Benchmark Calculations of OECD/NEA Reactivity-Initiated Accidents

Hyedong Jeong, Joosuk Lee, Swengwoong Woo
Korea Institute of Nuclear Safety, 19, Guseong-dong, Yuseong-gu, Daejeon, 305-338, Republic of Korea
hyedong@kins.re.kr

1. Introduction

The program of the OECD/NEA benchmark has been started to understand the phenomenon occurred in the fuel rod in a reactivity-initiated accident (RIA), to assess the ability of fuel codes for RIA, and to compare between the code calculation results. The benchmark-Phase I was done from 2011 to 2013 with a consistent set of four experiments on very similar highly irradiated fuel rods tested under different experimental conditions: low temperature, low pressure, stagnant water coolant, very short power pulse (NSRR VA-1), high temperature, medium pressure, stagnant water coolant, very short power pulse (NSRR VA-3), high temperature, low pressure, flowing sodium coolant, larger power pulse (CABRI CIP0-1), high temperature, high pressure, flowing water coolant, medium width power pulse (CABRI CIP3-1) [1,2]. Based on the importance of the thermal-hydraulics aspects revealed during the Phase I, the specifications of the benchmark-Phase II was elaborated in 2014. The benchmark-Phase II focused on the deeper understanding of the differences in modeling of the different codes. The work on the benchmark-Phase II program will last the end of 2015.

KINS was asked to participate in the program, and did calculate the problem cases in the program. In this paper, the results are summarized.

2. Methods and Results

In this section, the code and the method used in the calculation are introduced first. The brief conditions and the results for the problem cases are presented.

2.1 Code description

The code of FRAPTRAN was developed to estimate the nuclear fuel and cladding behavior during transient [3], and the latest version of FRAPTRAN 1.5 was used in this work. It was recommended to use the standard options for all models except for the failure model, fuel relocation model, and oxidation model.

2.2 Conditions of cases

There are 8 cases, and the 8 cases are defined with an increasing degree of complexity to assess the different phenomena: Case 1 is for the thermal behavior, Case 2 and 3 are for the thermo-mechanical behavior, and the rest are focused on the thermal-hydraulics behavior. The design parameters are shown in Fig.1, Fig.2, and the detail conditions are below [4]:

- Fixed conditions
  (T_{cool}=280℃, P_{plenum}= 20 bar, p_{max}=1x10^4 kW/m)
  Case 1: Clad D_{inner}=8.26mm, friction=1
  Case 2: Clad D_{inner}=8.36mm, friction=1
  Case 3: Clad D_{inner}=8.36mm, friction=0
- PWR conditions
  (V=4m/s, T_{cool}=280℃, P_{cool}=155bar, P_{plenum}=20bar)
  Case 4: p_{max}=4x10^3 kW/m
  Case 5: p_{max}=1x10^4 kW/m
  Case 8: p_{max}=1x10^4 kW/m, P_{plenum}=50 bar
- BWR conditions
  (V=0m/s, T_{cool}=20℃, P_{cool}=1bar)
  Case 6: p_{max} =3x10^3 kW/m
  Case 7: p_{max} =1x10^4 kW/m

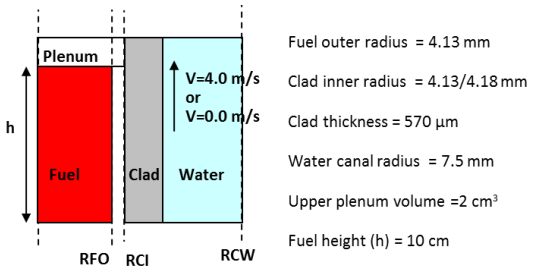

Fig. 1. General descriptions for cases

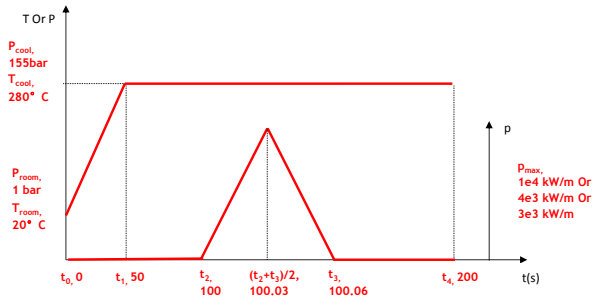

Fig. 2. Inlet coolant temperature or pressure evolution (left y-axis), and rod power history (right y-axis)

2.3 Enthalpy

At the given power, maximum variations of radial average enthalpy during the transient were almost same, irrespective of initial fuel and coolant conditions. This means the gap width, slip condition, rod internal pressure and coolant conditions do not affect the maximum fuel enthalpy change within current analysis conditions.

2.4 Clad outer temperature

In PWR conditions, nucleate and transition boiling heat transfer occurred at high power condition, whereas

nucleate boiling heat transfer mode was only activated at low power condition like Case 4. In Fig.3, the curve is bended due to rapid surface heat transfer coefficient changes at the mode change.

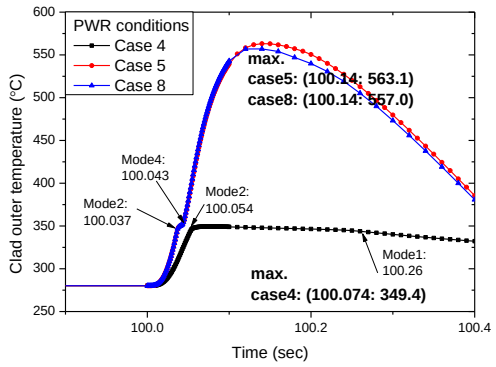

Fig. 3. Clad outer temperature at the mid-height with heat transfer modes. Mode1: Forced convection, Mode2: Nucleate boiling, Mode4: Post-CHF.

2.5 Strain

As shown in Fig. 4, the initial pellet-cladding gap width, and the slipping condition influence the development of the clad hoop strains.

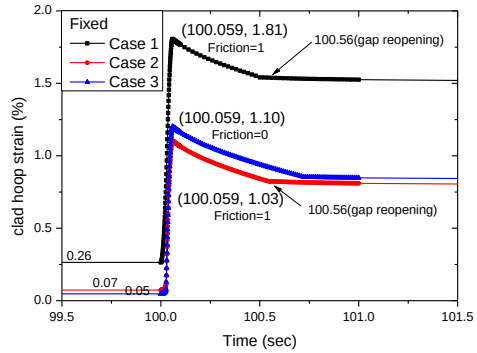

Fig. 4. Clad total hoop strains at the mid-height in Fixed conditions

3. Discussions

3.1 Sensitivity to time step sizes and nodes

The appropriate time step sizes and nodes are important, because they are directly linked with the calculation convergence. Therefore, the time step sizes and the number of nodes are restricted. For FRAPTRAN, the time step sizes for various types of problems are given in the code manual where $1x10^{-5}$ sec during RIA and less than 0.2 sec in other conditions are recommended [3]. However some cases in this work required the less time step size than $1x10^{-5}$ sec in transient and 0.2 sec in other conditions for convergence. For example, in case 6 it was figured out that even the calculation results after convergence were varied with the time step sizes. Also, even in the same conditions the number of radial and axial nodes can vary the results as shown in Fig. 5. This problem can imply that the calculation consistency in RIA conditions would not be guaranteed. It could be caused by the code of FRAPTRAN itself, and thus the further study about it should be required in future.

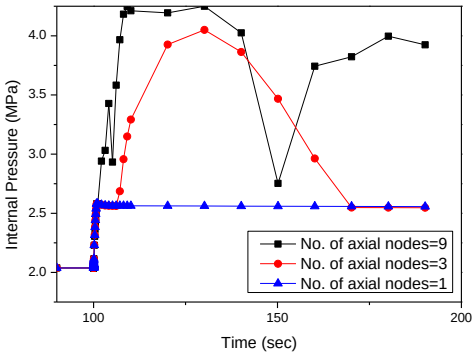

Fig. 5. Internal pressure in Case 6. Variations of calculation results are observed as the number of axial nodes changes.

3.2 Dimension changes

The fuel outer radius for Cases 2 and 3 (where the gap is open) seems incorrect, since the radius changes larger in the beginning state, no temperature change. The cause for this error could be because of the flawed relocation model which is basically embedded in FRAPTRAN. The option to turn off the relocation model will be needed for the next version of FRAPTRAN.

4. Conclusions

The benchmark cases for RIA are simulated with the code of FRAPTRAN 1.5, in order to understand the phenomena during RIA and to check the capacity of the code itself. The results of enthalpy, cladding strain and outside temperature among 21 parameters asked by the benchmark program are summarized, and they seem to reasonably reflect the actual phenomena, except for them of case 6. The further sensitivity study should be required to guarantee the calculation consistency in RIA conditions.

REFERENCES

[1] OECD-NEA, RIA Fuel Codes Benchmark, NEA/CSNI/R(2013)7, 2013.
[2] A. Shin, H. Jeong, J. Lee, and S. Woo, Pre-Calculation of CABRI Water Loop test CIP3-1 with FRAPTRAN, KNS spring meeting, Oct.26-28, 2011, Gyeongju.
[3] K.J. Geelhood, W.G. Luscher, J.M. Cuta, FRAPTRAN 1.5: A Computer Code for the Transient Analysis of Oxide Fuel Rods, Pacific Northwest National Laboratory, NUREG/CR-7023, Vol.1~2, 2014.
[4] WGFS, WGFS RIA fuel codes benchmark Phase-II specifications, OECD/NEA, draft, 2014.