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PHWR Modelling and Simulation Issues for SAM Enhancement in Korea after Fukushima

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Abstract

Severe Accident Management (SAM) strategies can typically be grouped into three categories such as (1) coolant injection, (2) containment condition control, and (3) fission product release control. After Fukushima, enhancements in SAM strategies and measures are under way in Korean PHWR plants corresponding to those categories by adding (1) new injection paths, (2) passive autocatalytic recombiners (PARs) for hydrogen control, (3) containment filtered vent system (CFVS) for over-pressurization control, and (4) new SAM strategies in SGTR (Steam Generator Tube Rupture) bypass events for source term control. New modellings for these are being integrated into SAM simulation aid, called SAMEX-CANDU, in Korea.

Keywords: PHWR, SAM, Modelling, Simulation, SAMEX-CANDU

1. Introduction

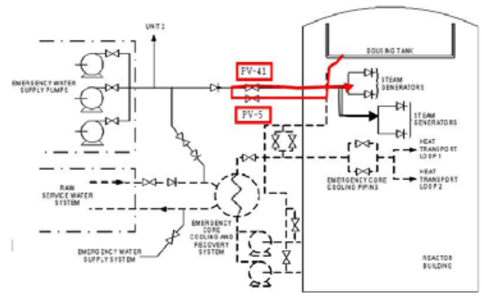
Pressurized heavy water reactor (PHWR) has been operated world-widely as one of the most efficient nuclear reactors owing to its superior neutron efficiency and flexibility to consider broad range of alternative fuel cycles. With the efforts for the life extension of the old reactors as well as for post-Fukushima safety enhancement, development of enhanced PHWR SAM technologies [1] draws attention all over the world.

In Korea, PHWR accounts for 17% in operating unit number and has taken an important role in providing national energy. The recent biggest issue was about continued operation of Wolsong-1 CANDU plant which was recently approved to operate 10 more years after 30 years of design age. During the approval process, safety enhancements, especially for SAM, was raised from public side and SA modelling computer code (called ISAAC [2]) has updated including SAM support simulators being developed in order to support analysing Wolsong safety issues for extended operation.

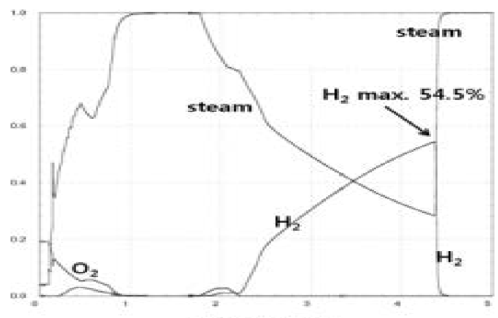
2. SAM Enhanced Modelling Issues

SAM strategies can typically be grouped into three categories such as (1) coolant injection, (2) containment condition control, and (3) fission product release control [3]. After Fukushima, enhancements in SAM measures or needs are studied in Korean PHWR plants corresponding to those categories using (1) new injection paths, (2) passive autocatalytic recombiners for hydrogen control, (3) a containment filtered vent system for over-pressurization control, and (4) SAM enhancements in SGTR bypass events for source term control. The new modellings for each category are summarized as follows.

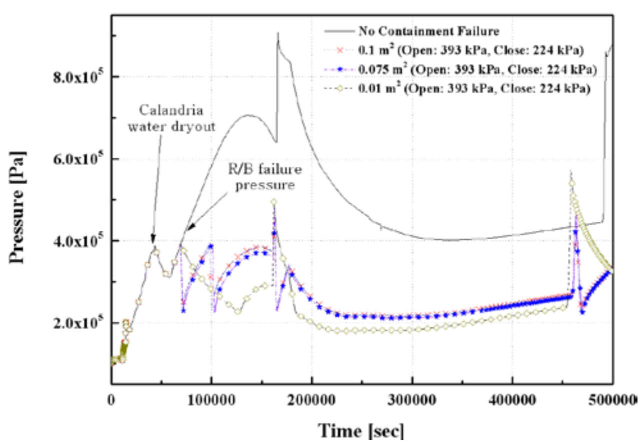
(1) New injection into steam generators (SGs): For the strategy implementation, the dousing tank inventory is assumed to be injected into four steam generators by gravitational force when the pressure is decreased enough after a crash cool-down operation. The decay heat can be removed through the SGs, resulting in a significant delay of accident progression. The accident progression of major phenomena such as a calandria vessel failure can be delayed about more than two or three days with only several valve operations.



(2) PARs for hydrogen control: Hydrogen behavior was analysed at Wolsong, which is equipped with PARs and CFVS after the Fukushima plant accident. The following variables as uncertain parameters affecting the hydrogen generation are studied for sensitivity runs: zircaloy oxidation in the suspended debris bed (SDB), corium spreading area and rebar density in the concrete. The hydrogen mass generated inside the calandria (In-vessel) ranges between 115-780kg depending on the SDB oxidation, and about 1,550-2,850kg from outside the calandria (Ex-vessel) depending on the rebar density, resulting in a total mass of about 2,300-3,700kg. Excluding natural hydrogen burn and containment failure shows a hydrogen concentration of about 11-17%. When they are taken into consideration as a real case, the hydrogen mass left in the containment decreases to about 1,100kg, but the concentration range is still 22-37% due to the decrease of steam mass in the containment. If PARs are available, about 480kg of hydrogen can be removed, but the hydrogen concentration increases to 35% as PARs do not work properly following the depletion of oxygen in the containment after molten corium concrete interaction begins. When CFVS only or both CFVS and PAR are working, it reaches about 30%. For the conditions of the minimum hydrogen generation (i.e., no SDB oxidation and low rebar density), the hydrogen concentration reaches about 25%. Though the hydrogen concentration is high, there is no hydrogen explosion threat due to the depletion of oxygen in the containment.



(3) CFVS for over-pressurization control: Unlike PWRs, CANDU plants have about twice the coolant inventory mass while the design and failure pressures of the CANDU containment are less than one-half that of the PWRs. Hence, steam over-pressurization is a big threat to the containment integrity if no recovery action can be taken for a long time, as in the Fukushima case. For evaluation of CFVS effectiveness, the containment pressure is calculated with different vent sizes and



actuation/closure pressures [4]. As a result, the containment pressure is controlled between the CFVS actuation and closure pressures during most accident periods, but some peak spikes (at failure times of calandria and calandria vault) appeared difficult to be controlled. If the vent size is smaller or the closure pressure is higher, the peak pressure becomes higher, which makes the CFVS less successful. This study suggests that the optimal size and operation strategy need to be enhanced if the containment failure possibility should be removed even for high peak pressure occurrences. In Wolsong plants, the probability of no containment failure will increase from 35% to about 90% even after severe core damage occurs, if the venting strategy is successful.

(4) SAMG enhancements in SGTR for source term control: An SGTR accident, leading to severe core damage, can become a bypass scenario because of the potential for a direct release of fission products (FPs) into the environment. FPs located in the SGs can be released into the environment through the MSSVs if the valves (1) open passively due to high SG pressure, or (2) are locked open for a crash cool-down manually by operator action or when the loss-of-coolant accident (LOCA) signal is generated by a drop in the PHTS pressure. In the latter case, there is a potential for a continuous discharge of FPs into the environment. An operator can mitigate the release of FPs through the open MSSVs, by closing all valves, or at least the valves in the broken SG, but this would require an enhanced specification in severe accident management guidelines, or significant operator intervention.

3. SAM Simulation Aid

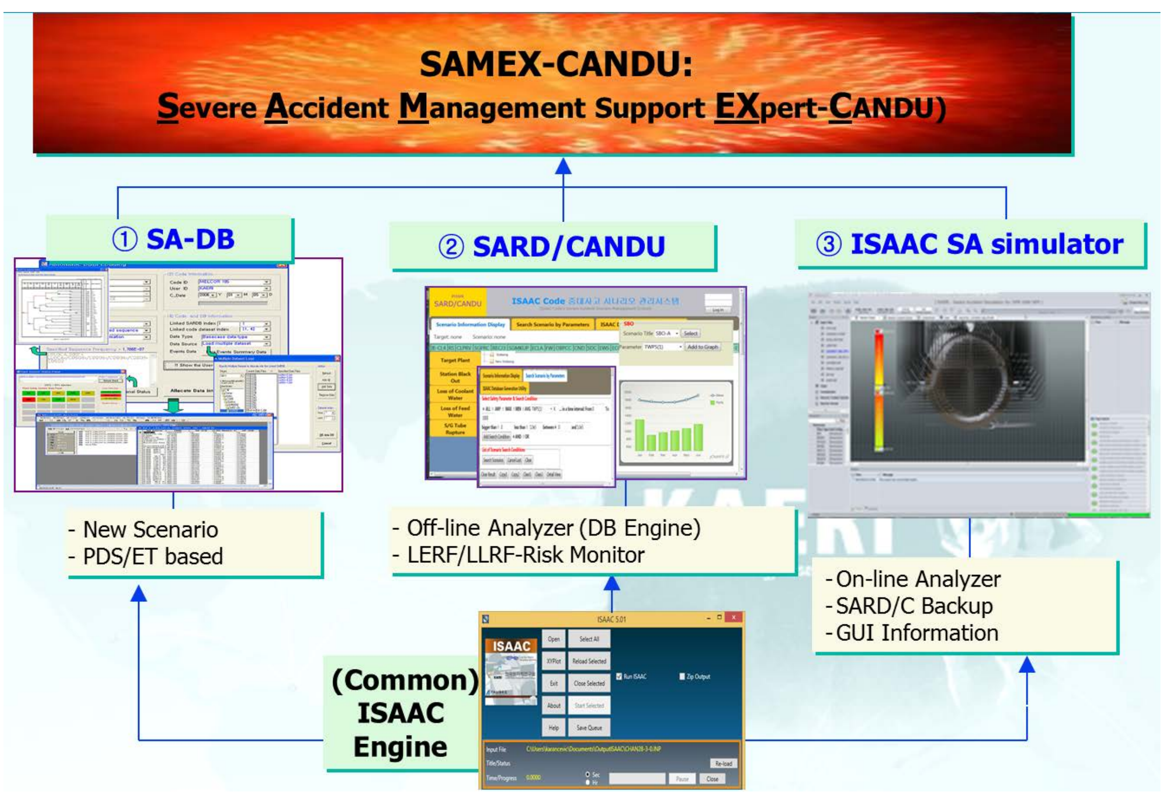


Figure 1 Decision Supporting Simulation Aid for SAM

A decision-supporting computational aid, called SAMEX-CANDU, is being developed in Korea to support experts who need to analyse and predict ongoing accidents under emergency situations in PHWR plants, as shown in the above Figure 1. This aid comprises three modules of analysis database (SA-DB) based on pre-defined scenarios from PSA [5], accident inferring engine (SARD/CANDU) and SA simulator based on ISAAC engine (ISAAC SA simulator). Especially, ISAAC SA simulator called PSAIS, which can mimic operator or SAM actions, has developed with the following features as shown in the Figure 2.

- Windows 7/8 Interface
- Pre- and Post-Processor
- Interactive Control
- Animation

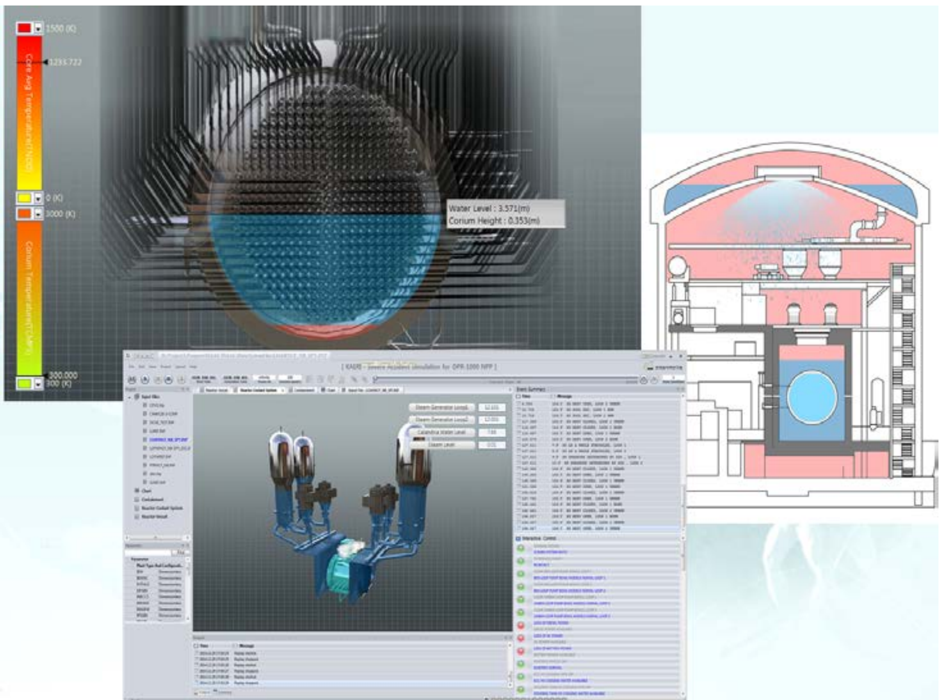


Figure 2 PSAIS (PHWR Severe Accident ISAAC-based Simulator)

4. Conclusion

While the fraction of electric power from PHWR is more than 10% in Korea, the establishment of PHWR safety enhancement based on the SAM technology is still weak. The final approval on extended operation and the stress test of Wolsong-1 have made on the condition that SAM is to be enhanced. Under this situation, the current research has a vision to strengthen the unique value of PHWR by resolving the key safety issues which deteriorate the original value of PHWR. Current SAM guidance lacks information on the accident diagnostic and prognostic analysis, which makes the work of the TSC (Technical Service Center) emergency staffs difficult in real accident conditions. Thus the prototype technologies (such as accident inferring engine and simulator) together with SAM updates are being developed as key elements to SAM supporting tools called SAMEX-CANDU.

5. References

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