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Code-to-code Comparison of ISAAC on SBO Sequences at CANDU6 Reference Plant

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1. Introduction

In order to benchmark the severe accident analysis codes for pressurized heavy water reactors, IAEA organized the coordinated research project (CRP), "Benchmarking Severe Accident Computer Codes for Heavy Water Reactor Applications." Seven institutes from five countries joined the CRP for 4 years from 2009. Each participant analyzed the station blackout sequence with its computer code and KAERI participated in the CRP with the ISAAC computer code [1] which was used for the severe accident analysis for the Wolsong units. Thermal hydraulic behavior and the fission product transport from fuel to the reactor building and to the environment are analyzed and compared among the participants.

2. ISAAC analysis on SBO sequences

2.1 Plant Familiarization and Scenario

The heavy water reactor plant considered for the benchmarking analysis is a generic CANDU-6 power plant with 2064 MW thermal output to the steam generators. AECL provided the CANDU6 reference plant information [2] and the PHTS configuration is shown in Figure 1. When the given information was not sufficient, Wolsong data were used for the simulation.

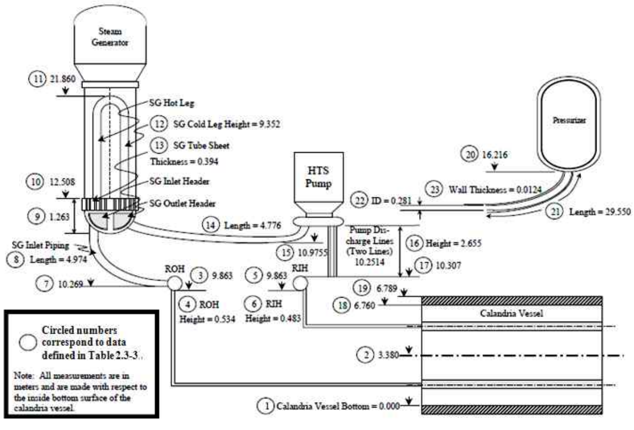

Figure 1 Reference CANDU6 PHTS configuration with elevation information[2]

The station blackout (SBO) sequence is chosen for the benchmarking analysis. As there is no electric power available for the safety systems, all the cooling systems and the auxiliary feedwater system fail initially. Main steam safety valves open at their set points to relieve the pressure from the secondary side. The liquid relief valves are assumed to open when the PHTS pressure reaches their set points. The passive containment dousing sprays and the local air coolers are assumed to be unavailable and all the operator interventions are not credited. The accident was simulated with ISAAC 4.02 until 500,000 seconds to see the reactor vault concrete melt-through.

2.2 Overview of Severe Accident Progression

The accident progression was analyzed by 4 phases: Phase 1 (accident Initiation to fuel channel dryout), Phase 2 (fuel channel dryout to core collapse), Phase 3 (core collapse to calandria failure), and Phase 4 (calandria failure to containment failure).

The LRVs are first open around 6200 s to relieve PHTS pressure and the fuel channel fails at 10178 s when the pressure tube starts to balloon. The steam generators lose water inventory through the MSSVs and they are depleted around 7446 s. The moderator gets saturated at about 12000s and depleted around 38271 s.

The relocation of molten material from the core to the suspended debris bed starts from around 15840 s in both loops. The mass difference between the leaving mass from the channel and the staying mass in the suspended debris bed goes to the calandria vessel bottom. Finally about 134 tons of corium is delivered to the calandria vessel bottom before calandria vessel fails at 160794 s. Soon after the shield water depletion, the reactor vault bottom concrete starts to be ablated and finally melts through at 378904 s after 2 m of ablation.

When the moderator provides steam to the containment, the containment pressure increases. After the calandria tank moderator was depleted at 38 271 s, the containment pressure decreases for a short period until steam is produced from the reactor vault after 52200 s, causing containment pressure to rise again. The containment fails at 80697 s when the pressure reaches at 324 kPa(a).

About 1960 kg of hydrogen is generated from the reactor vault from MCCI, while about 504 kg is coming inside the calandria vessel. Out of the hydrogen from core, about 58% of the hydrogen comes from the suspended debris bed in this scenario. The hydrogen mole fraction reaches about 16.1% around 287 500 s. When the containment fails around 80 697 s, most of the noble gas is released outside the containment. In the meantime, about 1.2% of the initial inventories of CsI and CsOH are released to the environment.

3. Comparison among computer codes

A variety of severe accident analysis codes or code combinations were used by the participants to simulate the station blackout scenario. The codes used are: ATMIKA.T, CONTACT, SEVAX, PACSR/STAR, ACTREL (Nuclear Power Corporation of India Limited (NPCIL)), ISAAC 4.02 (KAERI), SCDAPSIM/RELAP5 Mod 3.4 (Politechnical University of Bucharest (PUB)), SCDAP/RELAP5 Mod 3.4 (Shanghai Jiao Tong University (SJTU)), RELAP5 Mod 3.2, ANSWER, CAST3M, MELCOOL (Bhabha Atomic Research Center, Reactor Engineering Division (BARC–RED)), SCADAP/RELAP5 Mod 3.2 , PHTACT, ASTEC (Reactor Safety Division (BARC–RSD)), and MAAP4-CANDU v4.0.6A (AECL).

Figures 2 to 4 show the comparison of moderator dryout time, containment pressure behavior, and hydrogen mass generated from in & ex-calandria vessel, respectively. In spite of the complex phenomena of the channel failure, core disassembly and core collapse, the differences in the moderator dryout timing appear in a reasonable range. However the containment failure time is different among participants and the variation is rather large. Also the hydrogen masses generated from in & ex-calandria vessel are different.

4. Conclusions

Among other codes, ISAAC shows reasonable timings for the important phenomena related with heat balance like LRVs' first opening time, steam generator dryout time, moderator and shield water depletion time, etc. At the same time, however, different trends and results are identified. Some of them can be clarified by checking input parameters as well as model comparison and model update. Also model validation efforts for the CANDU-specific phenomena are needed to get consensus among HWR severe accident analysis codes.

ACKNOWLEDGEMENTS

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[1] KAERI, ISAAC Computer Code User's Manual, KAERI/TR-3645/2008 (2008)
[2] B. Awadh and S.M. Petoukhov, "CANDU 6 Plant Parameters for Severe Accident Codes Comparative Analysis for the Coordinated Research Project (CRP # 1451)," AECL Report, 153-115380-440-006, 2010 March

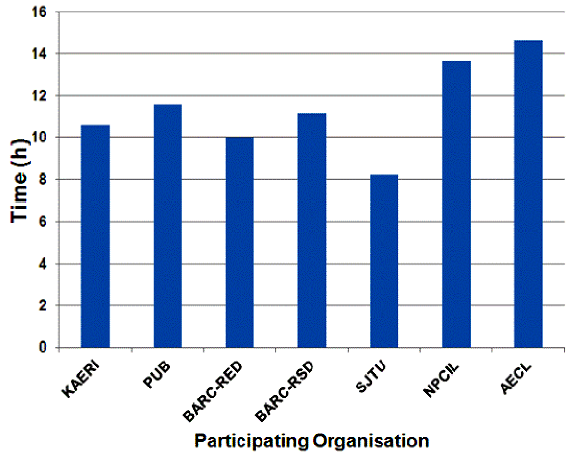

Figure 2 Comparison of moderator dryout time

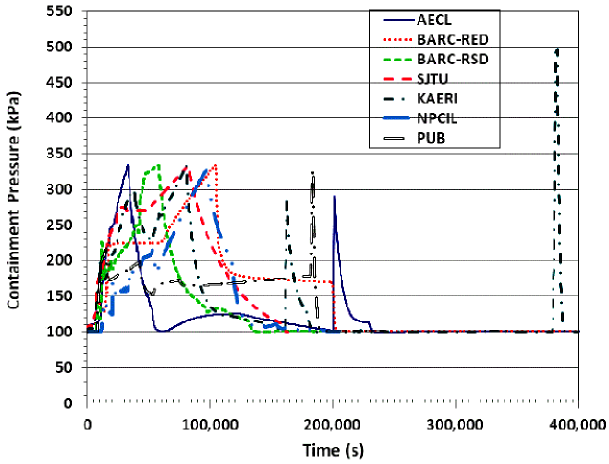

Figure 3 Copmparison of containment pressure behavior

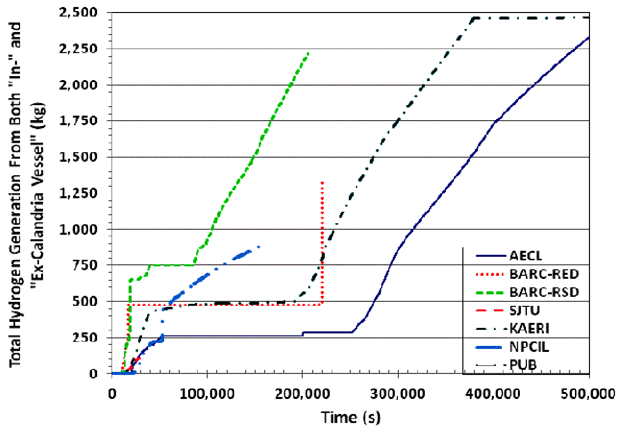

Figure 4 Comparison of H_2 mass generated from in- & ex-calandria vessel