INL/CON-22-66710-Revision-0

Progress on Pu-238 Production at INL From March 2021 to February 2022

May 2022

Changing the World's Energy Future

William Spencer Green, Joshua David Fishler, David Reeder Blair, Ryan L Marlow, Mark A Hill, Paul Francis O'Donnell Jr, Joshua L Peterson-Droogh, Richard Harmon Howard, Andrew John Zillmer, Craig Tyler, Justin D Lower, Jill R Mitchell, Brittany Jean Grayson, Erik S Rosvall, Austen David Fradeneck

Idaho National Laboratory

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Progress on Pu-238 Production at INL From March 2021 to February 2022

Overview

- Program Overview
- New ATR GEN I Target Design
- Advanced Test Reactor (ATR) Position Qualification and cycles
- North East Flux Trap (NEFT) Qualification Analysis
- Transportation of irradiated targets to Oak Ridge National Labs (ORNL) in the Battelle Research Reactor (BRR) cask
- Questions

Pu-238 Production Background

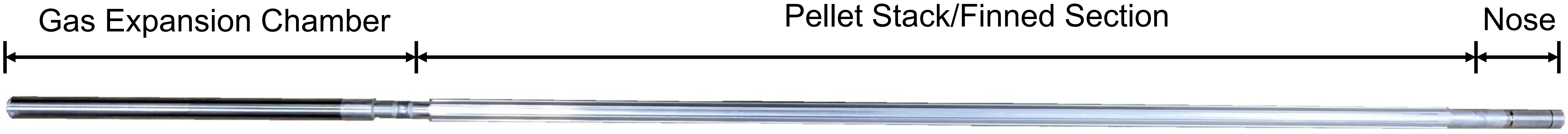
- Previously work was performed to find the ‘best position’, but those positions are also wanted by most other programs
  - Switched effort to qualifying positions that were likely available, and then move to positions with lower availability
  - Enables flexibility in core loading to maximize production with available targets
- Pu-238 production will be a backup experiment in these positions
  - If experiments have difficulty qualifying and miss the insertion date, Plutonium Fuel Supply (PFS) will replace the experiment
  - Enables better utilization of the ATR core by ensuring that positions are fully utilized
- Goal is to produce 1.5 kgs of heat source material between ORNL and INL
  - ORNL produces 800 g at the high flux isotope reactor (HFIR)
  - INL produces 700 g at ATR

INL Pu-238 Production Life Cycle

1. INL Package and Transfer Np-237 to ORNL
2. ORNL Fabricates targets and inserts Np-237 pellets. Then ORNL ships the completed targets to INL for Irradiation*
3. Targets are irradiated in INL's ATR to convert Np-237 to Pu-238. Then the targets are shipped back to ORNL in BRR cask.
4. ORNL processes the targets and ships the Pu-238 to LANL
5. LANL fabricates Pu-238 into iridium clad pellets and ships them to INL to fuel radioisotope thermoelectric generators (RTG).
6. INL fuels the RTG and completes acceptance testing. Then the RTG is shipped to NASA's Kennedy Space Center.

*ORNL also irradiates the same design of targets in HFIR. Targets from both facilities are processed at ORNL and sent to LANL.

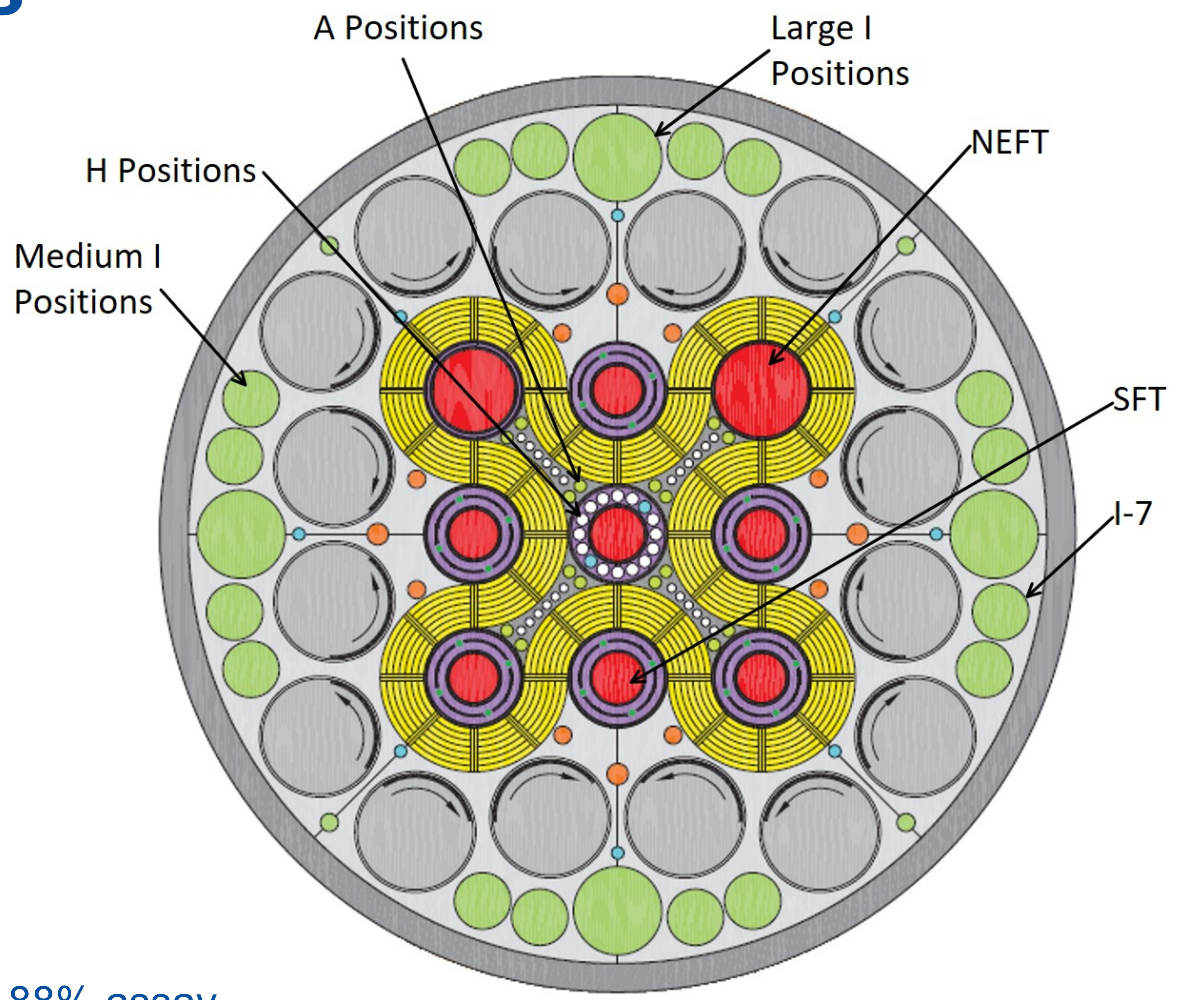
ATR Gen I Target



- The ATR GEN I was designed by ORNL to have a second ATR Gen I target stacked nose to nose in each basket at ATR.
- Stacking targets allows the full height of the ATR core to be utilized while the shorter target length allows the targets to be processed in ORNL's hot cells.
- The ATR Gen I is 28.69" long whereas the HFIR Gen II is 33.53" long. The difference in length and the flat nose design allows for the target to be stacked.
- ATR Gen I targets weigh approximately 200g and contain approximately 30g Np
- Np Pellet stack is identical for ATR Gen I and the HFIR Gen II targets.
- Each ATR Gen I target contains one internal Sm spacer to reduce the flux at the center where the targets meet.

ATR Position Qualifications

Previous Qualifications	Current Qualification	Future Qualifications
I-7 (Medium I) Position HFIR GEN II Targets	North East Flux Trap ATR GEN I Target	South Flux Trap ATR GEN I Target
South Flux Trap HFIR GEN II Targets	A Positions ATR GEN I Target	Medium I positions ATR GEN I Target
	H Positions ATR GEN I Target	Large I positions ATR GEN I Target



Cross Section of the ATR Core

- Inner core positions provide high production rate with 84% to 88% assay
  - One cycle to complete production
- I positions provide low production rate with 90% to 96% assay
  - Typically will take 5 or 6 cycles to complete production

ATR Cycles

CIC

329 Day outage and 55 day testing, approximate completion date May 15th

ATR's entire Core is being replaced and testing will be performed on the new core.

171 A

60 Day Cycle, approximate start date June 10th

Plan to irradiate up to 50 ATR Gen I Targets in the NEFT, A and H positions and 7 HFIR Gen II Targets in the SFT.

172 A

7 Day Cycle, approximate start date September 14th

No targets will be irradiated during this cycle

173 A

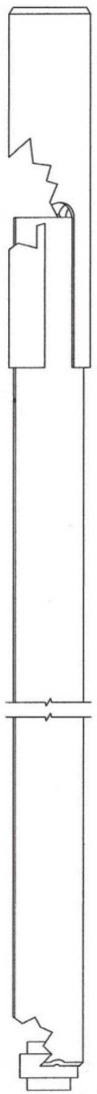
60 Day Cycle, approximate start date October 24th

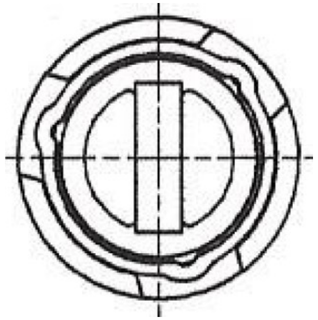
Potential to irradiate up to 104 ATR Gen I targets in the NEFT, SFT, A, and H positions.

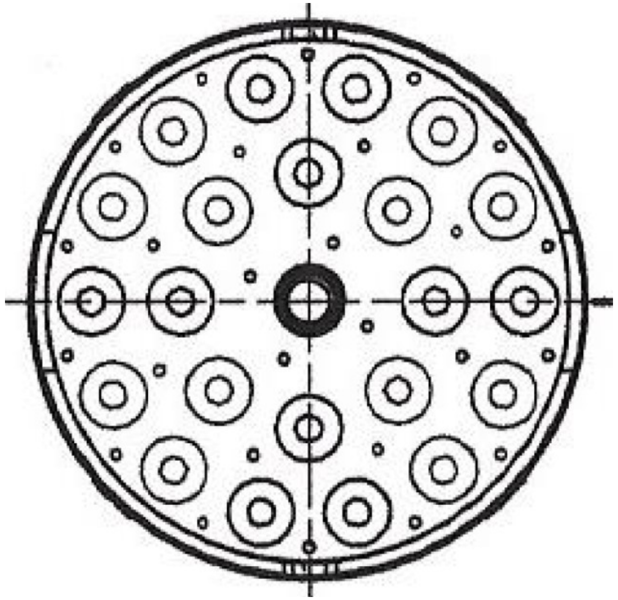
Core Internal Changeout (CIC)

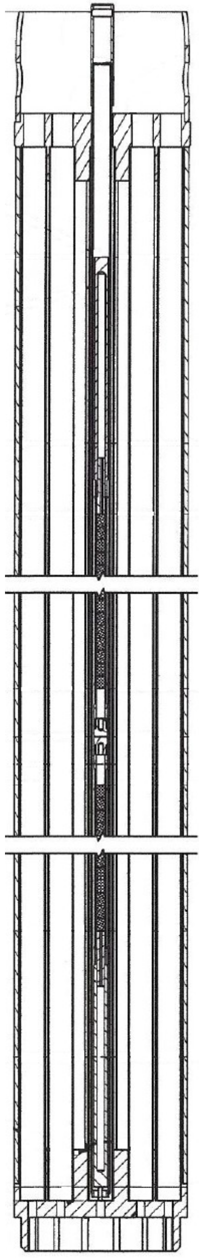
NEFT Mechanical Design

- NEFT basket design is based upon previous designs that used an extruded thin wall tube with ridges to keep the basket vertically centered in the irradiation housing.
- The basket's head is designed to allow hand tools to be used to manipulate the baskets under water.
- The nose of the basket was redesigned to allow for a stronger fillet weld than previous baskets while still allowing for the optimal flow through the basket
- Each Basket allows for two targets to be stacked nose to nose
- The irradiation housing has positions for 23 baskets which will allow 46 targets to be irradiated in the NEFT.





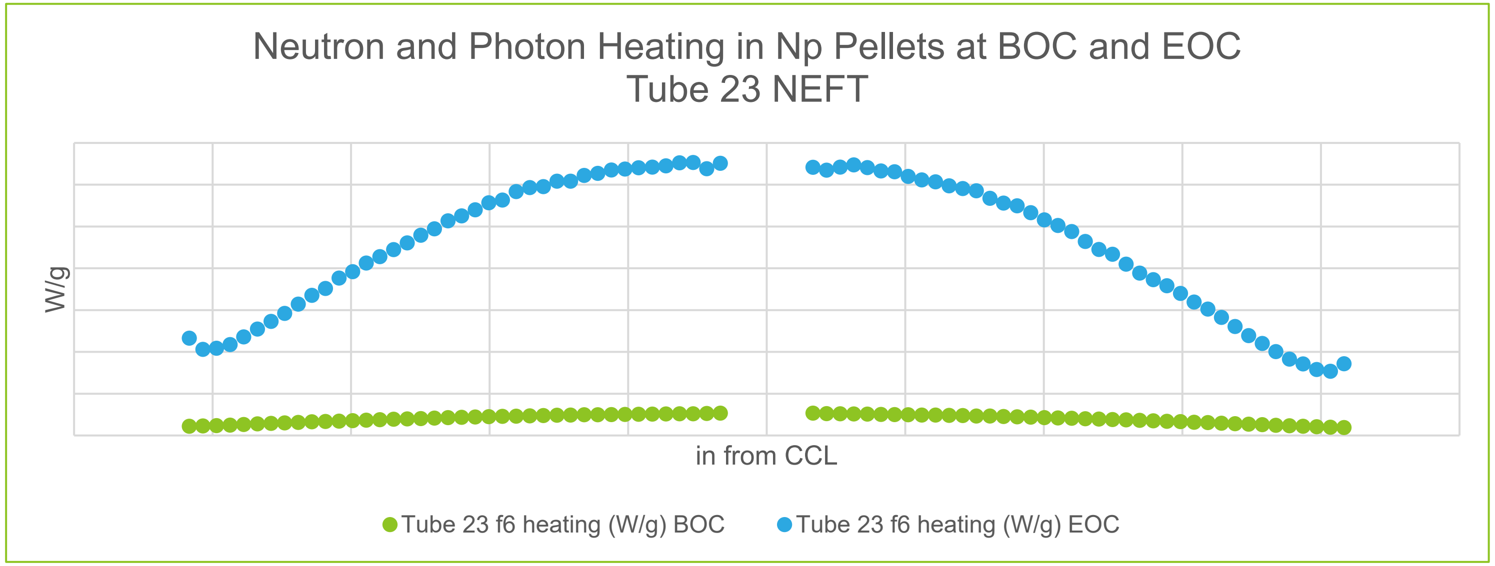




Left Picture: NEFT Basket, Top Picture: Bottom View of Basket, Right Picture: NEFT Irradiation Housing, Bottom Picture: Top View of Irradiation housing

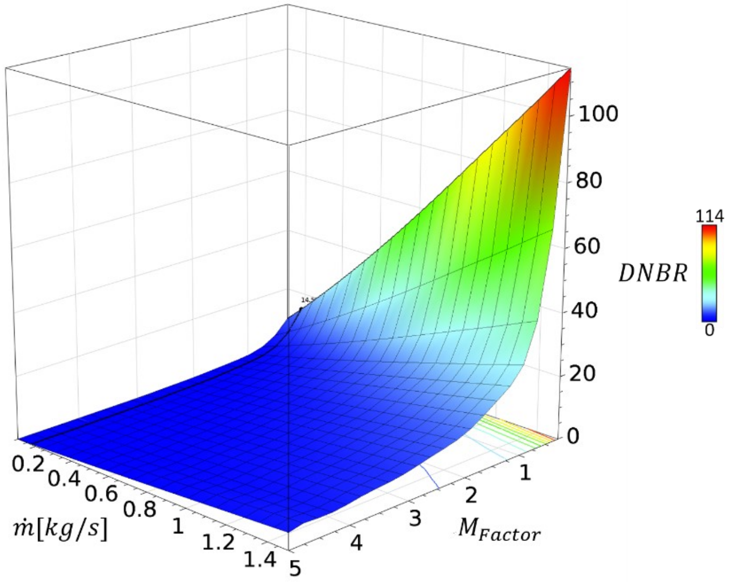
Neutronics Analysis

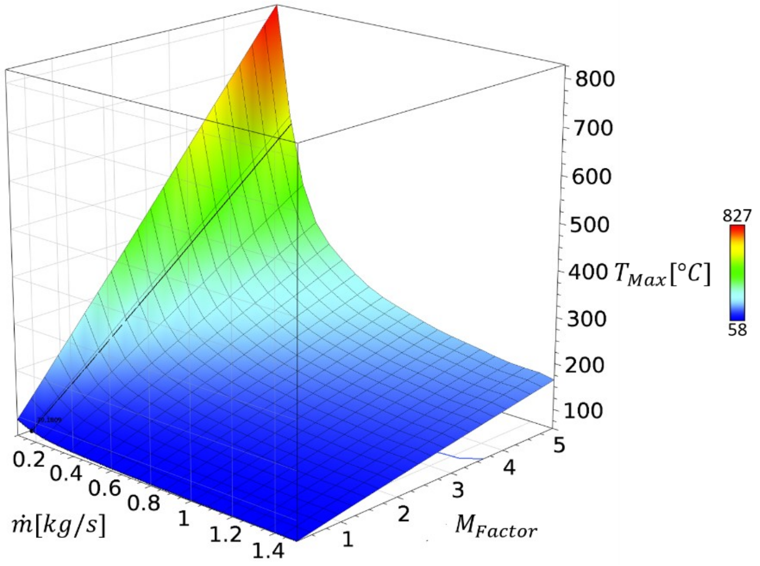
- MCNP was used to properly capture the axially dependent behavior of the neptunium pellet stack. The pellet stack was divided into 40 axial segments.
- MCNP5 was used to calculate the pertinent neutron and photon heat generation rates within all experiment materials
- 60 Day average Pu-238 assay for the NEFT is 88.53%
- Estimated to produce approximately 190 grams of Pu-238 Oxide during cycle 171A



Thermal Analysis

- The inputs for the heating rate and flow rate were parameterized using the software package HEEDS (v.2021.1) which automated the writing and submission of the ABAQUS input files. The inputs were varied over a wide enough range to encompass as many thermal/hydraulic conditions as possible.
- A safety factor multiplier of 1.26 was applied to all heat rates to account for instrumentation and lobe power uncertainties.
- The minimum departure from nucleate boiling ratio (DNBR), flow instability ratio (FIR) and maximum temperature and subsequent internal pressure were extracted from each simulation as quantities of interest. These quantities were used to generate a system response surface
- The response surface was used to create a lookup table of minimum required flow rates for a given total experiment heat rate to facilitate qualification of the target in different positions in ATR





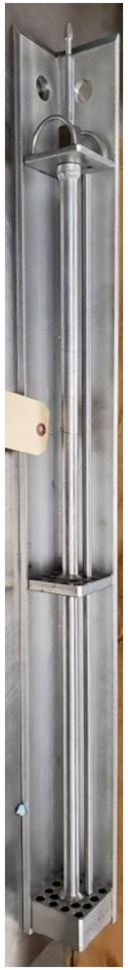
Structural Analysis

- The loadings considered in this evaluation included the following:
  - Internal pressure within the target due to the release of fission gas,
  - External pressure and external pressure differential acting on the length of the assembly,
  - Pressure and skin friction drag forces due to coolant flow velocities, flow induced vibrations, thermal loads, and cyclical loads.
  - Accidental drop through water from a height of 45 ft.
- ASME Boiler and Pressure Vessel Code were used.
  - Provides a nationally accepted design/analysis approach which INL has used and adapted to various nuclear experiments.
- Utilized a bounding case approach
  - Calculated maximum limits for temperature, pressure and coolant velocities.
  - Compared the maximum limits to the those calculated in thermal analysis.

ATR Safety Considerations

- A new experiment safety analysis (ESA) is being developed to cover the ATR GEN I target insertion into the NEFT, A and H positions
- This ESA will utilize the neutronics, thermal, and structural analysis to demonstrate the new ATR Gen I targets can be irradiated in the ATR in compliance with the requirements of technical safety requirements and the approved authorization basis established by ATR's Safety Analysis Report
- The PFS Gen I ESA must demonstrate that experiment receipt, reactor loading, irradiation, discharge, storage, preparing for shipping from ATR, and waste disposal of the PFS experiments are in accordance with the restrictions identified in the ESA and within the authorization basis of the ATR

Transportation of Irradiated Targets in BRR Cask



Target Racks

- Designed to hold up to 96 targets (HFIR GEN II or ATR GEN I) in 6 positions with 16 targets per position.
- Performed a comparison of targets in the NEFT to the generic targets in the SARP.
  - The generic targets in the SARP were based upon a 65 day irradiation in the A position followed by 180 days of decay.
  - The calculations was performed in ORIGIN 2 and was performed on a per inch of NpO2-AL stack height basis. The SARP used a generic stack length of 23” and the actual stack length is 19.5”
  - The dose rates were compared to the 10 CFR 71.47 dose radiation limits and both the generic and the NEFT irradiated targets are significantly less than the limits.

BRR Cask loaded on trailer

Conclusion

- INL has qualified the ATR Gen I target for Irradiation in the NEFT, A and H positions
- The first irradiations of the ATR GEN I target is expected to start in June
- INL has confirmed that the irradiated targets can be shipped to ORNL in the BRR cask
- INL is on track to meet or exceed production goals by 2025

Questions

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