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Impacts of Fuel Rod Performance to the Safety Analysis

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1. Introduction

The current licensing fuel burnup was achieved almost twice as great as expected when the fuel was used in 1970s. And in these days the fuel has been used more harsh environments than the previous ones. Thereby, the performance of fuel rod in the core was changed significantly. For example, at the same power levels the fuel temperature was increased due to the thermal conductivity degradation(TCD) of the UO_2 pellet, and cladding temperature was increased also due to the growth of zirconium oxide layer as well as the deposition of crud layer on the cladding surface. Rod internal pressure(RIP) was increased also because of the acceleration of fission gas release(FGR) with burnup increase. These altered conditions of fuel rod probably can influence the results of safety analysis by changing its initial conditions.

Meanwhile, for the assurance of fuel rod integrity and coolability during the steady-state operation, anticipated operational occurrences and design basis accidents, regulators imposed safety criteria related to the fuel temperature(enthalpy), heat flux and cladding temperature[1]. But unfortunately altered fuel rod performance stated above will reduce the margins to the safety criteria. Thereby, in this paper we assessed the impacts of changed fuel rod performance to the safety analysis. And based on the assessment results required research for further in detail analysis was discussed as well.

2. Analysis Details

For the evaluation of impacts of rod performance to the safety analysis with burnup increase FRAPCON3.4 and FRAPTRAN1.4 code were utilized. And following assumptions and methodologies were used.

- Considered fuel rod burnup and peak linear heat rate(LHR) for safety analysis was 30MWd/kgU and 14.2kW/ft, respectively.
- Uncertainty of the thermal conductivity of UO_2, FGR, thickness of oxide was modeled in FRAPCON3.4 already and its range was assumed as ±2σ in this study. Uncertainty of thickness of crud layer was set as 0~30 μm. Uncertainty of thermal conductivity of oxide and crud was assumed as 0.5~1.1 and 0.5~1.5, respectively.
- Sampling probability density function(PDF) was assumed as a uniform distribution except for the thermal conductivity of crud and UO_2 fuel. These were assumed as a normal.
- Non-parametric order statistics approach was utilized for the evaluation of rod performance. For this, several sets of 124 FRAPCON and FRAPTRAN inputs were produced by the simple random sampling(SRS) technique.
- Except for the uncertainty parameters described above, additional 28 uncertainty parameters(28P) were also included in the 124 SRS analysis. Detailed information on these parameters can be founded in ref.[2].
- An error of FRAPTRAN1.4 code was fixed because it cannot calculate the temperature rise properly due to the oxide layer during the transient calculation mode.

3. Results and Discussion

3.1 Changes of fuel rod initial conditions

Fig.1 shows the stored energy(SE) distribution of UO_2 fuel at the fuel burnup of 30MWd/kgU. This reveals the effect of thermal conductivity uncertainty(TCU) to the SE. Within the assumption of TCU, ±2σ, the SE was changed about -12%~+17% with respect to the base case. But, as the TCU was not factorized, the SE was changed about only –2%~+2%. As the authors identified already in the previous study, the SE of the 30MWd/kgU fuel was increased about 12.5% with

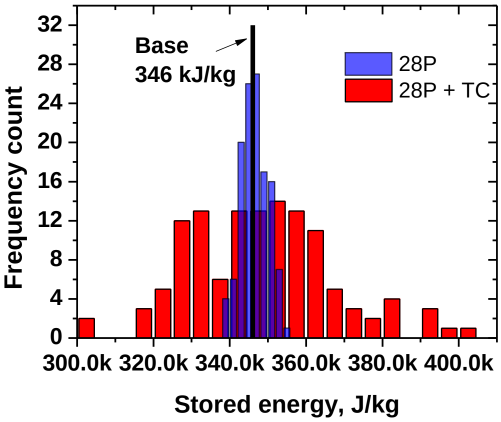

Fig.1. Stored energy distribution with the consideration of TCU at the fuel burnup of 30MWd/kgU.

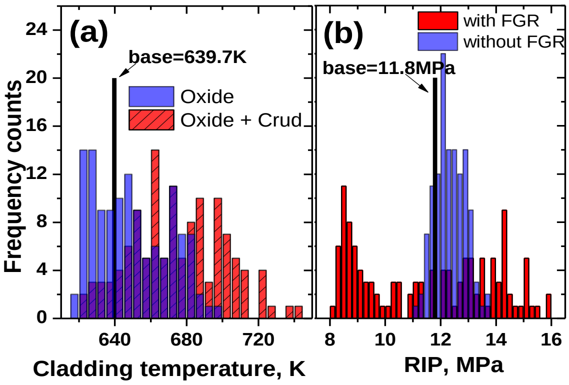

Fig.2. Frequency counts of (a) outer diameter cladding temperature and (b) rod internal pressure at the fuel burnup of 30MWd/kgU.

respect to the 0.5MWd/kgU fuel due to the TCD effect[3]. Thereby if the effect of TCU is combined with the TCD, it will result in even stronger impacts to the safety analysis.

Fig.2 shows the cladding temperature and RIP at the fuel burnup of 30MWd/kgU. When the oxide uncertainty was taking into account alone, the cladding temperature was ranging about 620~690K. But the uncertainty of crud was factorized altogether it was ranging about 620~740K. The RIP was ranging about 8.5~15.7MPa when the uncertainty of FGR was considered. But If the uncertainty of FGR was not taking into account, it was ranging about 11.2~13.6MPa. These results revealed that the uncertainties such as the TC of UO_2, oxide, crud and FGR could induce significant impacts to the initial conditions of fuel rod.

3.2 Impacts of initial conditions to the PCT during LOCA analysis

Fig. 3 shows the effects of initial fuel rod conditions to the peak cladding temperature(PCT) during LBLOCA. And the third highest PCTs in 124 SRS analysis were summarized in Table 1. If the 28 uncertainty parameters(28P) were considered, as shown in fig.3(a), the increase of the third highest PCT with respect to the base case was not so much. But as the TCU was factorized, shown in fig.3(b), the blowdown and reflood PCT was increased about 37K and 57K, respectively.

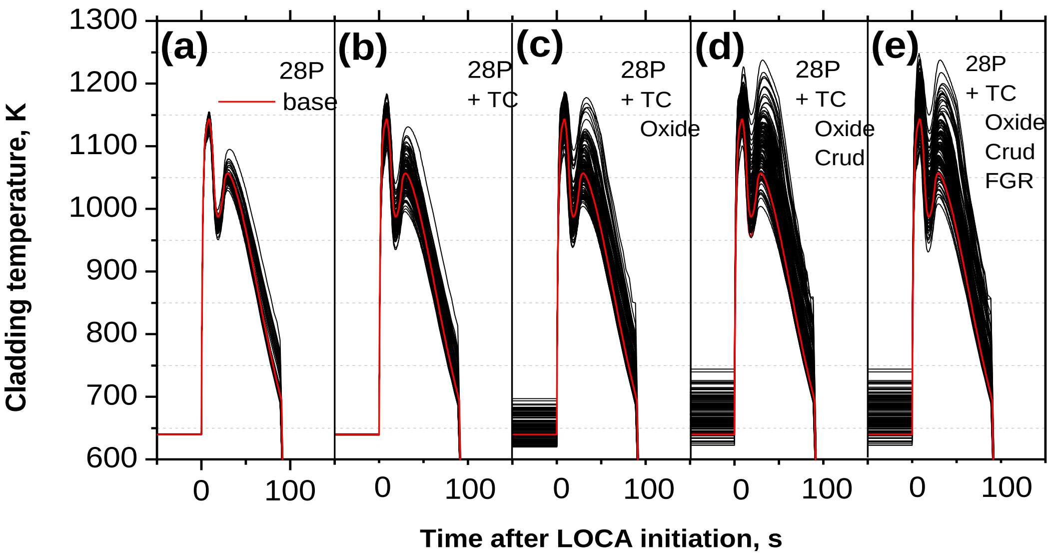

Fig.3. Effects of uncertainty parameters on the 124 cladding temperature evolution curves during LOCA at the fuel burnup of 30MWd/kgU. (a) 28 uncertainty parameters(28P), (b) 28P + TC of UO_2, (c) 28P + Oxide, TC, (d) 28P + oxide, crud, TC, (d) 28P + TC, oxide, crud, FGR.

Table 1. Changes of the third highest PCT and rod internal pressure(RIP) in 124 SRS depending on the combined uncertainty parameters.

	$PCT_{blowdown}$ ( )*, K	**$PCT_{reflood}$, K**	**RIP, MPa**
Base	1143.4	1056.7	11.8
28P	1154.2(+10.8)	1079.0(+22.3)	12.5(+0.7)
28P + TC	1180.5(+37.1)	1114.2(+57.5)	12.4(+0.6)
28P + TC, Oxide	1184.0(+40.6)	1162.0(+105.4)	12.9(+1.1)
28P + TC, Oxide, Crud	1202.4(+59.0)	1211.3(+154.6)	13.5(+1.7)
28P + TC, Oxide, Crud, FGR	1237.9(+94.5)	1200.1(+143.4)	15.7(+3.9)

*Values inside of ( ) are representing the variations of PCT and RIP with respect to the base case

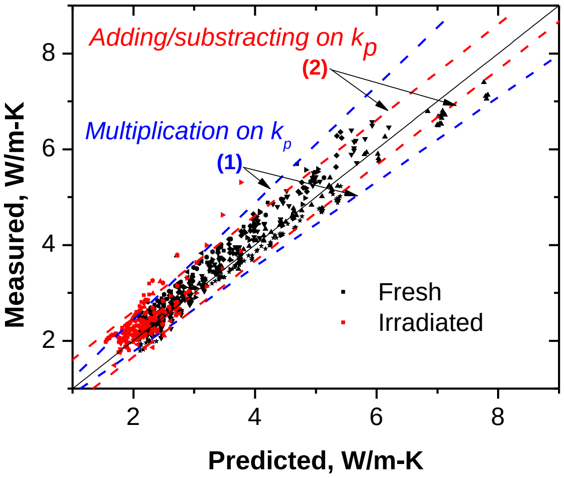

Fig. 4. Measured and predicted thermal conductivity of UO_2 fuel evaluated by modified NFI model.

And as the oxide uncertainty was taking into account with the TCU, fig.3(c), the PCT was increased also but the impact was not significant. However, as the uncertainty of crud was considered with the uncertainty of oxide and TC, fig.3(d), the blowdown and reflood PCT was increased about 59K and 159K, respectively. In this situation as the uncertainty of FGR was added additionally, fig.3(e), the blowdown and reflood PCT increased about 95K and 143K, respectively.

3.3 Required research works for future in detail analysis

Analysis results shown in section 3.2 revealed the importance of the selection as well as the determination of each uncertainty. Fig. 4 shows the measured and predicted thermal conductivity of UO_2 fuel. Modified NFI model was used in this analysis. As we can see in the figure the number of irradiated fuel data is limited. And it is not clear which ways is more proper to represent the model uncertainty. For example, the model uncertainty should be set in terms of the multiplication factor(line 1 in Fig.4) or just adding/subtracting the conductivity to the model(line 2 in Fig.4). And measurement uncertainty needs to be accounted for the evaluation of the model uncertainty.

Uncertainty on the thermal conductivity of zirconia is also important, but it is not known clearly. In this study we assumed it as 0.5~1.1. The lower bound was taken from the differences of the conductivity model between the FRAPCON and MATPRO. But, according to the data described in NUREG/CR-7024, the lower bound seems to be reached up to about 0.2[4]. Thus, this should be clarified further.

In a case of crud, the uncertainty of thickness and its thermal conductivity was not evaluated so far. In this analysis the thickness of crud was assumed as 0~30 μm based on the information of occurrences of axial offset anomaly. For the uncertainty of crud conductivity, if sub-cooled nucleated steam bubbles are encapsulated in the porous crud layer, significant conductivity deterioration will be expected because of the lower thermal conductivity of steam phase. On the other hand, there is possibility that the increase of the conductivity depending on the crud characteristics. Therefore further research would be required to clarify these uncertainties in detail.

4. Summary

The impacts of rod performance to the safety analysis with fuel burnup increase were evaluated by considering the performance uncertainty. Evaluation was carried out by utilizing the FRAPCON/FRAPTRAN code. Following results can be drawn.

- Fuel rod performance which could be represented as the fuel stored energy, cladding temperature, rod internal pressure was strongly affected by the uncertainty parameters.
- Among the many numbers of uncertainty parameters, thermal conductivity of UO_2, thermal conductivity and thickness of oxide and crud layer, FGR played major role to the rod performance. And as expected, these also resulted in significant impacts to the LOCA safety analysis.
- However, uncertainties on these parameters were not identified clearly so far. Therefore, further research in this area is demanding for in detail analysis.

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