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Key Models for a Double Cooled Annular Fuel Performance Analysis

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1. Introduction

The development of double cooled annular fuel research has been started at KAERI. A double cooled annular fuel has a many advantages in view of fuel safety and its economy due to the increased heat transfer area[1]. Similar to other reactor fuels, a double cooled annular fuel requires fuel performance model and code system to evaluate its in-reactor fuel behavior and integrity. Efforts for the fuel behavior modeling under in-reactor condition have been studied and various models which can predict the fuel rod thermal and mechanical behavior have been proposed. But, because of the shape change of double cooled annular fuel, a new fuel performance model and calculation method will be required.

The main difference of current cylindrical shape with double cooled annular fuel are fuel element formation, double cladding and both sides cooling condition. For these reasons, all the currently used fuel performance models were reviewed for the development of double cooled annular fuel performance model. Among the various models, a selected key model and its effect are summarized in this paper.

2. Key change models

2.1. Radial power and burnup distribution

Due to the radial variation of the neutron flux inside the UO_2 fuel pellet, the local power and burnup are varied radially in the pellet[2]. A local burnup and power are required in calculation of fuel temperature, swelling, densification and rim microstructure formation. In cylindrical dimension fuel, it is assumed that the local burnup and power distribution have a symmetrical shape and the pellet center is a standard of symmetry. But in double cooled annular fuel, there is no symmetrical distribution due to the neutron moderation difference between inner and outer coolant channels. So, a new local power and burnup calculation model which can consider a both sides moderation will be required.

2.2. Fuel volume change

An initial pellet dimension can vary with a reactor operation condition. In the case of a cylindrical pellet dimensional change, pellet center is always fixed and all dimensional changes are assumed as a symmetry behavior. Because of the isotropic behavior of UO_2 pellet during operation, a volume change which is caused by swelling and densification can be converted easily to an axial and radial dimension change(equally 1/3 percent)[3]. But in the double cooled annular fuel, a dimensional change of inner and outer fuel surface will show more complicated behavior. Consequently, a modification of fuel the current dimensional change model is very important scope.

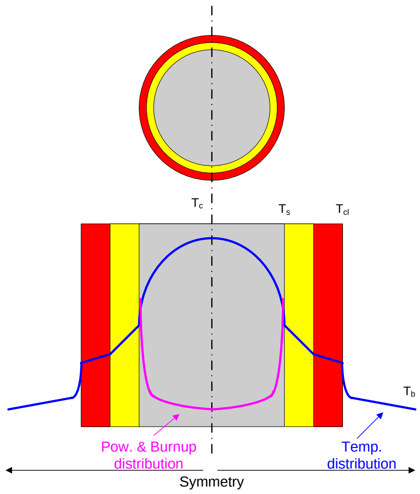

Figure 1. Cylindrical shape fuel structure

2.3. Cladding creep

A creep is one of the most important dimensional change phenomena in water reactor fuel cladding and the creep deformation requires proper temperature and difference of pressure(stress). In cylindrical shape fuel, cladding creep down can occur due to the pressure difference between coolant pressure and rod internal pressure. Similarly, in double cooled annular fuel, an outer cladding will suffer cladding creep down, but, oppositely, an inner cladding will undergo creep out. Though, stresses of inner and outer cladding is equal, an inner cladding suffers hoop stress and outer suffers compressive stress. As we already know, although stress is equal, a creep strain rate under hoop stress condition is higher than compressive stress condition. So, it is expected that an inner cladding creep rate will be larger than outer cladding one and this can cause gap width calculation complexity.

2.4. Fuel temperature calculation

In cylindrical shape fuel, a temperature calculation between fuel center and coolant bulk temperature is very simple. A coolant bulk temperature can be calculated by enthalpy increase as a function of heat flux, inlet coolant temperature, coolant mass flux rate and equivalent channel diameter. For the calculation of film temperature drop between fuel rod surface and coolant, Dittus Boelter correlation can be used under PWR conditions. Consequently, a fuel rod surface temperature is fixed and only a iteration scheme is required to determine gap temperature drop and fuel inner temperature distribution. In this calculation, the maximum fuel temperature location is fixed at pellet centerline and radial temperature distribution has a symmetrical shape as can be seen in fig. 1.

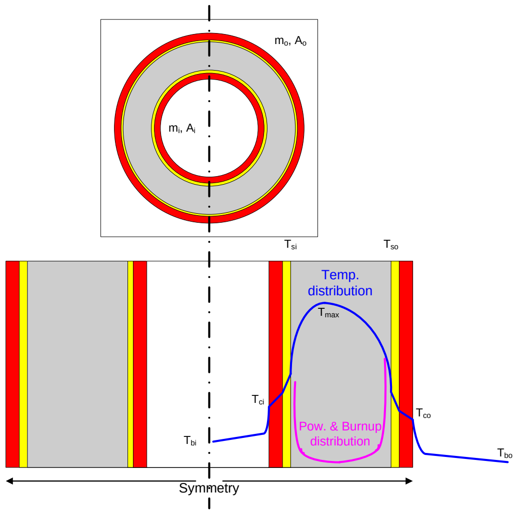

Figure 2. Double cooled annular fuel structure

In a double cooled annular fuel, a fuel temperature calculation is more complex than cylindrical shape fuel. Generally, inner(T_{bi}) and outer(T_{bo}) coolant bulk temperature are not identical due to a difference of inner and outer mass flow rate and flow area. Therefore, an inner(T_{ci}) and outer(T_{co}) cladding temperature and inner(T_{si}) and outer(T_{so}) fuel surface temperature are different. Consequently, a radial temperature of inside fuel element may show an asymmetrical distribution as shown in fig.2[4]. Consequently, contrary to cylindrical shape fuel, a new solution scheme will be required to determine the maximum temperature location and radial temperature distribution and these will require entire iteration scheme for inner coolant center to outer coolant bulk temperature.

2.5. Fuel rod mechanical behavior modeling

In cylindrical shape fuel mechanical behavior modeling, it is assumed that fuel center is always fixed and fuel and cladding deformation and interaction can be considered as only one direction motion[3,5]. But, in double cooled annular fuel geometry, pellet and both sides cladding can move two directions freely and mechanical interaction will occur from both sides. So, a new modeling will be required which can solve more complex solid body interaction problem.

3. Summary

For the development of double cooled annular fuel performance model, currently used fuel performance models were reviewed under consideration of both fuel shape difference. As a result of investigation, it is concluded that some models such as rod mechanical behavior analysis model and fuel temperature calculation scheme must be reconstructed for the double cooled annular fuel analysis and some models such as fuel volume change and cladding creep behavior models need modifications. Many models such as material property, fission gas release, clad oxidation & hydrogen pick-up and other fuel rod shape independent models can be used in double cooled fuel rod analysis without any modifications.

4. Acknowledgements

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5. References

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