RIC 2010
Impact of Fuel Thermal Conductivity Models on Peak Cladding Temperature

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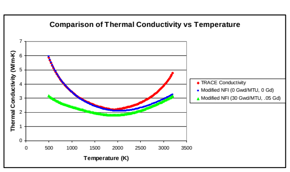
Introduction

- The US NRC Office of Research has developed TRACE as a reactor systems analysis code for light water reactors to perform independent confirmatory analysis
- A code improvement has been identified in the physical modeling of fuel thermal conductivity
- Advancements in experimentally determining fuel thermal conductivity have led to new correlations, which are more physically based and are valid over a wider range of conditions
- The effect of this enhancement on a full reactor model is of great interest in terms of testing the validity of the results

Modeling of Fuel Thermal Conductivity

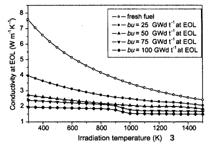
- The model located in TRACE 5.0 has the following characteristics:
  - The correlation is a curve fit with experimental data
  - The range of applicability was 0-2840 degrees C
  - Two curves were used and are joined at a discrete point at 1650º C .
  - The only dependency required to calculate thermal conductivity is temperature



1. Philip E. MacDonald and Loren B. Thompson, compilers and editors, "MATPRO Version 09: A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior,"

Modeling of Fuel Thermal Conductivity (continued)

- Using FRAPCON3, the NRC's fuel performance code, an updated correlation was extracted that was originally developed by the Nuclear Fuels Institute. (NFI)
- The original correlation contains 2 dependencies, burnup and temperature.
- The model is split between a phonon term that contains the burnup effect and an electronic contribution term which captures the increase in fuel conductivity at high temperatures



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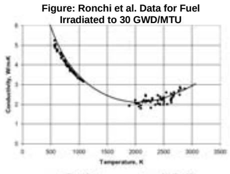
2. Ohira, K., and N. Itagaki. "Thermal Conductivity Measurements of High Burnup UO2 Pellet and a Benchmark Calculation of Fuel Center Temperature," in *Proceedings of the ANS International Topical Meeting on LWR Fuel Performance*
3. C. Ronchi, et al., 2004, "Effect of burn-up on the thermal conductivity of uranium dioxide up to 100 MWd/t", Journal of Nuclear Materials, 327, p 58-76

Modified NFI Model

- The NFI model was modified for implementation into FRAPCON 3.
  - A gadolinia concentration term was added to the phonon term
  - The electronic contribution term was changed to correct an under prediction of thermal conductivity
  - The phonon term applies the full annealing effect at low exposure levels
- The recommended ranges for the Modified NFI model are:
  - Temperature: 30 – 2730 degrees Celsius
  - Burnup: 0 – 62 GWD/MTU
  - Gadolinia Content: 0 – 10 wt%

Figure: Ronchi et al. Data for Fuel Irradiated to 30 GWD/MTU



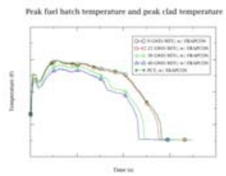
4. D. D. Lanning, C. E. Beyer, K.J.Geelhood, "FRAPCON-3 Updates, Including Mixed-Oxide Fuel Properties," NUREG 6534 vol. 4, pg 2-5
5. Ronchi, C., M. Sheindlin, M. Musella, and G.J. Hyland. "Thermal Conductivity of Uranium Dioxide Up to 2900K from Simultaneous Measurement of the Heat Capacity and Thermal Diffusivity." *Journal of Applied Physics* 85(2):776-789. 1999

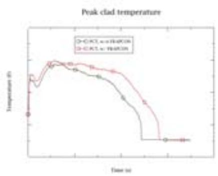
Full Plant Model

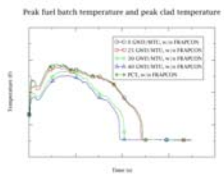
- The TRACE model run simulates a 4 loop PWR
- The representative core chosen has a prototypical fuel layout with fresher fuel on the interior and irradiated fuel on the periphery
- Uniform burnup cores were also run to test the effect burnup has on results
- Two accident scenarios were chosen to test the effect of the model
  - Double ended shear of the cold leg
  - Main steam line break

Double Ended Cold Leg LOCA

- Peak fuel cladding temperature follows the same trend in both models
- With the TRACE 5.0 model in place, the gap conductance heat transfer was the only burnup dependent effect being accounted for.
- With the Modified NFI model in place the accident is more severe in duration and temperature (50º F higher PCT and 40 seconds longer for Core Reflood)







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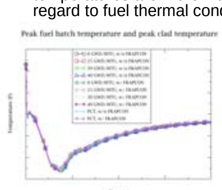
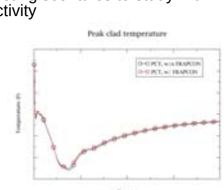
Main Steam Line Break

- Main Steam Line Break represents an increased load being taken off of the primary system
  - The cooling causes the thermal conductivities in the fuel to approach an area of the model where there is very little difference in the values for conductivity
  - This shows that scenarios involving greatly increasing fuel temperatures are more interesting scenarios to study with regard to fuel thermal conductivity





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Summary

- The Modified NFI model reflects advancements in experimental techniques in measuring the thermal conductivity of nuclear fuel
- Additionally, data is now available which shows the impact of gadolinia and burnup on fuel thermal conductivity and can be used to make models applicable over a wider range of conditions
- For the LBLOCA TRACE simulation, differences were observed in the figures of merit, because of an increase in fuel temperature causing degradation of the fuel thermal conductivity in the Modified NFI Model
- The MSLB showed limited differences between the models, because the event caused core cooling and brought the temperature of the fuel to a point where the models produce similar results for thermal conductivity
- In implementing the Modified NFI model TRACE can better serve its purpose as a confirmatory tool

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