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Phenomenological Modeling of Fission Gas Release in LWR UO_2 Fuel under RIA Conditions

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1. Introduction

Several analytical attempts have been made so far to develop a fission gas release model for RIA conditions considering both fuel and test conditions. However, mechanistic approaches to correlate observed fission gas release with fuel and accident conditions have not been successful partly because the number of gas release data points is limited and the number of factors that should be considered is rather large.

With the available data in open literature on gas release in LWR UO_2 fuel, a phenomenological model based on experimental observation is developed which can predict FGR under RIA conditions using parameters fuel average burnup, peak enthalpy and pulse width. These parameters are considered because they either affect the fission gas inventory available for release or determine the release paths that are operable during RIA.

2. Phenomenological modeling

It is generally known that FGR under RIA conditions increases with burnup and peak enthalpy together with the fact that it increases as the pulse width becomes shorter. However, it is difficult to apply this explanation to all the cases because several factors affect the FGR simultaneously and the final FGR would depend on which factor would be dominant for a particular test.

For example, it can be seen in Fig. 1 that FGR during RIA is not proportional to the pellet average burnup because other factors except for the burnup had larger effect on FGR. As for the peak enthalpy, the same argument can be applied. Therefore, in this paper, a phenomenological model is developed.

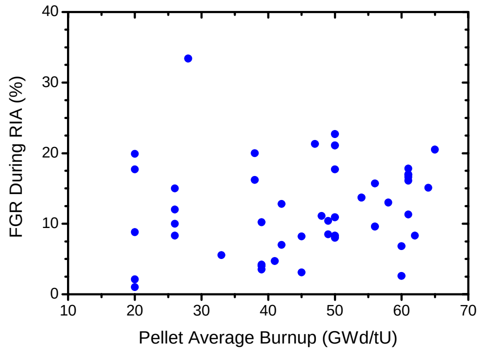

Fig. 1. FGR during RIA as a function of pellet average burnup.

2.1. FGR in the HBS region

It has been observed that during RIA majority of the fission gas retained in the high burnup structure (HBS) region of fuel pellet is released from the grain boundary due to grain separation and subsequent pellet fragmentation caused by the rapid thermal expansion of intergranular gas bubbles. The degree of grain separation and pellet fragmentation depends on the peak fuel enthalpy and pulse width. Therefore, based on RIA test results, it is assumed that fractional release from the HBS region during a RIA event can be described as follows:

$$fgr_{HBS} = f(inv_{HBS}) \cdot f(rel_{HBS}), \quad (1)$$

where fgr_{HBS} is the fractional gas release in the HBS region, $f(inv_{HBS})$ is the fractional inventory of fission gas in the HBS region (%), and $f(rel_{HBS})$ is the release fraction in the HBS due to grain separation and pellet fragmentation.

The fractional inventory in the HBS region is calculated using the following assumptions: 1) the bestestimate HBS width (w_{HBS}) is calculated by $6.7 \cdot 10^{-3}(Bu-30)(mm)$ [1], where Bu is the pellet average burnup, 2) the ratio of HBS burnup to pellet average burnup is 1.33 [2], and 3) the pellet radius (r_p) is 4.2 mm. Then $f(inv_{HBS})$ is calculated to be

$$f(inv_{HBS}) = 1.33 \cdot \left\{1-(1-w_{HBS}/r_p)^2\right\}. \quad (2)$$

The fractional release in the HBS obtained by analyzing the relationship between the release fraction of HBS inventory and the ratio of peak enthalpy (cal/g) to pulse width (ms), an indicator showing how fast energy is stored per unit time, is given by

$$f(rel_{HBS}) = 0.664 + 0.0192 \cdot \frac{peak\ enthalpy\ (cal/g)}{pulse\ width\ (ms)}. \quad (3)$$

If $f(rel_{HBS})$ is higher than 1 (one), it is taken to be 1.

2.2. FGR in the central region

Although fission gas is released mainly in the outer part of fuel pellet which experience rapid temperature increase, when the temperature in the central part of fuel pellet is also high due to large peak enthalpy, some amount of fission gas has been observed to be released in this region. The major part of release would have occurred in the grain boundary gas bubbles and some fraction of gas retained in the matrix could have been released by diffusion.

Using test results, it is assumed that the release in the central region is active if the peak fuel enthalpy is larger than 100 cal/g.

The additional release in the central part fgr_{center} during a RIA event is calculated as follows by analyzing the FGR data for the cases that the peak enthalpies are higher than 100 cal/g:

$$fgr_{center} = 3.89 + 0.012 \cdot peak\ enthalpy(cal/g)\ (\%). \quad (4)$$

2.3. Total FGR

Since the total release fgr_{RIA} during a RIA event is the sum of the release in the HBS and central region, fgr_{RIA} is expressed by

$$fgr_{RIA} = fgr_{HBS} + fgr_{center}. \quad (5)$$

3. Analysis of FGR data for RIA

Fig. 2 shows the comparison between the measured FGR and the calculated one by the phenomenological model developed in this paper for 28 data points. Except for 4 data, the present model predicts the FGR within the uncertainty of 5%. The average ratio of calculated to measured value was 1.10 and the standard deviation of the ratio was 0.32.

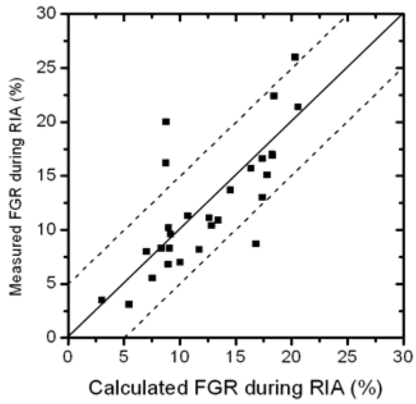

Fig. 2. Comparison of the FGR calculated by the phenomenological model with the measured one.

4. Conclusion

Based on the experimental observation on RIA tests, a phenomenological model was developed that can predict fission gas release under RIA conditions as a function of pellet average burnup, peak enthalpy and pulse width.

Acknowledgements

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REFERENCES

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