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

Idaho National Laboratory

Overview

- Program Overview
- Advanced Test Reactor (ATR) GEN I Target Design
- ATR Position Qualifications and Cycles
- Progress on ATR Position Qualification Analysis
- Shipping Targets from Oak Ridge National Lab (ORNL) to Idaho National Lab (INL) for Irradiation
- Conclusion
- Questions

INL Pu-238 Production Life Cycle

1 INL Packages and Transfers 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 Battelle Research Reactor (BRR) cask.

4 ORNL processes the targets and ships the Pu-238 to Los Alamos National Lab (LANL)

5 LANL fabricates Pu-238 into iridium clad pellets and ships them to INL to fuel radioisotope thermoelectric generators (RTG).

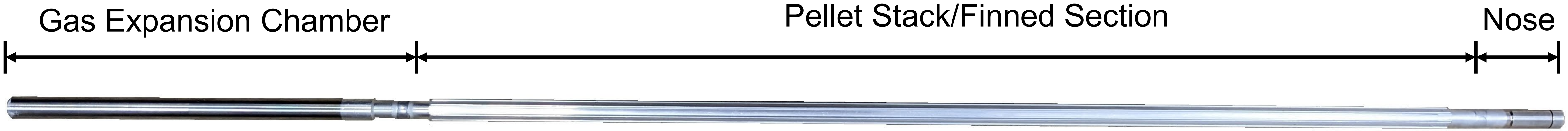
6 INL fuels the RTG and completes acceptance testing. Then the RTG is shipped to NASA's Kennedy Space Center.

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

Pu-238 Production Background

- Goal is for ATR and High Flux Isotope Reactor (HFIR) to contribute to the 1.5 kg per year constant rate production goal of Pu-238 in the United States by 2026.
- Current goal is to qualify as many positions as possible so Pu-238 production will be a backup experiment in these positions
  - If other experiments are having 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
- The HFIR GEN II is a previous target design that was specifically designed for use HFIR. The ATR GEN I target is a newer target design that was specifically designed for use in ATR as well as HFIR. Both types of targets have been qualified for use in ATR.
- The northeast flux trap (NEFT), inner-A and H positions have been qualified for the insertion of the ATR GEN I target, and work is in progress to requalify the south flux trap (SFT) and qualify the east flux trap (EFT)

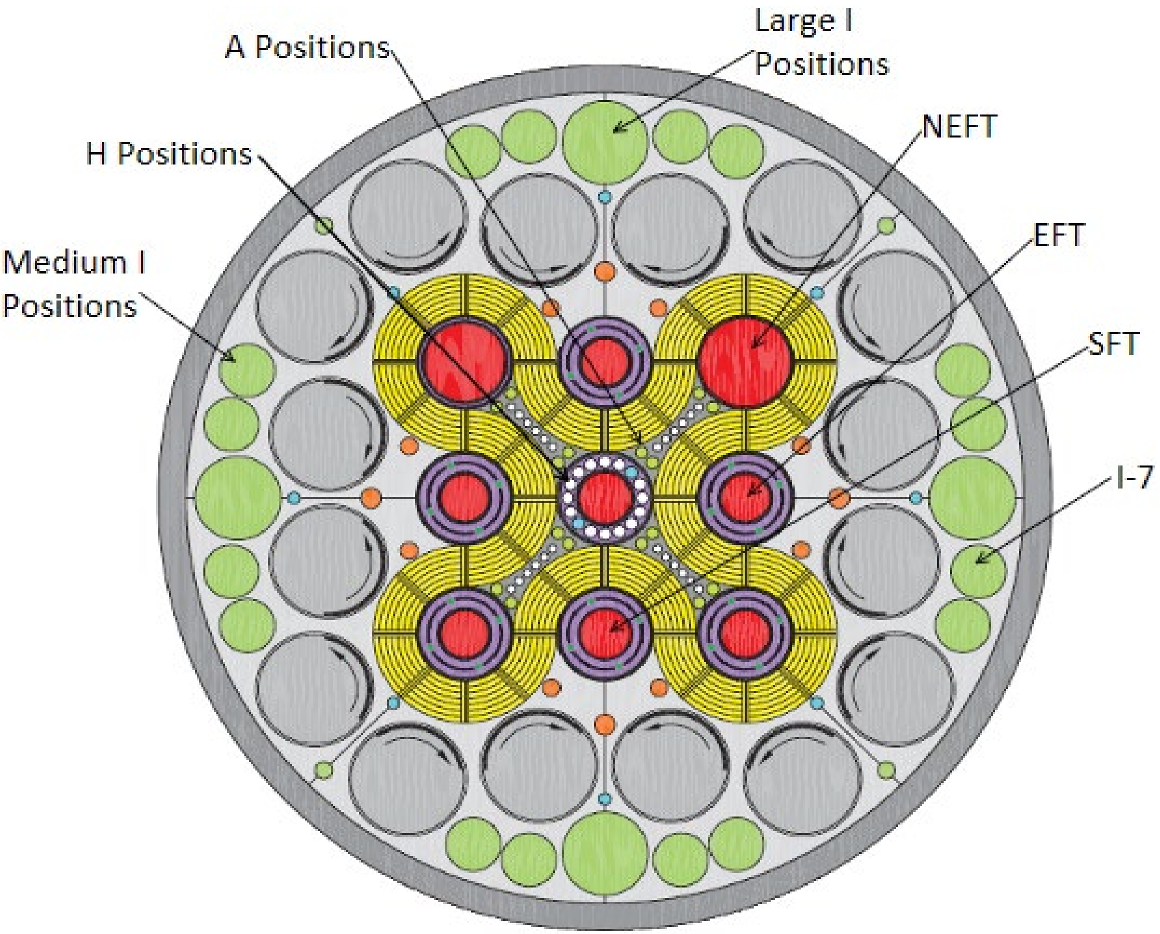
ATR Gen I Target



- 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 target	Inner A Positions ATR GEN I Target	Medium I positions
South Flux Trap HFIR GEN II Target	H Positions ATR GEN I Target	Large I positions
North East Flux Trap ATR GEN I Target	SFT and EFT ATR GEN I Target	
	30% Np for NEFT, SFT, EFT, A, and H positions.	



Cross Section of the ATR Core

- Inner core positions provide high production rate with approximately 84% to 92% assay
  - One cycle to complete production
- I positions provide low production rate with approximately 90% to 96% assay
  - Typically will take 5 or 6 cycles to complete production

ATR Cycles

171 A

60 Day Cycle, approximate start in early 2023

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.

171 B

60 Day Cycle, approximate start spring 2023

Due to target availability only 46 targets will be irradiated in the NEFT.

172 A

7 Day Cycle, approximate start date in fall 2023

No targets will be irradiated during this cycle.

173 A

60 Day Cycle, approximate start in fall 2023

Potential to irradiate up to 80 ATR Gen I targets in the NEFT, SFT, A, and H positions.

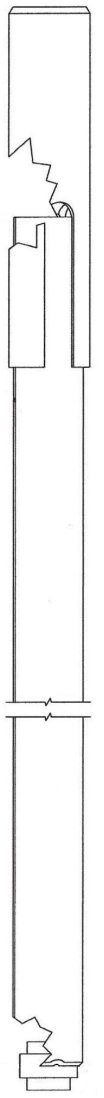
173 B

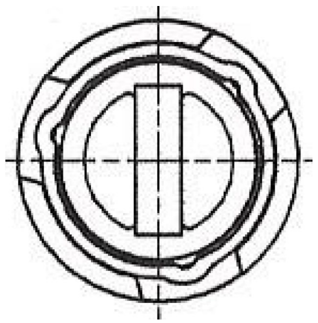
60 Day Cycle, approximate start date in early 2024

Potential to irradiate up to 34 ATR Gen I targets in the A, and H positions. Potential to Irradiate 310 targets in the I positions.

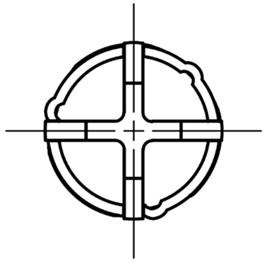
Mechanical Design

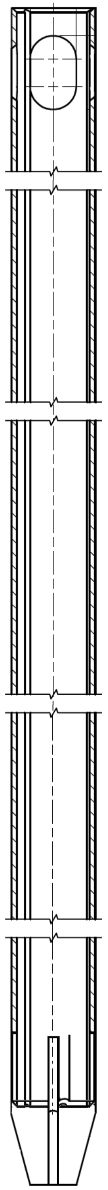
- NEFT, inner A, and H position baskets design is based upon previous designs that used an extruded thin wall tube with ridges to keep the basket vertically centered in the irradiation housing or position.
- The basket's head is designed to allow hand tools to be used to manipulate the baskets under water.
- The nose of the H position basket was redesigned to allow for a stronger fillet weld than previous baskets while still allowing for the optimal flow through the basket. This is the same as the NEFT.
- Each Basket allows for two targets to be stacked nose to nose
- The NEFT irradiation housing has positions for 23 baskets which will allow 46 targets to be irradiated. There are 8 inner A and 14 H positions that will accommodate 1 basket each with 2 targets.





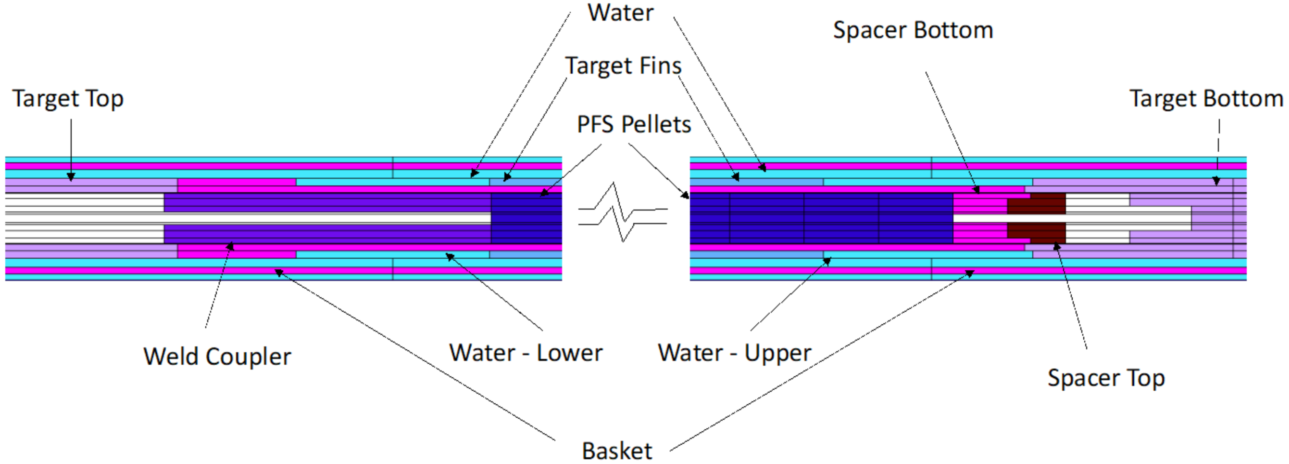
Left Picture: H Position Basket; Top Picture: Bottom View of H position Basket; Right Picture: A Position Basket; Bottom Picture: Bottom View of A position Basket





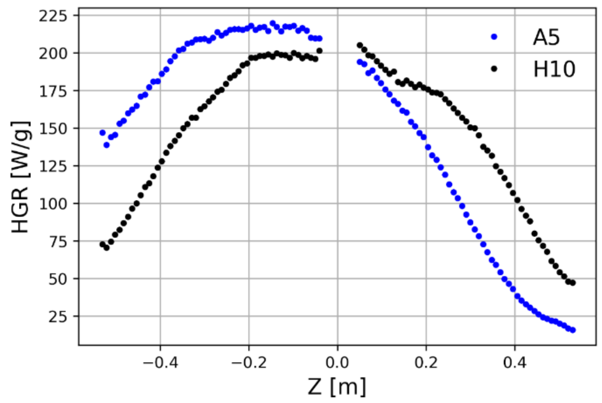
Neutronics Analysis

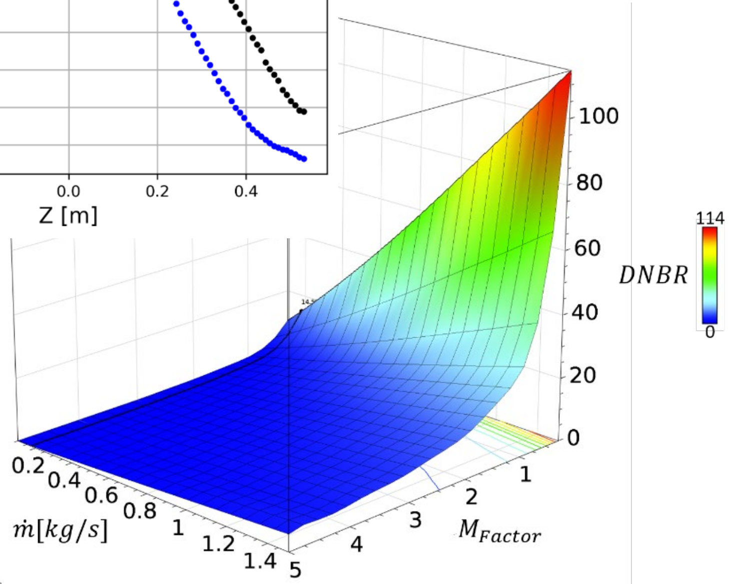
- MC21 was used to calculate neutron and photon heat generation rates during irradiation, fission gas production, Pu-238 production, fission density, and experiment reactivity for the A and H positions . The pellet stack was divided into 52 axial and five radial discretization's per target.
- Due to the lack of development of the ATR model in MC21 for decay heat and dose consequence at the time calculations were performed, MCNP5 coupled with ORIGEN2 (MOPY) was used to calculate the decay heat and the dose consequence instead.
- The nominal cycle length that the targets will be irradiated for is 60 days. However, the A and H positions were qualified to a total of 65 days and to a maximum power of 25 MW. This allows for the targets to be qualified for multiple cycles under one analysis for up to 65 days at 25 MW.
- Existing hardware in the inner-A positions causes the targets in the inner-A positions to be raised 5.25 in. above core centerline.
- 60-day average Pu-238 assay for the A and H position is approximately 92%
- South Flux Trap and East Flux analysis is underway and the preliminary results at peak power and 65-day cycle suggest a production of approximately 61g of Pu-238 with an assay of about 87%.

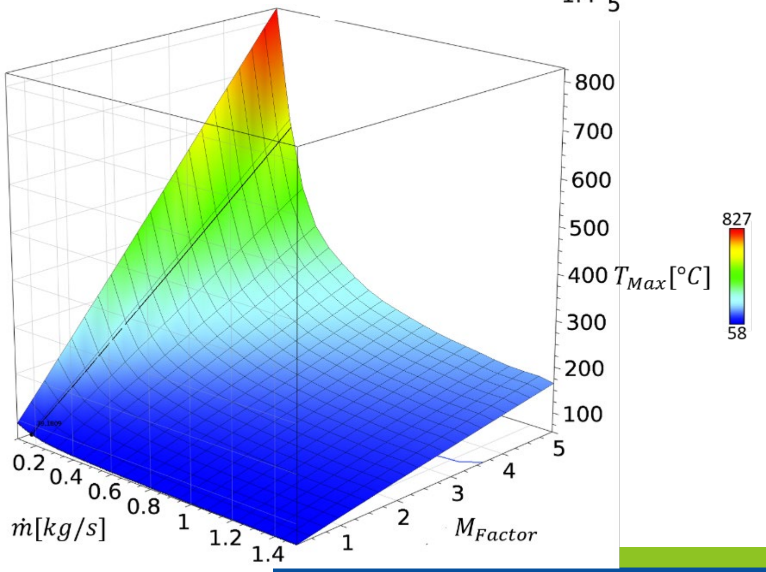


Thermal Analysis

- The results of the NEFT analysis provided system response surfaces for critical safety quantities such as departure nucleate boiling ratio (DNBR), flow instability ratio (FIR) and peak component temperature. These quantities were used to generate a system response surface
- The response surfaces generated from the NEFT qualification were used to facilitate the qualification of the A and H positions, by verifying that the mass flow rate and total heat rate for the most limiting positions were within the analyzed bounds.
- The most thermally limiting positions were A5 and H10.

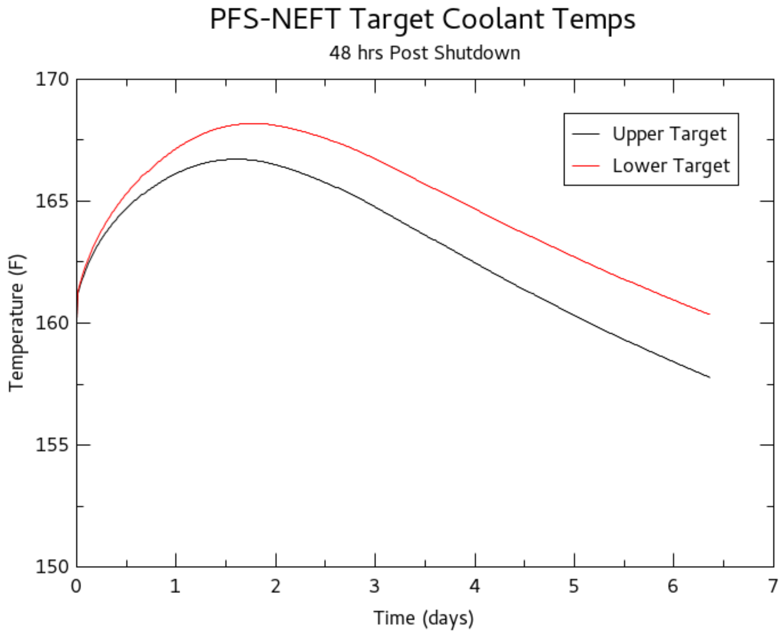


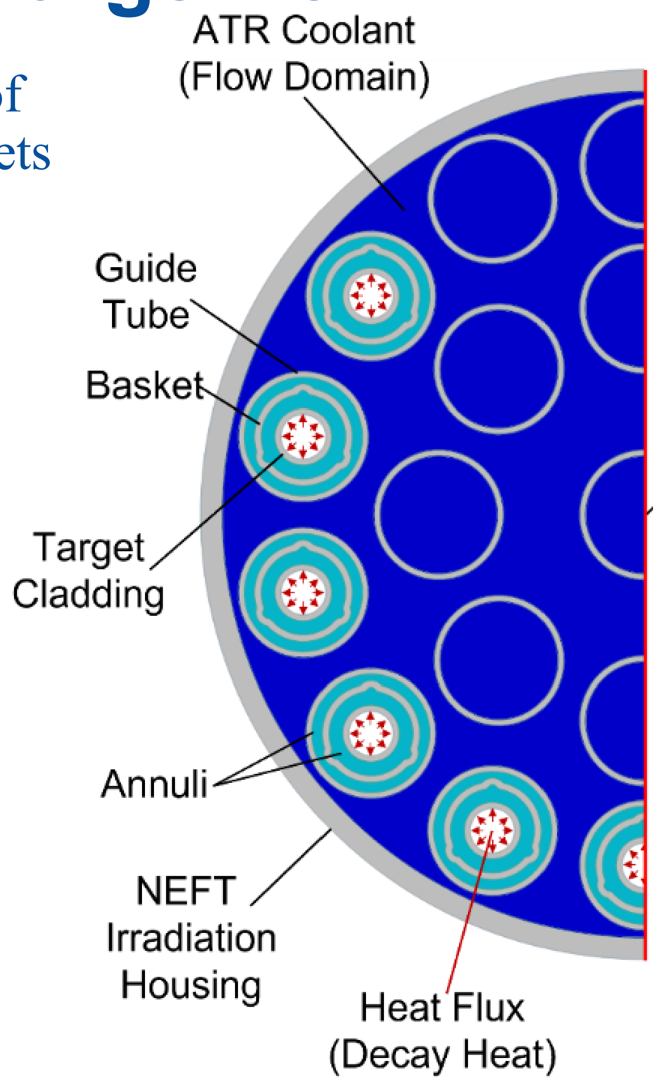




Thermal Analysis to Support NEFT Discharge from ATR

- A CFD analysis was performed to determine the number and configuration of targets to be removed to ensure that if dropped horizontally in water the targets would dissipate heat and not boil the canal water.
- The analytical approach features a simplified geometry, specifically a 2-D symmetrical cross section at the axial center.
- The results of this analysis predicts a maximal coolant temperature of 85 °C (185 °F)
- RELAP5 was used as a supporting calculation and the maximum temperature was 76 °C (168 °F). This calculation enabled the removal of some conservatism that was implemented in the CFD analysis.





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, which is the deepest portion of the ATR canal.
- ASME Boiler and Pressure Vessel Code were used as a guide although other acceptance criteria could have been 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 from the thermal analysis and from the design specification of the ATR. The Comparison showed that the NEFT, inner-A and H positions were within the calculated limits and each structural component was considered to meet the safety requirements; thus, the targets are allowed into the ATR

ATR Safety Considerations

- Along with existing Experiment Safety Analysis (ESA) already developed for both the PFS experiment in the I-7 and SFT positions, an additional ESA was developed for the ATR Gen I target irradiations in the NEFT, inner-A, and H positions
- This ESA will utilize the neutronics, thermal, and structural analyses to demonstrate the new ATR Gen I targets can be irradiated in the ATR in compliance with technical safety requirements and the approved authorization basis established by ATR’s Safety Analysis Report
- The Gen I ESA was also developed and authorized under an ATR Complex procedure that addresses experiment receipt, reactor loading, irradiation, discharge, storage, preparation for shipping from ATR, and waste disposal
- The PFS ATR Gen I ESA demonstrates that operation of the PFS experiments are in accordance with the restrictions identified in the ESA and within the authorization basis of the ATR

Shipments of Targets from ORNL to INL

- INL has received 4 shipments of targets from ORNL
  - Originally 1 target per drum but with collaboration between ORNL and INL the drums were modified to hold 5 targets per drum.
  - This design will allow for a maximum of 40 targets to be shipped to from ORNL to INL in each shipment.
- The updated design was completed to support the need to ship and receive approximately 200 targets per year.

Conclusion

- INL has successfully completed qualification for the ATR GEN I targets in the NEFT, inner A, and H positions.
- This included using a CFD and Relap analysis to support unloading the NEFT within operational time limits.
- Efforts on re-qualifying the SFT and qualifying the EFT for the ATR GEN I target are in progress and preliminary results have been obtained.
- With the qualification of more positions and increased efficiency in shipments, INL is on track to meet production goals by 2026.

Acknowledgments

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