Validation tests of SPACE code for analysis of reactivity insertion in IAEA benchmark research reactor

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1. Introduction

SPACE(Safety and Performance Analysis CodE) is a computer program to analyze transient phenomena in nuclear power plants, which is object-oriented programmed using C++ language. The code is based on a nonhomogeneous and nonequilibrium model for two-phase flow system and it solves 2 phase-3 field governing equations. And the code includes many generic models such as heat transfer models, reactor point kinetics, reflood model and etc.

Since the SPACE was developed based on the operational conditions of nuclear power plants, it is necessary to validate the SPACE for the analysis of transients in research reactors. In this study, reactivity insertion transients in a research reactor of IAEA benchmark were simulated using the SPACE. And the simulation results were compared with those by the RELAP5 code which has been used for safety analysis of many research reactors in order to identify the applicability of the SPACE to safety analysis of research reactors.

2. Research reactor in IAEA benchmark

IAEA TECDOC-233[1] and TECDOC-643[2] are to provide guidance for determining both the feasibility of converting specific reactors from HEU to LEU fuel and options available for implementation. It includes generic studies of typical MTR-type research reactor. Calculations were performed by different laboratories for typical MTR-type reactors to determine their potential for conversion. The IAEA benchmark problems were specified in order to compare calculation methods used in various research centers and institutions.

A generic research reactor for the benchmark problem is the idealized light-water, pool-type reactor. Fig. 1 presents core configuration and fuel element.

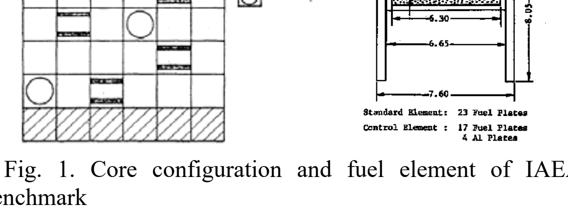

Fig. 1. Core configuration and fuel element of IAEA benchmark

The detailed specifications of the reactor for IAEA benchmark are shown in Table 1, which are selected for this study among IAEA benchmark cases.

Table 1: Specifications of IAEA benchmark

Reactor	
Reactor type	Pool type MTR
Steady state power	10 MW
Coolant, Moderator	H_2O
Reflector	Graphite, H_2O
Fuel & control assembly	
Type	Plate
Number – Standard Assembly	23
Number – Control Assembly	5
Size	76 x 80 x 600 mm
Total number of fuel plates in core	614
Material – Meat	19.75% enriched U_3Si_2 alloy
Material – Cladding	Al

3. Calculation methods

Using the SPACE[3] and RELAP5/MOD3.3[4] codes, a couple of reactivity insertion events were simulated based on the IAEA benchmark research reactor; fast insertion and ramp insertion according to insertion rate. The fast insertion transient is that a 1.5$ inserted into the core during 0.5sec, while the ramp insertion is a continuous insertion of 0.09$ per second.

Fig. 2 shows node diagram for IAEA Benchmark reactor. Since the reactor cooling system is in operation though the reactivity insertion transients occur, the model of the IAEA benchmark is simplified using time-dependent components (boundary conditions). Node #203 indicates a flow channel through hot assembly, while node #204 represents a flow channel through average assemblies. Upper and lower parts of the core is modeled as node #206 and #202, respectively. The reactor pool model consists of node #201, 206 and 207.

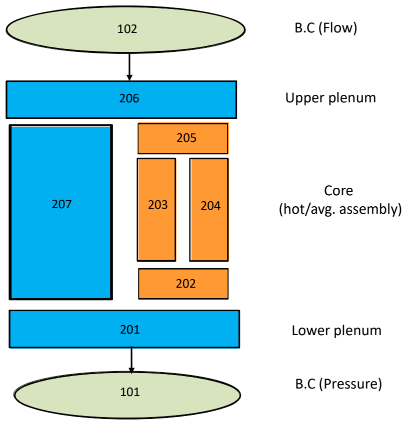

Fig. 2. Node diagram of IAEA benchmark

The initial conditions including thermal hydraulic conditions and kinetics parameter values are shown in Table 2. The axial power distribution accords to the cosine-shape. Reactor trip set point is high reactor power level of 12 MW and trip delay time is 0.025 seconds.

Table 2: Initial conditions for the analysis of reactivity insertion transients

Parameter	Value
Initial power level	1 W
Radial peaking factor	1.4
Axial peaking factor	1.5
Engineering factor	1.2
Core flow rate	275.9 kg/s
Coolant inlet temperature	38 °C
Coolant inlet pressure	1.7 bar
Effective delayed neutron fraction	727.5 pcm
Mean neutron generation time	43.74e-6 s
Coolant temperature reactivity coefficient	-1.0930e-2 $/K
Fuel temperature reactivity coefficient	-3.3456e-3 $/K

There is a difference in the method of calculating the reactivity feedback due to coolant temperature change between the SPACE and the REALP5/MOD3.3. The reactivity feedback model related to the coolant in SPACE follows equation (1) and the model in RELAP follows equation (2).

$$W_\rho \cdot [R_\rho(\rho(t)) + a_W \cdot T_W(t)] \quad (1)$$

$$W_\rho \cdot R_\rho(\rho(t)) + a_W \cdot T_W(t) \quad (2)$$

In order to make the same feedback effect in both codes, the reactivity feedback due to coolant density change ($R_\rho(\rho(t))$) were used instead of the coolant temperature coefficient ($\alpha_W(t)$), which is a table defining reactivity as function of the current density of coolant in the hydrodynamic volume.

4. Calculation results

The analysis results of the fast insertion transients are shown in Fig. 3. The reactor power increases sharply since the positive reactivity of 1.5$ is inserted into the core in a very short time of 0.5 seconds. Reactor trip occurs by the high reactor power and the reactor power decreases rapidly. The reactor power variation by the SPACE is almost the same as that by the REALP5. The peak reactor power levels are 151.0 MW in SPACE and 149.8 MW in RELAP5/MOD3.3, respectively.

Fig. 4 presents the analysis results of the ramp insertion transient. The sequence of the event is the same as in fast insertion case but it is relatively slow transient. The peak reactor power levels are 12.66 MW in SPACE and 12.64 MW in RELAP5/MOD3.3.

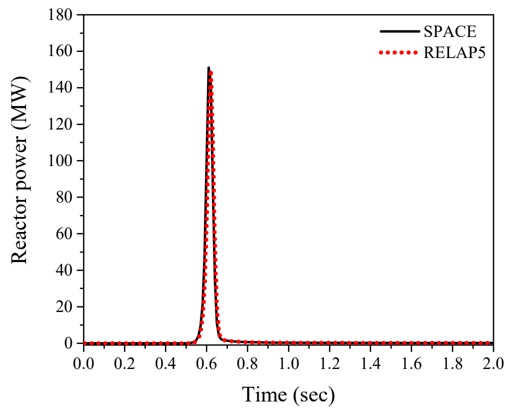

Fig. 3. Fast insertion: Reactor power

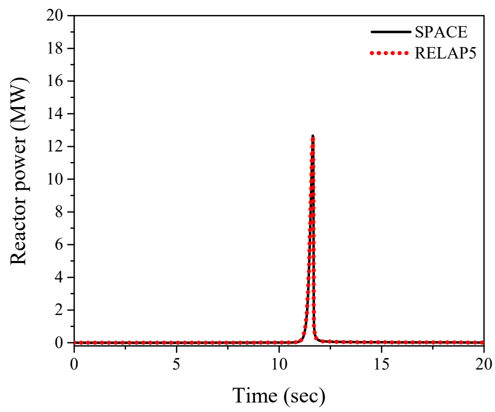

Fig. 4. Ramp insertion: Reactor power

5. Conclusion

Simulations of reactivity insertion transients of IAEA benchmark reactor were performed using the SPACE and the RELAP5/MOD3.3 and codes in order to identify the applicability of the SPACE to safety analysis of research reactors. The simulation results from both codes are almost identical. Through this study, it might be confirmed that SPACE is applicable to the analysis of reactivity insertion transients in research reactors.

ACKNOWELGEMENTS

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