Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

A Simple Fully Passive Safety Option for SMART SBLOCA

Won Jae Lee
Korea Atomic Energy Research Institute, 150 Deukjin-dong, Yuseong, Daejeon, 305-353, Korea,
wjlee@kaeri.re.kr

I. Introduction

SMART reactor, an integral pressurized water reactor (iPWR), is developed by KAERI and now under standard design licensing review. Integral reactor design of the SMART has small diameter penetrations below 2 inches at upper parts of reactor pressure vessel (RPV) and the core is located at very lower part. Amount of reactor coolant inventory is around 0.55tons/MWth during normal operations, which is seven times more than that of conventional PWRs. Such intrinsic safety features of the SMART can provide prolonged core cooling during a small-break loss-of-coolant accident (SBLOCA). As an engineered safety feature for SBLOCA, electrically two-train and mechanically four-train active safety injection (SI) systems are provided to refill the RPV, whose safety been proven through safety analysis and experiments. In addition, four-train passive residual heat removal systems (PRHRSs) are provided to remove core decay heat by natural circulation in the secondary side of steam generators during transient and accident conditions.

After Fukushima disaster, a passive safety of nuclear power plants has become more emphasized than conventional active safety, even though there are still debates whether it can really insure the realistic safety. Passive safety is defined such that the core safety is ensured for 72 hours after accidents without any active safety systems and operator actions. In light of this, a simple fully passive safety option for SBLOCA is proposed: low-pressure safety injection tanks (SITs) and heat pipes submerged in the PRHRS emergency coolant tanks (ECTs). Post-LOCA long-term cooling after 72 hours is provided by sump recirculation using shutdown cooling system.

Realistic analysis method using MARS3.1 is used to derive fully passive safety option, and then to screen design and operating parameters and to demonstrate the safety performance of SITs. SI line break is selected as a reference SBLOCA scenario.

II. Fully Passive Safety Option

Regulation requires that the top of the active core should be submerged under the two-phase mixture level to prevent core heat up during SBLOCA. Since potential break elevation of the SMART is at least 8m higher from the core top, the core can be submerged with sufficient margin even when the RPV water level decreases down to uncover the break. Once the break is uncovered, RPV inventory slowly decreases at the rate of single phase steam discharge so that equivalent amount of passive inventory makeup can maintain the core submerged. Thus, underlying idea of the option is to keep the break uncovered while replenishing the RPV inventory by passive means of safety injection to maintain the core mixture level high enough to ensure core cooling. This measure enables effective utilization of SI inventory for a required time. Another concern is that RPV pressure decreases to very low pressure long before the core gets uncovered. This is because RPV energy removal by break discharge and PRHRS is order of magnitude larger than core decay heat until the primary side of steam generators is covered.

Based on the above consideration, a fully passive safety option is proposed to replace existing active SI systems with low-pressure passive SITs individually. In order to control SIT flow to the amount equivalent to steam break discharge flow, flow orifice is located at each SIT surge line. Another feature is to put heat pipes in the PRHRS ECTs for preventing boil-off of final heat sink. Design concept is given in Fig. 1 and elimination of single failure criteria increases the availability of proposed passive systems.

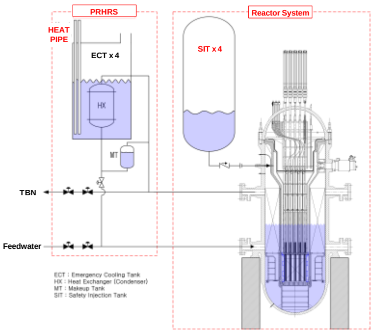

Fig. 1 Fully Passive Safety Option

III. Analytic Models and Methods

MARS3.1 code, a thermal-hydraulic system analysis code developed by KAERI, is used to simulate realistic response during SBLOCA. As shown in Fig. 2, SMART reactor coolant system and four trains of secondary system and PRHRS are modeled one-dimensionally. Four SITs are connected to the upper parts of RPV downcomer of existing SI penetrations, however, only three are assumed available except that located at the break location. Heat pipes in the ECTs are not modeled conservatively to minimize heat removal through PRHRS.

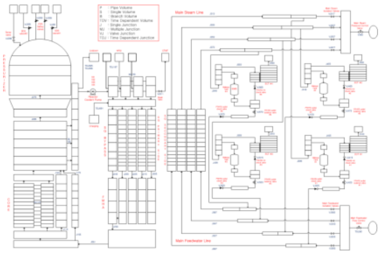

Fig. 2 SMART Reactor System Nodalization

Two case studies were performed: 1) SBLOCA without SI to investigate limiting response of the system and 2) SBLOCA with passive SITs to screen design and operating parameters and to demonstrate SITs performance.

IV. SBLOCA without SI

Limiting response of the SMART system has been investigated for the scenario, SI line break without SI. Quantitative results are assessed to justify technical background of fully passive safety option proposed.
With RPV mass decrease through the break, break located at upper part of RPV becomes uncovered in 0.5 hours. Break flow turns from single phase liquid, two-phase, then, to single phase steam discharge as shown in Fig. 3. RPV pressure decreases below 10 bars in 1.5 hours, since RPV energy removal by the break and the PRHRS is order of magnitude larger than the core decay heat as shown in Fig. 4. As RPV energy removal decreases with RPV pressure and emptying of steam generator primary side, rate of RPV pressure decrease slows down and reaches to a quasi-steady pressure below 3 bars in 4 hours. Thereafter, steam discharge flow is maintained below 1 kg/s and RPV collapsed water level decreases slowly at this rate. Since RPV inventory make-up by SI is not assumed, continuous reduction of RPV level eventually uncovers the core at 12 hours and the fuel starts to heat up at 15 hours when the collapsed level reaches around half of the core as shown in Fig. 5.

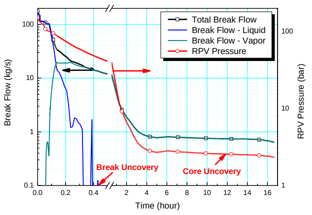

Fig. 3 Break Discharge Flow and RPV Pressure

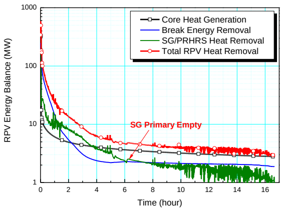

Fig. 4 RPV Energy Balance

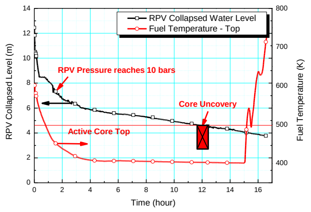

Fig. 5 RPV Collapsed Level and Fuel Temperature

From the above observation, it is found that: 1) core cooling is ensured as far as core is submerged, that is, RPV water level is between the break and the core, 2) sufficient margin to core heat up is available even when RPV depressurizes below 10 bars and 3) RPV level, that is, the core cooling, can be maintained by making up the RPV at single phase steam discharge rate. These justify the use of low-pressure SITs as a fully passive safety option as proposed in section II.

V. SBLOCA with Low-Pressure SITs

After screening the design and operating parameters of SITs, appropriate parameters have been selected; four identical SITs at existing SI penetrations, single SIT volume of 62 m^3, nitrogen gas volume fraction of 20%, operating pressure of 8 bars, surge line of 3/4” sch80 with orifice coefficient of 300.
Safety performance of SITs has been assessed for SI line break scenarios with all PRHRS and 3 PRHRS available. As shown in Fig. 6, RPV water level, that is, the core cooling is maintained with sufficient margin for 72 hours by low-pressure SITs.

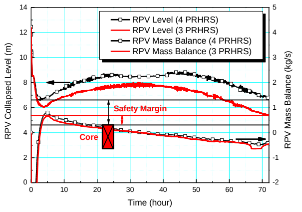

Fig. 6 RPV Collapsed Level and SIT Flow

VI. Summary and Conclusions

A fully passive safety option using low-pressure SITs has been proposed and its safety performance has been demonstrated feasible. Simple nature of the option should facilitate its implementation to current design. For future licensing, not only experimental validation but also SBLOCA realistic evaluation model with uncertainty quantification should follow.

REFERENCES

1) B.D. Chung, et al, “MARS Code Manual”, KAERI/TR-2811/2004 (2009)
2) W.J. Lee, et al. “Core Cooling Assessment of SMART against Severe Station Blackout Accident Scenarios, *KNS Spring Meeting* (2011)