Parametric Study : The effect of QT model factors on axial relocation

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1. Introduction

Fuel fragmentation, relocation, and dispersion coolant accidents (LOCA) and has a significant impact on the safety of nuclear fuel [1]. Fragmentation can be caused by thermal stresses and various studies have shown that pulverization are generated in high burnup pellets. If the cladding expansion is significant, fragmented pellets can migrate from the upper region to the balloon region. This relocation can result in a localized increase in heat due to the presence of more pellets in the balloon region, which can cause cladding expansion. When the cladding ruptures, pellet fragments can disperse outside the rupture opening.

As one of the various studies to incorporate the FFRD phenomenon into safety analysis, the Quantum Technologies AB (QT) redistribution model has been applied as an optional part of FRAPTRAN2.0 [2][3]. The model includes the axial rearrangement of fragmented pellets, the packing fraction of broken pellets, and the thermal effects of fragmented pellets.

The key factors in the QT model are the size of the pulverized pellet fragments as a function of temperature and burnup, the threshold gap size at which relocation can occur, and the packing fraction of crumbled pellet fragments in the balloon region.

In this study, we examine the effect of the key factors assumed in the QT model and, for a more realistic approach, we investigate the sensitivity of the relative pellet mass in the balloon region using key factor values based on experimental measurements as user input.

2. Parameters effect for relocation

The IFA650.5 test performed in Halden was used to evaluate the effect of variables in the QT relocation model. In the QT model, the size of the crumbled pellet fragments was assumed to be a mixture of two types of particles (large fragments formed by fragmentation and small fragments formed by pulverization). The large fragment size(1.86 mm) is calculated by the operation history and the small fragment size is fixed at 100 μm.

Small fragments can be present in different sizes(20~60 μm)[4], which also affect the packing fraction (crumbled pellet volume/total volume enclosed by the cladding) of the crumbled pellet. Therefore, we investigated the change in the crumbled pellet mass according to the small fragment size.

FRAPTRAN was modified to accept small fragment size as input, and the mass change of the crumbled pellet was compared for 20, 50, 100, and 200 μm.

Figure 1 shows the relative mass of the crumbled pellet with small particle size. The relative mass of crumbled pellet increases as the small fragment size decreases because more small particles can be present between the larger particles.

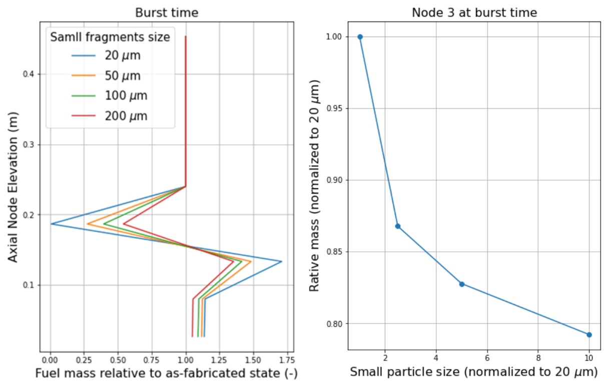

Fig. 1. Comparison of mass change of crumbled pellet with small particle size (20, 50, 100, 200 μm)

In the QT model, relocation is evaluated by the pellet-cladding gap size, which is larger than 0.2 mm and will result in relocation. The pellet-cladding gap size can be replaced by the cladding strain because it is eventually calculated from the cladding strain and the cladding strain is used to determine the relocation from the experimental results. According to RIL[5], the average value of the strain threshold for relocation is 3.7-+1.7%. Figure 2 shows the mass change of crumbled pellets according to the change of strain (2%, 3.7%,
5.4%).

As the strain threshold increases, the time at which relocation occurs tends to be delayed. This is because the strain threshold only determines when the pellet begins to crumble.

In IFA650.5, the time for the first occurrence of relocation was similar for gap size (0.2 mm) for relocation and 2% cladding strain.

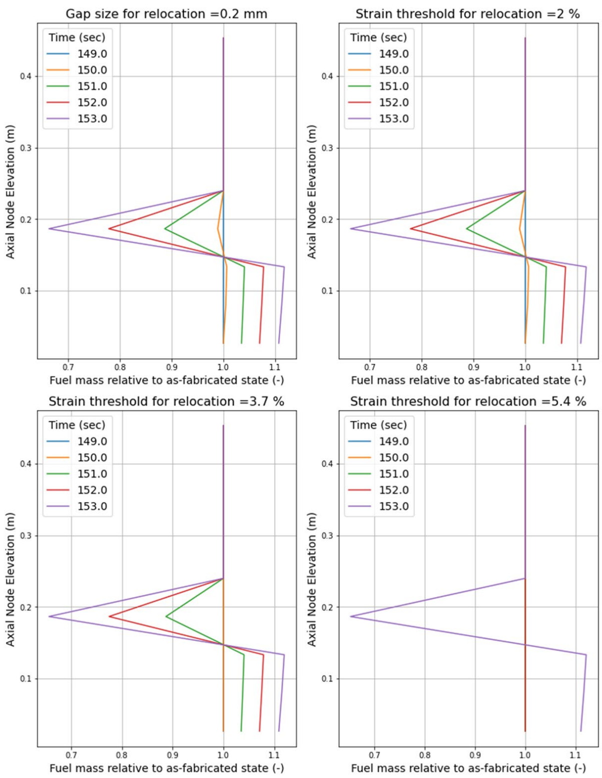

Fig. 2. Comparison of the mass change of crumbled pellet as a function of strain threshold for relocation

The packing fraction of the crumbled pellet is affected by the fragment size, which changes the power distribution and the localized cladding temperature. In the QT model, the packing fraction is calculated using the Westman[6] equation, assuming that the crumbled pellets are a mixture of two types of particle sizes.

Since QT model assumes only two sizes of pellet fragments, the uncertainty in the packing fraction is very large. Therefore, values based on experimental results were used as user input. According to RIL[5], test results show that the percentage of packing in the balloon region is in the range of 70-85%.

Figure 3 shows the mass change of crumbed pellet with packing fraction(78, 79, 80, 85, 90 %). As the packing fraction increases, the crumbling time at which axial relocation occurs is accelerated. This phenomenon is caused by the assumption (Figure 4) in the QT model that relocation occurs when the maximum mass(m_k^M) of the crumbled pellet in segment is greater than the initial pellet mass(m_k^i).

The maximum mass of the crumbled pellet is the pellet mass in the segment (in case it is completely filled with crumbled pellet) multiplied by packing fraction of pellet fragments. Thus, for the same segment, if the packing fraction is below a certain value(78% in this case), the maximum mass of the crumbled pellet will be less than the initial pellet mass, and if it is above a certain value, it will be greater than the initial pellet mass.

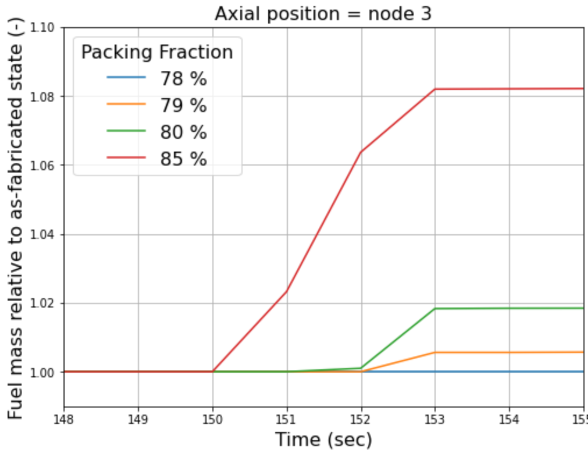

Fig. 3. Comparison of the mass change of crumbled pellet as a function of packing fraction

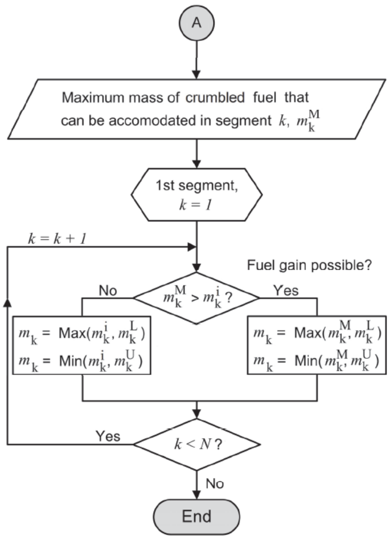

Fig. 4. Comparison of the mass change of crumbled pellet as a function of packing fraction[2]

3. Conclusions

The mass change of the crumbled pellet as a function of small particle size, packing fraction, and cladding strain threshold was investigated in a QT relocation model. The mass change of the relative pellet increased as the size of the small particle decreased, and the timing of the relocation occurred shorter as the packing fraction increased. In addition, the change of cladding strain changed the timing of the relocation.

Since the mass change of the crumbled pellet increases the axial power change and local temperature, it is also necessary to evaluate the ECR.

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