COLLEGE OF ENGINEERING

Nuclear Science and Engineering

MULTIPHYSICS MODELING OF A PEBBLE BED REACTOR

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INTRODUCTION:

- The Pebble-Bed Modular Reactor (PBMR) is a promising Generation IV design with enhanced safety features. However, there is concern that a seismic event may cause fuel densification due to increased pebble packing.
- This increased core packing fraction is not accounted for in traditional homogenized diffusion modeling techniques.
- This project seeks to determine the validity of modeling individual pebbles for neutronic analysis compared to the standard homogenized method.

MATERIALS:

- The Discrete Element Method (DEM) code PEBBLES developed by Dr. Josh Cogliati at Idaho National Laboratory (INL) is used to produce individual pebble locations.
- TetGen is used to generate the Pebble-Tracking Transport (PTT) mesh and Cubit is used for the homogenized mesh. The heat conduction mesh was provided by Dr. Javier Ortensi at INL.
- Simulations are executed using MAMMOTH, which is part of the MOOSE framework at INL.
- Data analysis is done in Python. Paraview is used to compare the results from the three scenarios.

METHODS:

- The three models are homogenized diffusion, Pebble-Tracking Transport, and heat conduction.
- Homogenized diffusion and PTT neutronics comparisons were done considering pebble packing before and after a seismic event.
- The heat conduction model is performed after a depressurized-loss of forced-coolant (DLOFC) using only the data from before the seismic event.

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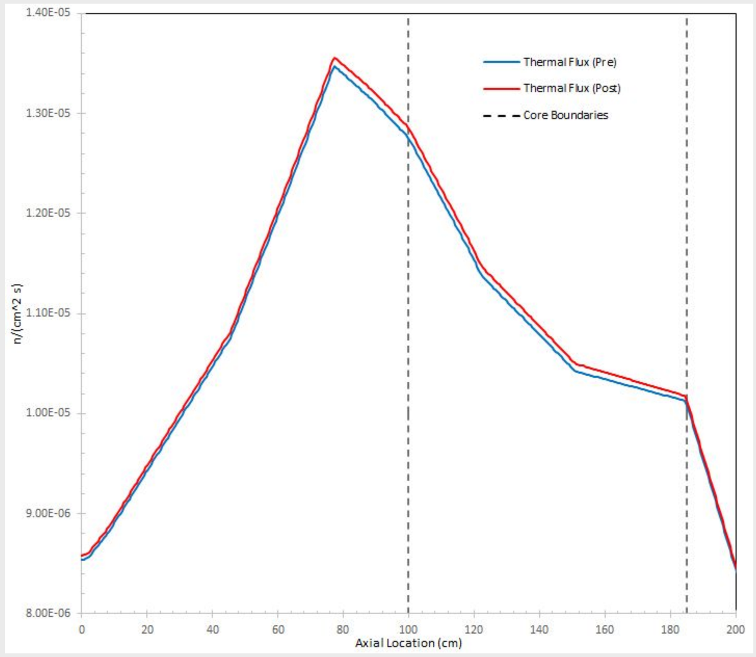
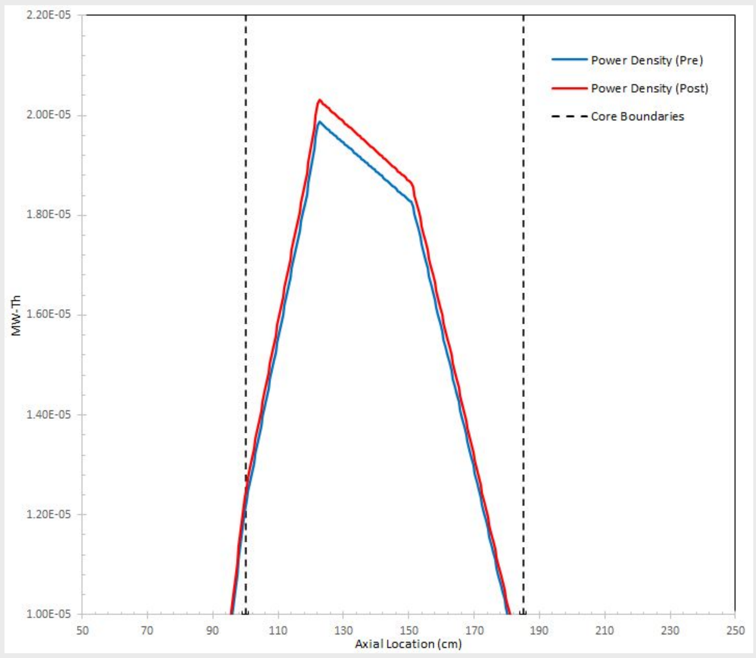
HOMOGENIZED DIFFUSION:

- Average packing factors were calculated from the core PEBBLES data (0.605 and 0.620 for "pre" and "post").
- Meshes were generated for core region containing fuel pebbles before and after the seismic event.

$$\frac{1}{v}\frac{\partial \varphi}{\partial t} = s - \Sigma_a \varphi + D\nabla^2 \varphi$$





Figures 1 and 2: Thermal flux (top) and power density (bottom) peaks for Pre vs Post scenarios.

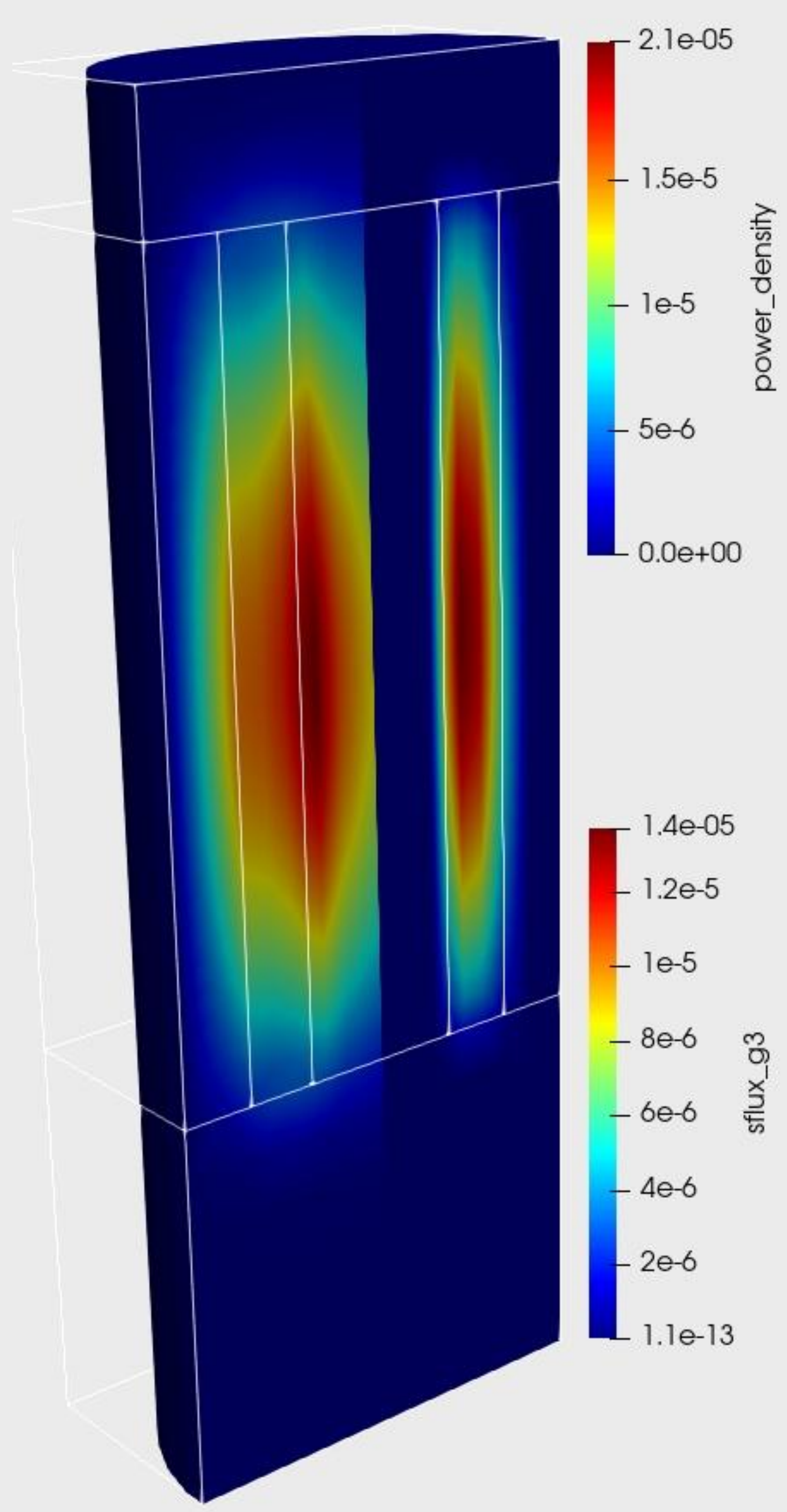


Figure 3: Color map of the post-seismic core cut through the center. Thermal flux (left) reaches a maximum just inside the central reflector. Power density (right) peaks inside of the fuel region.

PEBBLE TRACKING TRANSPORT:

- The PTT method uses pebble center location data from the PEBBLES program. This allows us to fill our core with modeled fuel spheres which make the model more physically accurate.
- Due to the computational requirements of running MAMMOTH with each pebble defined, the simulation cannot be performed in a timely manner on the OSU HPC.
- The PTT neutronic simulation will need to be run at INL. This section of the project was not able to be completed before the poster deadline. However, input files, meshes, and data have been prepared for INL.

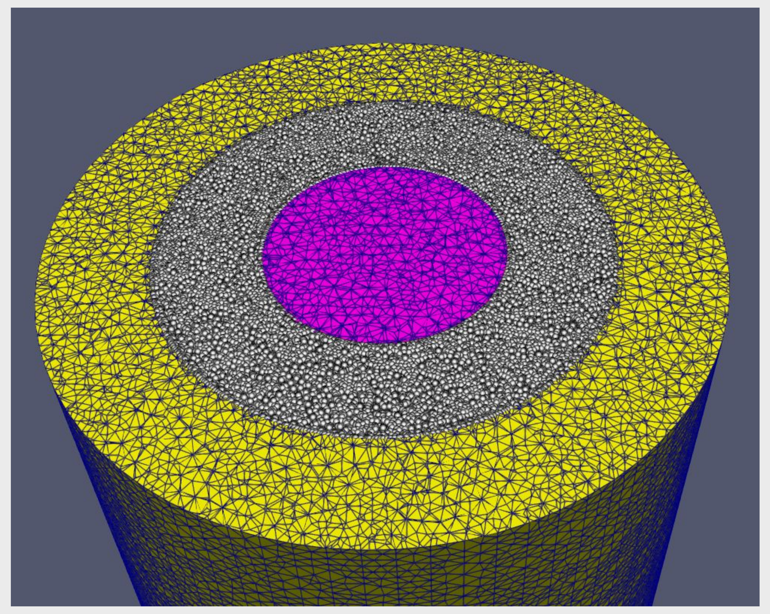


Figure 4: Post-seismic PTT mesh with visual representation of the pebbles. The active core is cut at the halfway point.

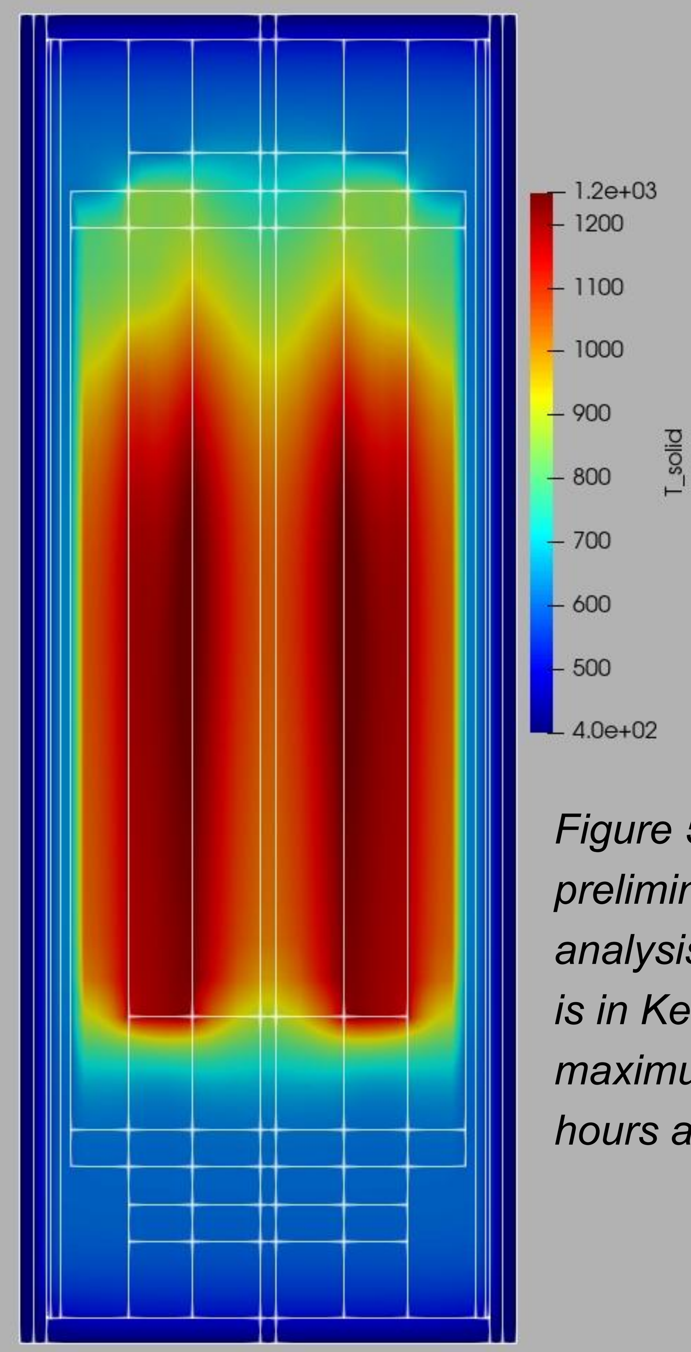


Figure 5: Cross section of preliminary heat conduction analysis. Fuel temperature is in Kelvin. It reaches a maximum of 1265.654 K 10 hours after the DLOFC.

HEAT CONDUCTION:

- Solving the solid phase energy balance equation for the temperature distribution requires: porosity as a function of location, thermal conductivity as a function of solid temperature, and fluid temperature distribution throughout the core.

$$(1-\varepsilon)\rho_s C_{p,s}\frac{\partial T_s}{\partial t} - \nabla\cdot(\kappa_s \nabla T_s) + \alpha(T_s - T_f) + \dot{q}_s = 0$$

- The overall goal for the heat conduction model is to determine maximum fuel temperatures within the pebble-bed.

EXPECTED RESULTS:

- The fluid temperature distribution significantly influences core neutronics as the upper section of the core will be at a much lower temperature and as a result will have a lower reactivity feedback compared to the bottom of the core.
- Thermal neutron flux is expected to peak slightly inside the central reflector, in the upper region of the core. Fast neutrons are thermalized and leakage is relatively minimal.
- The bottom of the core is the farthest region from the coolant inlet. It is expected to have the highest solid temperatures, despite having a much lower neutron flux.
- The goal is to compare the methods at the same physical reference to determine any major differences.

HOMOGENIZED DIFFUSION

These graphs show the difference between the pre and post seismic thermal flux and power densities. On our poster, this same data is displayed, however the peaks of interest are enlarged.

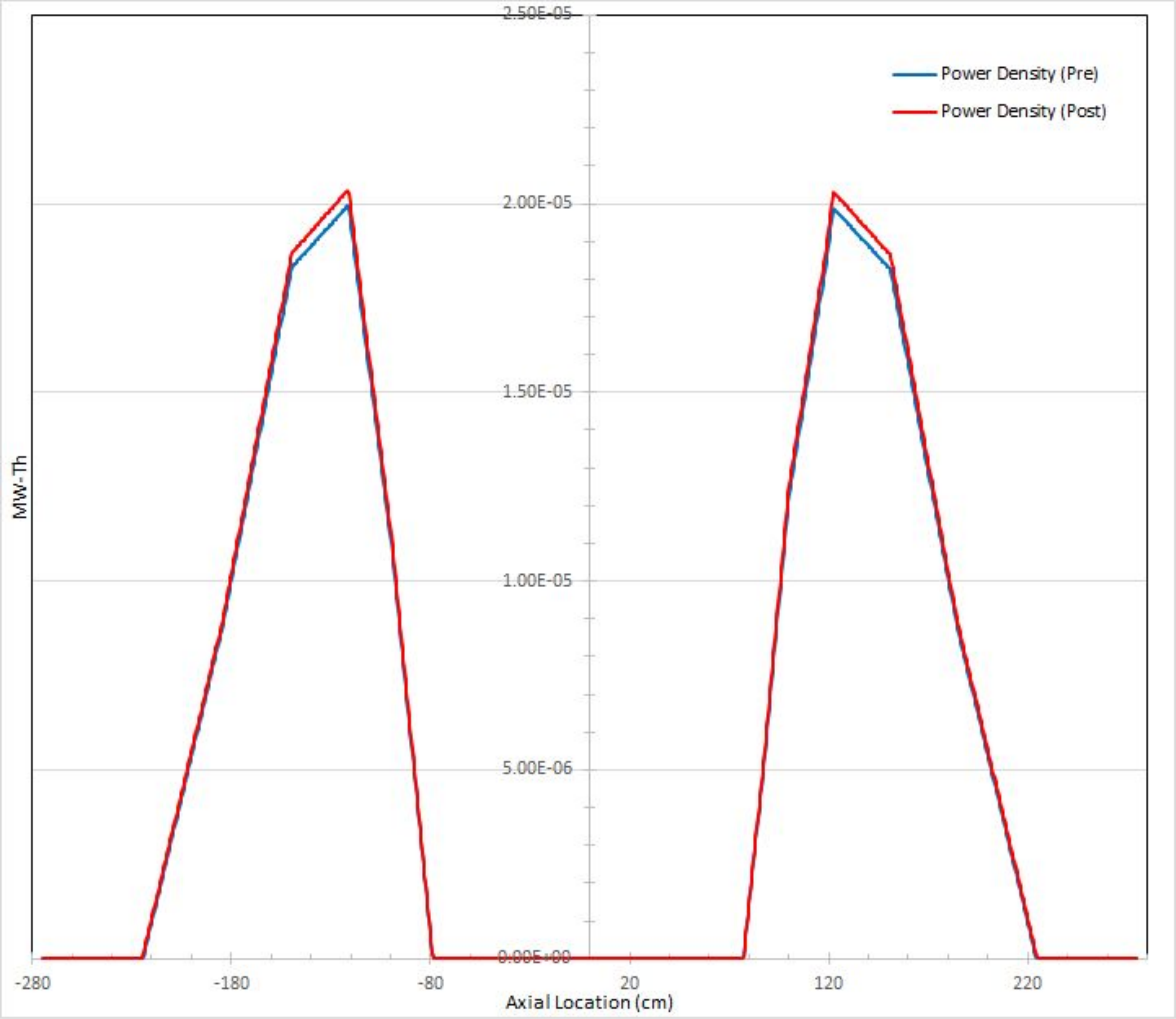


Figure A1: Power density for pre and post seismic event.

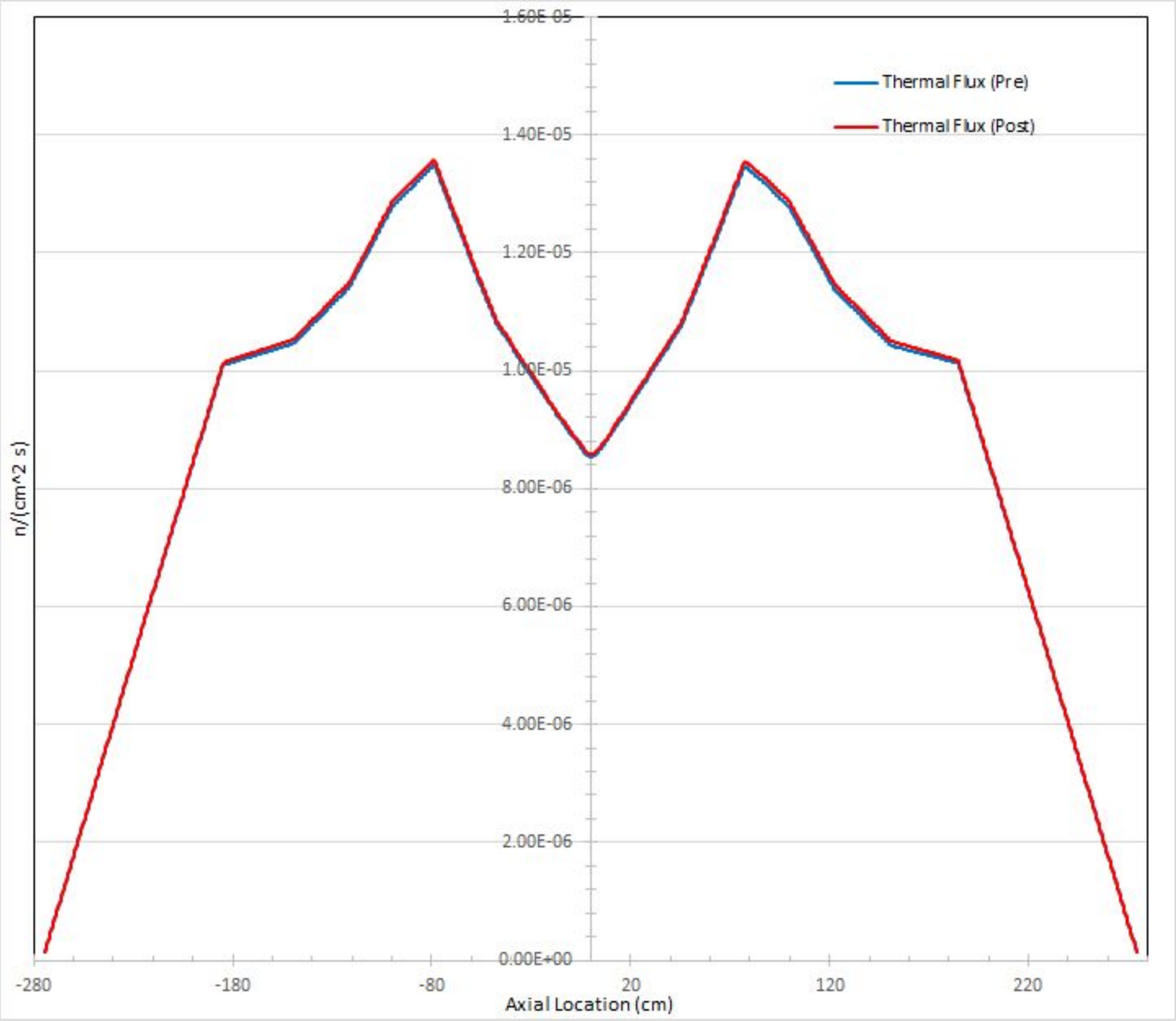


Figure A2: Thermal flux for pre and post seismic event.

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HOMOGENIZED DIFFUSION

These cross sectional cuts show thermal flux on the left and power density on the right. Pre seismic event is on the left and post seismicevent is on the right.

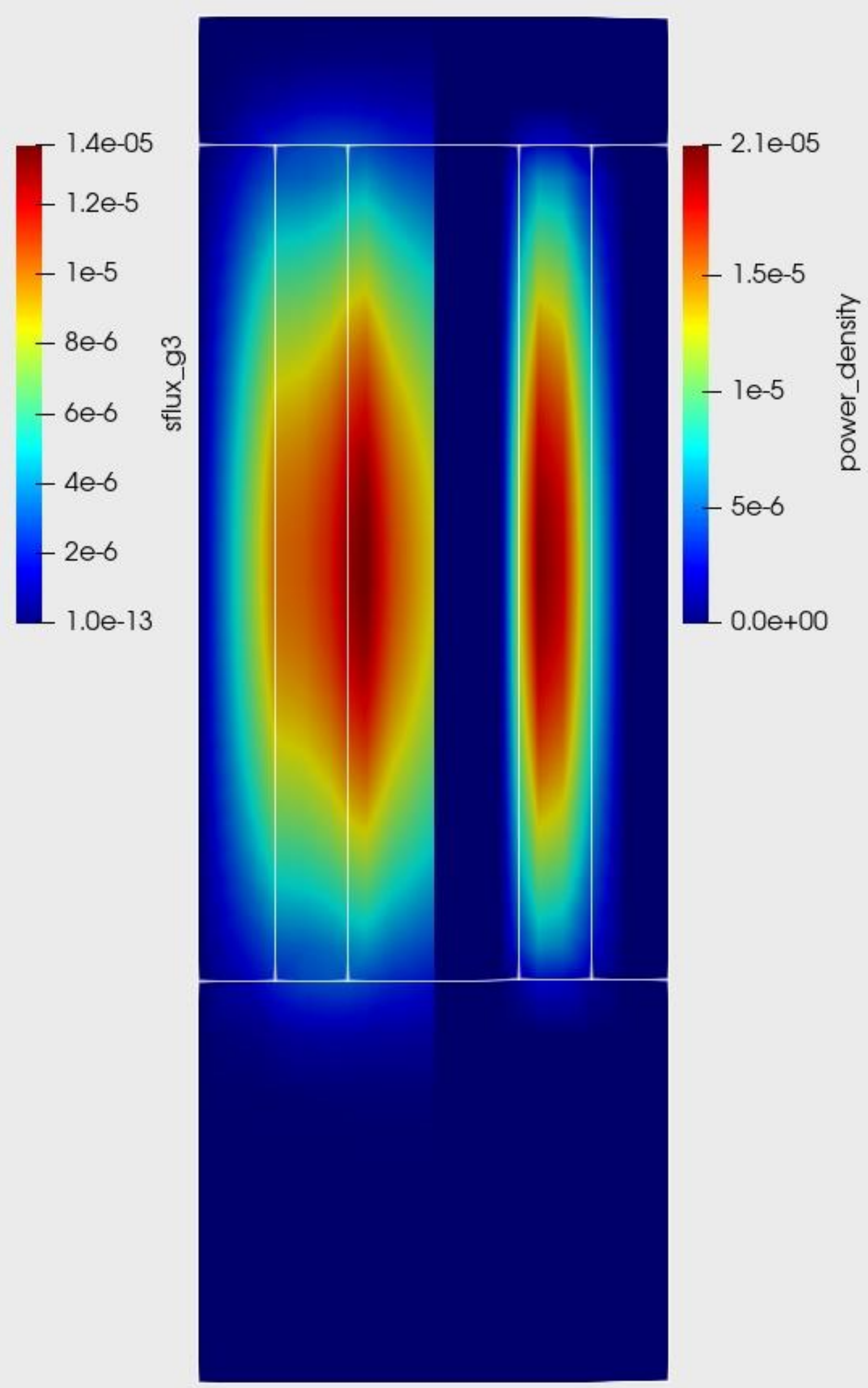

Figure B1: Pre-seismic event core cross section. Thermal flux is on the left and power density on the right.

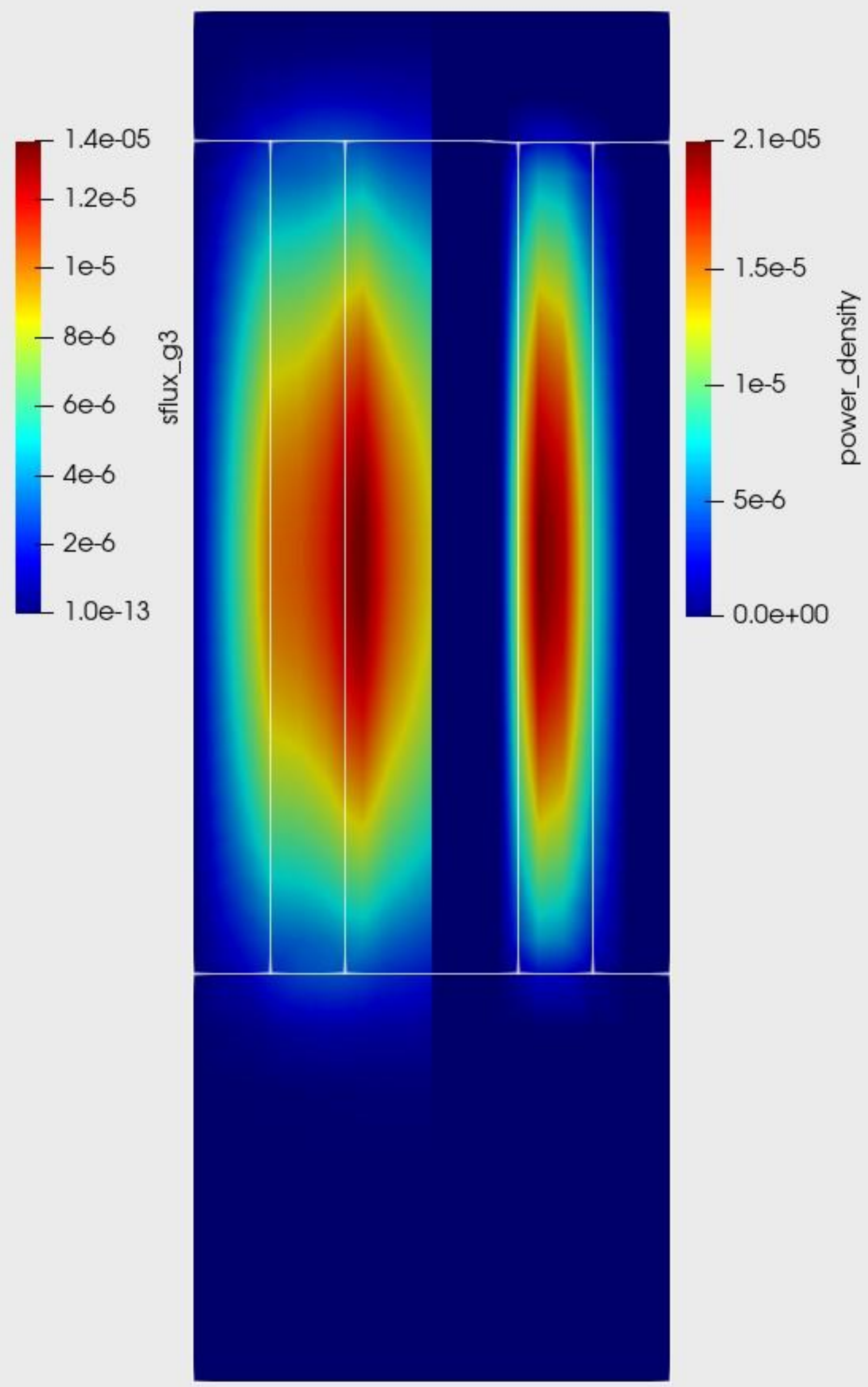

Figure B2: Post-seismic event core cross section. Thermal flux is on the left and power density on the right.

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