INL/CON-24-77506-Revision-0

Conceptual Spacer Design for the ATR GEN I Target for Pu-238 Production in the Advanced Test Reactor at Idaho National Laboratory

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Changing the World's Energy Future

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

May 2024

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Introduction

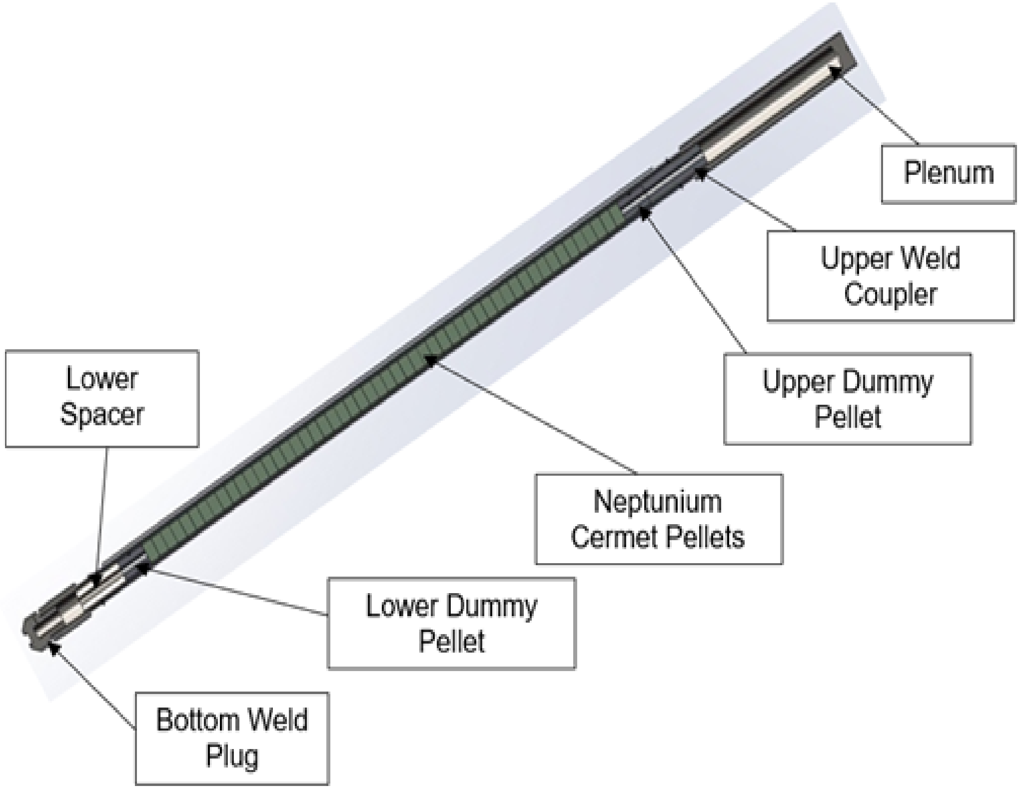
- Qualification of multiple Advanced Test Reactor (ATR) positions for Pu-238 production has been ongoing at Idaho National Laboratory (INL) as part of the campaign to restart domestic production of plutonium-238 used in radioisotope power systems (RPS) by the National Aeronautical and Space Administration (NASA) and Department of Energy (DOE) Office of Nuclear Energy (NE), Office of Nuclear Infrastructure Program (NE-3).

- As part of the qualification process, multiple target designs and Np concentrations have been evaluated to support and optimize Pu-238 production in ATR.

- The purpose of this presentation is to document the design considerations and conceptual calculations that were required to move from a single Pu-238 production target to two Pu-238 production targets per ATR position.

HFIR Gen II Target

- The initial target design used for Pu-238 was designed by Oak Ridge National Laboratory (ORNL) and is referred to as the High Flux Isotope Reactor (HFIR) GEN II target.
- HFIR GEN II Targets:
  - consist of a stack of fifty-two cylindrical pellets.
  - composed of 20-volume% neptunium oxide (NpO_2), 70-volume% aluminum, and 10-volume% void,
  - aluminum dummy pellet on the top and bottom of the stack up.
  - approximately 33 inches long.



Enlarged Image of HFIR GEN II Target (not to scale).

Pu-238 Production Target Designs

HFIR Gen II Target

Interface with both HFIR and ATR.

Streamline the production and post irradiation processing of the targets.

HFIR Gen II Limitations in ATR

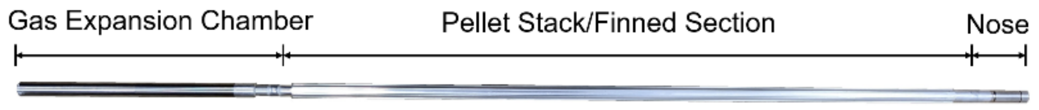
ATR has a much larger active core region than HFIR.

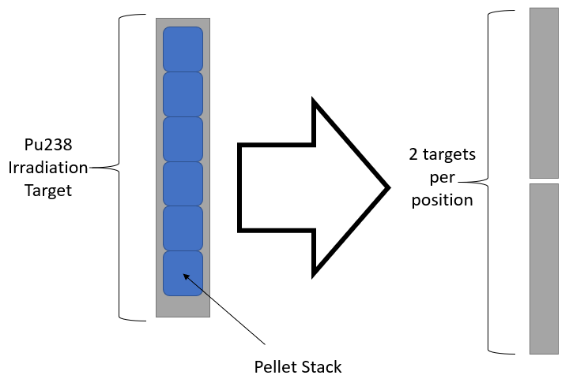
The single target design resulted in a lower Pu-238 production than desired due to the low amount of Np pellets that could be irradiated.

A new design was proposed that included reducing the height of the HFIR Gen II target and then stacking two targets nose to nose around the core center line of ATR that would make better use of ATR's core height.

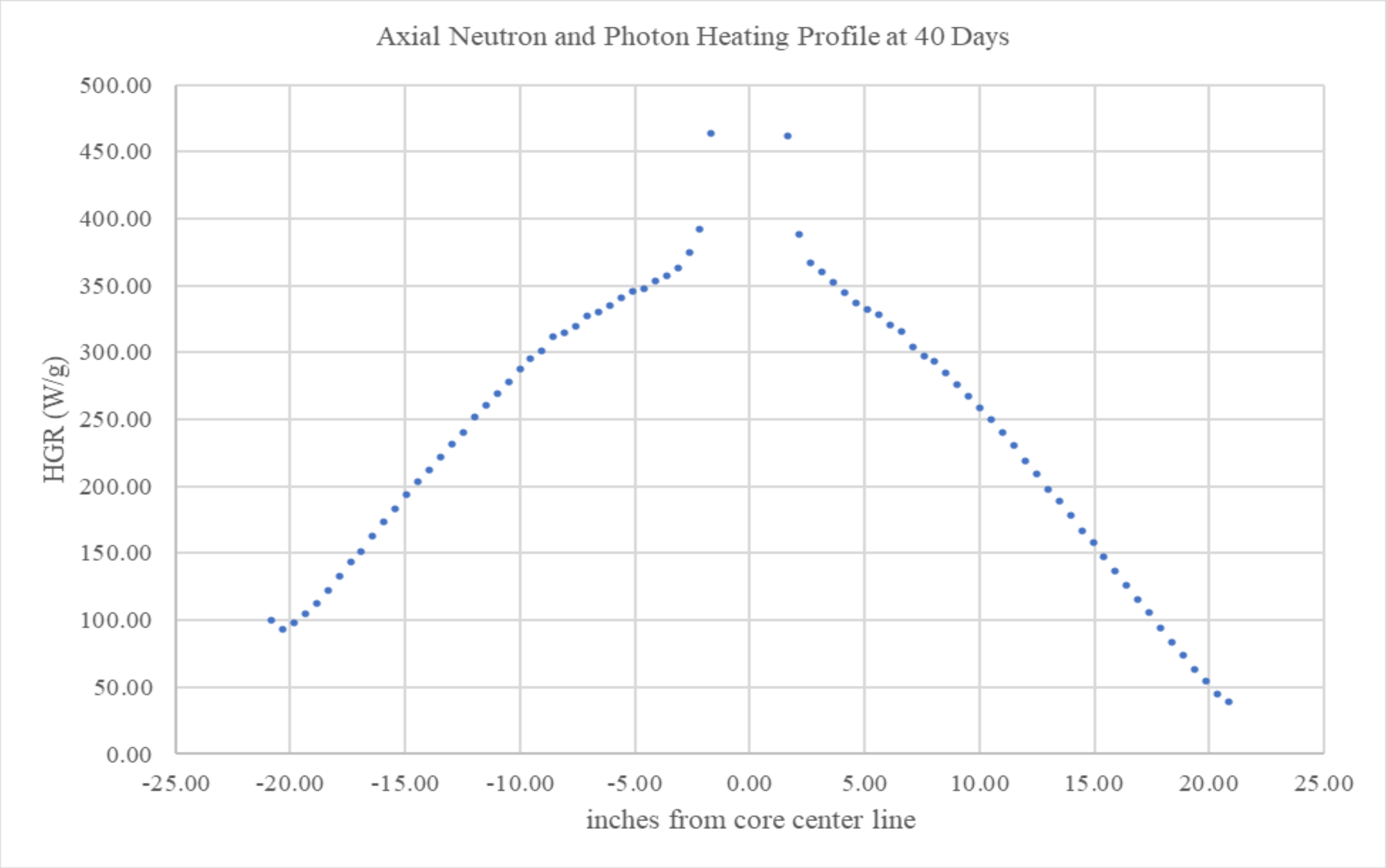
ATR Gen I Target Design

- The new targets are referred to as ATR Gen I targets.
- The target endpoints of the ATR Gen I targets are oriented around the core center line, increasing the number of pellets that can be irradiated.
- ATR Gen I Target Designs
    - Consists of a stack of 52 cylindrical pellets,
    - Composed of 20-volume% neptunium oxide (NpO_2), 70-volume% aluminum, and 10-volume% void.
    - Spacer pellet on the top of each stack.
    - Approximately 28.69 inches long.





ATR Gen I Preliminary Heating



- Preliminary evaluations of stacking the two targets nose to nose showed significant neutron and gamma heating at the core center line.
- 480 W/g after 40 days of irradiation in ATR at 23.1 MW.
- This significant heating is outside the desired design parameters.
- To mitigate this problem, it was proposed to replace the existing Al spacers located at the top of the pellet stack with a new spacer composed of different material.

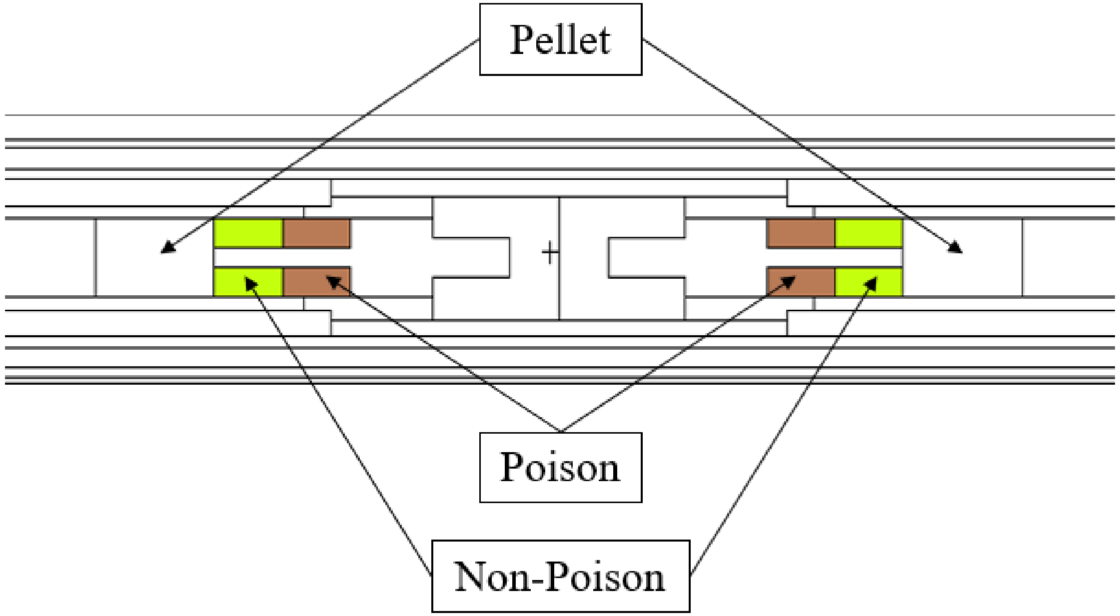
Spacer Requirements

Needed to reduce the significant heating of the target ends.

Additional Requirements:

1. The material needed to be compatible with ATR requirements and limitations.
2. The material needed to be compatible with HFIR requirements and limitations.
3. The material needed to be one that could be obtained without excessive cost, wait times, or machining.

Spacer Requirements (continued)…



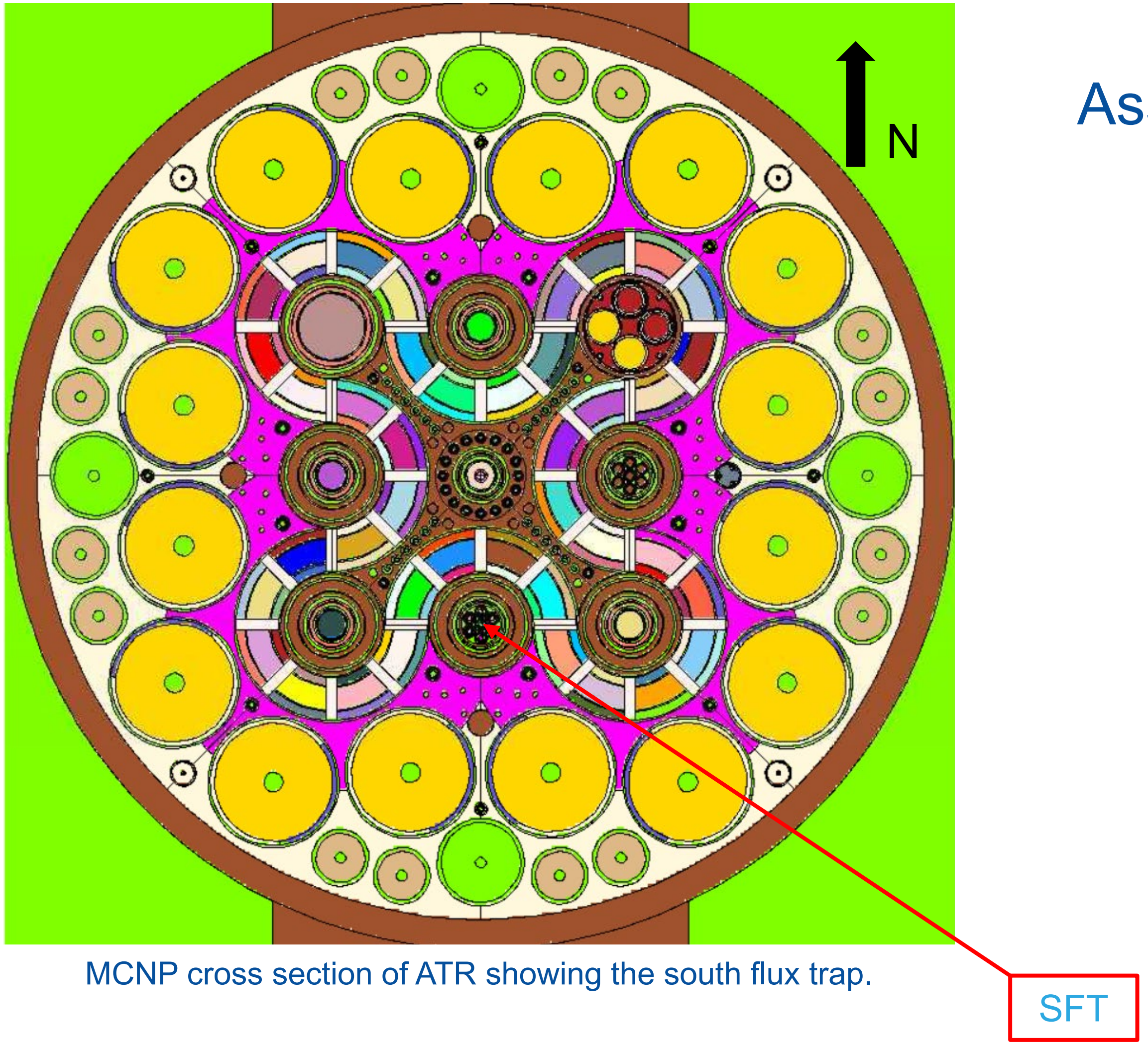
Simplified MCNP model identifying the location of the spacer materials in reference to the pellet.

- Three material configurations were considered as possible options during the conceptual design:
    1. Tantalum plus stainless steel.
    2. Hafnium plus stainless steel.
    3. Samarium plus stainless steel.
- These materials were placed at the top of each pellet stack and are near each other when the targets are placed nose to nose.
- To determine if they were viable design options, heat generation rates were calculated.

Computer Methods & Models

- The general-purpose Monte Carlo N-Particle transport code, MCNP, was used to model and evaluate the ATR Gen I targets during the conceptual design.
- MCNP was used to calculate the neutron and photon heat generation rates within all Pu-238 experiment materials.
- MCNP was also used to calculate the neutron fluxes and reaction rates for pertinent reactions on the neptunium pellet material and this information was then passed into ORIGEN2 to deplete the neptunium pellet material.
- The ENDF/B-VII.0 cross section library was used along with the neptunium-236m cross section library obtained from TENDL-2017. The standard ATR cross section library was used for ORIGEN2 calculations along with MCNP-calculated replacement cross sections.
- The python-based code, MCNP to ORIGEN2 in Python (MOPY), was used to more easily extract the fluxes and reaction rates calculated from MCNP and pass them to ORIGEN2.

Assumptions



MCNP cross section of ATR showing the south flux trap.

Assumptions

- 3 radial, 7 axial region fuel model of the ATR.
- Targets are located in the South Flux Trap.
- 40-day irradiation time. This time frame was adequate to demonstrate the rise in pellet heating through an ATR cycle and see the impacts of the new spacer material on the heating rates.

Calculations

- Each corner lobe in ATR is designed to operate individually.
- The core power used in calculating heat generation rates and flux must be scaled to the nearest lobe.
- By tallying the fission energy in the driver fuel in each lobe, then summing them, the core fission energy is calculated as shown in Equation (1).
- The lobe power is then calculated in Equation (2) by multiplying the expected core power by the lobe energy fraction of the calculated core energy. The expected core power is the sum of all the lobe powers for a given ATR Cycle.
- The scaled core power is then calculated by dividing the expected lobe power by the calculated lobe and multiplying by the expected core power as shown in Equation (3).

$$Calculated\ Core\ Energy\ (MeV) = \sum_i^4 \left[Calculated\ Lobe\ Fuel\ Mass\ (g)_i \times Calculated\ Lobe\ Fuel\ F7\ Tally \left(\frac{MeV}{g}\right)_i \right] \quad (1)$$

$$Calculated\ Lobe\ Power\ (MW) = Expected\ Core\ Power\ (MW) \times \frac{Calculated\ Lobe\ Energy\ (MeV)}{Calculated\ Core\ Energy\ (MeV)} \quad (2)$$

$$Scaled\ Core\ Power (MW) = Expected\ Core\ Power\ (MW) \times \frac{Expected\ Lobe\ Power\ (MW)}{Calculated\ Lobe\ Power\ (MW)} \quad (3)$$

Calculations (continued)…

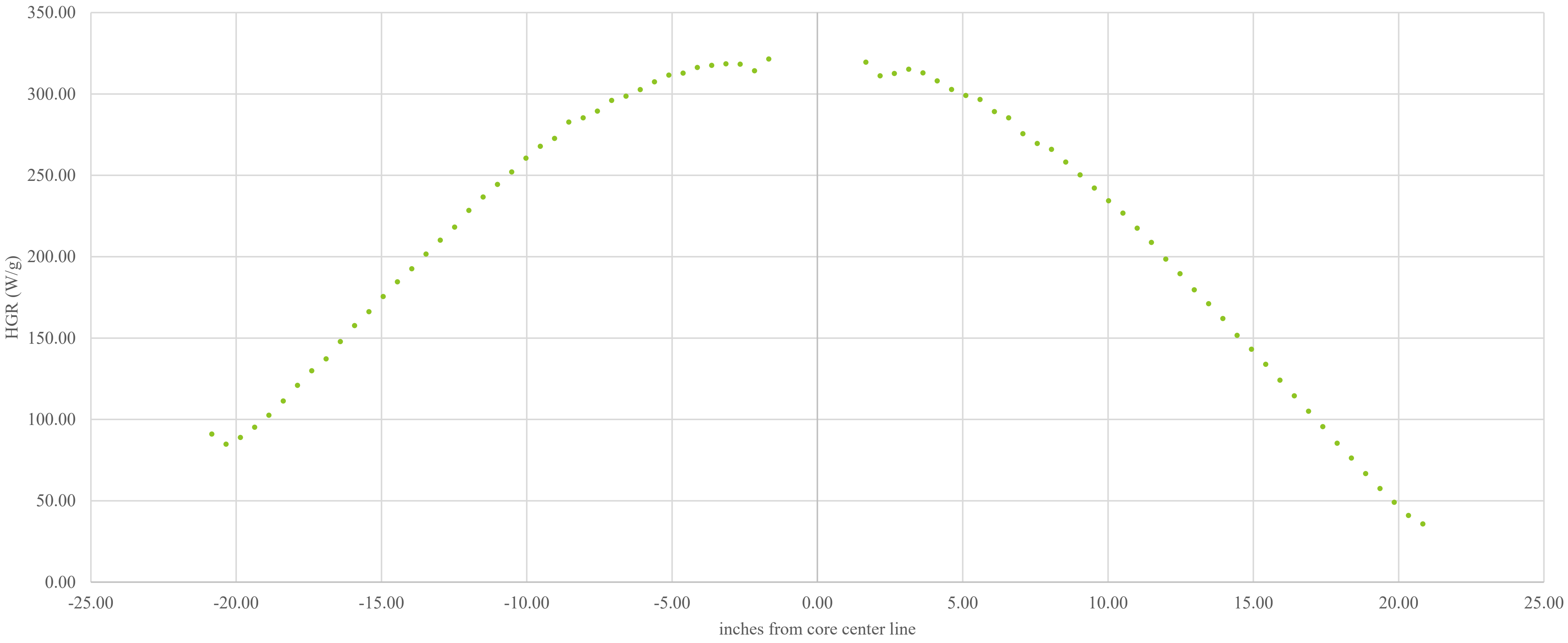
- MCNP reports tally results normalized per source particle. The MCNP tally type 6 has units of MeV/g per source particle (fission neutron for prompt neutron, gamma heating, and fission heating.
- The heat generation rates are calculated using the MCNP tally type 6 results, the heating normalization factor (HNF), and the ATR core power.
- Prompt neutron and gamma heating rates (PHR) are calculated using the equation shown.

$$\text{PHR} = (\text{f6})(\text{HNF})(\text{Core Power})\ \frac{W}{g}$$

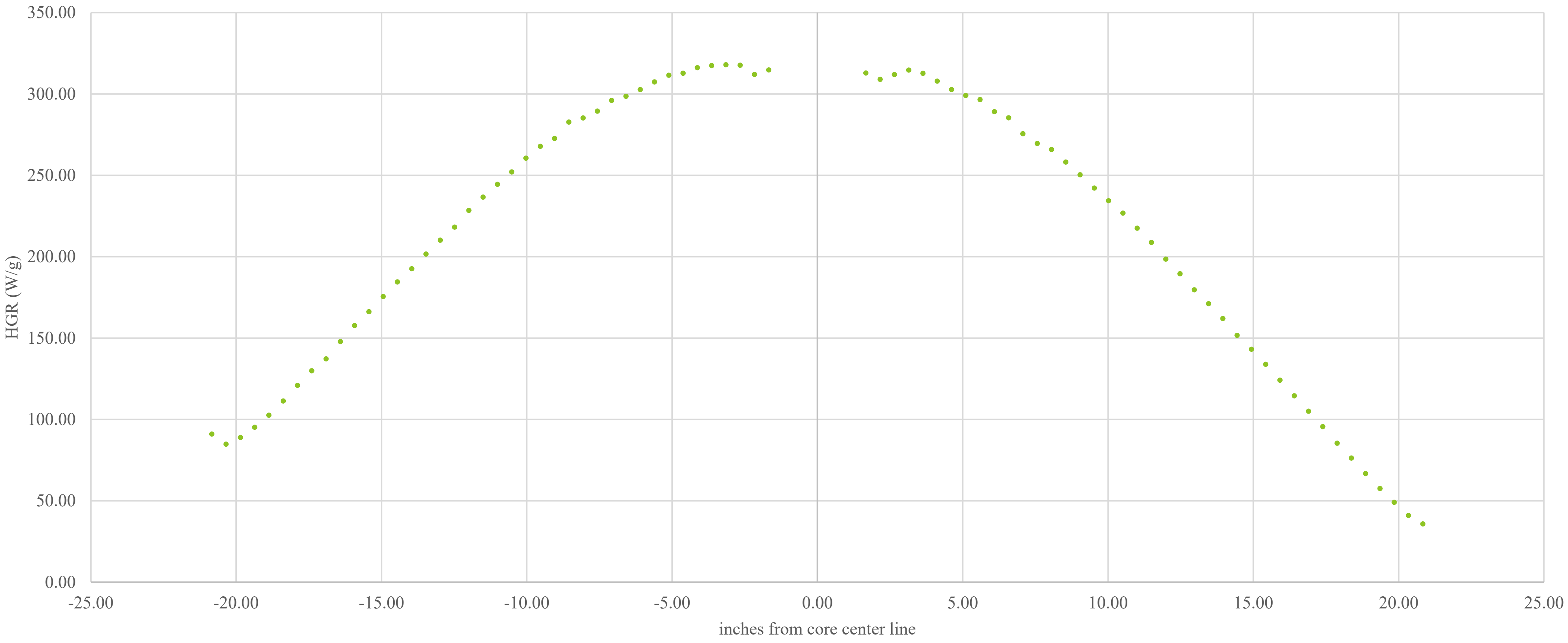
Results

- When first evaluating two ATR Gen I targets placed nose to nose in the same position, it was discovered that significant heating occurred in the center of the stack-up.
- To reduce this heating three material configurations were considered.
  - MCNP models were created for each material configuration.
  - MOPY was executed to obtain the tallies needed to calculate the neutron and photon heating rates.

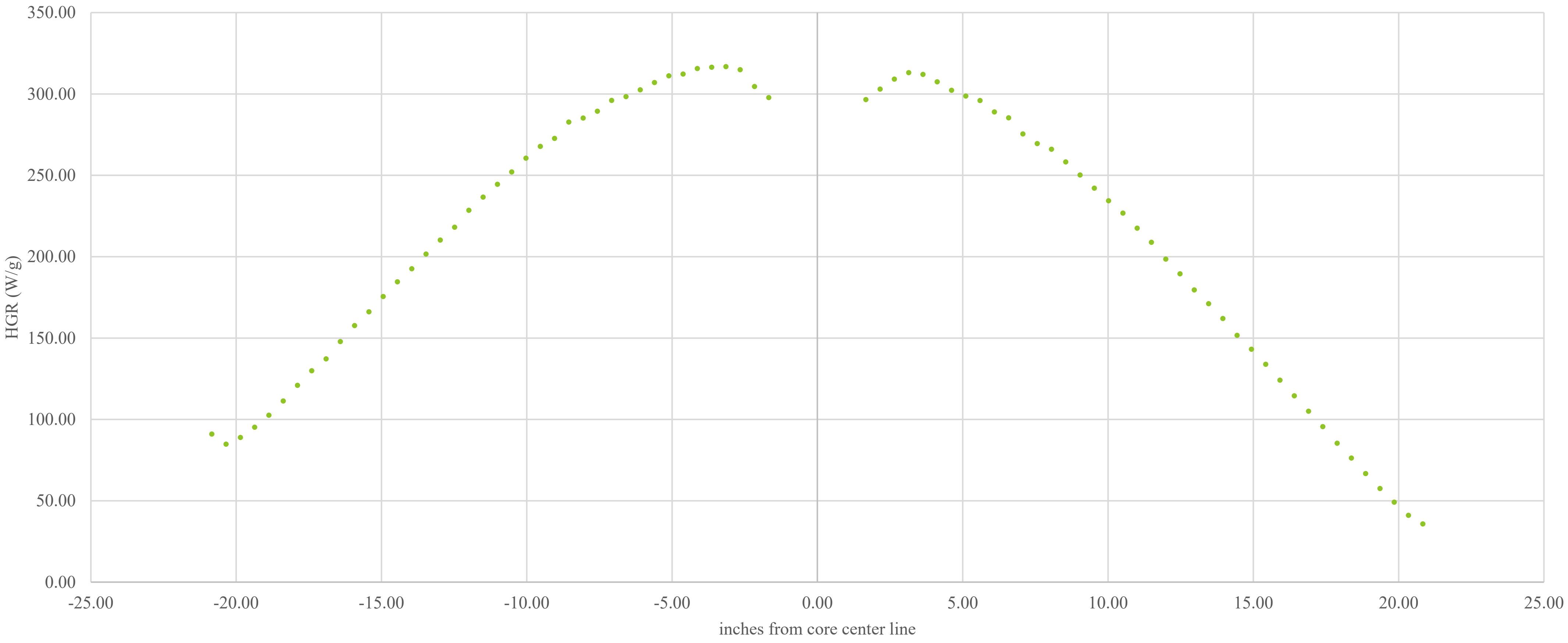
Neutron and Photon heating rates in Pu-238 targets with a Tantalum/Stainless Steel spacer after 40 days of irradiation.



Neutron and Photon heating rates in Pu-238 targets with a Hafnium/Stainless Steel spacer after 40 days of irradiation.



Neutron and Photon heating rates in Pu-238 targets with a Samarium/Stainless Steel spacer after 40 days of irradiation.



Peak Heating Rates

The heating profiles showed that applying the spacers reduced the heating peaks appropriately.

	Neutron and Photon Heating Rates (W/g) With Ta - SS Spacer				
	BOC	10 EFPDs	20 EFPDs	30 EFPDs	40 EFPDs
max	26.39	237.1	260.95	289.24	321.44
min	8.35	27.88	29.18	32.04	35.74

	Neutron and Photon Heating Rates (W/g) With Hf - SS Spacer				
	BOC	10 EFPDs	20 EFPDs	30 EFPDs	40 EFPDs
max	26.43	237.00	260.67	287.82	317.92
min	8.35	27.88	29.18	32.04	35.74

	Neutron and Photon Heating Rates (W/g) With Sm - Al Spacer				
	BOC	10 EFPDs	20 EFPDs	30 EFPDs	40 EFPDs
max	26.97	236.27	259.63	286.81	316.72
min	8.35	27.88	29.18	32.04	35.73

Percent Difference

Spacer Configuration	% difference
Original Spacer	--
Ta-SS	39.6%
Hf-SS	40.6%
Sm-SS	41.0%

Conclusions

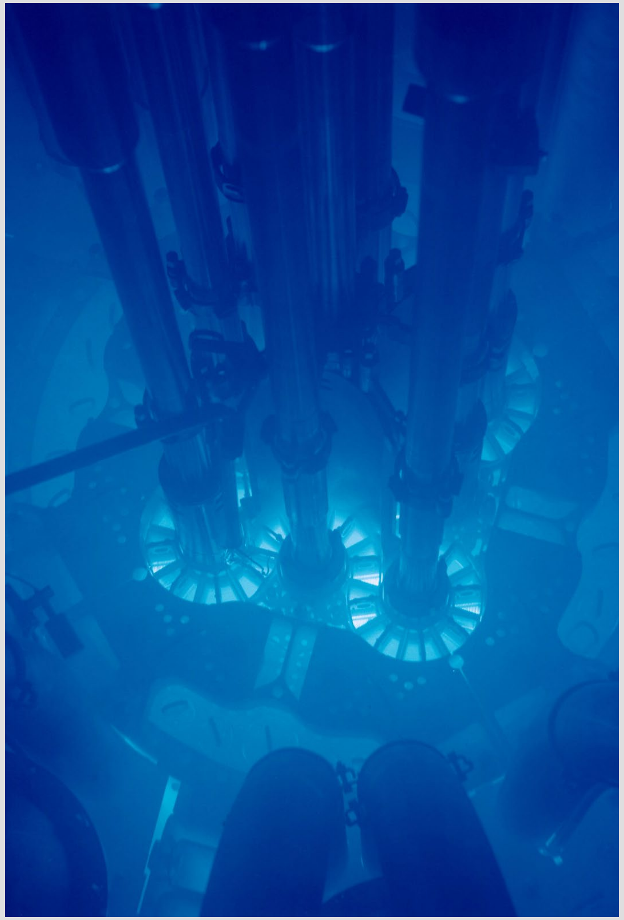
- Pu-238 production at INL is ongoing using ORNL manufactured targets, which are referred to as PFS ATR Generation I Targets.
- To mitigate the peak heating that was calculated when stacking two targets nose to nose, three spacer configurations were evaluated using the python-based code, MCNP to ORIGEN2 in Python (MOPY). MOPY was used to specifically look at the neutron and photon heat generation rates for each spacer configuration.
- Analysis showed that all three configurations, tantalum/stainless steel, hafnium/stainless steel, and samarium/stainless steel significantly reduced the peak heating with the samarium configuration showing the greatest reduction.
- Due to the lower heating and additional program requirements, the samarium/stainless steel spacer was recommended as part of the conceptual design to irradiate the ATR Gen I targets.
- As a follow-up to this conceptual analysis and in moving to the next phase of the ATR Gen I qualification, it was determined that a samarium/aluminum spacer provided the best configuration to reduce the neutron and photon heat generation rates.

Acknowledgments

Multiple INL staff members contributed to the development of the MOPY tools.

This work was funded through DOE & NASA Interagency Agreement # NNH19OB05A and DOE contract DE-AC05-00OR22725 and DE-AC07-05ID14517.

This research also made use of the resources of the High-Performance Computing Center at Idaho National Laboratory, which is supported by the Office of Nuclear Energy of the U.S. Department of Energy and the Nuclear Science User Facilities under Contract No. DE-AC07-05ID14517.



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