Development of a Static Gap Pressure Model for the SPACE Code

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1. Introduction

The fuel gap model is very important in nuclear safety analysis since it plays a major role in determining the fuel temperature. Therefore, most of nuclear safety analysis codes have a fuel gap model with different modeling depth. In the fuel gap model, the gap pressure is one of the major factors. For example, RELAP5 or MARS, mainly used to analyze a large break loss of coolant accident (LB-LOCA), has a simplified gap pressure model based on the vapor temperature at the top of fuel rod [1]. Even the TRACE code has no gap pressure model [2]. On the other hand, RETRAN-3D [3], which is used for non-LOCA analysis such as a reactivity insertion accident (RIA), has a more realistic gap pressure model based on the gap volume and gap temperature including the plenum region of the fuel rod.

Although the SPACE code is equipped with a simple gap pressure model [4] similar to RELAP5, it is not enough to be used for both LOCA and non-LOCA accident analysis. Therefore, a realistic gap pressure model is required for the SPACE code. For this purpose, a static gap pressure model similar to RETRAN-3D has been developed and verified in this study.

2. Model Development

2.1 Existing Gap Pressure Model

The existing gap pressure model of the SPACE code is the same as RELAP5 and gap pressure, P_g is defined as follows:

$$P_g = \frac{T_p}{T_0} P_0 \text{, } (P_0 \text{ : initial gap pressure by user}) \qquad (1)$$

T_0 is an initial plenum temperature of the fuel rod and determined as the maximum value of the vapor temperature and saturation temperature at the top core. T_p is the current plenum temperature determined as the same manner as T_0. As seen in Eq (1), the gap pressure of the simple model only depends on the fluid temperature at the top core. Such a relationship may be acceptable for a LB-LOCA analysis but in case of the RIA in which the temperature of the top core rarely changes, it can't predict the gap pressure properly (see Fig. 3).

2.2 Static Gap Pressure Model

The static gap pressure model is based on the following assumptions.

(1) The perfect gas law holds.
(2) Total moles of gas are constant.
(3) Plenum volume and temperature are constant.
(4) The gas pressure is the same throughout the fuel rod.

From the assumption (1), (2) and (3), the total mole number of the gas including the plenum region is calculated as shown in Eq. (2).

$$M_0 = M_{0,P} + \sum_{i=1}^{N} M_{0,i} = \frac{P_0}{R}\left[\frac{V_P}{T_P} + \sum_{i=1}^{N}\left(\frac{V_{0,i}}{T_{0,i}}\right)\right] \qquad (2)$$

where, M_0: total moles of gap gas,
$M_{0,i}$: initial moles of gas in each region,
R: universal gas constant,
$V_{0,i}$: initial gap volume in each region,
$T_{0,i}$: initial gap temperature,
V_P, T_P: volume and temperature of plenum given by user,
N: number of axial nodes in a fuel rod

From the assumption (4), the gap pressure is calculated by Eq. (3)

$$P_g = \frac{M_0 R}{V_P / T_P + \sum_{i=1}^{N}\left(V_i / T_i\right)} \qquad (3)$$

The gap volume can be changed by the thermal, elastic and plastic deformation of the pellet and clad, and the gap temperature is determined by the fuel conduction equation. During a steady-sate calculation, the gap pressure is not calculated but the total mole number of gap gas is updated using the initial gap pressure. However, the gap pressure is updated with the fixed total mole number during a transient.

2.3 Fuel Stack Model

In most of safety analyses, especially LOCA, the fuel rods or assemblies are modeled by single heat structure component. However, the fuel rod in non-LOCA analysis consists of the multiple heat structure components to simulate the different radial mesh interval of each axial node. Fig. 1 shows the difference of a single fuel rod with multiple axial nodes and a multiple-fuel rod with single node.

The static gap pressure model works only within a single heat structure component. Therefore, the fuel stack model has been developed so that the static gap pressure model can work throughout the multiple heat structure components.

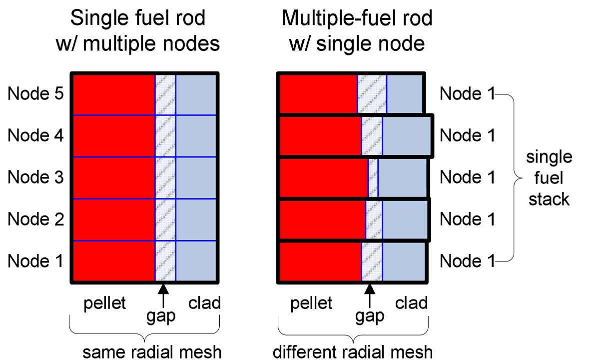

Fig. 1. Comparison of two fuel rod models

3. Verification Test

To verify the capability of the static gap pressure model, a postulated RIA test was conducted and the test conditions are summarized in Table I. There are two test cases and Table II shows the test condition of each case. The fuel rod is modeled by a multiple-fuel rod with single node for both cases. Differences of two cases are the gap pressure model and whether a fuel stack model is used. The plenum temperature in Case-2 is determined by the code as described in section 2.1.

Table I: Conditions for RIA test

Parameters	Unit	Value
Number of rods	-	1
Core power	kW	71.4
Inlet flow condition	Pressure (psia)	2175
	Temperature (^{o}F)	563
	Flow rate (lb/s)	0.622
Feedback reactivity	Doppler (pcm/^{o}F)	~ -1.0
	Moderator (pcm/^{o}F)	0.0
Reactivity insertion	Max. reactivity (pcm)	+145.9
	Insertion time (s)	20~20.05

Table II: RIA test cases

ID	Gap pressure model	Fuel stack	T_{plenum} (^{o}F)
Case-1	Static	Yes	656.6
Case-2	Simple	No	calculated

Fig. 2 shows the liquid and vapor temperature at the top core region. The fluid temperature difference of two cases is negligible because the RIA is a very short transient. However, there is a large dicrepancy between two cases in the gap pressure (Fig. 3). In this figure, black symbol means the result of the STRIKIN code which is a nuclear fuel design code. Apparently, the gap pressure of the static gap pressure model (Case-1) comes closer to the STRIKIN code than a simple gap pressure model (Case-2) even though there is a little difference between two fluid temperatures at the top core in both cases.

4. Conclusions

In order to predict the accurate gap pressure during non-LOCA transient, the static gap pressure model and the fuel stack model of the SPACE code have been developed. In addition, the analysis capability of them has been verified with the comparison test against the nuclear fuel design code, STRIKIN.

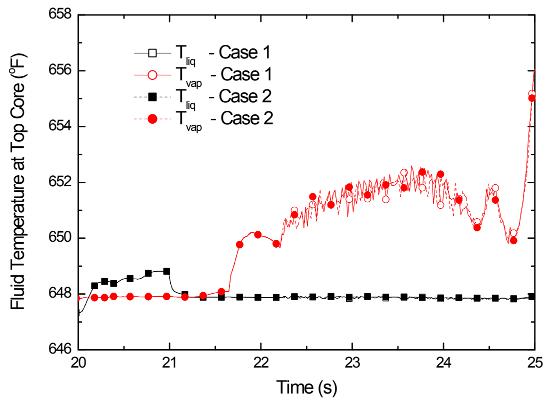

Fig. 2. Comparison of fluid temperature at top core

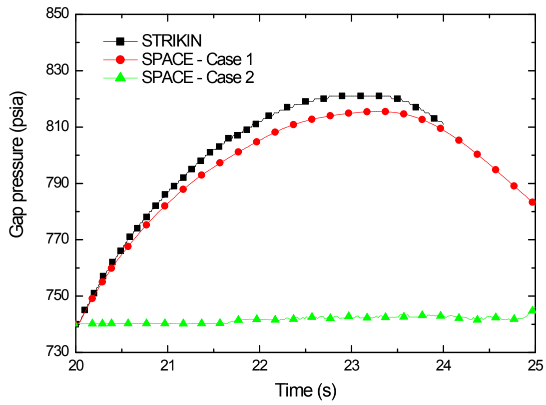

Fig. 3. Comparison of gap pressure

Acknowledgements

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