Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Impacts of Fuel Rod Burst Criteria on LOCA Safety Analysis

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1. Introduction

For the period of large break loss-of-coolant accident (LBLOCA), fuel rod can be ruptured due to the excessive plastic deformation of zirconium alloy cladding at high temperature. This deformation and rupture process is typically called as ballooning and burst. Cladding ballooning can reduce the sub-channel flow area and consequently flow blockage may occur in the worst condition. Heat conduction from fuel pellet to coolant is also strongly affected by the gap width, which can be varied with the extent of ballooning. Thereby prediction of cladding ballooning and burst is important to LOCA safety analysis.

Typically, two types of cladding burst criteria at high temperature are established, a strain-based or a stress-based[1,2]. These criteria are fully empirical. In this paper, effects of fuel rod burst criteria on the peak cladding temperature(PCT) and oxidation for the LOCA period were assessed. FRAPCON-4.0 and FRAPTRAN-2.0 fuel performance code were utilized[3,4].

2. Analysis Details

2.1 Rod burst criteria

Two different cladding burst criteria were used in this study. Fig. 1(a) shows a stress-based burst criterion, which is adapted in FRAPTRAN-2.0. Fig. 1(b) shows a well-known NUREG-0630 burst strain criterion(fast ramp). For the uncertainty study, uncertainty of burst stress was prescribed as +100/-40MPa, and minimum burst stress was set to 10MPa. Uncertainty of burst strain was set as +100/-80%.

2.2 Analyzed safety analysis condition

Initiation of LOCA was supposed to occur at the fuel burnup of 30MWd/kgU. Peak linear hear rate before LOCA was set to 14.5 kW/ft. PLUS7 fuel with ZIRLO cladding was utilized, and 20 evenly spaced axial nodes were allocated at the fuel rod. FRAPTRAN-2.0 transient fuel performance code was used in this calculation.

Thermal-hydraulic boundary conditions, such as coolant heat transfer coefficient(HTC), coolant pressure and temperature during LOCA period were obtained from APR1400 LBLOCA analysis. LOCA analysis was performed by using the MARS-KS1.3, which is a regulatory auditing system code. More detailed information about the analysis can be founded in ref. 5.

Fuel rod ballooning and burst phenomena strongly depend on the rod internal pressure(RIP), heat transfer coefficient of coolant, and fuel thermal conductivity(FTC). Thereby, uncertainties of RIP, HTC and FTC were also considered, and these were assumed as ±2σ, ±50%, and ±2σ, respectively. Initial fuel performance at the fuel burnup of 30 MWd/kgU before LOCA was analyzed by FRAPCON-4.0. For the

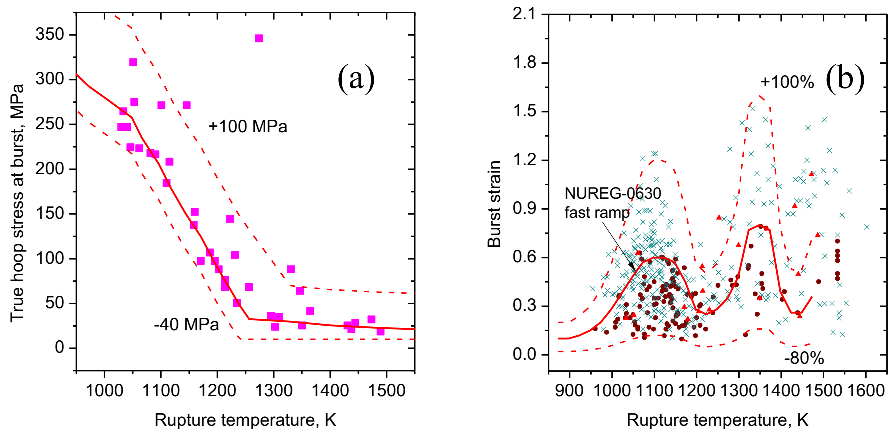

Fig. 1. Considered fuel rod burst criteria and their uncertainty. (a) cladding true hoop stress, adapted in FRAPTRAN-2.0, and (b) NUREG-0630 fast ramp cladding hoop strain criteria.

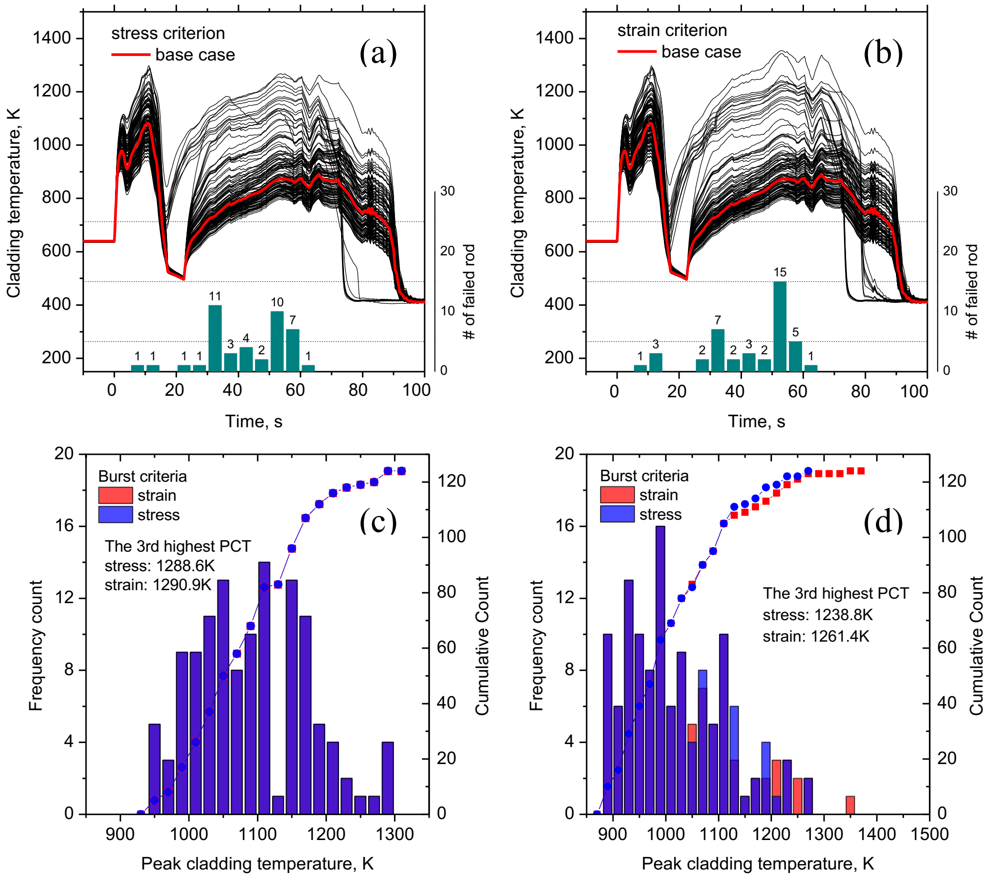

Fig. 2. 124 cladding temperature behaviors during LOCA as (a) a stress and (b) a strain burst criteria applied. The distribution of (c) blowdown and (d) reflood PCT. Uncertainty of burst criteria was not considered.

combined uncertainty analysis, 124 code runs based on simple random sampling were carried out.

3. Results

3.1 Cladding temperature

Fig. 2 shows the 124 cladding temperature behaviors as the stress and strain burst criteria applied. In this calculation, uncertainties of burst criteria were not factorized, but other uncertainties such as RIP, FTC and HTC were considered. Basically, there are no significant differences between two analysis results. Blowdown peak cladding temperatures(PCTs) are almost identical, and the third highest blowdown PCT is 1288.6K and 1290.9K as the stress and strain rupture criteria applied, respectively. The difference of the third highest PCT is only about 2K. In case of reflood PCTs, some differences were observed. The third highest reflood PCT is 1238.8K and 1261.4K as the stress and strain criteria were used, respectively. The difference is about 23K. This implies that the strain based NUREG-0630 cladding burst criterion is not exactly equivalent to the stress criterion, adapted in FRAPTRAN-2.0. The number of burst fuel rods and occurrence times of rod failure during LOCA are also very similar. Burst rods are 42 and 41 as the stress and strain criteria applied, respectively. Failing times are ranging from 10 to 60 seconds after LOCA initiation in either case.

Effects of burst criteria uncertainty, described in section 2.2, were evaluated as well. Generally, there are no significant influences. As the burst strain uncertainty involved, the reflood PCTs were only varied with small

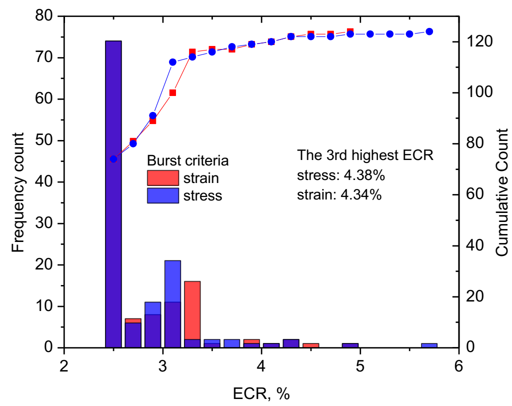

Fig. 3. Cathcart-Pawel(C-P) ECR distribution as the stress and strain criteria applied.

amounts. The third highest reflood PCT changed about 7K. But burst stress uncertainty did not induce any differences on the blowdown and reflood PCTs. This is explained that ballooning is localized phenomenon and once the ballooning model activated in FRAPTRAN, no further strain is calculated for any axial nodes. And cladding burst occurs within a few seconds after cladding ballooning started.

3.2 ECR

Fig. 3 shows the predicted Cathcart-Pawel equivalent cladding reacted(C-P ECR) as the stress and strain criteria applied. Even though the highest and the second highest one were predicted in small difference, the third highest ECR was almost identical(~4.3%) between two cases. Furthermore, both burst criteria uncertainties do not induce any meaningful differences in $ECR_{95/95}$ also.

4. Summary

Effects of cladding burst criteria to the fuel rod performance for a LOCA period were assessed. Stress-based(adapted in FRAPTRAN-2.0) and strain-based(NUREG-0630 fast ramp) burst criteria were used in this analysis. Followings are identified.

- Blowdown PCT and ECR were almost not changed depending on the burst criteria. But small differences on reflood PCT were discovered.
- Burst criteria uncertainties do not induce any meaningful effects on the PCT and ECR.

Above results are valid within current analysis conditions. If the heat transfer coefficients were influenced by the extent of cladding ballooning, above conclusions might be changed.

ACKNOWLEDGMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KOFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea.

REFERENCES

1. Ali R. Massih, Lars Olof Jernkvist, "Assessment of data and criteria for cladding burst in loss-of-coolant accidents", SSM 2015:46, ISSN:2000-0456
2. D.A. Powers, R.O. Meyer, "Cladding swelling and rupture Models for LOCA analysis", NUREG-0630, 1980
3. KJ Geelhood, WG Luscher, JM Cuta, IA Porter, "FRAPTRAN-2.0: Computer Code for the Transient Analysis of Oxide Fuel Rods", PNNL-19400, Vol.1 Rev2., 2016.
4. KJ Geelhood, WG Luscher, PA Raynaud, IA Porter, "FRAPCON-4.0: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Duel Rods for High Burnup", PNNL-19418, Vol.1 Rev2., 2015.
5. Shah Asad Ullah Amin, Young Seok Bang, Joo-Seok Lee, "Assessment of post-LOCA long-term cooling considering the in-vessel downstream effect", Annals of Nuclear Energy 110 (2017) 63–72.