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Development of DUO_THERM Ver. 1.0

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1. Introduction

The concept of an internally and externally cooled annular fuel employs an internal cooling channel with its own cladding so that the fuel can be cooled from both sides[1]. All heats which are generated in fuel pellet must flow to the inner or outer coolant channel. However, it is difficult to predict inner and outer fuel surface heat flux. The direction of heat flow is determined by heat resistance, R1(outer resistance) and R2(inner resistance). If R2 is larger than R1, a generated heat at point A flows to the outer coolant channel, R1.(Figure 1).

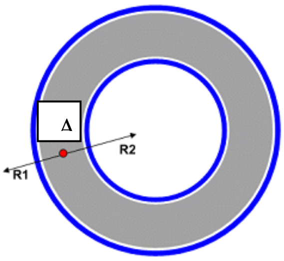

Figure 1. Heat flow of annular fuel

The heat resistance in the fuel can be classified into 2 groups such as coolant and fuel component (clad, gap and pellet). Coolant heat resistance variation is almost the same during an irradiation, however, the heat resistance of fuel component is changed by deformation, temperature variation and material property degradation. Therefore, when we calculate the heat resistance of fuel component, we must the consider irradiation and thermal behavior of the clad, gap and pellet. For these reasons, the DUO_THERM program was developed. In this paper, We would like to introduce the DUO_THERM program briefly and We will summarize test results such as the convergence check and the prediction results of fuel temperature and heat flux.

2. DUO_THERM structure

Figure 2 is a flow chart of the main DUO_THERM subroutines. At the first step, the program calculates the temperature independent of fuel rod deformations(called cold dimension change) such as pellet densification and swelling. At the second step, base upon cold dimensional deformation result, a coolant flow rate of the inner and outer channel is computed from pressure drop correlation. And then, the inner and outer rod surface temperatures can be calculated by assumed heat flux condition. After the determination of both sides boundary temperatures, a heat conduction equation is computed iteratively until fuel, clad temperature and gap conductance are converged(called conductance loop). As we know, gap conductance depends on gap width and temperature, and gap width depends on pellet and clad thermal expansion. For the calculation of pellet temperature, there is a small iteration loop which for considering temperature dependent pellet thermal conductivity(called temperature loop).

After the temperature, deformation and material property are converged, the maximum temperature location is decided and inner and outer direction heat fluxes are re-calculated. If the initial assumed heat flux is equal to re-calculated one, the program is terminated and goes to the next time step.

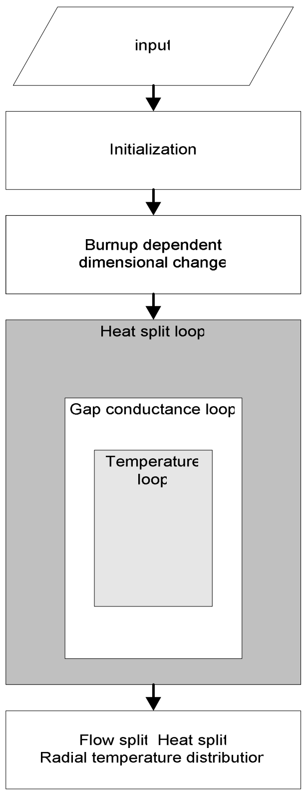

Figure 2. Flow of the main DUO_THERM routine

3. DUO_THERM models

Fuel performance models which are contained in the DUO_THERM program are listed below.

- Pellet densification, swelling and thermal expansion
- Clad thermal expansion and creep
- Gap conductance (including gas conductivity model)
- Dittus-Boelter and Jeans-Lottes correlation
- Material property (UO_2, Zr-4, H_2O)
- Pressure drop calculation model
- Numerical models (conduction Eq., Integration etc..)

At the current stage, there are some assumptions and limitations in the program due to the difficulty of modeling or insufficient understanding of annular fuel behavior. For example, a fission gas release phenomenon was ignored in the program and, fuel rod internal pressure change which is caused by FGR was ignored too. However, due to the very low fuel temperature characteristics of annular fuel, no FGR assumption is applicable.

4. Sample running and results

A test run of the DUO_THERM was performed to confirm its calculation capability. The important input variables are summarized in Table 1. In the sample input, the inner and outer coolant bulk temperature were assumed as 320℃. A rod power was assumed as 2.33×10^5W during a whole irradiation.

Table 1. Detailed sample input condition

Input variable	Value
Outer clad OD	15.8 mm
Inner clad ID	7.6 mm
Outer gap width	70 micron
Inner gap width	70 micron
Outer clad thickness	870 micron
Inner clad thickness	470 micron
Stack length	3.81 m
Coolant pressure	15.5 MPa
Rod internal pressure	5.0 MPa
Coolant mass flux	4137.1 kg/m^2-s
Rod pitch	17.13 mm

To examine a program convergence, the inner/outer heat flux was checked at a zero burnup(figure 3). After 50 iterations, heat flux variation was very stable and converged at 223 iterations.

Figure 4 shows the calculated fuel temperature, and the inner/outer heat flux changes during an irradiation are shown in Figure 5. Due to the heat resistance and dimensional change of fuel rod, a heat flux change occurs during an irradiation.

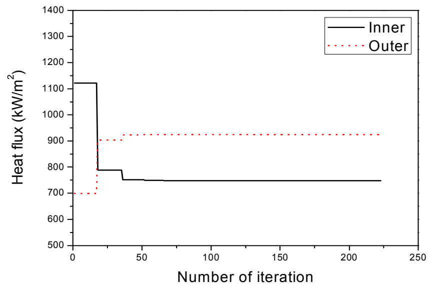

Figure 3. Convergence of Heat flux at a zero burnup

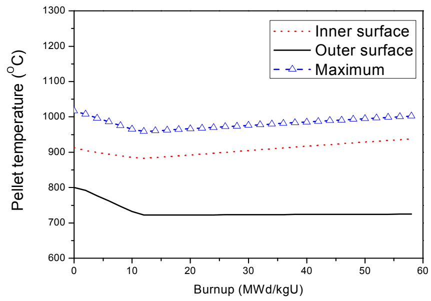

Figure 4. Fuel temperature during an irradiation

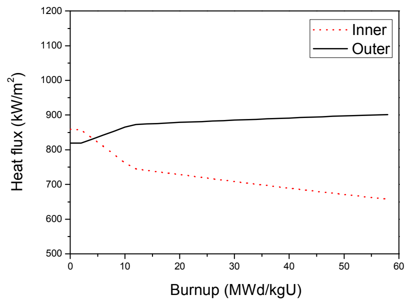

Figure 5. Heat flux change during an irradiation

5. Conclusion

The DUO_THERM is a program for simulating the thermal behavior of a double cooled annular fuel during irradiation. This program can calculate the inner/outer heat fluxes and fuel temperature as a function of power and burnup under consideration with various irradiation effects such as a pellet/clad deformation, a material property degradation and a gap conductance change.

6. References

[1] Y. S. Yang et al., “Conceptual Design of OPR-1000 Compatible Annular Fuel Assembly”, ICAPP2007, France