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Preliminary Study on Effect of the Crud Deposits during LBLOCA Condition

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1. Introduction

The severe crud deposits on fuel rod could result in the increment of the fuel temperature during the operation of nuclear power plants. The crud inhibits heat transfer, causing the cladding temperature to increase due to the low thermal conductivity. In the event of LBLOCA at the NPP operated with heavy crud layers, the peak cladding temperature (PCT) will be higher than it would be if the cladding were clean. Therefore, NRC has been reviewing a petition for rule making to set the limit of crud and/or oxide thickness. Also, it requires that LOCA analysis be calculated by factoring the role of crud [1].

Since the crud deposits caused the stored energy in the fuel to increase, it could influence the following requirement: *The Initial Stored Energy in the Fuel* in Appendix K to Part 50 – ECCS Evaluation Models, to require that the steady-state temperature distribution and stored energy in the fuel at the onset of a postulated LOCA. Also, safety review guidelines in NUREG-0800 [2] state: "*Oxidation, hydriding, and the buildup of corrosion products (crud) should be limited. Allowable oxidation, hydriding and cure levels should be discussed in the safety analysis report and shown to be acceptable.*" Therefore, the LOCA analysis is needed to understand the PCT changes due to the crud deposits.

In this study, as the preliminary study on effect of the crud deposits, the sensitivity study in terms of parameters on fuel performance have been carried out in LBLOCA condition. And the importance of the crud deposition on LOCA condition has been discussed.

2. LBLOCA analysis

The effect of the crud deposition can not be factorized in RELAP5 code. Therefore, the internal stored energy, oxide thickness and gap internal pressure obtained by FRAPCON-3 were used to evaluate their influences on the PCT during LBLOCA. Generally, the gap conductance is one of the most important parameters to influence the stored energy. The gap conductance model is a function of the mole fraction of gases, width of fuel gap, the surface roughness, etc. However, the gap conductance values obtained by RELAP5 do not meet the results of FRAPCON-3 due to the difficulty in considering all corresponding parameters. Therefore, the sensitivity of the internal stored energy on the PCT is evaluated by changing the internal heat source multiplier in RELAP. The sensitivity of the oxide thickness and internal pressure is also evaluated. For the LBLOCA analysis, the Westinghouse 3-loop plant was used with assumption of 100% reactor power and 7% steam generator tube plugging. From the FRAPCON-3 analysis[3], the maximum stored energy appeared not at the BOL fuel but at the fuel burnup of 28 MWd/kgU, irrespective of crud accumulation rates. Therefore, input values for LOCA analysis were obtained at that burnup. The internal stored energy (ΔE) was expressed as a function of equivalent total oxide thickness ($\delta_{equi-tot}$) from the results of FRAPCON-3. Equivalent total oxide thickness for the thin layer crud can be obtained by the following relation.

$$\delta_{equi-tot} = \delta_{oxide} + (k_{oxide}/k_{crud}) \times \delta_{crud} \quad (1)$$

where, δ_{oxide} and δ_{crud} is the thickness of the oxide and crud, and k_{oxide} and k_{crud} is the thermal conductivity of oxide and crud, respectively.

3. Sensitivity study

The sensitivity study of the stored energy, oxide thickness and the internal gap pressure on the PCT changes during LBLOCA have been performed by using the Table I.

Table I. Evaluation conditions for sensitivity analysis

Increment of source multiplier, %	0 (Base)	3	6	9	12	15
Internal gap pressure, MPa	8.15	8.38	8.63	8.89	9.14	9.41
Oxide thickness ($\delta_{equi-tot}$), μm	14.5	50.6	86.7	122.8	158.9	194.9

Fig. 1 shows the fuel and cladding temperature at the specific elevation (about 2.10 m above the fuel bottom, which is the peak power location) of the fuel rod in steady-state condition. The fuel centerline and average temperature is linearly proportional to the internal heat source multiplier. Centerline temperature changed from 1726 to 1964 K as the stored energy increased from 0 to 15%. The average fuel temperature was also increased from 1152 to 1260 K. In base case, the fuel and cladding temperature showed a relatively good agreement between the RELAP5 and FRAPCON-3 results.

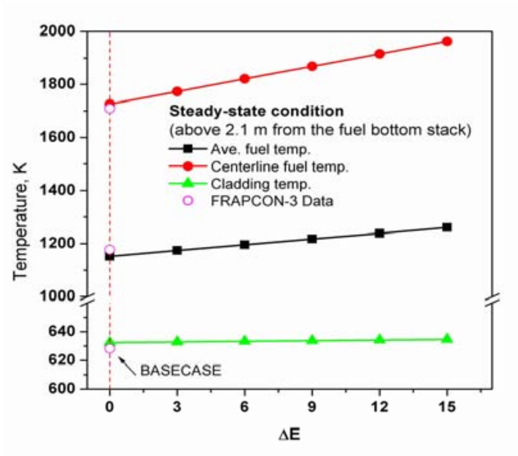

Fig. 1. Fuel and cladding temperature as a function of the stored increment in steady-state condition

In sensitivity studies, six different cases were considered the changes of the initial stored energy, oxide thickness and the internal gap pressure in Table I, respectively. The changes of the blowdown PCT are shown in Fig. 2 for the stored energy increment. As expected, the fuel stored energy affects the blowdown PCT such that about 48 K PCT rise with the 15% stored energy increment. This value is not great but it will be significant to the plant that has small safety margin to the maximum PCT criteria and uses the best-estimate method with uncertainty analysis in LOCA calculation. Thereby, the more detailed analysis method will be necessary to fully consider the fuel rod conditions.

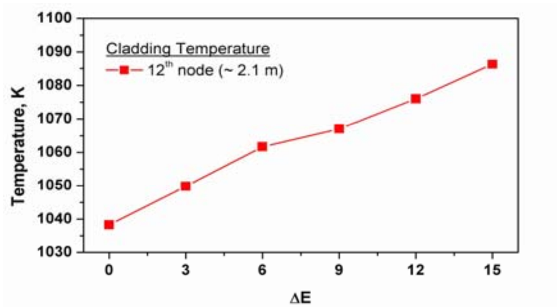

Fig. 2. Blowdown PCT change as a function of the stored energy increment during LBLOCA condition

Fig. 3(a) and (b) shows the effects of the oxide thickness and internal gap pressure on the blowdown PCT, respectively. As shown in Fig. 3(a), the effect of the oxide thickness is negligible since the oxide thickness is used only for the calculation of metal-water reaction in RELAP5 and it does not alter the overall heat transfer mechanism of the cladding due to the increment of oxide thickness. However, the blowdown PCT was reduced to about 12 K as the internal pressure increased from 8.1 to 9.8 MPa. This may be resulted from the increment of gap conductance. The increase in gap conductance due to the increases of internal pressure results in the cladding temperature decrease. From these results, we could know that the effect of oxide thickness and internal pressure was not significant to the PCT change in LBLOCA anlaysis by using RELAP5.

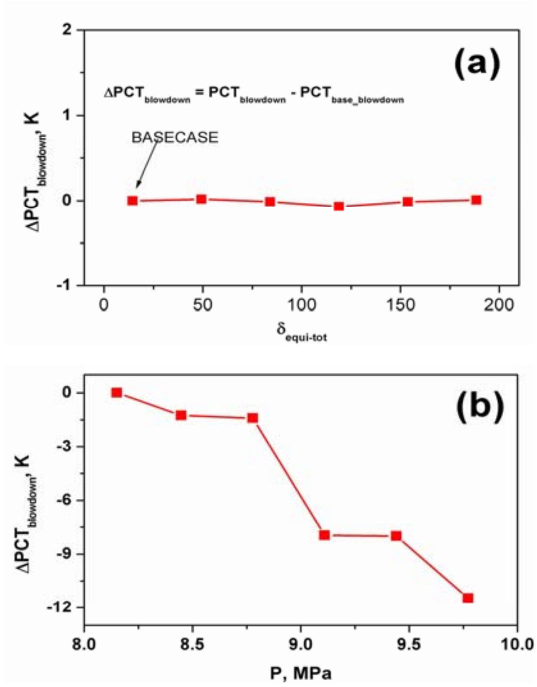

Fig. 3. Blowdown PCT change as function of (a) the oxide thickness and (b) internal pressure

4. Conclusion

Based on the results of FRAPCON-3, the PCT changes in the LBLOCA analysis have been performed for various stored energy conditions. The increment of stored energy due to the crud deposits resulted in the PCT rise during blowdown phase in LBLOCA. The results indicated that it is important to consider the crud deposits in steady-state and transient condition of LBLOCA and the more detailed analysis of LBLOCA by reflecting the crud buildup would be needed.

REFERENCES

[1]NRC Docket No. PRM-50-84, located at: www.nrc.gov, Electronic Reading Room, ADAMS Documents, Accession Number: ML070871368, May 27, 2007.

[2] USNRC, Standard Review Plan, NUREG-0800 R3, 1996.

[3] J.S. Lee and et al., Effects of crud on the fuel rod integrity in steady-state and LBLOCA condition, 2008 WRFPM, Seoul, 2008.