  - Fast time capability
- Fast time capability(examples)
  - The rate of condensation has been limited.
  - Fictional choking model has been developed for internal junctions.
  - Wall heat transfer coefficients and heat fluxes has been limited.

In this study, various NISTs (Non-Integrated Standalone Tests) were performed to verify the capability of RELAP-RT as APR1400 simulator by the comparison with RELAP5/MOD3.3.

2. NISTs for Various Transients

2.1 Preparation of APR1400 simulator Input Model

The original input model of APR1400 simulator is coupled with 3-D kinetics data for 3-D kinetics module (PARCS). So the 3-D kinetic model of APR1400 simulator was modified to point kinetics model to verify the thermal-hydraulic prediction capability of RELAP-RT by the comparison with RELAP5/MOD3.3 based on the same condition.

And the thermal-hydraulic system of APR1400 is comprised of the primary and secondary system. The downcomer parts of APR1400 were modeled with six channels to consider the multidimensional flow effects. Figure 1 shows the nodalization model of APR1400 simulator. It contains DVI, fluidic device, charging and letdown system, pressurizer spray valves, pressurizer POSRV, and so on. And the K values cross the six channels are modified to properly simulate the phenomena of emergency core cooling coolant bypass discharge. The models of downcomer heat structure are modified to represent the phenomena of downcomer boiling. Fluidic device was modeled with two accumulator components and the two K values were used differently based on the KAERI Workshop [3].

In the case of transient analysis, safety related systems like as reactor protection system, reactor control system, and reactor safety system are very important to certify the reactor integrity. But the current input model of APR1400 simulator does not contain those systems. So the boundary conditions and control logics related to reactor protection system, reactor control system, and reactor safety system are added to the input model of APR1400 simulator. Figure 2 shows the reactor protection system and the related trip signal. Figure 3 shows the reactor control system and reactor safety system.

2.2 Steady-State Calculation

The steady-state calculation of APR1400 simulator for full power operation was performed with the operation of reactor protection/control/safety systems. The calculated results are well agreed with the design value within the error range of 2 %.

2.3 NIST Performance

The following eleven transient cases are calculated using both RELAP-RT and RELAP5/MOD3.3.

- manual reactor trip
- closure of all main steam isolation valves
- trip of all reactor coolant pumps
- turbine trip
- large break LOCA with loss of offsite power

- loss of all AC Power
- SGTR (Steam Generator Tube Rupture)
- ATWS(Anticipated Transient Without Scram) with total loss of main feedwater flow
- small break LOCA
- inadvertent opening of pressurizer POSRV
- turbine power ramp change (100=>75%, 75=>100%)

All of these tests have been successfully performed. But in the cases like as LBLOCA, SGTR, and inadvertent opening of pressurizer POSRV, the discharge coefficient of critical flow model of RELAP-RT should be chosen carefully due to the differences of the critical model between RELAP5/MOD3.3 and RELAP-RT. The default critical flow model of RELAP5/MOD3.3 is Henry-Fauske model, but that of RELAP-RT is the original RELAP5 critical model. There were some differences in the case of inadvertent opening of pressurizer POSRV and ATWS with total loss of main feedwater flow, but the differences could be tolerable and the overall transient scenario was similar.

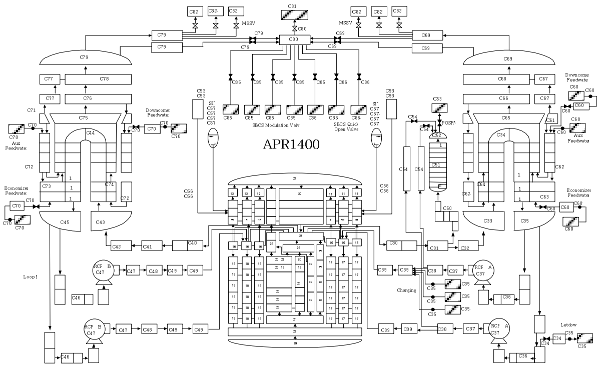

Figure 1. APR1400 Nodalization Model

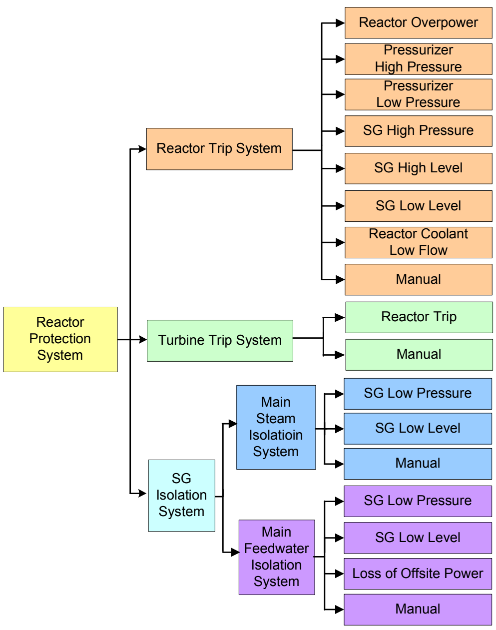

Figure 2. Reactor Protection System and Related Trip Signal

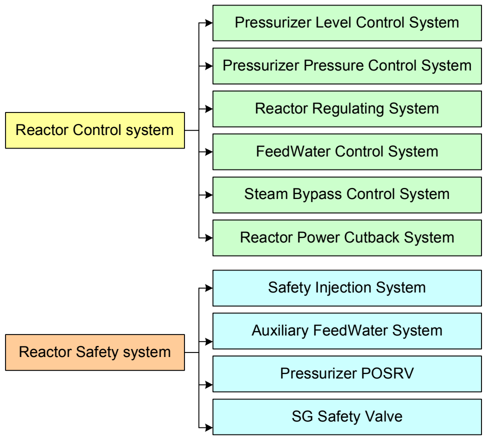

Figure 3. Reactor Control and Safety Systems

Table 1. The Results of Steady-State Calculation

	Plant Parameter	Design	Calculation	Error(%)
Reactor	Core Power [MWt]	3983.0	3983.0	0.0
Primary Side	Hot Leg Flowrate [kg/sec]	10495.6	10289.2	2.0
	Hot Leg Temperature [K]	597.4	596.9	0.02
	Cold Leg Temperature [K]	563.7	563.4	0.06
	PZR Level [%]	52.6	52.4	0.4
	PZR Pressure [bar]	155.1	155.1	0.0
Secondary Side	Downcomer FW Flowrate[kg/sec]	113.1	113.1	0.0
	Economizer FW Flowrate [kg/sec]	1018.2	1017.8	0.03
	Steam Flowrate (each line) [kg/sec]	1131.2	1131.	0.03
	SG Dome Pressure [bar]	69.0	69.0	-0.1
	SG Recirculation Ratio	3.9	3.9	0.0

3. Conclusion

The capability of RELAP-RT as APR1400 simulator was verified through various NISTs. The calculated results of RELAP-RT for various NISTs were well agreed with those of RELAP5/MOD3. But the discharge coefficient of critical flow should be chosen carefully. For RELAP5/MOD3.3, the restart problem can be started from the previous steady-state calculation using both STDY-ST and TRANSNT as the problem option. But for RELAP-RT, the restart problem can be started only from the case using STDY-ST option. For the convenience of APR1400 simulator, this weakness should be improved.

REFERENCES

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