Effect of Fuel Temperature Profile on Eigenvalue Calculations

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INTRODUCTION

Use of an average fuel temperature is a current practice when modeling fuel for eigenvalue (k-inf) calculations. This is an approximation, as it is known from Heat-transfer methods that a fuel pin having linear power q′, will have a temperature that varies radially and has a maximum temperature at the center line [1]. This paper describes an investigation into the effects on k-inf and isotopic concentrations of modeling a fuel pin using a single average temperature versus a radially varying fuel temperature profile. The axial variation is not discussed in this paper.

A single fuel pin was modeled having 1, 3, 5, 8, or 10 regions of equal volumes (areas). Fig. 1 shows a model of a 10-ring fuel pin surrounded by a gap and then cladding.

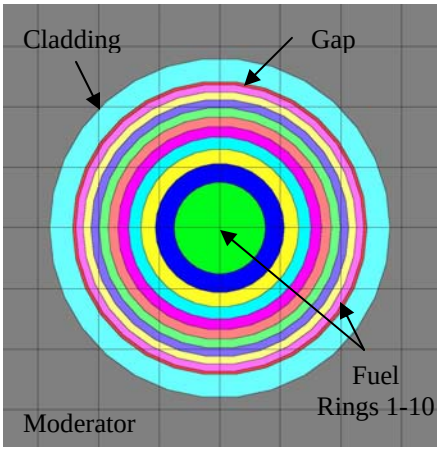

Fig. 1. Fuel pin divided into 10 rings

A temperature profile for the pin was calculated using a simple, one-dimensional heat-transfer approximation [1] [2], $T = T_m - \frac{q''' r^2}{4k_f}$, and the average temperatures for each of the regions were analytically determined. Separate cases were analyzed for two different values of linear power: 1) q′=15 kW/m to represent a low power fuel pin with an average fuel temperature of 1065.8 K and 2) q′=45 kW/m to represent a high power fuel pin with an average fuel temperature of 2057.5 K. Temperature profiles for the 2 cases are shown in Fig. 2.

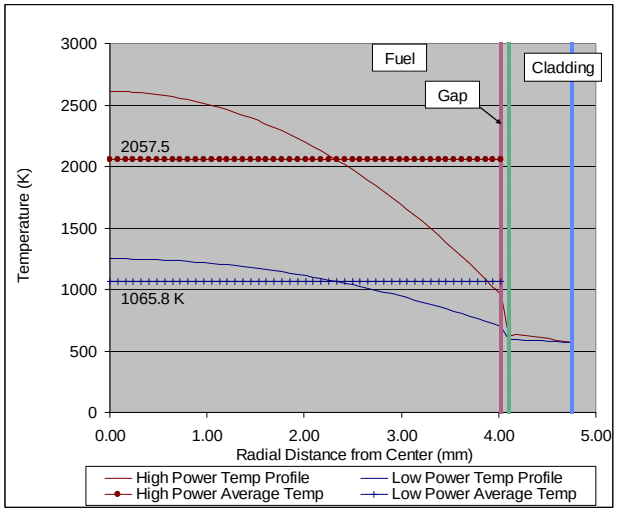

Fig. 2. Radial Temperature profile of high power and low power fuel pins with associated average temperatures.

DESCRIPTION OF THE ACTUAL WORK

The eigenvalue calculations were performed using SCALE 5.1 [3] for the high and low linear power fuel pin cases.

Using the analytic temperature, an eigenvalue calculation was performed for each of the 1-, 3-, 5-, 8-, and 10-ring models, where the 10-ring model will be the reference case and considered the best approximation.

An analysis was then performed using average temperatures for each of the 1-, 3-, 5-, 8-, and 10-ring models. Note that the 1-ring models for both the analytic and average temperature profiles are identical. The purpose of the multi-ring, average-temperature eigenvalue calculation was to investigate what impact the refined spatial meshing, without regard to temperature, would have between the 1-ring model and the 10-ring, analytic

temperature model. Results were then compared to estimate the effect of using a flat (average) temperature profile as compared to a radially changing temperature profile.

RESULTS

The eigenvalue results using a flat fuel temperature profile from 1- to 10- rings models showed a maximum relative difference of 0.087%. On the other hand, the eigenvalue results for the analytic temperature fuel profile show a maximum relative difference of 0.711% for the high power pin case and 0.283% for the low power pin case between the 1- and 10-ring models. Table one shows the relative difference between the 10 ring reference model and the 1-, 3-, 5-, and 8- ring analytic temperature models. In all cases, the 10 ring model had a greater reactivity.

TABLE 1. Relative Difference to 10-Ring model in k-inf for Analytic Temperature Profile Cases.

	10-Ring	8-Ring	5-Ring	3-Ring	1-Ring
q′ Value	k-inf	Relative Difference (%)			
45 kW/m	1.2936	0.021	0.055	0.140	0.711
15 kW/m	1.3132	0.015	0.038	0.093	0.283

By using an average fuel temperature, we are underestimating the temperature in the center of the fuel pin and overestimating the temperature on the surface. In the case of the high power pin, the 1-ring model had a k-inf of 1.2844 compared to k-inf of 1.2936 for the 10-ring model.

The difference in k-inf does show that a varying, analytic temperature profile will have an effect on the eigenvalue calculations and that simply modeling fuel as a one volume pin with an average temperature may not be sufficiently accurate and may lead to an underestimation of fuel reactivity at the beginning of life.

An additional analysis was performed for a depletion simulation, comparing k-inf over a burnup range of 50 GWd/MTU. Figure 3 shows a general comparison in k-inf of the 10-ring reference model versus the other approximation cases.

As it can be seen from figure 3, the biggest contributor to the difference in k-inf is again, not the spatial meshing but the temperature profile and isotopic depletion. We note that near the end of life, the reactivity of our profiled temperature cases is actually less than the average-temperature cases. This is different then what we observed at the beginning of life, which indicates a possible change in isotopics due to the increased reactivity which will be discussed during the presentation.

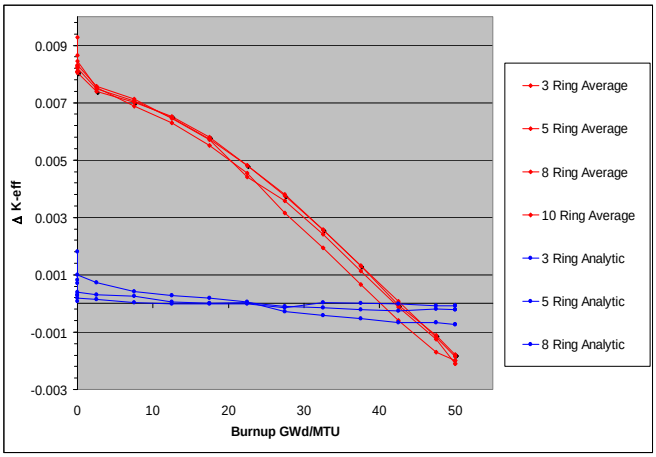

Fig. 3. Difference of high power 10-ring case k-inf versus other simplified cases over burnup range of 50 GWd/MTU

Methods to calculate an effective temperature have been identified and one such formula is shown as

$$T_{F,eff} = T_s + \frac{4}{9}\left(T_C - T_S\right) \qquad [4]$$

where T_S is the fuel temperature at the surface and T_C is the fuel centerline temperature. Using the above formula results in new effective temperatures of 943 K and 1690 K for the low and high power pins respectively. Using these effective temperatures as the temperature of a single ring pin, and comparing these new k-inf results to our reference case shows a significant improvement in our k-inf calculations with a relative difference of 0.05% for the low power and 0.16% and high power fuel pins at BOL and having a Δ k-inf from the 10-ring reference pin trend similar to the other analytical cases.

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