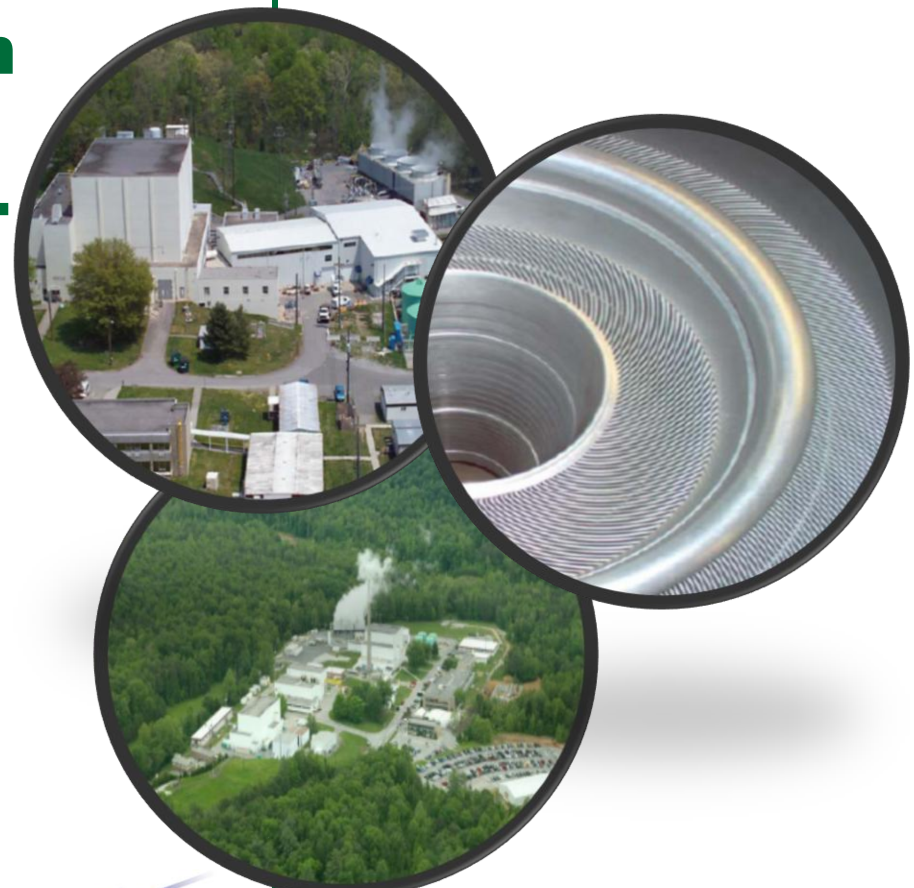
Design and Nuclear-Safety Related Simulations of Bare-Pellet Test Irradiations for the Production of Pu-238 in the High Flux Isotope Reactor using COMSOL

COMSOL CONFERENCE BOSTON 2012



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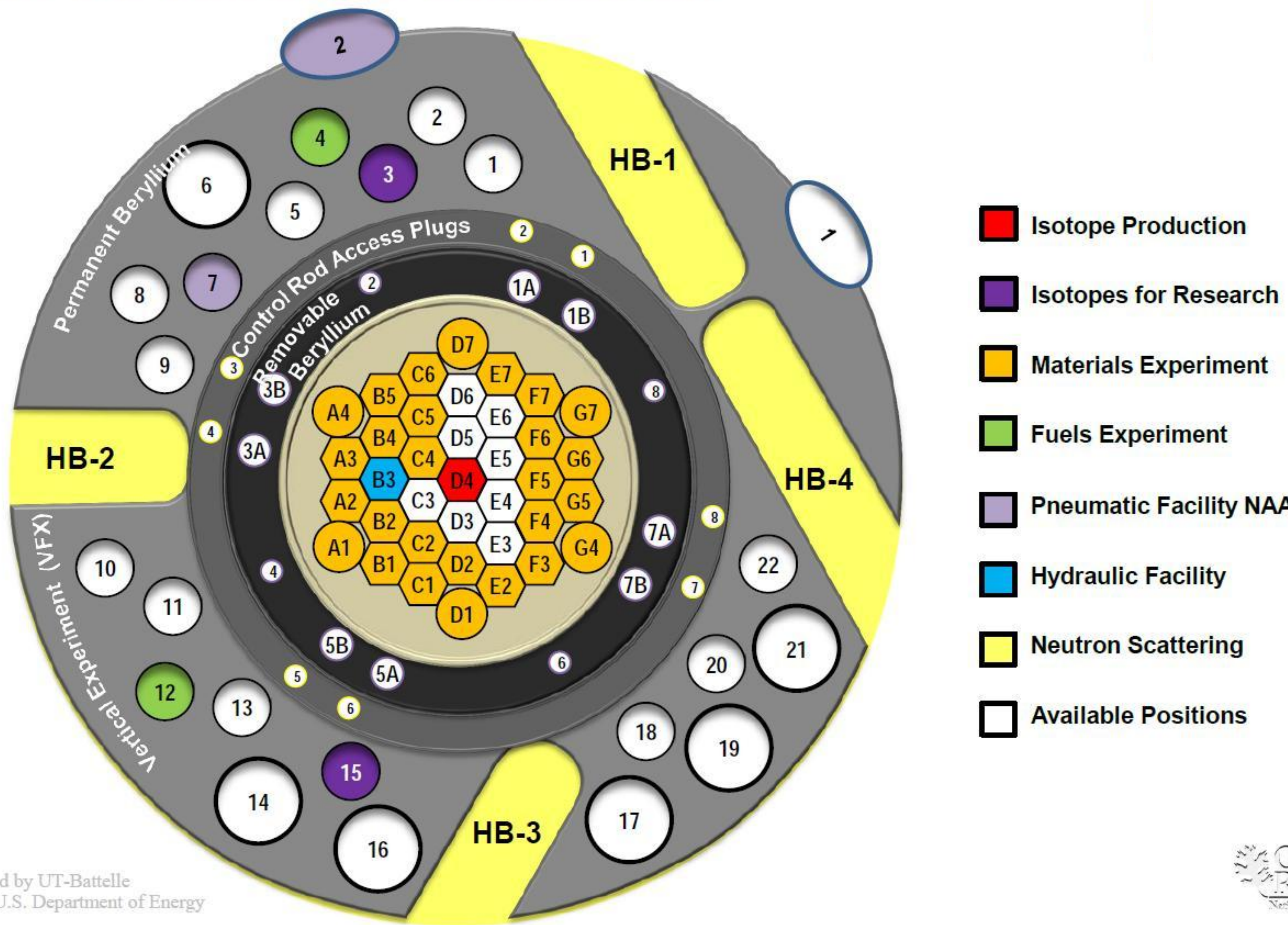
U.S. DEPARTMENT OF ENERGY

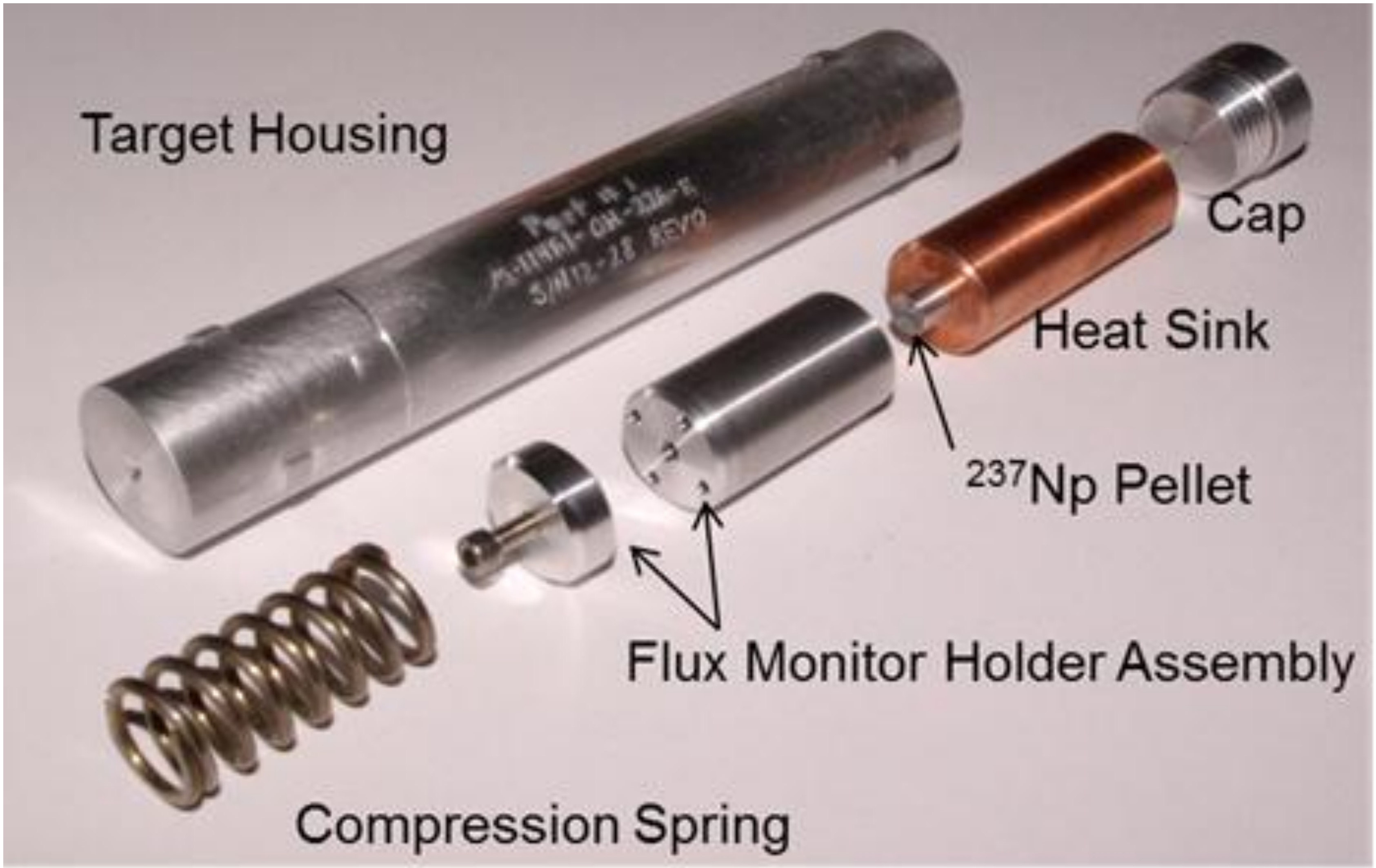
HFIR

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

HFIR is a multi-purpose research reactor used for material irradiation tests, isotope production, and neutron scattering. Cycle 443 included the insertion of NpO_2 pellets to test for the production of Pu-238.



Component Parts for the Bare-Pellet Assembly Test Target for the Production of Pu-238 at HFIR



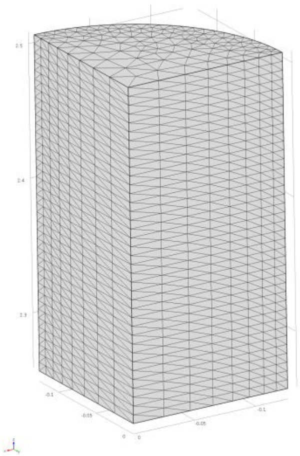
ORNL Nuclear-Safety Quality Assurance Requirements for this COMSOL Calculation

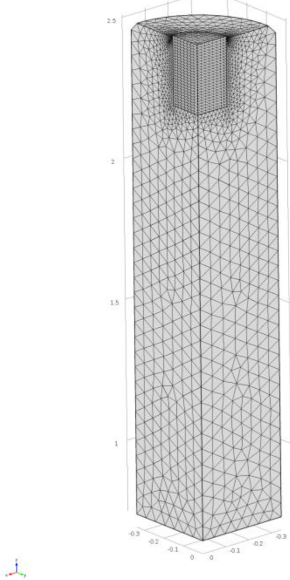
- COMSOL was registered with centralized ORNL database.
- Additional nuclear-safety related requirements were completed for code installation verification per established procedures.
- Reverification is required for changes to code versions and computer hardware.
- Currently, v3.5a and v4.2a are cataloged and approved for HFIR use (v4.3 will be entered soon).
- A nuclear-safety related calculation must be rigorously prepared, checked, reviewed, and independently reviewed following established procedures in order to gain approval.
- Validation requirements are implicit within the calculation.
- The analysis described here was performed and completed by the authors and has met all these requirements using COMSOL v4.2a.
- A separate independent review was performed by another ORNL analyst using ANSYS.
- COMSOL is also routinely used for independent reviews of ANSYS calculations.

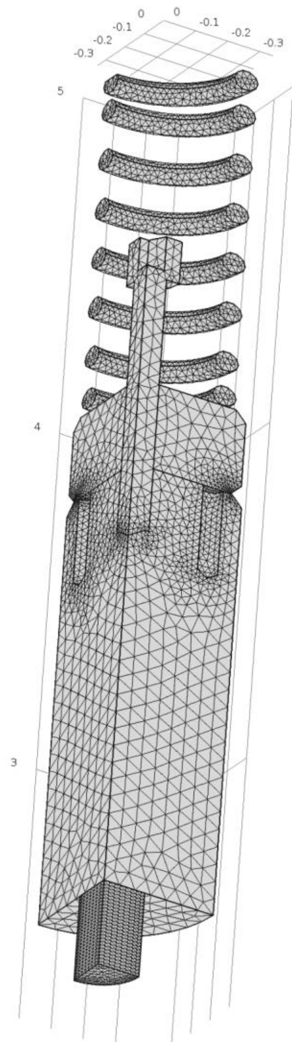
ORNL Pu-238 Bare Pellet Target COMSOL Geometry and Meshing

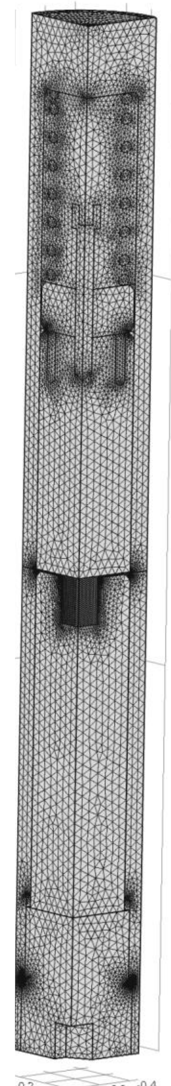
- Imported CAD geometry from Microstation 3D CAD in parasolid format.
- Used “cap” feature of CAD import kernel to create helium volume from voids within capsule geometry.
- Removed very thin helium volumes and replace with thin-film resistance boundary conditions.
- Removed small helium volumes that had little impact on the results and replaced with insulated boundary conditions.
- Created a ¼ “pie slice” to provide symmetry boundary condition and to make the problem smaller.
- Performed other minor cleanups and manipulations to arrive at a workable geometry.
- Created 4 mesh designs: 1) extra-coarse, 2) coarser, 3) coarse, and 4) normal.

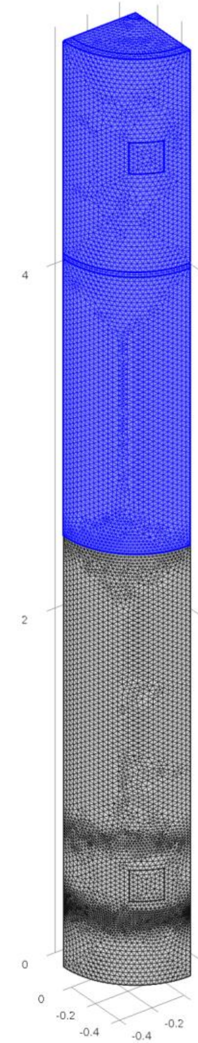
Pu-238 Bare Pellet Target Mesh Results











ORNL Pu-238 Bare Pellet Target COMSOL Material Properties

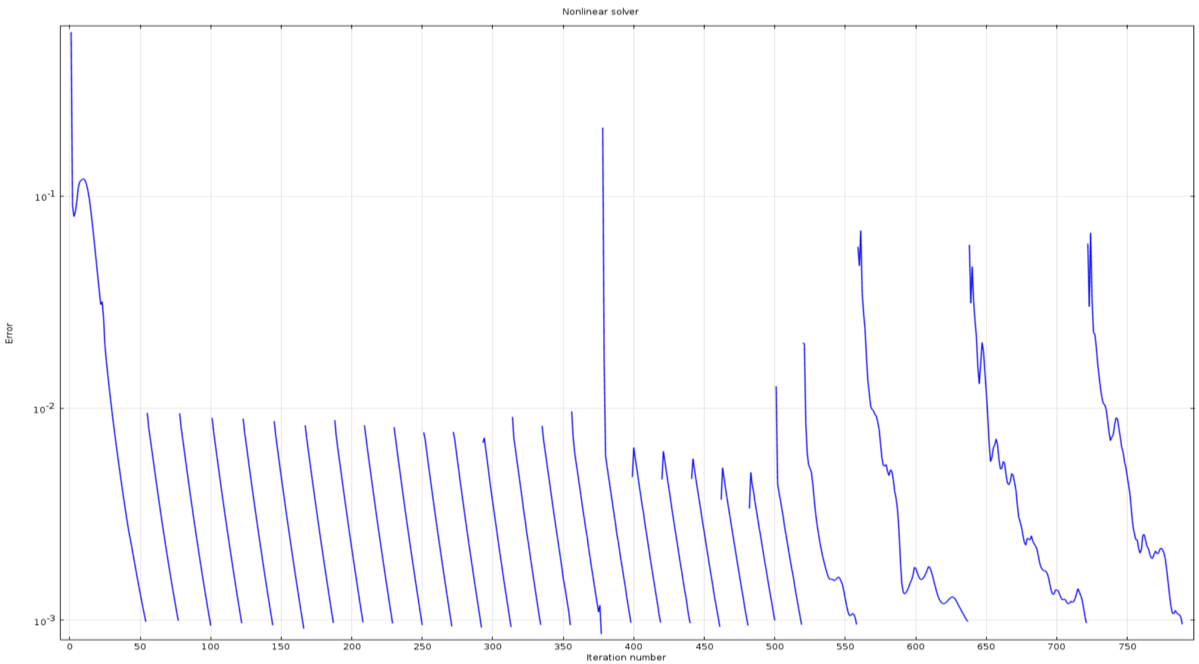
- Except for the pellet, all material properties were obtained directly from the COMSOL Material Library.
- COMSOL Material Library properties were compared to more commonly used sources at ORNL and found to be adequate for use.
- Pellet properties are not fully characterized, and conservative estimates were utilized.
- One purpose of the bare-pellet tests is to measure some of the material properties of the pellet.

ORNL Pu-238 Bare Pellet Target Physics Implementation into COMSOL

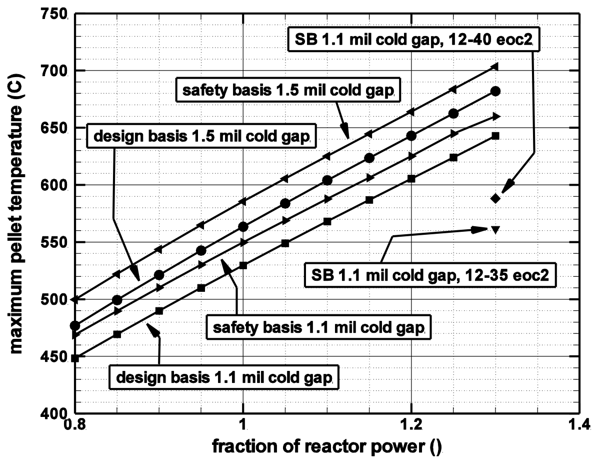
- Nuclear heating data is supplied from a separate MCNP calculation and imported into the COMSOL model.
- COMSOL modules “heat transfer in solids” (which allows for fluids) and “structural mechanics” (which allows to enable thermal expansion) were utilized.
- COMSOL “thin film resistance” was utilized for heat transfer and contacts.
- The following text was followed for the gas-gap conductances: Madhusudana, C., *Thermal Contact Conductance*, Springer-Verlag, Inc., New York, 1996.
- Particular attention was paid to the pellet structural-mechanics constraints which led to the need to use symmetry boundary conditions and the ¼ slice of the entire geometry.

ORNL Pu-238 Bare Pellet Target Solver Details

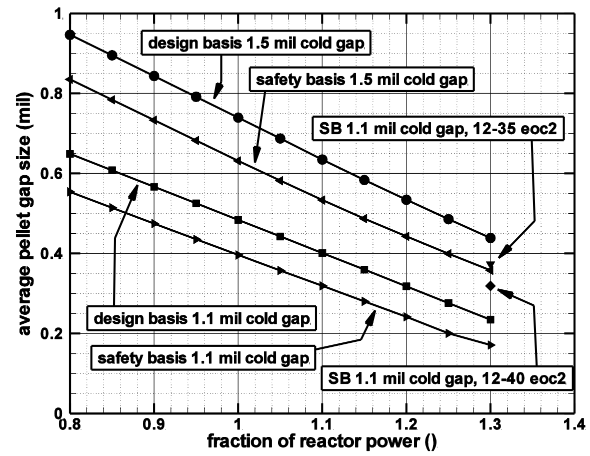
- The most successful configuration settings found to be the fully-coupled, fully-implicit (damping factor=1.0), direct solver.
- Solution became much more nonlinear after the pellet and housing “touched”; i.e., pressure feedback from contact into the gap conductance equations.
- A typical convergence pattern for consecutive power levels (0,.05,1.3) is shown below (27 solution cases using parametric sweep).



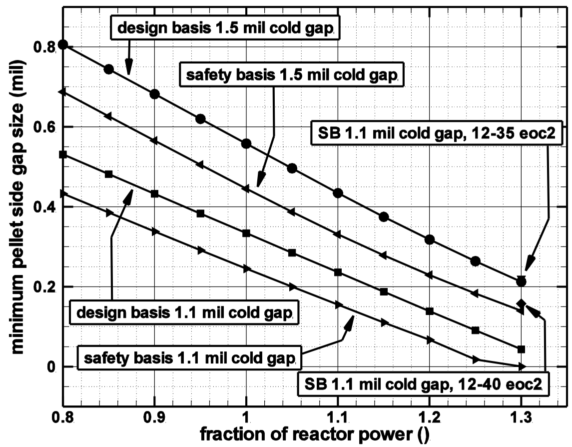
COMSOL Results Aide the Target Installation Decisions



maximum pellet temperature
vs fractional reactor power

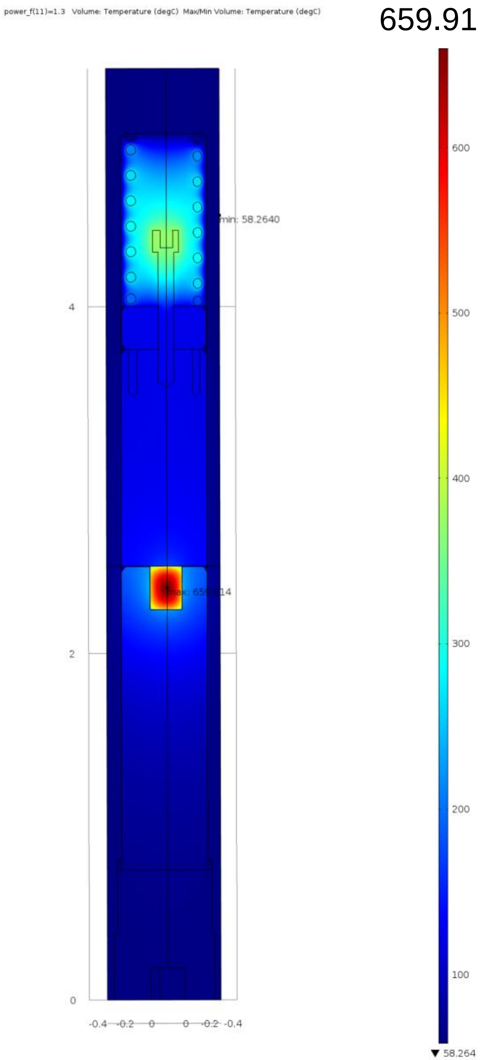


average pellet side-gap
vs fractional reactor power

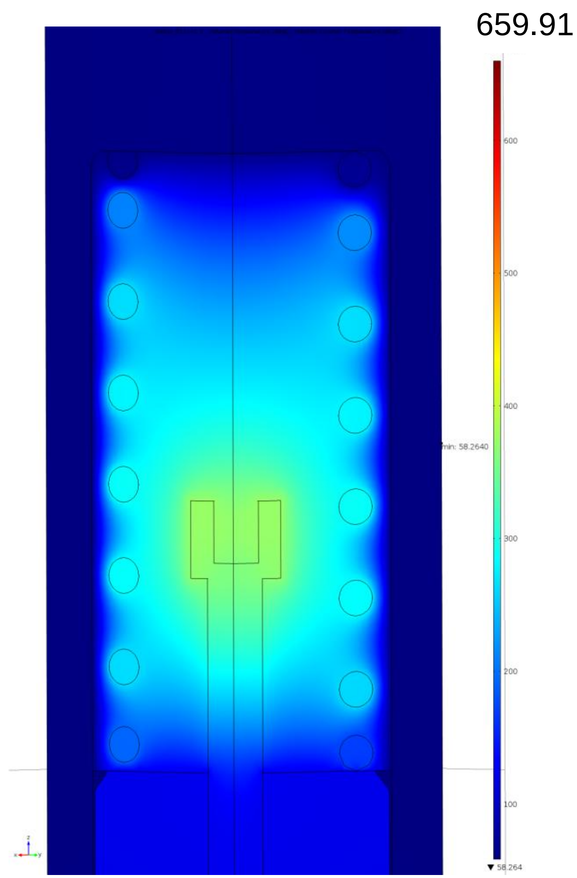


minimum pellet side-gap
vs fractional reactor power

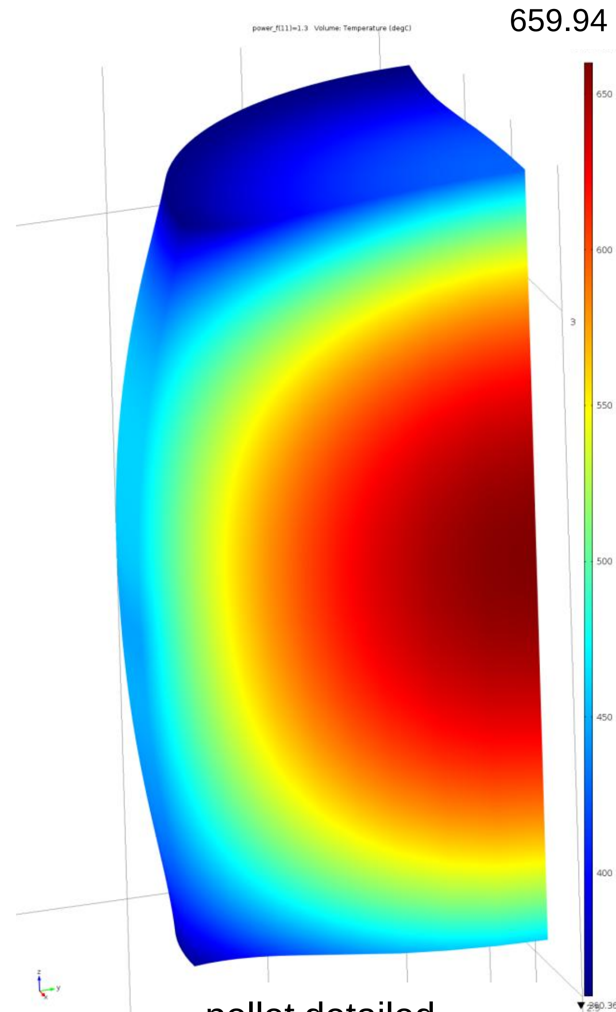
ORNL Pu-238 Target Modeling with COMSOL: Detailed Views of Results 1/2



overall temperature distribution (C)

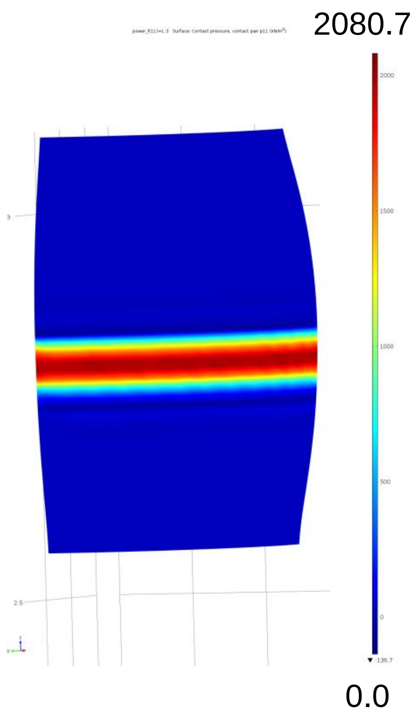


screw/spring detailed temperature distribution (C)

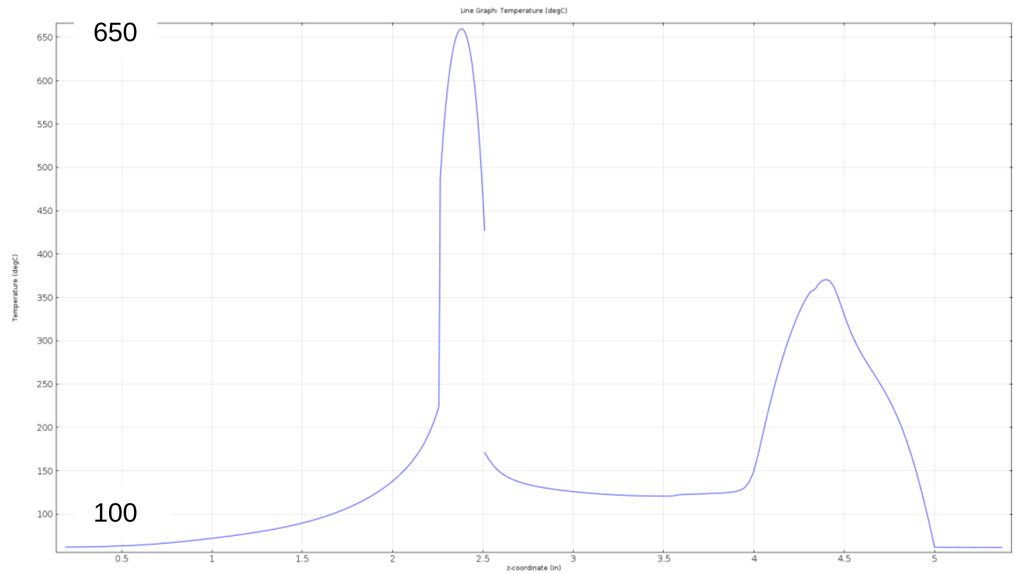


pellet detailed temperature distribution (C) [100X deformation]

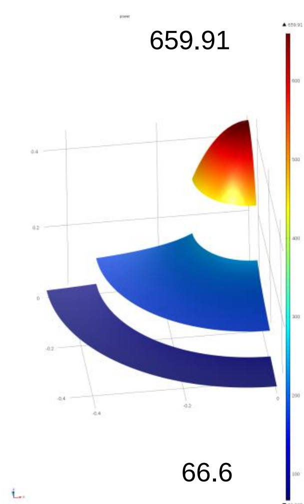
ORNL Pu-238 Target Modeling with COMSOL: Detailed Views of Results 2/2



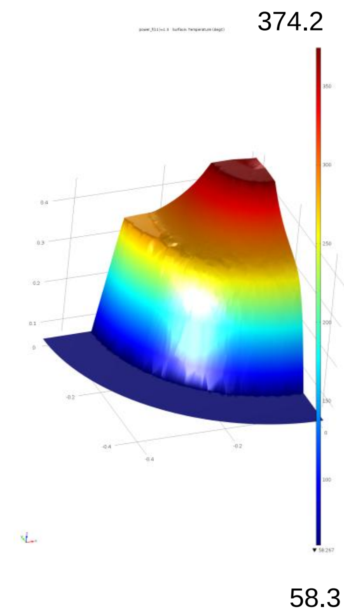
average pellet side gap imposed pressure (Pa) for the 1.1 mil cold-gap safety-basis conditions at 130% power, shown at 100X deformed view.



temperature cut line in the axial direction at the capsule centerline for the 1.1 mil cold-gap safety-basis conditions at 130% power.



temperature cut planes at the location of pellet maximum temperature (left) and screw maximum temperature (right) for the 1.1 mil cold-gap safety-basis conditions at 130% power (C) .



COMSOL Simulations of ORNL Pu-238 Bare Pellet Test Targets: Conclusions

- COMSOL has contributed an important early role toward the production of Pu-238 for NASA at the HFIR.
- Exclusive of the nuclear physics, all aspects of the thermal-structural interaction physics have been captured by the developed COMSOL models.
- Post-irradiation examinations (PIE) have confirmed that COMSOL has performed well.
- COMSOL should continue to contribute toward the success of the production of Pu-238 at HFIR for NASA.

Thank you for your attention.

Questions?

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Extra Slides not presented

The number of Cycle 443 irradiations rises to a new high - driven by materials and ^{238}Pu research

113 Materials and Fuels Experiments

- Silicon Carbide
- V, Mo, & Cu alloys
- Zircaloy
- UO_2 Fuels
- Graphite
- Uranium
- Steels
- UCN Fuels

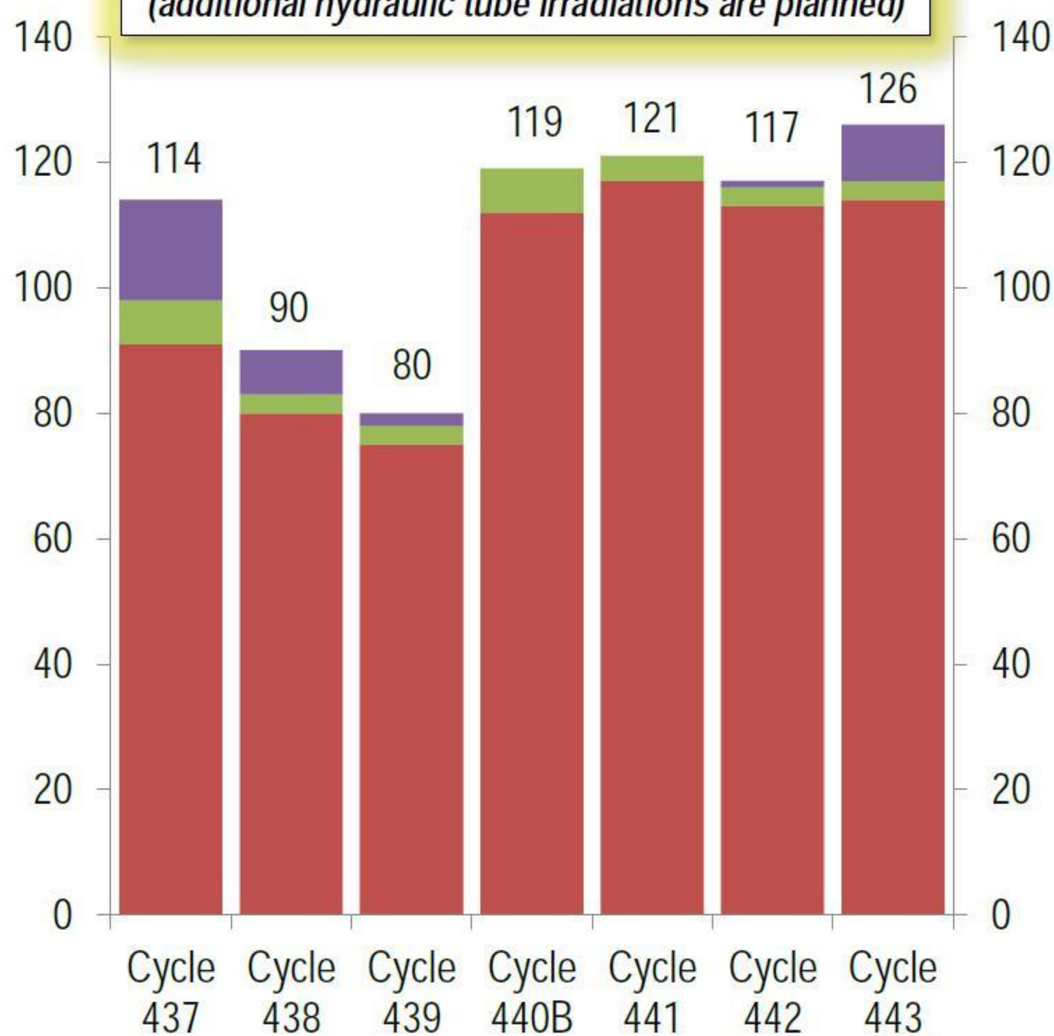
3 Commercial Isotope Production Capsules

- 3 Selenium (Se-75) - production

Isotopes for Research

- Pneumatic Tube Isotopes research
- Np-237 Capsules for Pu-238 production research

126 total irradiations to date for Cycle 443 (additional hydraulic tube irradiations are planned)



 Managed by UT-Battelle for the U.S. Department of Energy

Oak Ridge National Laboratory

Irradiations for ^{237}Np begin in Cycle 443 in support of ^{238}Pu technology development

Single pellet test irradiations are designed to increase understanding of pellet and cladding performance in order to establish confidence in ORNL's ability to incrementally scale-up to production targets