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Wolsong-specific ISAAC Modeling for PSA and Severe Accident Management

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1. Introduction

For the Wolsong plants which are CANDU-6 type reactors, severe accident progression will be much different from PWRs due to unique core and primary system configuration. The ISAAC (*I*ntegrated *S*evere *A*ccident *A*nalysis code for *C*ANDU plants) computer code [1] was initially developed for Wolsong unit 2 PSA and it is being improved for severe accident management. The main purpose of this paper is to introduce the capabilities of ISAAC for PSA and severe accident management by describing Wolsong-specific features modeled in the ISAAC computer code.

2. ISAAC Modeling for PSA

ISAAC has a capability to predict the severe accident progression in the Wolsong plants by modeling the Wolsong-specific systems like a figure-of-eight primary system, loop isolation valves, an over-pressure protection system, engineered safety features, etc, and by modeling the expected phenomena based on the state-of-the-art understanding of accident progression.

2.1 Plant Simulation

ISAAC was developed to simulate accident scenarios that could lead to a damaged core and eventually to reactor building (RB) failure at Wolsong plants. For that purpose, Wolsong-specific systems like a primary heat transport system with 2 separated closed loop having figure-of-eight configuration, a pressurizer connected to both loops with loop isolation valves, 4 individual steam generators (2 steam generators per loop), calandria containing the horizontal fuel channels, 2 end-shields, calandria vault surrounding the calandria, and the degasser condenser tank are modeled. The reactor building can be nodalized with a generalized containment model in ISAAC.

Over-pressure protection systems are also modeled in the code. Liquid relief valves, pressurizer safety valves, and degasser condenser tank valves for the primary heat transport system (PHTS), 4 calandria rupture discs and bleed valves for the calandria tank, and calandria vault over-pressure protection valves are included. Main steam isolation valves, main steam safety valves, and atmospheric steam dump valves are taken into account in the secondary side.

2.2 Safety Systems

ISAAC models following important safety systems to mitigate the accident: emergency core cooling system (ECCS), containment dousing spray system, reactor building local air coolers, shutdown cooling system, moderator and shield cooling system, and igniters.

The three-stage emergency core cooling system is modeled based on the system design manual. When the primary system pressure decreases below the high pressure ECCS tank pressure, high pressure ECCS works and the flow rate depends on the pressure difference between the tank and the primary system. Following the depletion of the tank, water from the dousing tank is injected by the medium pressure injection pumps. Finally water collected in the sumps is delivered into the core by the low pressure pumps through the heat exchangers.

Containment dousing sprays, which are designed for short-term heat removal system, are also modeled to control the containment pressure. Its flow rate depends on water level in the dousing tank. The dousing sprays turn on when the containment system pressure increases to the set-on point and turn off when it decreases to the set-off pressure. Once the dousing tank is empty, no more sprays are available.

In addition, local air coolers are modeled for long-term reactor building heat removal. As the Wolsong units have air coolers at several places in the RB, users can define as many as 12 locations of air coolers. Each air cooler has its own suction compartment and discharge compartment. Also air coolers can be modeled without heat exchangers.

The Wolsong units have inherent heat sinks to remove decay heat from the fuel such as the moderator in the calandria and the shield water in the calandria vault. When all active safety systems are not available, these water inventories will be useful to stop or delay the accident progression. ISAAC models moderator and shield cooling system, respectively, by removing heat through heat exchangers. Shutdown cooling system are also modeled in the code.

2.3 Core Degradation

Based on the thermal-hydraulic frame of the MAAP4 computer code [2], Wolsong-specific core degradation models have been developed and implemented into ISAAC. If water inventory in the pressure tube depletes and fuel rods are exposed to steam for any reasons, the cladding will be heated first and ballooned when the gap pressure exceeds the primary system pressure. During the high pressure transient, pressure tube is expected to balloon and touch the calandria tube. If the moderator cooling system fails, moderator level drops, horizontal fuel channels sag and finally channel integrity loses, causing severe core damage. ISAAC models these accident progressions from core heatup, pressure tube/calandria tube rupture after uncovery from inside and outside, relocation of damaged fuel to the bottom of calandria, debris behavior in the calandria, hydrogen burn, and to the reactor building failure. Along with the thermal hydraulics, fission product behavior is also considered in the primary system as well as in the reactor building.

3. ISAAC Modeling for Severe Accident Management

Severe accident management guidelines for Wolsong plants are being developed. Water injection strategy into the primary system, steam generators, calandria tank, and calandria vault is taken into account in the guidelines to mitigate the accident progression. For severe accident management, ISAAC has a capability to manage these strategies by adding the following systems.

3.1 Emergency Feedwater System

In the event of loss of feedwater to steam generators, the operator can turn on the valves to feed water from the dousing tank to steam generators after they have been depressurized. ISAAC has an emergency feedwater system model for operators to open and close the valves for water injection to the steam generators. When the valves are open, the gravity feed flow is available from the dousing tank.

3.2 D_2O Makeup System

ISAAC models a high tritium D_2O tank and a low tritium D_2O tank. This D_2O makeup system can supply water to the primary heat transport system (PHTS), to the calandria tank, or to the calandria vault. D_2O makeup flow into PHTS is modeled from the low tritium D_2O tank and the flow rate is controlled by the pressurizer level. Similar to the D_2O makeup to the PHTS, D_2O makeup to the calandria tank is modeled. The makeup flow can be supplied from high and low tritium tanks and the flow rate is determined based on water level in the calandria tank.

3.3 Light Water External Makeup to Calandria Vault

ISAAC models a light water makeup system to the calandria vault with an infinite source. The user can control water supply to the calandria vault with an input and the flow rate is determined to maintain the desired water level in the calandria vault [3].

3. Conclusion

As the Wolsong plants are unique compared to PWRs, a Wolsong-specific code is needed for the severe accident analysis. ISAAC computer code was developed for PSA purpose initially, and it is being improved for severe accident management. It models Wolsong-specific system including PHTS, secondary side, reactor building and important safety features. Also severe accident progression models are added from core degradation to reactor building failure. In order to mitigate the accident progression for severe accident management, ISAAC models the emergency water supply system for the steam generators and D_2O makeup system both for PHTS and calandria. External makeup for the calandria vault is also considered. ISAAC is expected to be used for SAMG development and strategy validation purpose.

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