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ISAAC Improvement for a PHWR Severe Accident Management

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1. Introduction

For the Wolsong plants which are CANDU-6 type reactors, a severe accident progression will be very different from PWRs due to their unique configurations of the core, primary system, calandria, calandria vault, etc. The ISAAC (*I*ntegrated *S*evere *A*ccident *A*nalysis code for *C*ANDU plants) computer code [1] was initially developed for the Wolsong unit 2 PSA and recently version 3.0 has been released. The main purpose of this paper is to introduce the capabilities of the ISAAC for a severe accident analysis and severe accident management by summarizing the new features of ISAAC 3.0.

2. ISAAC Improvement

2.1 Basic Models of ISAAC 1.0 for Accident Simulation

ISAAC was developed to predict a severe accident progression at the Wolsong plants by modeling the Wolsong-specific systems and the expected phenomena in the core, calandria and in the reactor building.

Basically the following systems are modeled in the code: a primary heat transport system (PHTS) with 2 separated closed loops of a figure-of-eight configuration, a pressurizer connected to both loops with loop isolation valves, 4 individual steam generators (2 steam generators per loop), a calandria containing horizontal fuel channels, 2 end-shields, a calandria vault surrounding the calandria, and the degasser condenser tank. The reactor building can be nodalized by the user.

In order to mitigate an accident progression, ISAAC models the emergency core cooling system, dousing spray system, local air coolers, shutdown cooling system, moderator and shield cooling system, and igniters. Also, the over-pressure protection systems like the liquid relief valves, pressurizer safety valves, and degasser condenser tank valves for the PHTS, 4 calandria rupture discs and bleed valves for the calandria tank, and the calandria vault over-pressure protection valves are considered. Main steam isolation valves, main steam safety valves, and atmospheric steam dump valves are also taken into account in the secondary side of the steam generators.

To simulate accident scenarios that could lead to core damage and eventually to a reactor building (RB) failure at the Wolsong plants, ISAAC models the thermal-hydraulics in the PHTS, SG, and RB. Also it models the core heatup and horizontal fuel channel failure due to a pressure tube/calandria tube failure, relocation of damaged fuel to the calandria, debris behaviour in the calandria, calandria failure, corium-concrete interaction in the calandria vault and in the basement, a hydrogen burn and fission product transport.

2.2 Systems Upgrade

In order to assess the severe accident management strategies, additional water injection systems are added to the current ISAAC code. For D_2O makeup to the PHTS or calandria, high/low tritium D_2O tanks are modeled. For water makeup to the calandria vault, infinite external water source can be defined by the user.

In the event of a loss of feedwater to the 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, a gravity feed flow is available from the dousing tank.

As the ISAAC 1.0 can only define local air coolers at two locations in the reactor building, it was extended to consider as many as 12 locations, as the Wolsong units have air coolers at several places in the RB. Each air cooler has its own suction compartment and discharge compartment.

2.3 Modeling Upgrade

2.3.1 Core degradation

When the sagged horizontal fuel channels are in contact with the channels below, less heat transfer to the moderator is expected. Current ISAAC 1.0 assumes step-wise area reduction when the conditions are satisfied by defining a model parameter. Instead, ISAAC 3.0 introduces a sagging time and a minimum heat transfer fraction for considering the gradual sag process.

As the CANDU configuration is different from PWRs, corium relocation phenomena would be much different. ISAAC assumes an imaginary holding space or a bin for the relocated corium debris inside the calandria, instead of modeling the detailed corium relocation process. The corium is first relocated into the holding bin and then onto the calandria bottom. Initially a single debris holding bin was defined per loop to track the suspended corium behavior. As this approach was too simple to simulate the actual core damage progression, two-dimensional holding bins (whose maximum is 6 by 4 in axial and radial directions, respectively) has been modeled per loop in ISAAC 3.0.

Hydrogen can be generated from both sides of the pressure tubes and the calandria tubes. After a calandria tube perforation, ISAAC 3.0 models a hydrogen generation from the inner surface of the calandria tubes prior to their relocation to the holding bin. Also, ISAAC considers a hydrogen generation from the suspended debris bed after a core disassembly. Previously, an adiabatic boundary condition was defined for the suspended debris bed. Now a heat transfer from the debris bed to the environment is included to determine the debris bed behavior, since the amount of hydrogen mass generated depends on debris bed temperature history.

2.3.2 Ex-Core Progression

ISAAC analyzes the calandria integrity after a corium relocation to the calandria bottom. Though the ISAAC 1.0 models a nuclear heat transfer between the calandria wall and the water in the calandria vault, new model parameters are introduced to define the maximum amount of heat flux for the sensitivity purpose.

In order to simulate the water behavior in the secondary side of steam generators, the current 1 region SG model has been extended to the more sophisticated 2 region model. The tube bundle, riser and the primary separators consist of region 1 and the downcomer, dryer and the upper dome of region 2. Two flow junctions are defined between them. Then the code tracks the mass and energy for the water, steam and the non-condensable gases, respectively, in each region. The user chooses the model as an input.

2.3.3 Fission Product Behavior [2]

Regarding the fission product behavior, more general options are newly added to the ISAAC 3.0. Previously Cubicciotti model and NUREG-0772 correlation were used for the volatile fission product, and Kelly's correlation for the non-volatile species. In ISAAC 3.0, recent release models like CORSOR-M, CORSOR-O, and ORNL-BOOTH are included with an option of a saturated vapor pressure limitation. Also ISAAC 3.0 considers a fission product release from the suspended debris bed, which was not modeled in ISAAC 1.0.

Compared to the ISAAC 1.0 which treats the iodine species only as inorganic compounds like CsI and RbI, a new chemistry model is included to trace the elemental or organic iodine forms in ISAAC 3.0. When CsI is deposited into the water pool (including water droplets), CsI dissociates itself immediately, changing its form into I^- iodine ions and its deposition rate becomes a source rate for the iodine in the pool. Throughout the accident, most of the iodine in the water pool exists as iodine ions (> 99.99%) while very small portions form highly volatile iodized compounds (such as, I_2 and CH_3I) and return to their gaseous phase. This model is useful to predict a trace of an iodine atmospheric concentration via a sump iodine revaporization at a late stage into a severe accident.

2.3.4 Simplified Graphical User Interface Development

In order to show the graphical simulation of the ISAAC results and the reflection of operator action on the accident progression, simplified GUI has been developed and added to ISAAC 3.0. Through the CAVIAR (CANDU Accident VIsualizer ARchitecture) system, the user conveniently accesses the code and follows the accident progression graphically [3].

3. Conclusion

ISAAC 3.0 has been recently released on a pc platform with improved models. In addition to the basic models in ISAAC 1.0, version 3.0 has more stable thermal hydraulics, new systems to mitigate an accident by considering operators actions, and model improvements from the core degradation, suspended debris bed behavior to the calandria integrity evaluation. Hydrogen issues as well as the fission product behavior are considered based on model improvement. ISAAC 3.0 is expected to be used for the severe accident analysis at Wolsong plants, SAMG development and for a strategy validation.

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