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Preliminary Analysis of Severe Accident Progression Initiated from Small Break LOCA of a SMART Reactor

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1. Introduction

SMART (**S**ystem integrated **M**odular **A**dvanced **R**eac**T**or) , is under the development at Korea Atomic Energy Research Institute (KAERI). SMART is an integral type pressurized water reactor which contains a pressurizer, 4 reactor coolant pumps (RCPs), and 8 steam generator cassettes(S/Gs) in a single reactor vessel [1]. This reactor has substantially enhanced its safety with an integral layout of its major components, 4 trains of safety injection systems (SISs), and an adoption of 4 trains of passive residual heat removal systems (PRHRS) instead of an active auxiliary feedwater system .

The thermal power is 330 MWth. During the conceptual design stage, a preliminary PSA was performed. PSA results identified that a small break loss of coolant accident (SLOCA) with all safety injections unavailable is one of important severe core damage sequences [2]. Clear understanding of this sequence helps in the developing accident mitigation strategies. MIDAS/SMR computer code is used to simulate the severe accident progression initiated from a small break LOCA in SMART reactor. This code has capability to model a helical steam generator which is adopted in SMART reactor [3]. The important accident progression results for SMART reactor are then compared with the typical pressurized water reactor (PWR) result.

2. MIDAS/SMR Input Model

Figure 1 shows the nodalization for the SMART reactor in this analysis [4]. Primary side nodes consist of two lower plenums, a core and a core bypass, two upper plenums, a pressurizer, a RCP suction and discharge, S/Gs and bypasses, and two flow mixing head assemblies. 8 S/G are modeled in two groups. One has 2 S/Gs and the other has 6 S/Gs. Both groups are divided into 12 nodes including 10 active helical tube nodes. 4 RCPs are integrated into one RCP by increasing the flow rate. Secondary side nodes consist of secondary of S/Gs and PRHRSs. PRHR-1 represents 1 train of PRHRS and PRHR-3 represents 3 trains of PRHRS.

A steady state calculation was performed in order to verify the input nodalization of MIDAS/SMR code.

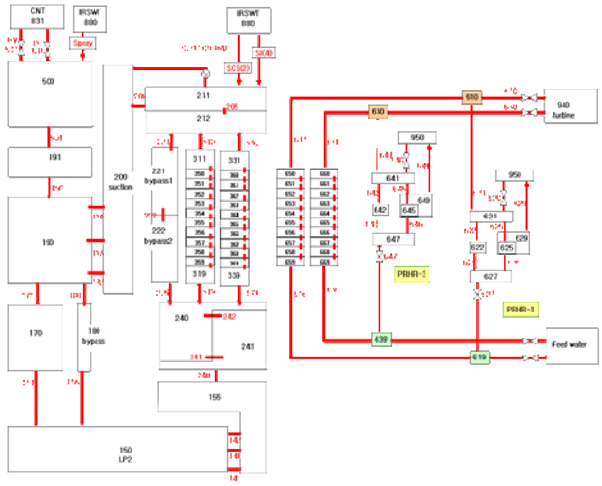

Figure 1 MIDAS/SMR nodalization for SMART reactor

Table 1 shows MIDAS /SMR code results with the important design values. The steady state results of the MIDAS/SMR code are in very good agreement with design values.

Table 1 Results of steady state calculation done by MIDAS/SMR code for SMART reactor

Parameters	Design Values	MIDAS /SMR Results
Primary System Pressure	15.0 MPa	15.0 MPa
Core Inlet Temperature	543 K	547 K
Core Outlet Temperature	584 K	587 K
Mass Flow at Core	1,550.1 kg/s	1,498.1 kg/s
Feed Water Mass Flow Rate	152.5 kg/s	153.1 kg/s
Feed Water Pressure	5.2 MPa	5.3 MPa
Feed Water Temperature	453 K	453 K
Steam Pressure	3.0 MPa	3.2 MPa
Steam Temperature	547 K	542 K

3. Simulation of a small break LOCA

A break occurred at the RCP discharge node at 200 seconds. The break area is 19.635 x 10^{-4} m^2 (5 cm diameter equivalent). It is assumed that none of 4 safety injection pumps are available. PRHRSs are also assumed unavailable. No operator actions are modeled. Hence the inherent resistance of the SMART reactor to the severe conditions can be seen in this scenario.

The timings of important events are summarized in Table 2. As shown in Table 2, the accident progression in SMART reactor is very slow compared to the OPR 1000. SMART has plenty of water in the reactor vessel compare to the loop type PWRs during normal operation (64% of OPR 1000), but the reactor power is about 12 % OPR 1000.

Table 2 Important events timing during 5 cm break LOCA without safety injection

Major Events	SMART (sec)	OPR 1000 (sec)*
Accident Start	200	0
Reactor Trip	270	109
RCP Trip	461	1,605
Core Uncovery	5,803	3,318
Core Dry Out	23,982	6,426
RV Failure	~70,000	12,072

* : Calculated by MAAP4 code

The water level change in the vessel is shown in Figure 2. As shown, the core starts to uncover around 5,803 seconds (1.6 hrs) and the active core gets completely uncovered around 23,982 seconds (6.7 hrs). If the reactor vessel is not submerged into the water, the reactor vessel fails around 70,000 seconds (19.4 hrs) due to creep rupture. Even the water is present in the lower plenum, the reactor vessel may experience a creep rupture after the relocation of the corium in MIDAS/SMR code.

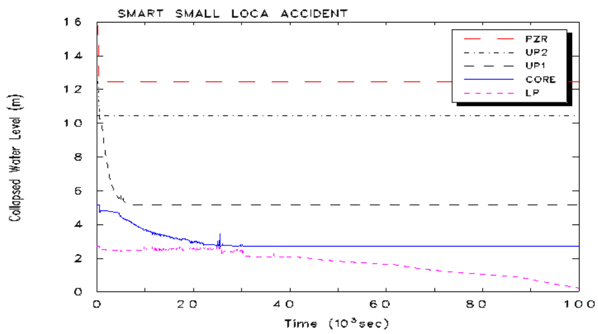

Figure 2 Water level change in the reactor vessel

Figures 3 show the UO_2 temperatures in the central core ring. The upper part of fuel temperature reaches 2750K and relocated to the lower plenum near 23,000 seconds and the lowest part of fuel relocated to the lower plenum near 31,000 seconds

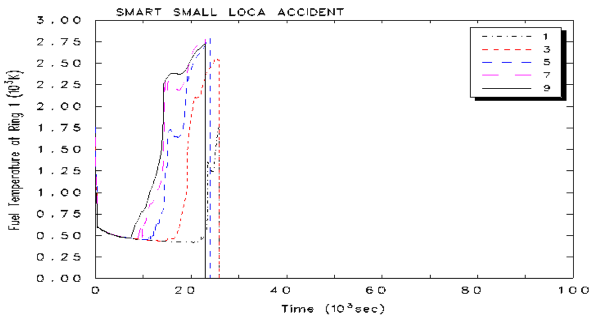

Figure 3 Central ring cladding temperatures behavior

Figure 4 shows the total hydrogen generated in the reactor. About 117 kg of hydrogen generated. This amount corresponds to 72% oxidation of zircaloy in the reactor. In this analysis 3657 kg of zircaloy is assumed in the fuel. For OPR 1000, only 36 % of zircaloy oxidized. This comes from the time difference between the core uncovery and the core dry out.

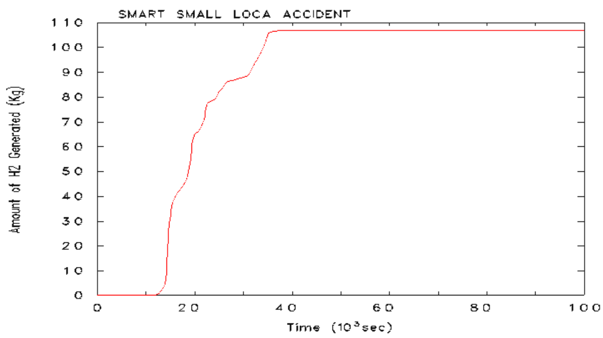

Figure 4 Total hydrogen generated in the reactor

4. Conclusions

The preliminary analysis for the small break LOCA without safety injection sequence showed that the core becomes uncovered about 1.5 hours after the accident initiation and the reactor vessel fails near 19 hours when the reactor cavity is dry. The core damage progression in SMART is much slower than in OPR 1000 due to the abundant water inventory in the reactor. This slow accident progression will allow operators to respond properly during severe accident progression if an accident management program is provided.

REFERENCES

[1] SMART Reactor System Description, KAERI, 2010
[2] Preliminary PSA Report for Internal Events in SMART, KAERI, 2010
[3] Evaluation of MIDAS/SMR model for SMART, KAERI, 2009
[4] Calculation sheet of MIDAS code for the simulation of severe accident in SMART reactor, KAERI, 2010