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Assessment of Conservative Core Conditions for LBLOCA in APR1400 using TRACE code

Hyungjoo Seo*, Byung Gil Huh
Korea Institute of Nuclear Safety, 62 Gwahak-ro Yuseong-gu Daejeon Korea
**Corresponding author: hjseo@kins.re.kr*

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1. Introduction

The APR1400 nuclear reactor design has recently undergone licensing procedures, including operating permits for Saeul Unit 3&4. The SPACE code is adopted for evaluating Emergency Core Cooling System (ECCS) performance in Saeul Unit 3&4[1]. As it become significant to independently verify ECCS performance of APR1400, this study employs the TRACE code to analyze a Large Break Loss-of-Coolant Accident (LBLOCA) scenario. Given the rising interest in safety criteria for high-burnup fuel, which considers burnup as a important factor in LOCA analyses, this study focuses on the impact of burnup and power distribution on LBLOCA outcomes. Four core conditions were established to examine these variables systematically, with the primary objective of identifying the most conservative conditions leading to the highest Peak Cladding Temperature (PCT).

2. LBLOCA calculation based on core conditions

2.1 Code and Core Conditions

The TRACE code[2], developed by the U.S. Nuclear Regulatory Commission (USNRC) since the mid-2000s, integrates the strengths of RELAP5 and TRAC codes to meet the demands of multi-dimensional analysis. TRACE patch 5 was selected for this study. In a previous study[3], TRACE code input for APR1400 reactors was developed and its applicability to LBLOCA analysis was validated. Building upon the previous study, the reactor core was modeled two flow paths: an average channel representing 240 fuel assemblies, and a hot channel representing a single fuel assembly with the highest power density. Within the hot channel, the hottest fuel rod is explicitly modeled.

Core conditions were established based on the core information of Saeul Unit 3&4, which is under regulatory review for an operating license since 2022 and represent a typical APR1400 reactor. With the increasing focus on safety criteria for high-burnup fuels, burnup has become a critical factor in LOCA analysis. Accordingly, a burnup sensitivity analysis was performed as part of the ECCS performance evaluation for Saeul Unit 3&4[1]. Reflecting this approach, the rod burnup was included as a key variable in the analysis for this study. The axial power distribution, which significantly affects the cladding temperature, was also considered. These two parameters were varied to construct four different core conditions (Cases 1 to Case 4), as summarized in Table 1.

The first variable considered was rod burnup, focusing on two specific conditions: 0 GWD/MTU and 30 GWD/MTU. The 0 GWD/MTU case represents the condition with the largest gap between the pellet and cladding, leading to minimal gap conductivity. Otherwise, the 30 GWD/MTU case corresponds to the maximum burnup range without applying the power reduction effect, resulting in higher stored energy in the fuel pellet. The effects of fuel burnup were incorporated by adjusting the heat structure of the average channel, hot channel, and hot rod, particularly in terms of fuel rod geometry and the material properties of the pellet and cladding.

The second variable was the power peaking factor (F_q). An F_q value of 2.31 represents the normal operating condition with a cosine-shaped axial power distribution, while an F_q value of 2.497 reflects a highly conservative condition with a top-skewed axial power distribution. The applied power distributions are illustrated in Fig. 1. To implement the in the TRACE input, axial power distribution was reflected.

Table 1: Core conditions of burnup and F_q

Case number	Core Conditions
Case 1	Rod burnup 0 GWD/MTU & Fq=2.31
Case 2	Rod burnup 0 GWD/MTU & Fq=2.497
Case 3	Rod burnup 30 GWD/MTU & Fq=2.31
Case 4	Rod burnup 30 GWD/MTU & Fq=2.497

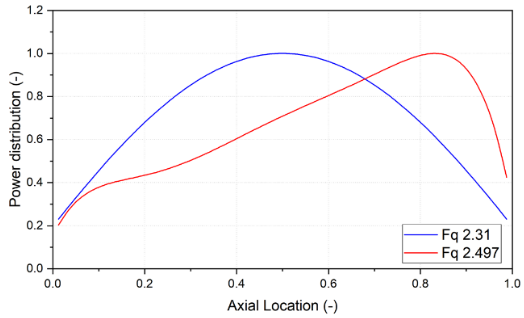

Fig. 1. Axial core power distribution according to F_q (Normalized by the maximum value)

2.2 Results

The LBLOCA transient analysis was performed under the following assumptions and operational conditions. It was assumed that a 100% double-ended guillotine break occurs in a cold leg coincident with a Loss of Offsite Power (LOOP). For the single failure assumption, one Emergency Diesel Generator (EDG) is considered unavailable, resulting in the failure of two Safety Injection Pumps (SIPs). Major input parameters for the transient analysis are summarized in Table 2.

Fig. 2 and 3 presents the LBLOCA analysis results for each core condition. The behavior of cladding temperature during the transient shows two temperature peaks. The first peak occurs due to coolant stagnation immediately after the break, while the second peak arises from continued coolant loss that leads to core uncover. The quenching time varied depending on the core conditions, which consequently affected the PCT results. Meanwhile, the collapsed level in the core doesn't shows the big difference. The PCT results for each core condition (Cases 1 to Case 4) are summarized in Table 3. The most limiting condition was observed in Case 4, where 30 GWD/MTU burnup and a high F_q value were applied. This result can be attributed to the increased temperature in the upper core region, which is caused by the top-skewed power distribution and the reduced heat transfer efficiency resulting from the degradation of thermal conductivity at high burnup levels. As a consequence, the concentration of heat generation in the upper core region led to the highest temperature observed during the reflood phase.

Table 2: Input parameter for LBLOCA transient calculation

Parameter	Input
Core and RCS	
Core power	3,983 MWt
Power distribution	Fig. 1
Decay heat	ANS-79
Mass flow rate in hot leg	10,494.4 kg/s
Pressure in PZR	15.51 MPa
Safety injection	
SIT pressure	4.245 MPa
SIT temperature	302.5 K
SIP injection temperature	302.5 K
Delay for SIP injection	40 seconds
Containment	
Pressure in containment	Atmospheric pressure

Table 3: PCT results of Case 1 to Case 4

	Case 1	Case 2	Case 3	Case 4
PCT (K)	996.85	1040.96	1027.00	1105.77

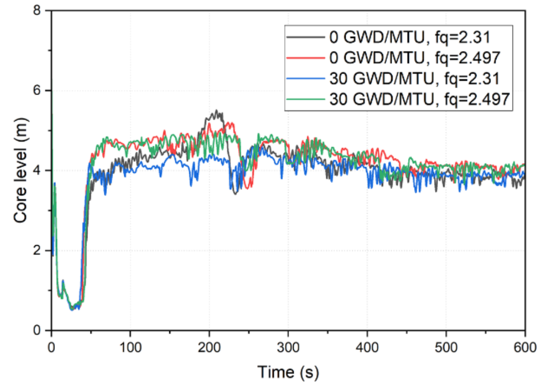

Fig. 2. Core level during LBLOCA transient

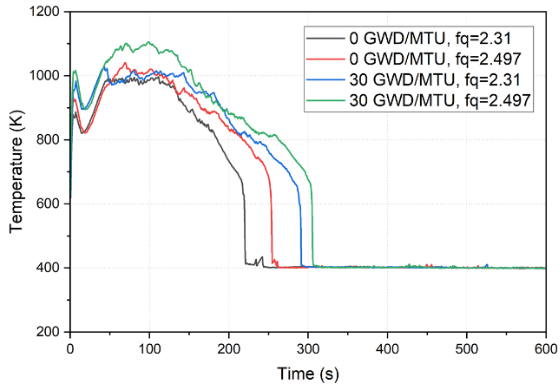

Fig. 3. Cladding temperature during LBLOCA transient

3. Conclusions

This study performed an LBLOCA analysis using the TRACE patch 5 code to evaluate the ECCS performance of APR1400 reactors. By systematically varying the core conditions with rod burnup and power peaking factors, the study identified the most conservative scenario as the combination of 30 GWD/MTU burnup and a high power peaking factor ($F_q = 2.497$). This condition resulted in the highest PCT, emphasizing the critical impact of core condition on thermal-hydraulic behavior during LB LOCA. Based on these findings, future work will focus on performing best-estimate analyses with uncertainty evaluations for APR1400 LBLOCA scenarios using the TRACE code.

REFERENCES

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