Cladding Deformation and Rupture Estimation during SBLOCA 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

A recent regulation trend for the LOCA accident is moving toward a level of fuel performance-based analysis in the Peak Cladding Temperature evaluation. So to speak, more realistic situation associated with material degradation and failure has to be taken into account, for example cladding embrittlement as burn-up increase and cladding ballooning/rupture during the transition. Particularly for the ballooning-and-burst, besides a flow area reduction it would cause an additional heat generation as well due to a cladding internal oxidation through the opening and possibly local power augmentation at the humped zone resulting from fragmented pellet relocation.

SCDAP/RELAP5 code [1] has a set of the cladding deformation and rupture models for the early phase progression over up to the fuel melting. However, there has been little work in the assessment of the capability of SCDAP/RELAP5 in terms of a thermo-mechanical behavior of the cladding in the LOCA accident [2]. In this regards, some analysis was performed for the estimation of cladding deformation and rupture with the SCDAP/ RELAP5.

2. Methods and Results

A unique SBLOCA-based scenario for OPR-1000 was postulated for this work. A break of 1.5 inch at a cold leg with one-out-of-two HPSI available is assumed. In order to make the scenario worse, it is also assumed that HPSI performance degraded down to 14 % because of the accumulation of non-condensable gas in the suction pipe connected to the RWST.

2.1 Analysis Model

The OPR-1000 system was modeled and nodalized in [3]. But to represent the actual reload core configuration, a burn-up dependent core model is newly developed here. Regarding the coolant flow passages, hot and average channels are formulated to analyze the core thermal-hydraulics and interconnected through junctions to allow cross flows along the axial direction via mass, momentum and energy balances. The active core region is axially divided by 12 volumes. Pertaining to the burn-up-specific fuel arrangement, all the fuel rods in the core are actually divided by 15 groups in terms of fuel cycle and assembly power. The overall core model is schematically depicted in Fig. 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. These six fuel groups belong to the hot channel. On the other hand, the remaining nine fuel assemblies in the core too divided by fuel cycle. These assemblies are categorized into three fuel groups on the basis of power (i.e. the high, medium and low) and included in the average channel.

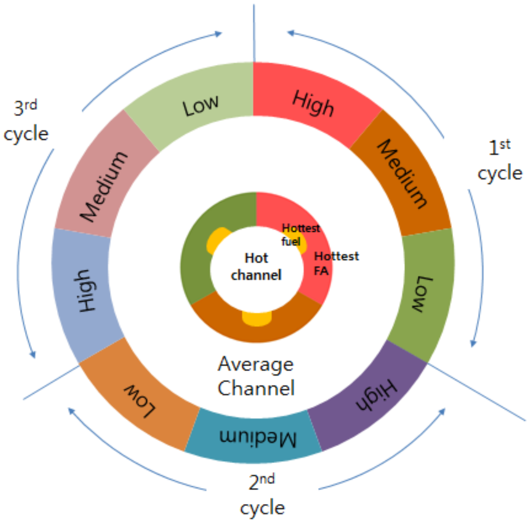

Fig. 1. Core hydrodynamic channel/fuel arrangement model

An octagonal-symmetric core physics data for the OPR-1000 was used, which corresponds to the BOC and all rod out condition with Xenon equilibrium at full power [4]. For an axial power shape a top skewed peak of AO=0.3 is chosen conservatively because upper part of the fuels is uncovered during the transient period of interest. Table 1 is the results of the fuel grouping and burn-up data on the above mentioned method. The initial gas pressure in the gap between cladding and pellets is simply determined by the burn-up condition. A typical relationship is shown in Fig.2. Generally, the more burned fuel group has lower assembly power factor but higher gas pressure. The gap conductance of the fuel for the analysis was not given as input but calculated by the code.

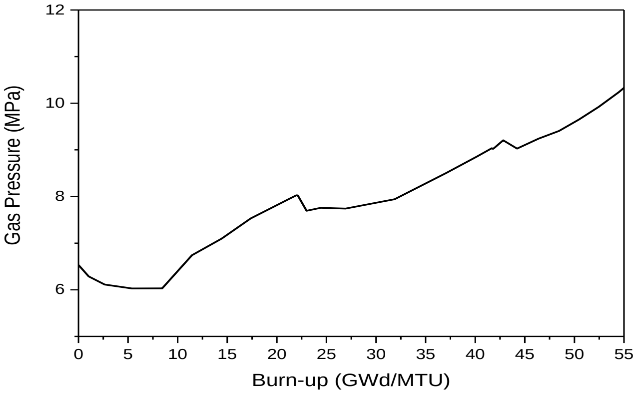

Fig. 2. Fuel burn-up vs. Gas pressure

2.2 Analysis Results

Fig. 3 demonstrates the variations of hoop strain for three cases. The lower cladding rupture strain means earlier start of the internal oxidation heat generation, and, accordingly larger total oxidation heat generation as shown in Fig. 4. It is also noticed that once the ballooning begins, as magnified in the circle for the 18% case in Fig.3, approximately after 5 minutes later the cladding burst happens. Fig.5 shows the PCT variations for 5, 10, and 18% rupture hoop strain cases; maximum values are 1190K, 1184K, and 1114K, respectively.

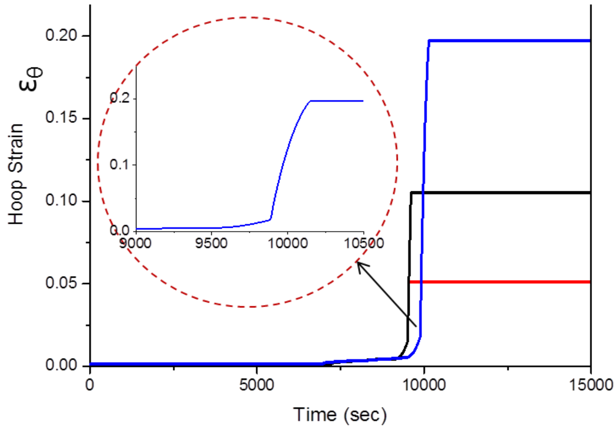

Fig. 3 Hoop Strain Variations and Ruptures

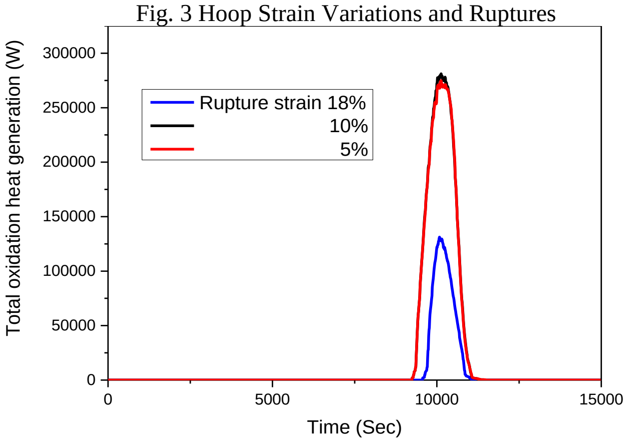

Fig. 4 Total Oxidation Heat Generation

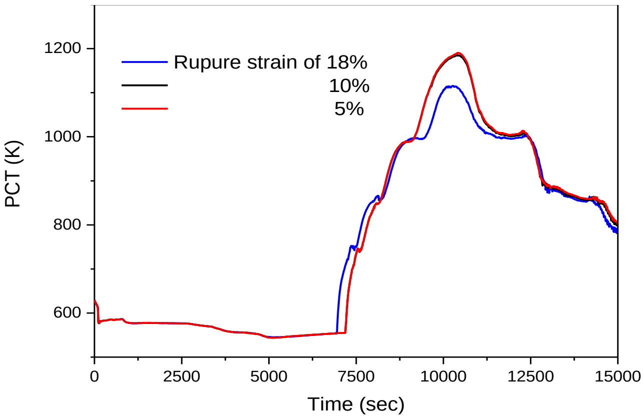

Fig. 5 PCT Variations

Fig. 6 shows the pressure variations of the RCS and cladding inside gas pressures. At a certain point around 10,000 seconds, the first burst occurred in the fuel group 3 (not fuel group 1 with highest power) having the 3rd high in power and the 2nd low in BU. The fuel group which experiences the burst goes quickly down in the pressure exactly identical to the RCS pressure. The next burst order was 1, 5, 4, 2, 6, 13 and 14. Actually the fuel group 14 has a power factor of 0.84 which is much lower than the average. So, not only power factor but also the burn-up have to be accounted in assessment of the cladding deformation and failure. Other fuel groups of 7, 8, 9, 10, 11, 12, and 15 are just ballooned without failure. From these results, it is estimated that approximately 25% of fuels in the core would be ruptured in this SBLOCA scenario.

3. Conclusions

A SBLOCA-based scenario for the OPR-1000 was analyzed to investigate the capability of SCDAP/RELAP5 using a burn-up dependent reload core model. Regarding the estimation of cladding deformation and rupture in the core during the accident, it can provide very useful information. However, to get more reliable results the user input for the rupture criterion has to be obtained through cladding-specific data base.

ACKNOWLEDGEMENT

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Table 1. Fuel assembly grouping and burn-up data in the core

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 Channel	Hottest Fuel	1	1.54	0 (6.21)	8	3	1.33	21,1 (7.49)	8	5	1.14	30.7 (8.17)	8
	Hottest FA	2	1.40	0 (6.21)	1880	4	1.20	18.9 (7.34)	1880	6	1.07	28.7 (8.03)	1880
Average Channel	High P. FAs	7	1.33	0 (6.21)	1888	10	1.12	20.8 (7.47)	4720	13	0.98	38.3 (8.76)	2832
	Med P. FAs	8	1.21	0 (6.21)	6608	11	1.07	22.7 (7.60)	4720	14	0.84	39.9 (8.89)	2124
	Low P. FAs	9	0.98	0 (6.21)	6720	12	0.83	19.4 (7.38)	3776	15	0.37	40.2 (8.92)	4720

$^{1)}$ Burn-Up (unit: GWd/MTU), $^{2)}$ internal gas pressure (unit: Mpa)

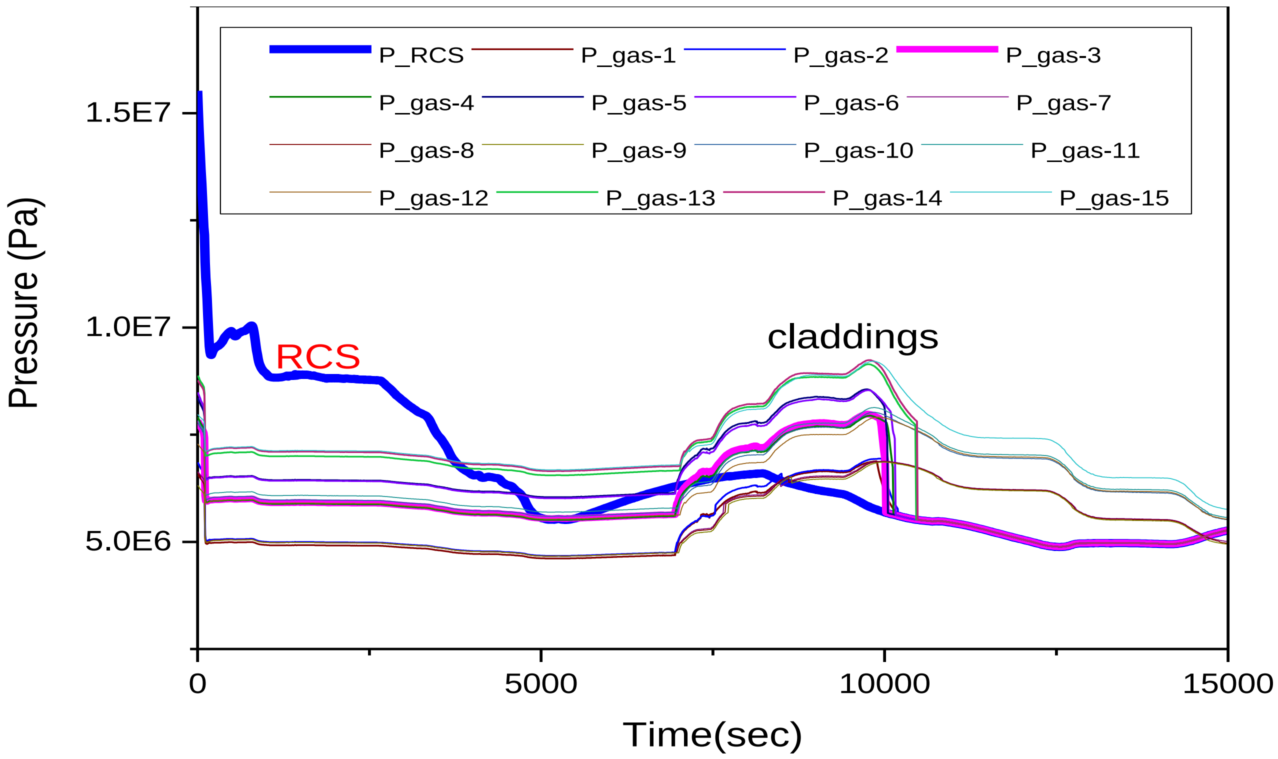

Fig.6 Pressure Variations in RCS and Cladding Internals