The Effect of Fission Gas Release on Reactivity Initiated Accident

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1. Introduction

Reactivity Initiated Accident (RIA) causes the sudden insertion of reactivity into the core due to a circumferential rupture of the control element drive mechanism (CEDM) housing or the CEDM nozzle in PWR. As a result of RIA, fuel rod and reactor core can be damaged. As shown in the CABRI and NSRR RIA experiment data from the early 1990s, unexpected fuel rod damage occurred in the high-burnup fuel behavior. Lately, U.S.NRC has issued the draft regulatory guide for RIA[1].

One of the draft guides about the fuel cladding failure is High Temperature Cladding Failure Threshold which is expressed in total peak radial average fuel enthalpy (cal/g) versus fuel cladding differential pressure (MPa). To evaluate the satisfaction of the draft guide, a conservative Rod Internal Pressure (RIP) calculation which considers transient fission gas release (FGR) is required.

In this paper, the empirical transient FGR model is applied to SPACE code in order to evaluate the RIP calculation during transient and other consequences.

2. Methods and Results

The transient FGR model and its implementation method in SPACE code are described. The results of transient FGR model are compared with those of original model.

2.1 Fission Gas Production Calculation

To calculate the transient FGR, the deposited fission gas production amount in fuel rod is required. It is expressed as a function of fuel rod burnup and described as following equations.

$$F_g = 2.7 \times 10^{15} \times m \times BU \times r$$

where,

F_g = Fission gas production(Atoms)

m = Uranium mass in a fuel rod(g)

BU = Fuel rod burnup(MWd/MTU)

r = Fission gas fraction in total fission amount

2.2 Fission Gas Release Model

The fission gas in the gap and plenum increases as the fuel burning progresses. As the fission gas release increases, the RIP is increased and thermal conductivity of the gap is decreased.

Fission gas in the gap and plenum consists of steady-state initial fission gas and transient fission gas which releases with the fuel burning. The amount of steady-state initial fission gas is obtained from the fuel rod design code which uses diffusion model. And the amount of transient fission gas is calculated using the empirical transient FGR model which recommended by NRC in draft regulatory guide[1]. The empirical transient FGR model is expressed as following equations.

$$\text{Transient FGR}(\%) =$$
$$(0.26 \times \Delta H) - 5, \text{ for BU } \geq 50 \text{ GWd/MTU}$$
$$(0.26 \times \Delta H) - 13, \text{ for BU } < 50 \text{ GWd/MTU}$$

where,

ΔH = peak radial average fuel enthalpy rise (cal/g)

2.3 Implementation

The transient RIP is calculated using the constant moles of gap gas in the current SPACE code. The constant moles of gap gas is calculated from steady-state initially using ideal gas raw. To calculate the transient FGR, some procedures are added to SPACE code in transient state calculation. Fig. 1 shows the original method and new method on SPACE code. In new method, steady-state calculation method for initial moles of the gap gas is same, but enthalpy rise calculation, fission gas production calculation and transient FGR calculation models are added.

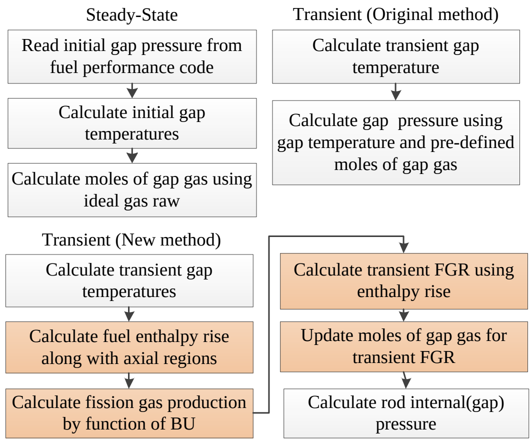

Fig. 1. Steady-state and transient FGR method

2.4 Rod Internal Pressure and Other Result

Control Element Assembly Ejection (CEAE) accident has conducted to evaluate the effect of transient FGR. To evaluate the satisfaction of the high cladding temperature failure criteria suggested by NRC, CEAE accident analysis is performed at HZP EOL condition. The RIP calculation results with original and new method are compared in Fig. 2 through Fig.6.

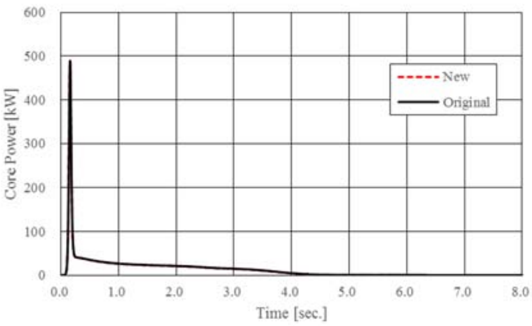

Fig. 2. Core power result according to each model

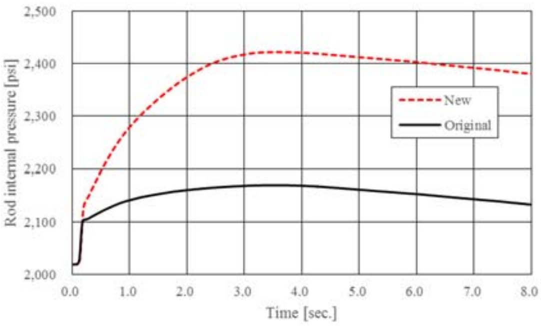

Fig. 3. RIP calculation result according to each model

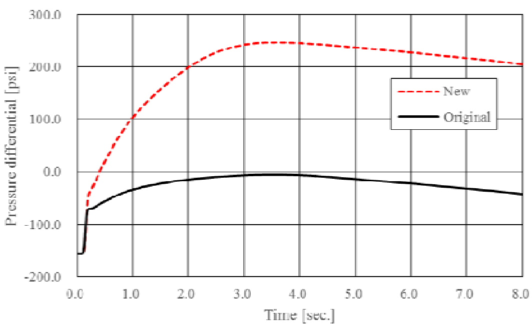

Fig. 4. Pressure differential result according to each model

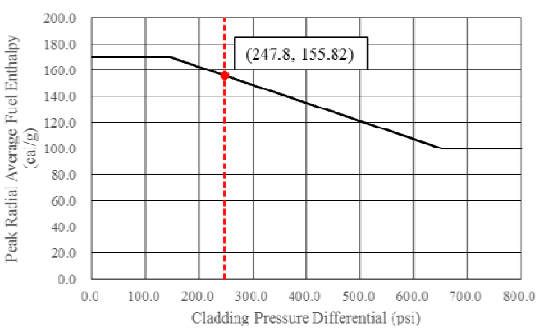

Fig. 5. High temperature cladding failure threshold [1]

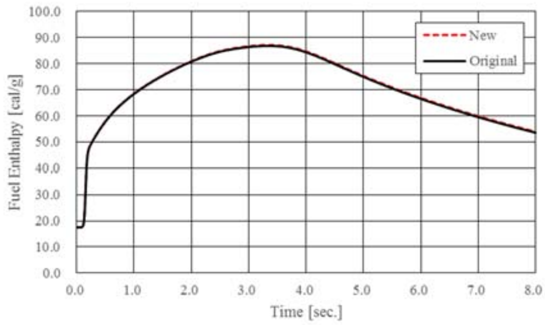

Fig. 6. Fuel enthalpy result according to each model

Fig. 2 shows typical core power behavior of CEAE accident in HZP condition. Fig. 3 shows RIP is increasing about 2,400 psi and Fig. 4 shows pressure differential is increasing about 250 psi with new model. Thus the maximum enthalpy criteria as a function of the pressure differential (about 250 psi) is calculated as about 155 cal/g in Fig. 5. As shown in Fig. 6, maximum enthalpy (about 87 cal/g) in the new model is met a criteria of draft guide.

The other effect of transient FGR is the changes of the gap gas compositions. SPACE code uses five gas compositions which are He, Ar, Kr, Xe, N. Major gas components released from transient FGR is Xe(85%), Kr(15%). And the conductivity of Xe, Kr is lower than the other gases. As a result of increasing of these noble gases, thermal conductivity of gap is decreasing than the original method.

Fig. 7 shows the degradation of thermal conductance in the gap caused by transient FGR. Table. I shows that the result of maximum temperatures and enthalpy rise in the hot spot region does not have significant changes.

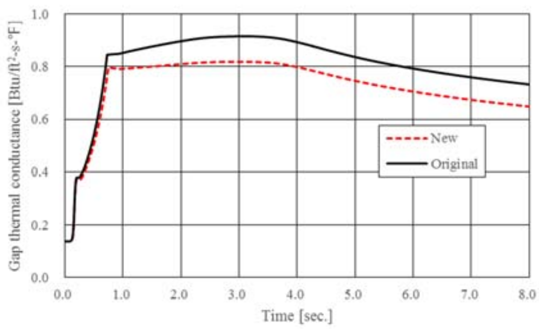

Fig. 7. Thermal conductance result of the gap according to each model

Table. I: Maximum temperatures and enthalpy rise result

	Original method	New method
Max. centerline temperature(˚F)	2912	2914
Max. clad temperature(˚F)	946.8	945.0
Max. enthalpy rise (cal/g)	69.3	69.6

3. Conclusions

In this paper, the effect of transient FGR model on RIA is studied using SPACE code. To evaluate the effect, transient FGR model and fission gas calculation model are added to the code.

The results show that the transient FGR model increases the RIP and the differential pressure. Based on the increased differential pressure, the maximum enthalpy criteria can be calculated with the high temperature cladding failure threshold which NRC suggested. And the maximum enthalpy calculated in this paper is satisfied with the threshold.

REFERENCES

[1] U.S. NRC, Pressurized Water Reactor Control Rod Ejection and Boiling Water Reactor Control Rod Drop Accidents, Draft Regulatory Guide DG-1327, November 2016.