Implementation of transient FGR model in the MUECURY

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1. Introduction

During LOCA conditions, the fuel pellet will be subjected to a rapid increase in temperature, which may cause transient fission gas release (FGR) by mechanisms such as fuel micro-cracking. This phenomenon was observed in out-of-pile raid heating tests[1,2] and integral-type LOCA simulation tests[3,4]. The accurate prediction of fission gas release in the transient conditions is important in terms of rod internal pressure that determines the overall performance of fuel rod.

KAERI has been developing MERCURY[5], a FEM(finite element method)-based nuclear fuel analysis code, to simulate the fuel behavior during LOCA conditions. The MERCURY code needs a model that can predict the transient FGR under LOCA conditions.

In this paper, we described the implementation process of the transient FGR model in the MERCURY code. Also, the verification calculation result of the applied model was presented.

2. Transient FGR model in FRAPTRAN

The FRAPTRAN code is widely used to simulate the behavior of the fuel rods in a transient state[6]. FRAPTRAN has a model to calculate the transient fission gas release as a function of temperature. The transient fission gas release is highly dependent on the radial location of the gas in the fuel pellet and gas location (in the grains and the grain boundaries) in each radial node. For this reason, the transient fission gas release model in FRAPTRAN should be used as gas available for the transient conditions calculated by FRAPCON[7]. To do this, FRPACON must have been run with the FRAPFGR model, which is one of the fission gas release models.

This transient fission gas release model is described below:

- All grain boundary gas for a given radial node is released when the temperature exceeds 1093°C.

- All gas in the restructured grains (matrix) of the high burnup structure for a given radial node is released when the temperature exceeds 1816°C.

- Five percent of the gas in the unrestructured grains (matrix) for a given radial node is released when the temperature exceeds 1816°C.

3. Implementation of transient FGR model in MERCURY

3.1 Main parameters for transient FGR model

For prediction of fission gas release in the transient state, the transient FGR model reads the gas fraction located in the grain and grains boundaries, calculated by the FRAPFGR model in FRAPCON in the grains and the grain boundaries. For the FRAPFGR model, a high burnup structure model characterized by sub-micron grains and high porosity was considered. Table 1 shows the main variables in FRAPCON used in the transient FGR model.

Table 1. Main parameter for predicting transient fission gas release.

Name	Description	units
gasavail1	All grain boundary for each radial node	[-]
gasavail2	- gas in the restructured grain(matrix) for each radial node - 5% of gas in the unrestructured grains for each radial node	[-]
fmgp	fission gas production for each axial node	[moles]

3.2 Mapping from FRAPCON to MERCURY

MERCURY reads fuel performance results calculated by FRAPCON4.0P1 to reflect fuel performance data during steady state. However, the fuel performance results cannot be used directly because the mesh size of FRAPCON4.0P1 does not match that of MERCURY. So, a mapping methodology was proposed to solve this problem in MERCURY code.
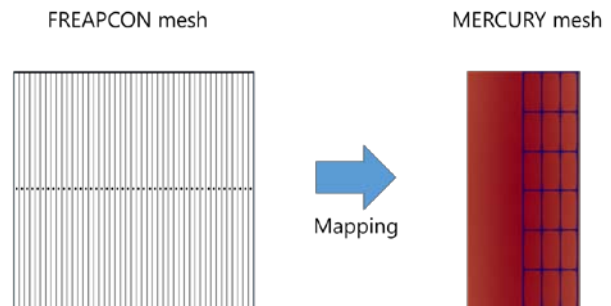

Figure 1. Gas available fraction mapping from FRAPCON to MERCURY

To take into account the gas fraction calculated by FRAPCON, the gas fraction (gasavail1 and gasavail2) of FRAPCON was mapped on that of the MERCURY mesh as shown in Fig. 1. In the mapping process, since gasavail1 in MERCURY was determined by the interpolation function, there is a difference between the total gas fraction in FRAPCON and the total gas fraction in MERCURY. For this reason, a scale factor was used to make the total gas fraction in MERCURY equal to the total gas fraction in FRAPCON.

3.3 Calculation of transient release of fission gases

Figure 2 shows a flow chart of the transient fission gas release model. Transient fission gas release was considered when the fuel centerline temperature calculated in MERCURY exceeds 1339K and 2089K.

When the temperature at the radial position of the fuel pellet exceeds 1339K and 2089K, the gas fraction released under transient state is determined by the temperature and time increment at each node of current timestep.

The number of moles of gas released in the transient state was determined by multiplying the gas fraction released in the transient state by the fission gas production. In addition, the total gas moles released during transient conditions were determined by dividing the total gas fraction by the total fission gas production. Finally, the total gas fraction released during the transient conditions was used to calculate the total amount of Xe and Kr released during the transient state.
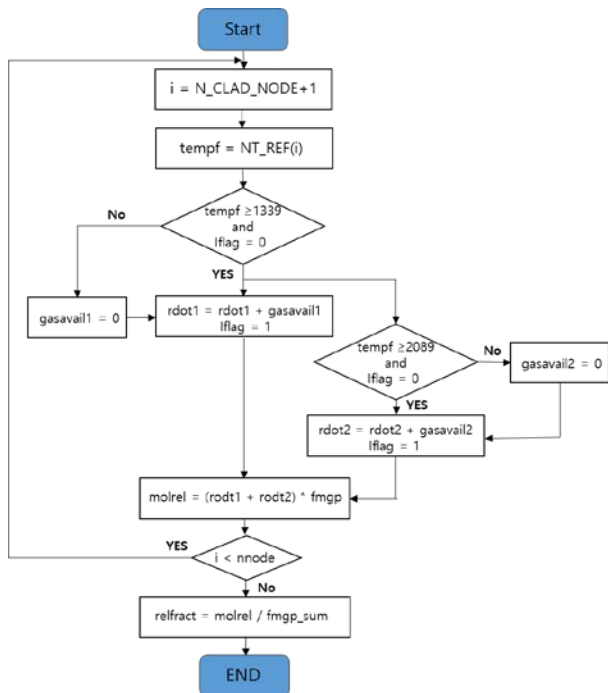

Figure 2. Gas available fraction mapping from FRAPCON to MERCURY

3.4 Evaluation of transient FGR model

For verification of the transient FGR model in MERCURY, the database of the IFA-650.5 test carried out in Halden was used. The rod power was modified to 5 kW/m to confirm the gas release from gasavail1 and gasavail2 in transient state. Figure 1 shows the peak fuel temperature and transient gas release when the rod power is 5 kW/m. At about 180s, when the peak fuel temperature exceeded 1339K, the gas stored in gasavail1 was released. In addition, at bout 240s, when the fuel temperature exceeded 2089K, the gas stored in gasavail2 was released. Through these results, it was demonstrated that the transient FGR model was implemented in MERCURY.
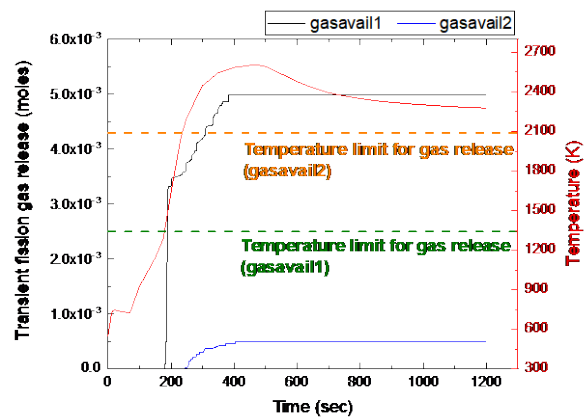

Figure 3. Transient fission gas release with temperature limit for gas release.

The total fission gas release change due to the additional fission gas in the transient state is shown in Figure 4. For without transient FGR model, the total gas moles were constant during transient conditions. However, for with transient FGR model, additional fission gas release occurred at about 180s, and then the total gas moles were increased up to about 400s. The additional fission gas release leads to an increase in rod internal pressure and a decrease in pellet-clad gap conductance.
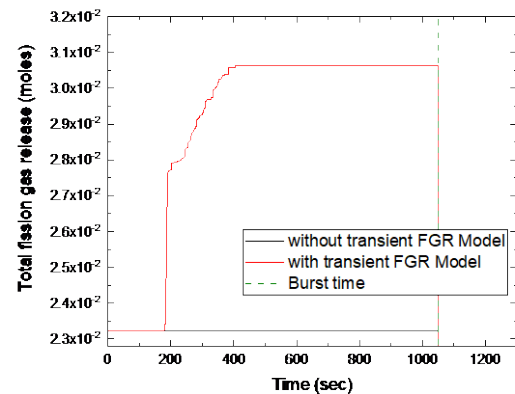
Figure 4. Comparison of total fission gas release with and without transient FGR model.

4. Conclusions

Implementation and evaluation of the transient FGR model in the MERCURY code were performed. Additional gas in the transient state is released from the gas available fraction calculated in the FRAPCON.

The mapping methodology was proposed due to the difference between FRAPCON mesh and MERCURY mesh. It was confirmed that transient gas release occurred when the temperature limit for gas release was exceeded. Since the additional fission gas release affects the internal pressure and gap conductance, it can be helpful to evaluate more realistic fuel behavior in transient fuel analysis.

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