Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 16-18, 2018

Thermo-Mechanical Analysis for LBLOCA of OPR-1000 with SCDAP/RELAP5

Tae-Hyun CHUN, Chang-Hwan SHIN, Yong-Sik YANG, Wang-Kee IN
LWR Department Division, Korea Atomic Energy Research Institute,
989-111 Daedeok-daero,Yuseong-gu, Daejeon, 34057, KOREA
**Corresponding author: thchun@kaeri.re.kr*

1. Introduction

The ECCS regulation for the LOCA accidents is being revised to require fuel performance-based analysis in the evaluation of Peak Cladding Temperature. Moreover, fuel fragmentation, relocation and dispersal phenomena during the LOCA are also an immersing serious issue. In this regards, the safety analysis codes need basically to have a capability to reliably predict the thermo-mechanical behaviors of fuel claddings. A SCDAP/RELAP5 system analysis code [1] was developed mainly for the severe accidents. In SCDAP module, there is a set of cladding deformation models simulating the ballooning and rupture of fuel cladding in early phase progression of severe accidents. However, there has been little work for the assessment of the SCDAP/RELAP5 during the LOCA accidents, particularly in the aspect of thermo-mechanical behaviors of the fuel cladding [2,3,4]. Here, some preliminary analysis have been performed to assess the capability of SCDAP/RELAP5 as well as to understand the thermo-mechanical behaviors along with a burn-up dependent core model for OPR-1000 in the event of LBLOCA.

2. Methods and Results

2.1 Analysis Model

A typical double-ended Large Break LOCA scenario for OPR-1000 was used for this work. The reactor trip is assumed to occur when the low PZR pressure reactor trip setpoint of 10.93 MPa is reached. A conservative ANS-73 decay heat curve is used with a multiplication factor of 1.2. The coolant in the safety injection tank (SIT) is injected into the cold leg when the RCS depressurizes to below the SIT pressure of 4.2 MPa. The high pressure and low pressure safety injection pumps are assumed to be actuated when the PZR pressure reaches 10.93 MPa with a time delay of 30 seconds. A failure of one emergency diesel generator (EDG) is considered as a single failure assumption. The nodalization of OPR-1000 system was taken from [5]. The core is modeled with a single hydrodynamic channel for simplicity. Regarding with the fuel rods, a refined model was attempted to draw more detail information. Fig. 1 represents an octagonal-symmetric core physics data for OPR-1000[6] at the condition of BOC and all rods out with Xenon equilibrium at full power. All fuel assemblies in the core are categorized to fifteen fuel groups in terms of fuel cycle and power, as described in Table 1. First of all, the hottest fuel of the hottest assembly in each cycle is separately taken as an independent fuel group to be closely monitored just like the conventional LOCA methodology does. They are designated as group 1, 3, and 5 for the 1st, 2nd, and 3rd cycles, respectively

Subsequently, the group 2, 4, and 6 are the rest fuel groups of the hottest fuel assemblies of three cycles. The remaining fuel assemblies in the core too divided also by fuel cycle and power. And then, the assemblies in each cycle are classified into three fuel groups again on the basis of power (i.e. the high, medium and low). The active core region is axially divided by twenty volumes. For an axial power shape a top skewed peak of 1.58 is chosen conservatively because upper part of the fuels is uncovered during the transient period of interest.

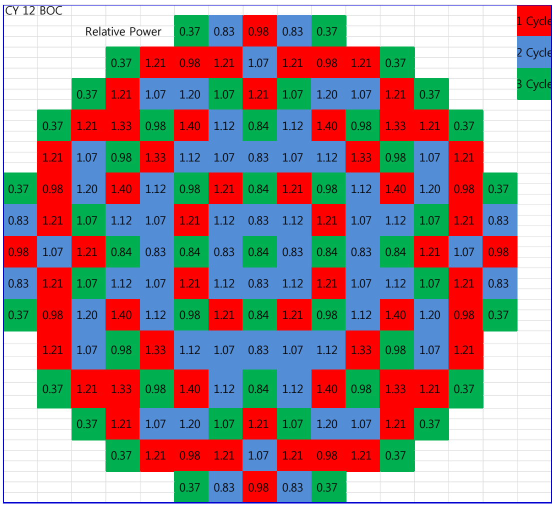

Fig. 1 Core fuel arrangement and power distribution

The initial gas pressure in the gap region between cladding and pellets is only determined by the burn-up condition. Generally, the more burned fuel group has lower assembly power factor but higher gas pressure. For the actual data used in the analysis is given in the Table 1. The gap conductance of the fuel for the analysis was not given as input but calculated by the code. The fuel rupture condition is taken as 0.18 which is default value.

2.2 Analysis Results

Fig. 2 shows the cladding temperature of each fuel group at the 16th node which is the location of maximum temperature in the axial direction. The peak temperature occurs in the blowdown phase and the value of hottest pin (fuel group 1, cadct-61601) is 1,195 K. And reflood peak is 931 K. The last fuel quenching is ended about 700 sec, which is rather longer compared with that of usual LBLOCA analysis results. It must be attributed to the fact that the SCDAP model has no Reflood option which can takes 2-D heat conduction into account for large axial variation of wall temperatures by means of the fine mesh rezoning scheme. In the box of Fig. 2, the effect of Reflood calculation is compared using RELAP 5. The reflood peaks are same but the quenching time is much shortened to 260 sec from 720 sec.

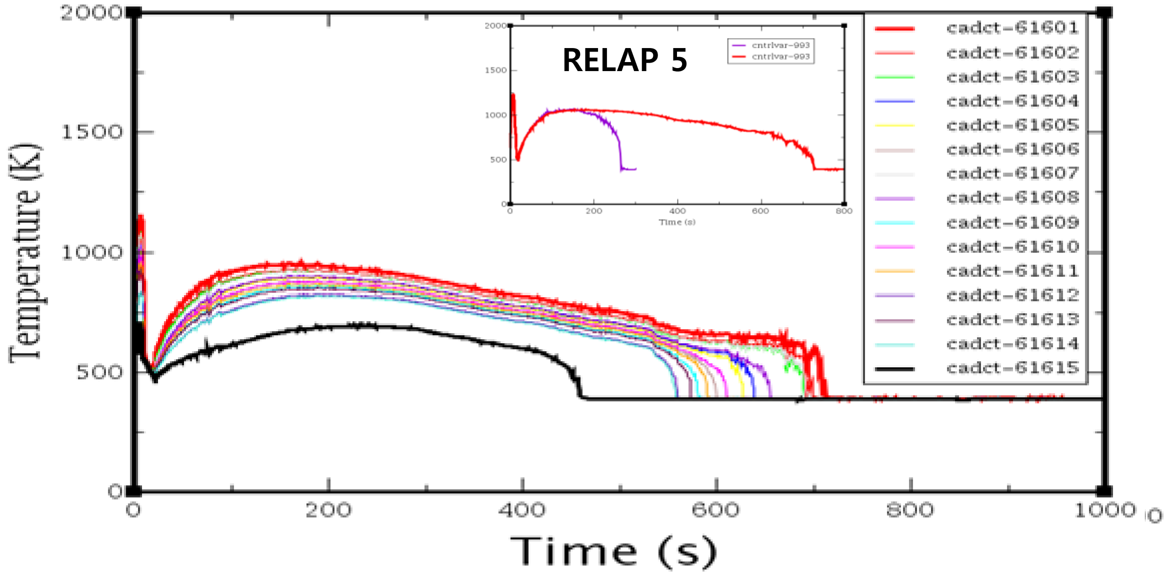

Fig. 2 Cladding temperaure changes of fifteen fuel groups during LBLOCA for OPR-1000

In Fig.3, the oxidation heat generation in Zircaloy cladding is shown. According to the results, there exists some additional chemical reaction heat to the cladding around the blowdown peak region where the temperature is above 1,000 K during the LBLOCA. The maximum amount is 3.2×10^5 W at 6.4 sec which is just 0.1 % of decay heat at that time. Therefore, it does not contribute much to the cladding temperature increase.

Fig. 4 demonstrates the variations of hoop strain for all fifteen fuel groups. The hoop strains start to increase and reach its maximum at the reflood peak temperature, not at blowdown peak with higher temperature. The value is about 0.06 at fuel group 1 (hoop-1601), but it is actually far below than the cladding rupture condition of 0.18.

Fig. 5 shows the pressure changes of reactor core system and fuel rod internal gas. As expected, the RCS pressure drastically decreases after the large break happens in the cold leg pipe. The gas pressures of fuel groups decrease also at the blowdown phase to some extent, but afterwards increase and stay for a while and decrease again over the reflood phase. The maximum gas pressure through the reflood phase is of fuel group 14 which belongs to the 3rd cycle with lower power than the average. However, no claddings go down to the RCS pressure which means any cladding does not experience the rupture during the LBLOCA in the analysis.

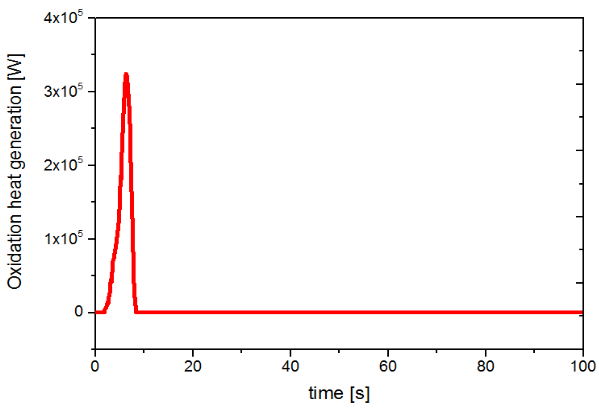

Fig.3 Oxidation heat generation

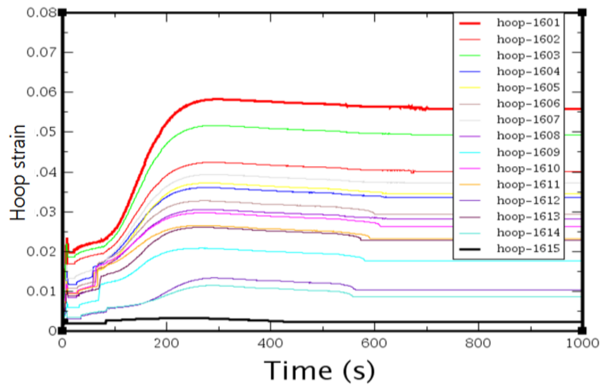

Fig. 4 Hoop Strain Variations

3. Conclusions

A LBLOCA-based scenario for the OPR-1000 was analyzed to investigate the capability of SCDAP/ RELAP5 using a burn-up dependent reload core model. It was turned out that 2-D heat conduction model should be furnished in the SCDAP fuel models for the best-estimate approach in the reflood stage. The material degradations associated with the fuel burn-up effect were not taken into account, except for internal gas pressure increase in the fuel due to fission gas release. In this work, as a main result, cladding deformation and rupture were investigated but no ballooning rupture was anticipated under the postulated LBLOCA scenario examined here for OPR-1000. More conservative input should be surveyed through the uncertainty analysis in terms of the thermo-mechanical behaviors.

ACKNOWLEDGEMENT

This work has been carried out under the Nuclear R&D Program supported by the Ministry of Science,) ICT & Future Planning. (NRF-2017M2A8A5015064

REFERENCES

[1] NUREG/CR-6150, INEL-96/0422 Revision 2, "SCDAP/ RELAP5/MOD3.3 CODE MANUAL," 2001.

[2] T.H Chun, et al, "*Cladding Deformation and Rupture Estimation during SBLOCA with SCDAP/RELAP5*," KNS Autumn Meeting, Korea, Oct. 27-28, 2016.

[3] R-L Julio, et al, "*Thermomechaical analysis of LBLOCA sequence in a PWR-Westinghouse 3 Loop with TRACE5 patch4*," NURETH-11, Korea, Oct. 9-13,2016.

[4] Heng Xie,"*Numerical simulation of AP1000 LBLOCA with SCDAP/RELAP 4.0 code*," J. of Nuclear Science and Technology, vol.54, No 9, 969-976, 2017.

[5] K.H. Bae et al, "*Performance evaluation of annular fuel in OPR-1000 plant during an LBLOCA*," *NTHAS6*, Japan, 2008

[6] D.H. Hwang et al, "*Evaluation of Physical Characteristics of PWR Cores with Accident Tolerant Fuels*," KNS Autumn Meeting, Oct. 29-30, 2011.

Table 1 Fuel grouping in the core in terms of fuel cycle and power

Fuel Cycle / Ass'y Power, BU Data / Coolant Channels & Ass'y Layout		1st cycle (Fresh)				2nd cycle (Once Burned)				3rd cycle (Twice Burned)			
		ID	Power Factor	BU[1] (IGP[2])	Fuel Rods	ID	Power Factor	BU (IGP)	Fuel Rods	ID	Power Factor	BU (IGP)	Fuel Rods
Hot Ass'y	Hottest Fuel	1	1.54	0 (9.21)	8	3	1.33	21,1 (10.5)	8	5	1.14	30.7 (11.2)	8
	Hottest FA	2	1.40	0 (9.21)	1880	4	1.20	18.9 (10.3)	1880	6	1.07	28.7 (11.0)	1880
Other Fuel Ass'ies	High P. FAs	7	1.33	0 (9.21)	1888	10	1.12	20.8 (10.5)	4720	13	0.98	38.3 (11.8)	2832
	Med P. FAs	8	1.21	0 (9.21)	6608	11	1.07	22.7 (10.6)	4720	14	0.84	39.9 (11.9)	2124
	Low P. FAs	9	0.98	0 (9.21)	6720	12	0.83	19.4 (10.4)	3776	15	0.37	40.2 (11.9)	4720

[1] Burn-Up (unit: GWd/MTU), [2] internal gas pressure (unit: Mpa)

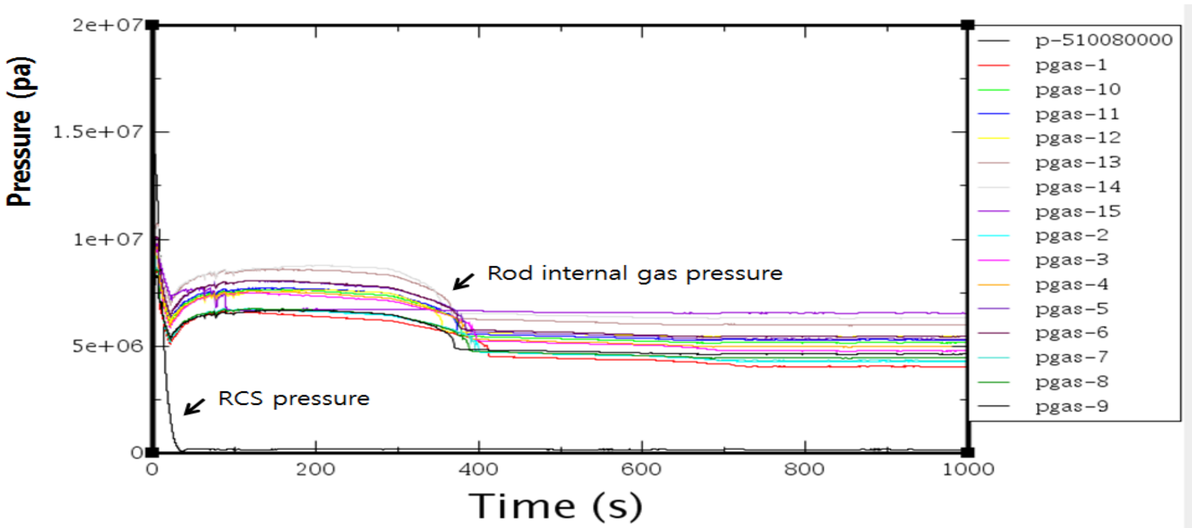

Fig.5 Pressure Variations in RCS and Cladding Internal gases