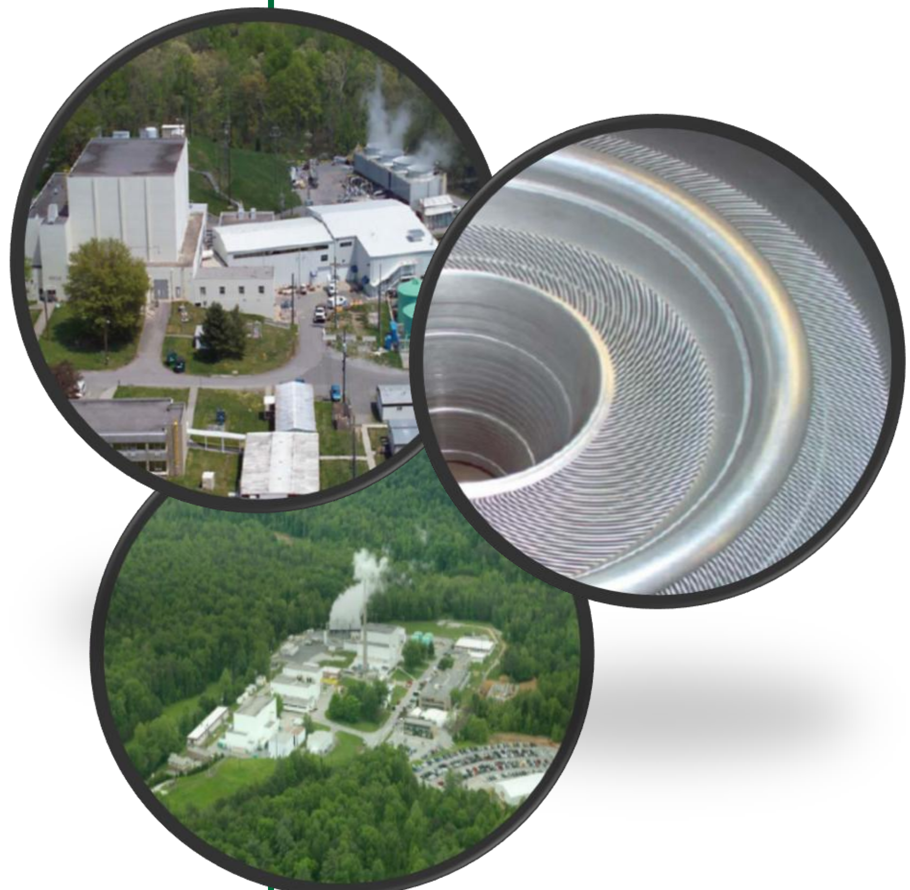
# Investigation of Thermal Contact Gas Gap Conductance Using COMSOL Multiphysics®

COMSOL CONFERENCE
BOSTON2013

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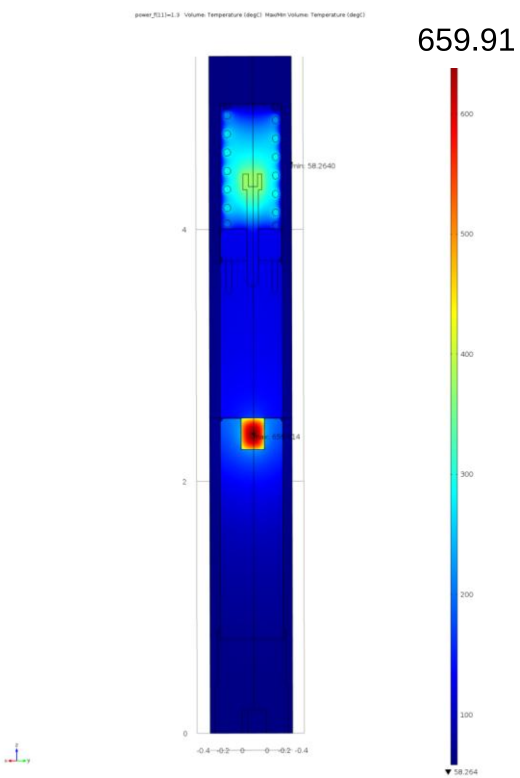
October 10, 2013

U.S. DEPARTMENT OF ENERGY

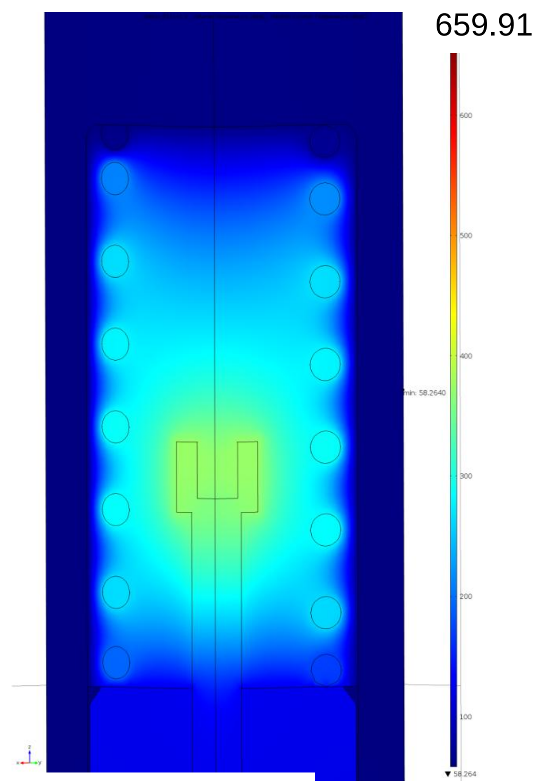
HFIR

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

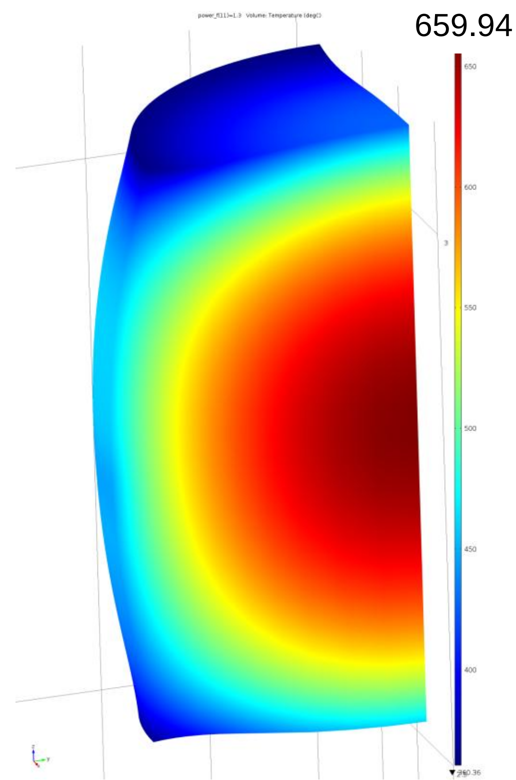
# Extension of Previous Work- Freels, Jain, Hobbs
# COMSOL Conference 2012 Boston Best Paper Award:
## *Design and Nuclear-Safety Related Simulations of Bare-Pellet Test Irradiations for the Production of Pu-238 in the High Flux Isotope Reactor using COMSOL*




overall
temperature
distribution (C)




screw/spring
detailed
temperature
distribution (C)

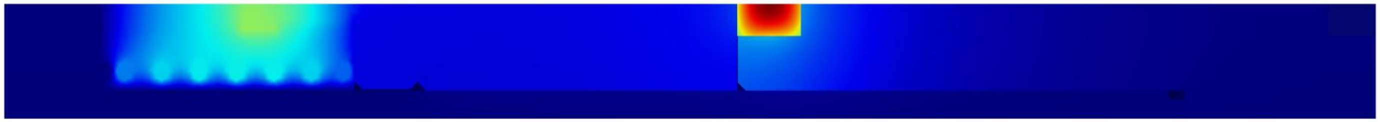



pellet detailed
temperature
distribution (C)
[100X deformation]

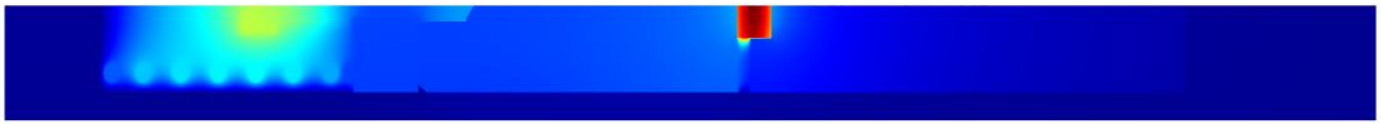
# Additional Target Designs have been COMSOL-Analyzed and Irradiated in the Past Year at HFIR

**(all temperature contours are shown 135 ℉ → 650 ℃)**

additional single bare pellets, also 2nd irradiation cycle, COMSOL 4.2a, 3D, ¼ pie slice

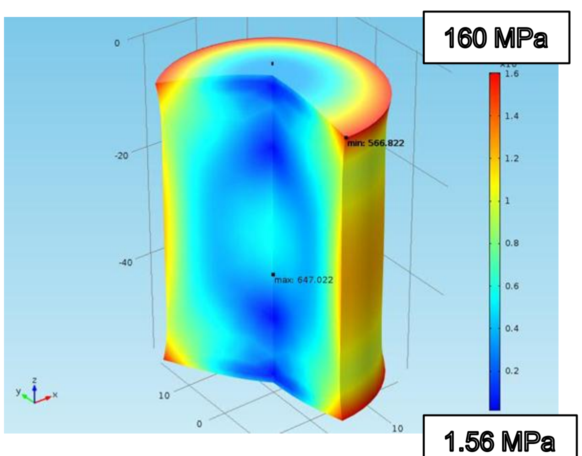


reduced-length bare pellets, 1 and 2 irradiation cycles, COMSOL 4.2a, 3D, ¼ pie slice



partially-loaded (7 pellets) prototype production target, 1 and 2 irradiation cycles, COMSOL 4.3, 2D axisymmetric

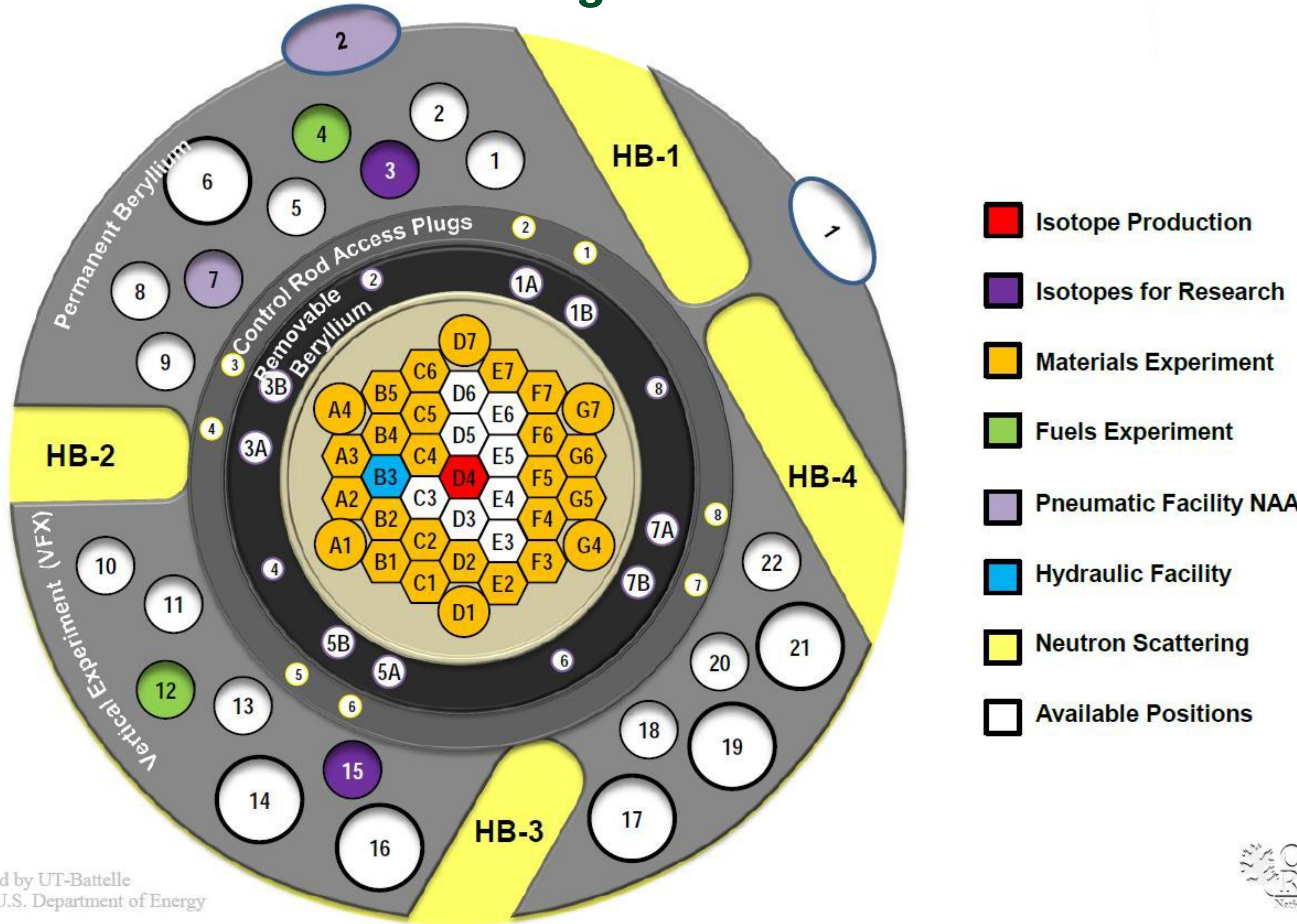
fully-loaded prototype production target (52 pellets), 1 irradiation cycle, COMSOL 4.3, 2D axisymmetric (cycle just started)




individual pellet at maximum temperature in stack: (note: classic hourglass shape)

3-D Rotated Stress Contour with 10000x Deformation of the 2D Axisymmetric Modeled Volume of the Hot Pellet for the VXF-15 EOC-1 Safety-Basis Conditions at 130% Power.

# The fully-loaded targets are bundled in groups of 7 and placed into a “holder”, then inserted into outer VXF positions of the HFIR – additional margin needed





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# A New “Thermal Contact” Boundary Condition was Released with COMSOL 4.3b

- Heretofore, we have been using the “thin-film resistance” boundary condition to account for the all-important gas-gap conductance between the pellet and the housing.

$$-\mathbf{n}_d \cdot (-k_d \nabla T_d) = -\frac{(T_u - T_d)}{R_s}$$

$$-\mathbf{n}_u \cdot (-k_u \nabla T_u) = -\frac{(T_d - T_u)}{R_s}$$

$$R_s = \frac{d_s}{k_s}$$

h_s_side_gap+
He_k_reduction*mat7.def.k(T_avg_side[1/K])/
(max(sigma_side_gap,solid.gap_p11)+
gap_jump_u+gap_jump_d)

- The new “thermal contact” boundary condition could potentially offer modeling efficiency over our present approach.

$$-\mathbf{n}_d \cdot (-k_d \nabla T_d) = -h(T_u - T_d) + rQ_{fric}$$

$$-\mathbf{n}_u \cdot (-k_u \nabla T_u) = -h(T_d - T_u) + (1-r)Q_{fric}$$

$$h = h_c + h_g$$

$$h_c = 1.25\, k_{contact} \frac{m_{asp}}{\sigma_{asp}} \left(\frac{p}{H_c}\right)^{0.95}$$

$$\frac{2}{k_{contact}} = \frac{1}{(k_u \mathbf{n}_u) \cdot \mathbf{n}_u} + \frac{1}{(k_d \mathbf{n}_d) \cdot \mathbf{n}_d}$$

$$h_g = \frac{k_{gap}}{Y_{gap} + M_{gap}}$$

$$M_{gap} = \alpha \beta \Lambda$$

$$\Lambda = \frac{k_B (T_u + T_d)}{2\sqrt{2}\pi D^2 p_{gap}}$$

# “Thermal Contact” BC Compared to the Existing Thin-Film Resistance BC

- The previous “thin-film resistance” boundary condition is implemented following the text by C. V. Madhusudana, *Thermal Contact Conductance*, 1996, Springer.
- The new “thermal contact” Mikic elastic correlation, is based on the *Heat Transfer Handbook*, A. Bejan et al., Wiley, 2003.
- Similarly, the default thermal contact Cooper-Mikic-Yovanovich (CMY) plastic correlation is also derived from the Wiley handbook.
- The Madhusudana text includes many references to Mikic, Cooper, and Yovanovich, and is essentially based on similar correlations.
- The present “thin-film resistance” approach uses the elastic (not plastic) formulations as presented by Madhusudana so is likely to be more similar to the Mikic “thermal contact” correlation.
- Past studies have found the elastic formulation to be more conservative than the plastic formulation with respect to producing maximum pellet temperature.
- The present study has confirmed this conservatism between the Mikic and CMY correlations.

# Equivalent Inputs for Comparison

- The original bare-pellet model includes significant contact between the pellet and surroundings and is a good test bed for the new “thermal contact” correlations.
- Equivalent inputs were available from the existing model so that exact comparisons between the correlations is possible (i.e., the same COMSOL model could be used for all the comparisons).
- Due to the manner in which the “thermal contact” module is structured, two important input parameters remain incomplete in our assessment: (1) how to properly address a gas gap mixture due to mixing of fission-product gases with the initial helium environment, and (2) how the “mean separation thickness,” *Y*, is computed and related to the contact gap distance variable, solid.gap_pXX.
- Using our best guess of how to interpret these two remaining questions, and not having asked for COMSOL technical support for help on these two questions, some preliminary conclusions have been reached.
- All results visually look identical to those on slides 2-3.

# Investigation of V4.3b Thermal Contact BC: Preliminary Conclusions

- Models approximately equal to the previous "thin-film resistance" BC for thermal contact were created and tested.
- Gas gap mixtures are approximated using the "user-defined" gas properties.
- The question of the difference in the "mean separation thickness" (*Y*), and the contact gap distance variable, solid.gap_pXX, remains unanswered.
- Solutions from the new "thermal contact" models were much more unstable and required significantly more iterations to converge.
- ***Preliminary results from these solutions indicates a potential for a large increase in thermal margin***.
- Additional investigation is required before a transition to the new "thermal contact" models in v4.3b is justified.

# Thank you for your attention.

# Questions?

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