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Transient Fission Gas Release Model of the INFRA Code

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1. Introduction

A fission gas release is the most important phenomena for a light water reactor fuel performance. The fission gas release behavior during a slow power transient and a steady-state condition had been studied for a long time and many empirical and mechanistic release models have been proposed. Fundamentally, steady-state or slow power transient fission gas release depends on fission gas atom diffusion and inter or intra-granular bubble behavior. But transient fission gas release during rapid power change is different in release mechanism with steady-state release.

In this paper, we have proposed empirical transient fission gas release model. The developed model was inserted into the fuel performance code INFRA and compared with transient test results.

2. Empirical Transient Fission Gas Release Model

In a steady-state, the diffused fission gas atoms from the grain matrix trapped in the grain boundary or edge bubbles. By the inter-connection of the bubbles, the trapped fission gas atom can be released to the free rod volume when the bubbles become open to the external surface. As we know, during a rapid power increase(transient), high thermal stress could create cracks along the grain boundary[1,2]. These cracks can contact with grain boundary bubbles and offers the release path without bubble growth and inter-connection[3]. So, rapid power increase can cause the instantaneous fission gas release (=burst release). In steady-state fission gas release model of the INFRA code, gas concentration of grain boundary bubbles (Cgb) can be calculated at end of each time step and Cgb roles as a main inventory of transient fission gas release. The INFRA transient FGR model is affected by power ramping condition such as a terminal power level (P), power difference between P and a threshold power P_{thres}, and a model constant A.

$$\text{Release}=\text{Cgb}\times\text{TR},\quad \text{TR}=A\times(P-P_{thres})^2 \qquad (1)$$

Where

TR = Transient FGR fraction
A = model constant (1.63×10^{-3})
P = after transient power level [kW/m]
P_{thres} = Threshold power [kW/m]

P_{thres} and the model constant A were derived from various experimental data and they are currently fixed as 20kW/m and 1.63×10^{-3} respectively.

For a verification, the developed model is inserted into the fuel performance code INFRA FGR model and the measured transient FGR experimental data was compared with predicted ones.

3. Transient FGR experiment

As presented in our previous paper, many reliable experimental data was included in the FUMEX-II database[4]. Among them, 7 database were offered to verify the transient (rapid power ramp) fission gas release model. The power ramping tests were performed in research reactor such as Halden, DR-3 and Siloe by using the re-instrumented test rod after the base-irradiation in commercial reactor. Detailed fuel characteristics including the base irradiation information are summarized in Table 1.

Table 1. Characteristics of test fuel

Rod	Burnup (MWd/kgU)	Max. power (kW/m)	Base-Irr. Release (%)	After ramp release (%)
A	~59.3	30	< 2%	4.68
B	~59.3	29	< 2%	8.89
C	67~69.8	27.4	2.5	15.8
D	~42	38.4	< 2%	29.7
E	~42	41	< 2%	38.3
F	~42	41	< 2%	40.9
G	~53.5	35	< 2%	10

4. Comparison with experimental data

Figure 1 shows the power rating and fission gas release during the rod C test. Between a 67~67.7 MWd/kgU burnup, several ramp tests were performed and a burst fission gas release was measured. The final FGR was estimated as about 15.8% from rod puncturing. Figures 2 and 3 show the comparison results of rod E and F with the measured fission gas release data. Each figure shows the burst release of the fission gases at a power ramping point and model prediction result shows a good agreement with measured data. After the ramp test of rod D, a detailed EPMA test was performed to investigate the remaining fission gases distribution. Figure 4 shows the comparison results of the predicted remaining fission gas with the measured data. Though, there is small difference at r/r_0=0.6~0.7, predicted fission gas distribution shows a good agreement with the measured data. Figure 5 shows the synthetic comparison result of all seven experiments.

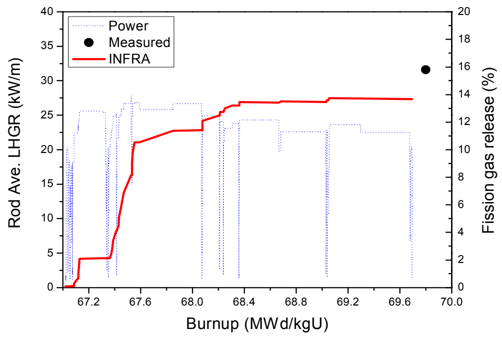

Fig 1. Fission gas release behavior of rod C

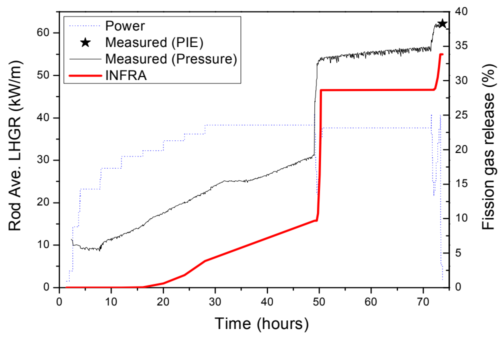

Fig 1. Fission gas release behavior of rod E

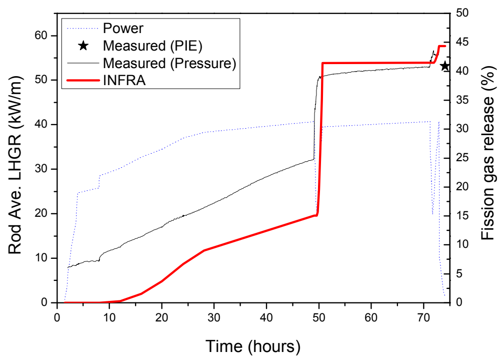

Fig 3. Fission gas release behavior of rod F

5. Results and Discussion

The empirical transient fission gas release model was developed and inserted into the fuel performance code INFRA. The burst fission gas release during the transient and the rapid power ramp condition can be calculated as a function of terminal power level and threshold power. By using the currently fixed model constants and threshold power, the predicted transient fission gas releases were compared with the FUMEX-II experimental results and they show a good agreement.

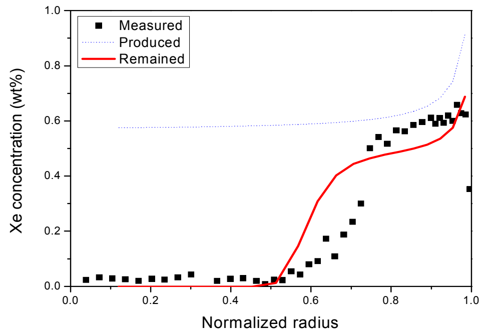

Fig 4. Radial fission gas distribution of rod D

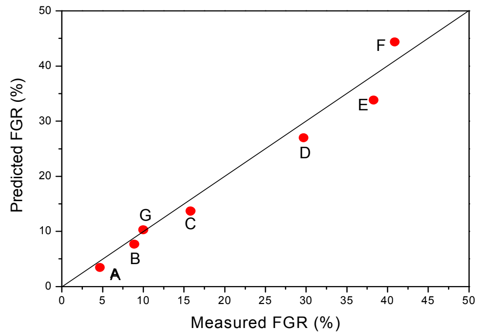

Fig 5. Transient FGR model verification result

6. References

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[4] Y. S. Yang, "INFRA Verification by Using the FUMEX-II Database", KNS Topical meeting, 29 Oct., 2004.