INL/MIS-23-72530-Revision-0

Isotope Production for UK PhD Student Visit

May 2023

Changing the World's Energy Future

Andrew John Zillmer

Idaho National Laboratory

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Idaho Falls, Idaho 83415

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1 to 1:30 pm

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Isotope Production at the Idaho National Laboratory (INL)

Idaho National Laboratory

Overview

- Isotopes at INL
- Organizational Structure
- Plutonium Fuel Supply (PFS)
  - Current work
  - Future plans
- Cobalt-60 Production
  - Current work
- BRR Cask Shipping
- Acknowledgements
- Questions

Making Isotopes at INL

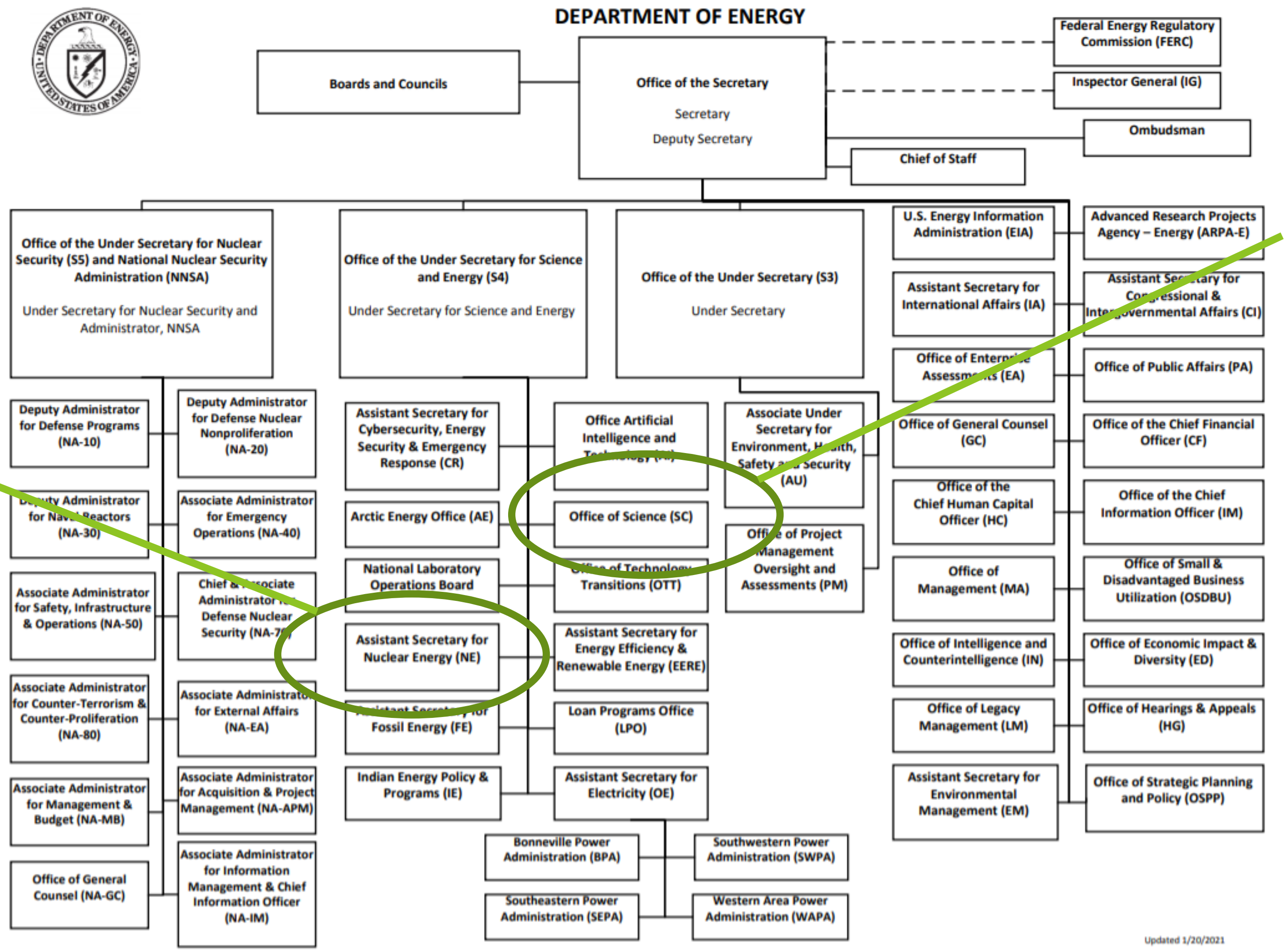
- Targets need to be qualified for irradiation and evaluated for production efficacy
  - Analysis to show that neutronics, thermal, and structural limits are not exceeded
  - Estimated production yields are calculated
  - Hardware needs to be fabricated to specifications
  - Safety review and analysis shows that ATR can safely irradiate a target
    - Follows same process as ATR experiment qualification
- Targets are received at ATR
- Reactivity worth is calculated in ATRC facility
- Targets are loaded and irradiated into ATR for one or more cycles
- Targets are stored in the ATR canal for the time between irradiation and shipment
- Targets are shipped from ATR to the end user

Isotope Production is Cross Cutting Across INL

- Materials and Fuels Complex (MFC)
  - Project management & project engineering
  - Supports cask and shipping
- Advanced Test Reactor (ATR)
  - Target irradiation
  - Operations
  - Experiment support
- Energy and Environment S&T (EES&T)
  - Assays and radiological modeling
- Nuclear Science and Technology (NS&T)
  - Neutronics analysis
  - Thermal analysis
  - Hydraulic analysis
- Facilities and Site Services
  - Structural analysis
- Environment, Safety, Health, and Quality
  - Quality Engineering
  - Quality Assurance
- Business Management
  - Financial Reporting
  - Scheduling

Isotopes Funding Comes From Different Parts of DOE

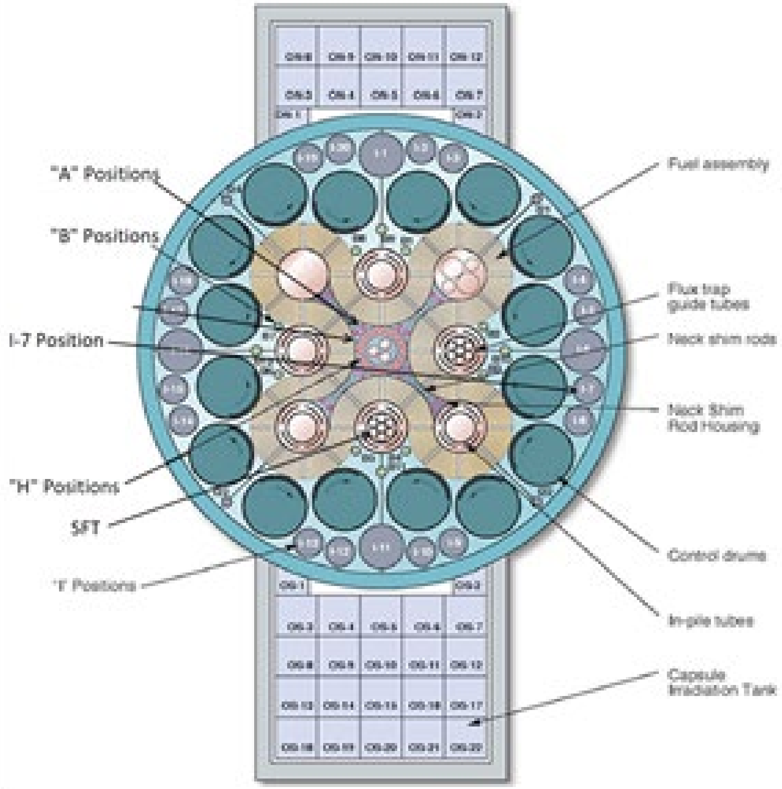
ATR and Pu-238 funding comes through DOE NE-3



Co-60 funding comes through DOE Office of Science's Isotope Program

Advanced Test Reactor Irradiation Positions

- Co-60 Irradiation Positions
  - A positions
  - H positions
  - B positions
- Pu-238 Irradiation Positions
  - A positions
  - H positions
  - B positions
  - I positions
  - Flux Traps



- Considerations
  - B positions have higher thermal flux compared to A and H positions
  - Flux traps have high flux and larger volume, but have limited availability
  - Due to uncertainty in position availability, a good strategy is to qualify as many positions as the budget allows

Overview of Plutonium Fuel Supply at INL

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.

DOE Lab Responsibilities

Idaho National Laboratory

- Holds the MMRTG contract
- Assembles GPHS modules
- Fuels radioisotope systems
- Delivers radioisotope systems to launch site
- Irradiates Np to make Pu-238 in ATR
- Stores Np-237 stockpile

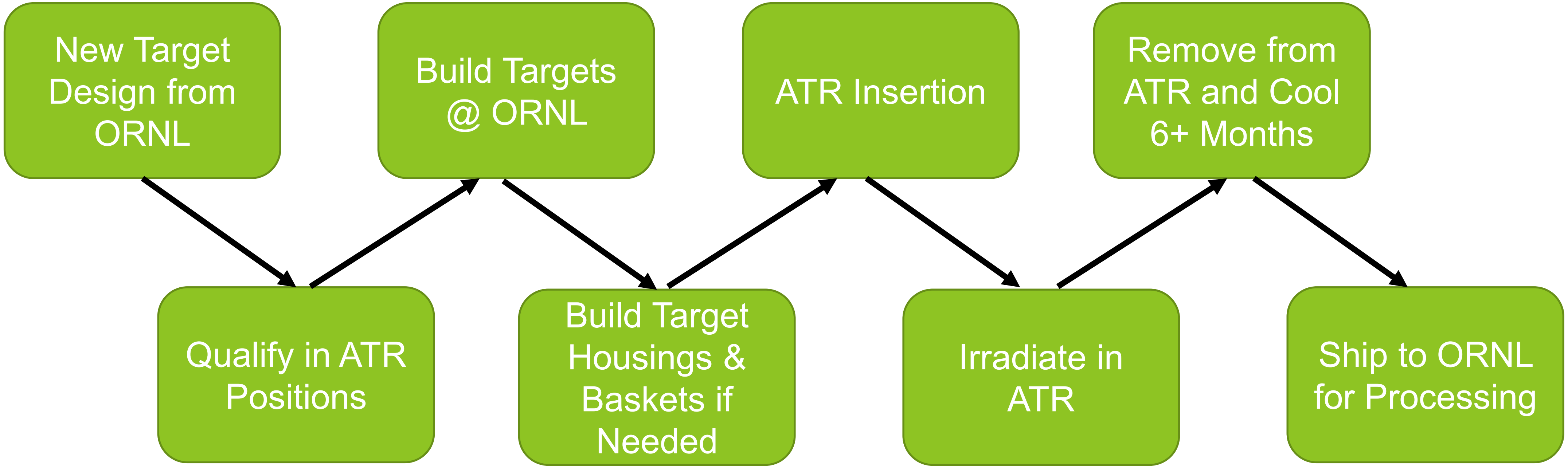
Los Alamos National Laboratory

- Receives Pu-238 from ORNL
- Stores Pu-238 stockpile
- Mixes various blends of Pu-238 product to meet specifications
- Produces Pu-238 fuel form
- Encases Pu-238 fuel form in a clad
- Ships fueled clads to INL

Oak Ridge National Laboratory

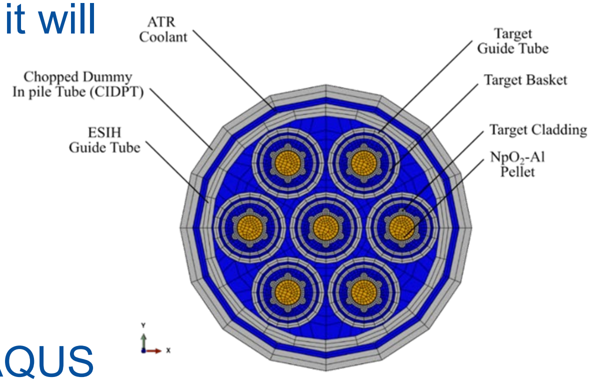
- Manufactures clads for Pu-238
- Produces Pu-238 in HFIR
- Processes irradiated targets to separate Pu from Np
- Manufactures Np targets for irradiation in HFIR and ATR
- Sends clads and Pu-238 to LANL

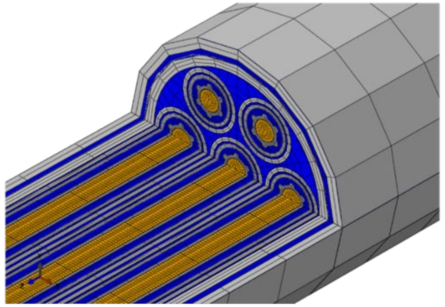
PFS Workflow at INL

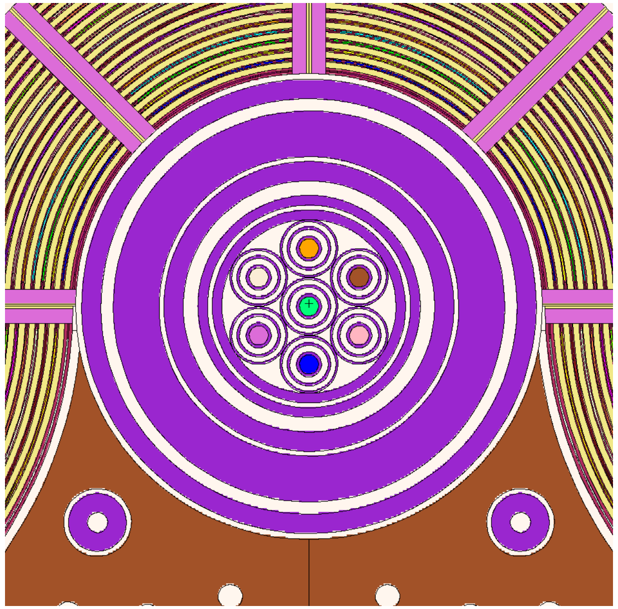


Target Qualification

- CAD drawings are created for the target as well as baskets and handling equipment
- Each model of target is qualified for each position that it will be irradiated in
  - Neutronics Analysis with MCNP
    - Reactivity worth
    - Axial flux perturbation
    - Neuron and gamma heating
  - Thermal Hydraulic Analysis with RELAP and ABAQUS
    - Heat transfer and temperatures during and after irradiation
    - Flow channel sizing
  - Structural
    - Static loading
    - Internal pressures
    - Flow induced vibrations
    - Handling loads







ATR Position Qualifications

Previous Qualifications

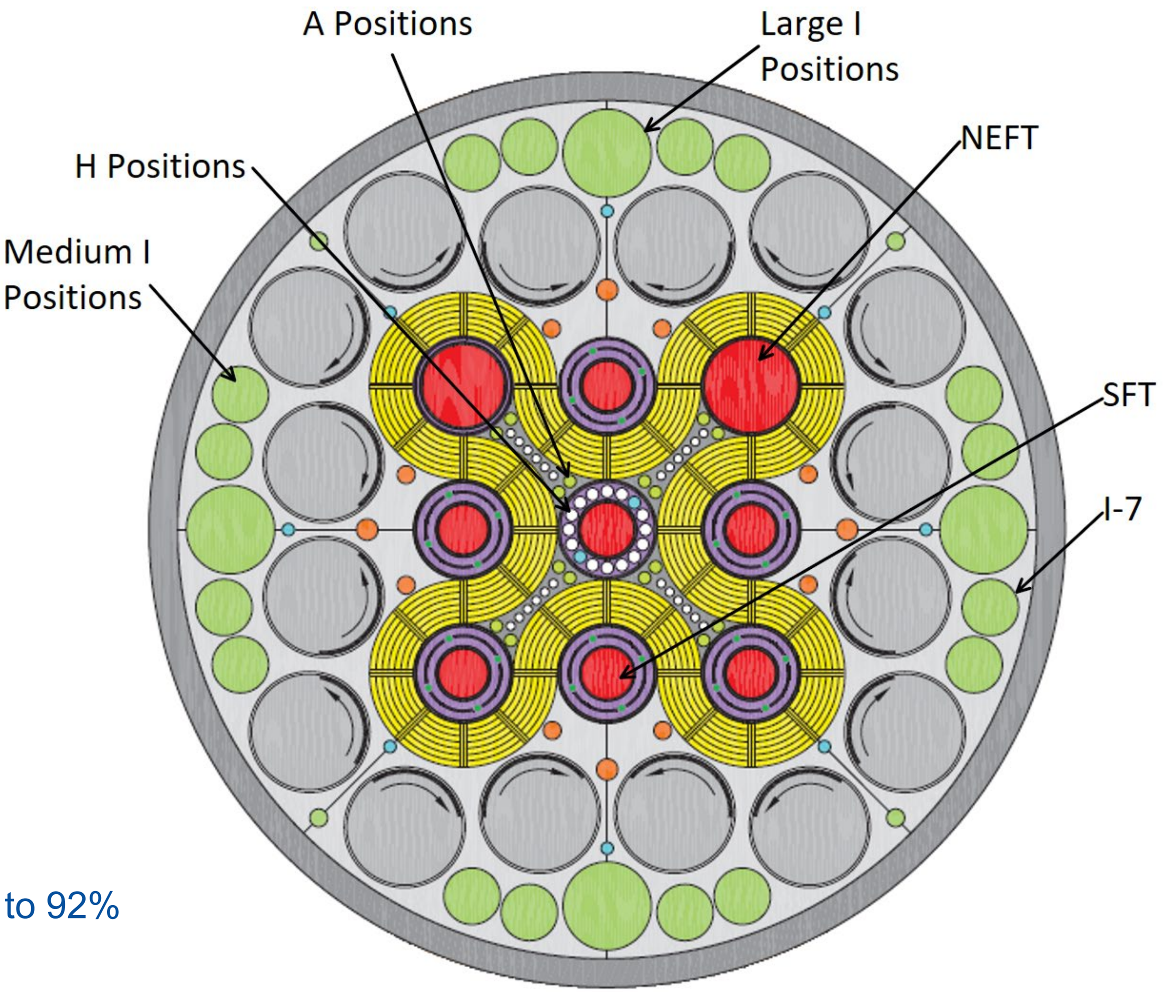
- I-7 (Medium I) Position
  HFIR GEN II target
- South Flux Trap
  HFIR GEN II Target
- North East Flux Trap
  ATR GEN I Target

Current Qualification

- Inner A Positions
  ATR GEN I Target
- H Positions
  ATR GEN I Target
- SFT and EFT
  ATR GEN I Target
- 30% Np for NEFT, SFT, EFT, A, and H positions.

Future Qualifications

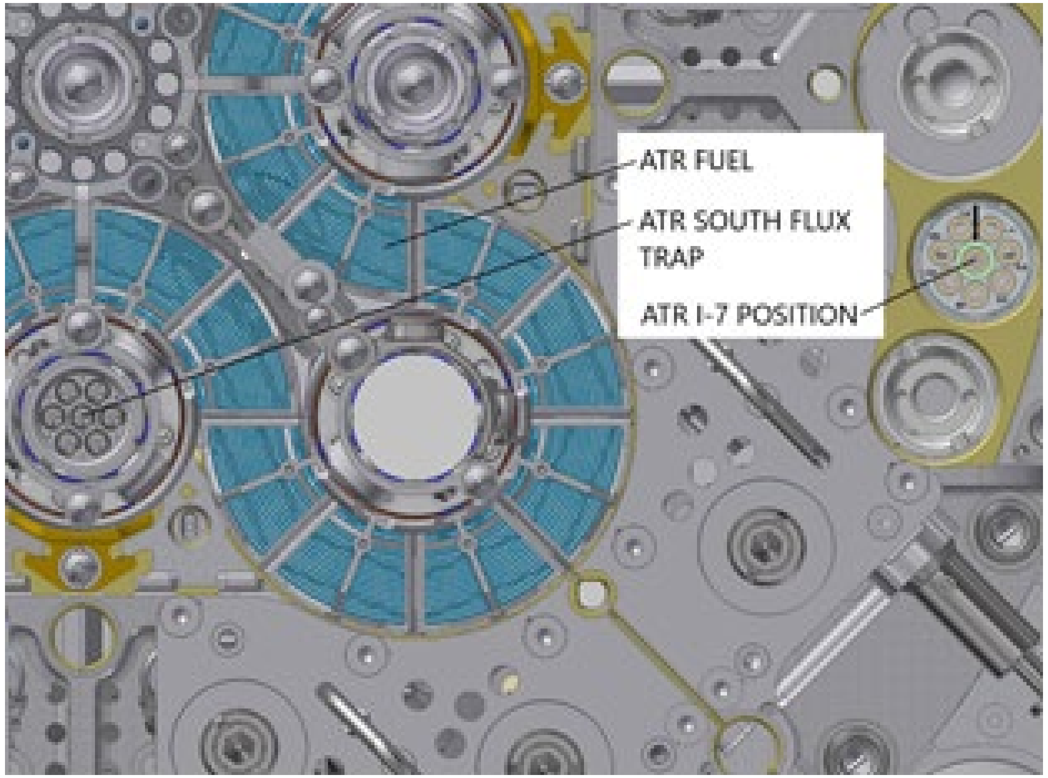
- Medium I positions
- Large I positions

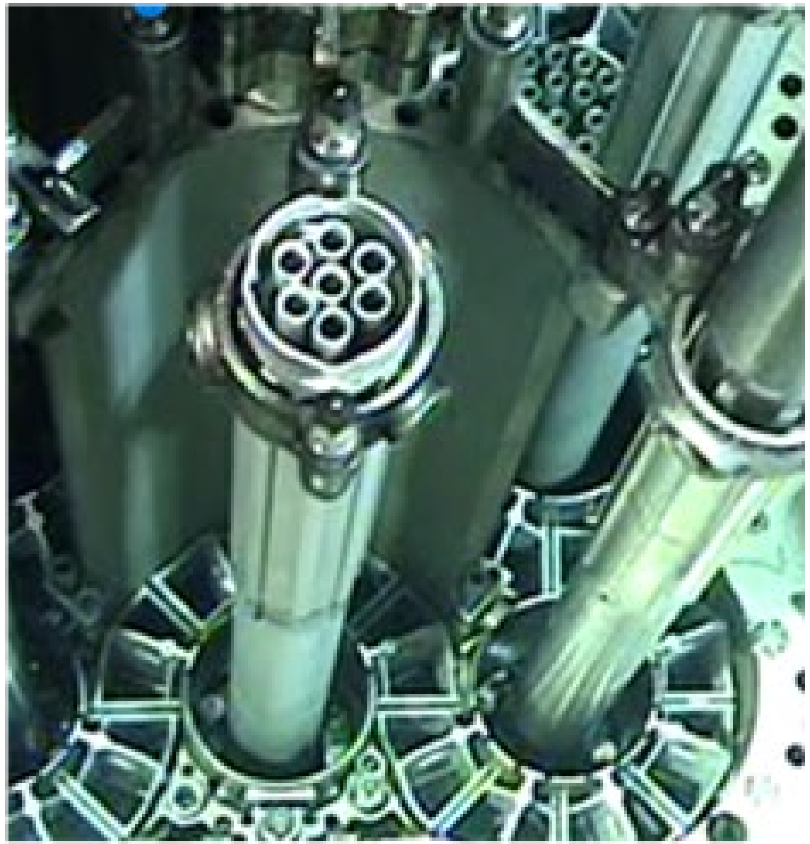


Cross Section of the ATR Core

- 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

Insertion Into ATR

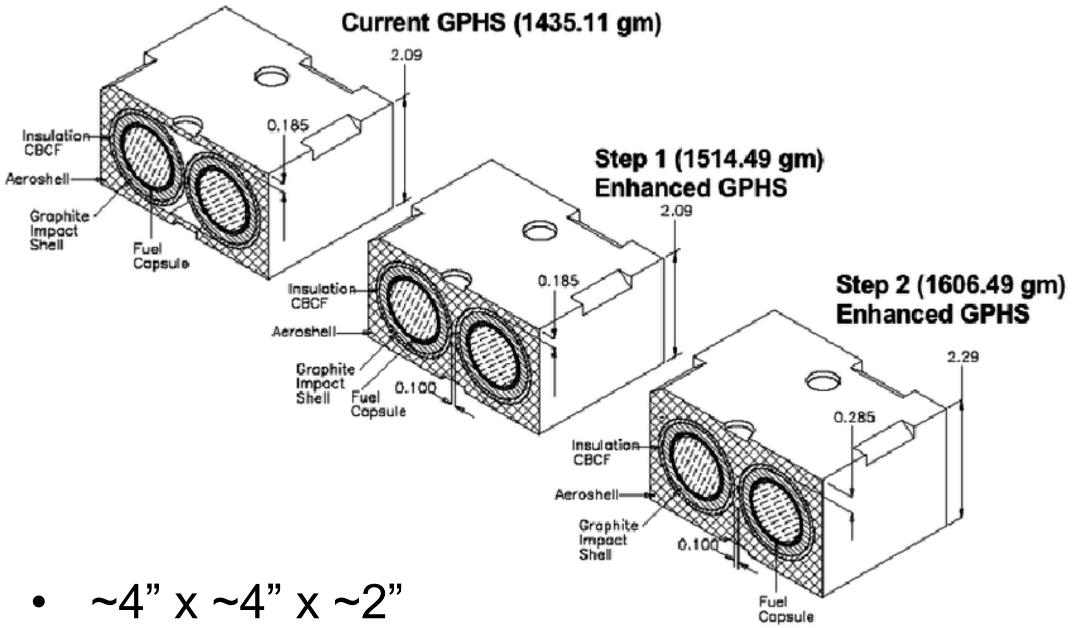


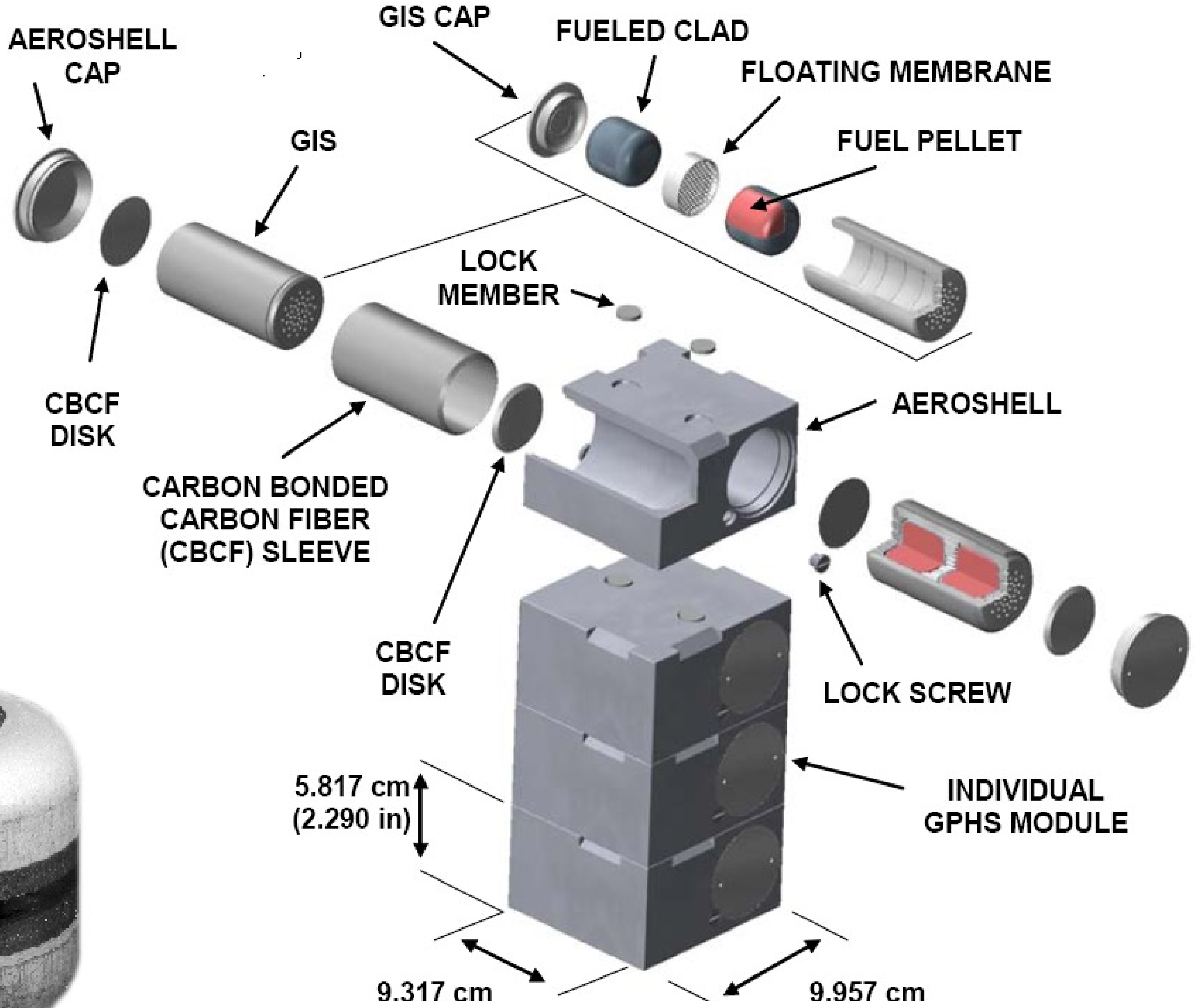


After Irradiation

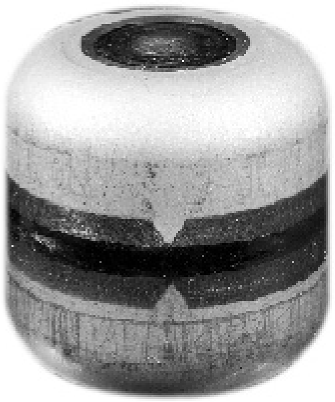
- Targets are left to cool for at least 6 months to cool down
  - Allows hard gamma emitters to decay
  - Reduces dose at ORNL for personnel processing the targets
- ORNL processes the targets to extract Pu-238 and recover Np-237
- ORNL sends Pu-238 to Los Alamos National Laboratory (LANL) for storage an incorporation into future heat sources
- High assay Pu-238 can be mixed with old heat source material to bring it up to current specifications and extend the supply of usable material
- At LANL Pu-238 is formed into a heat source, clad in an Iridium alloy, and then sent to INL for integration into a power source

General Purpose Heat Source (GPHS) Assembly

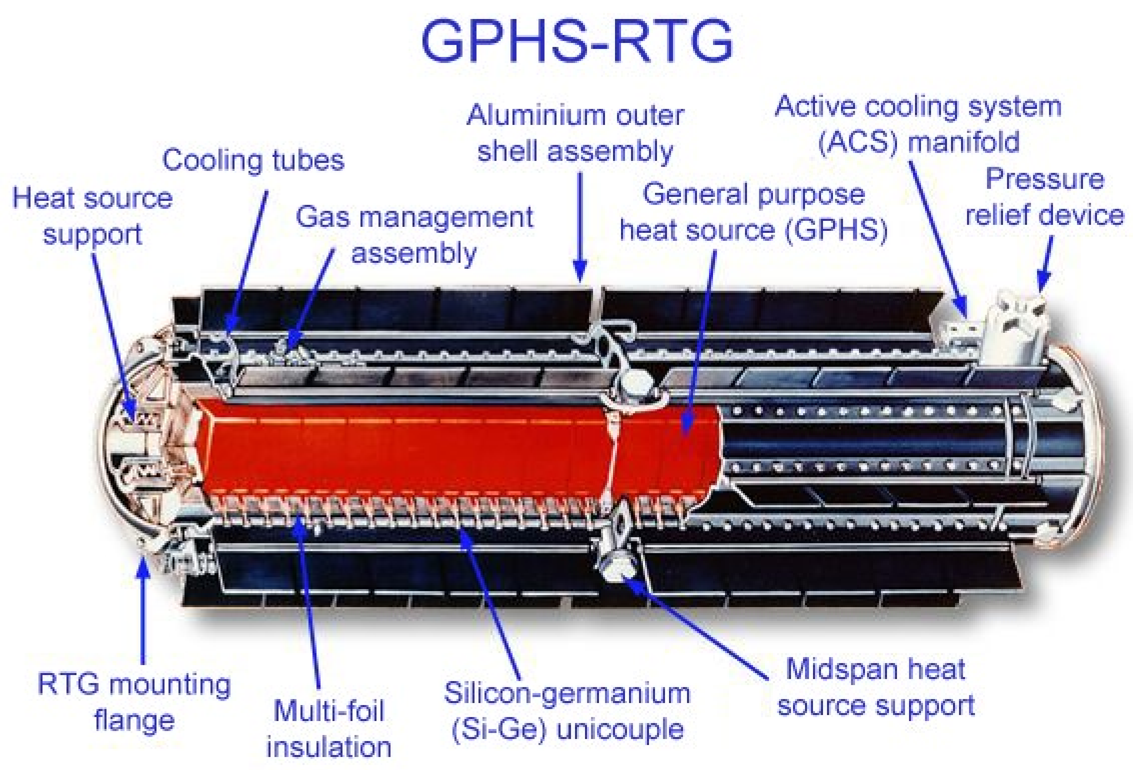


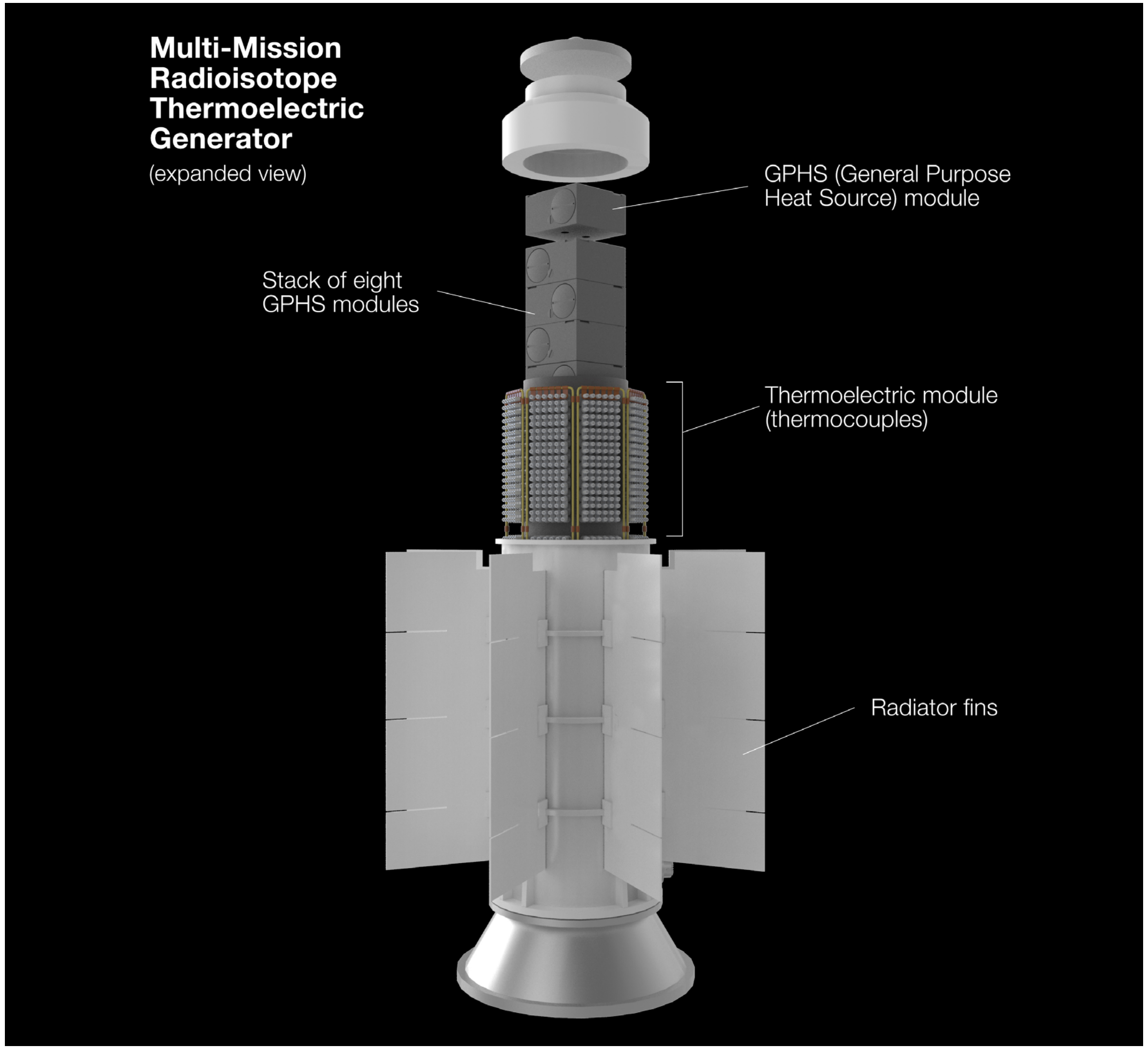


- ~4” x ~4” x ~2”
- Weighs ~3.5 pounds (~1.5 kg)
- Thermal output of 250 watts

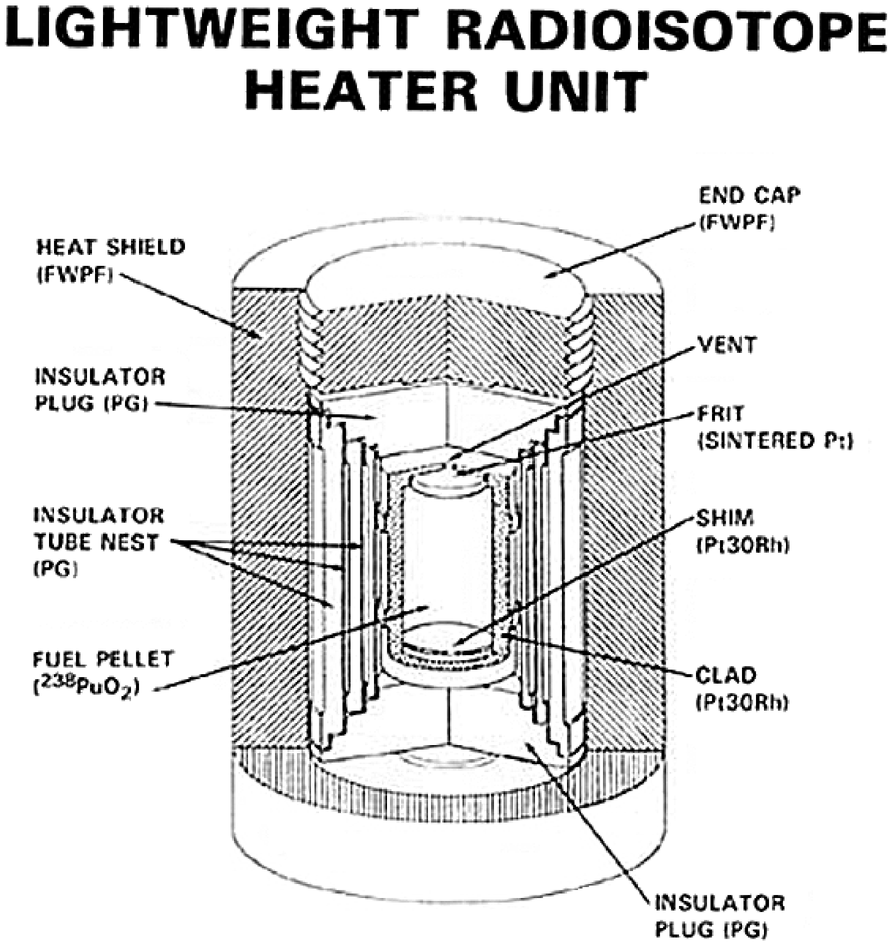


Radioisotope Thermoelectric Generator (RTG) Assembly





Radioisotope Heating Unit (RHU)

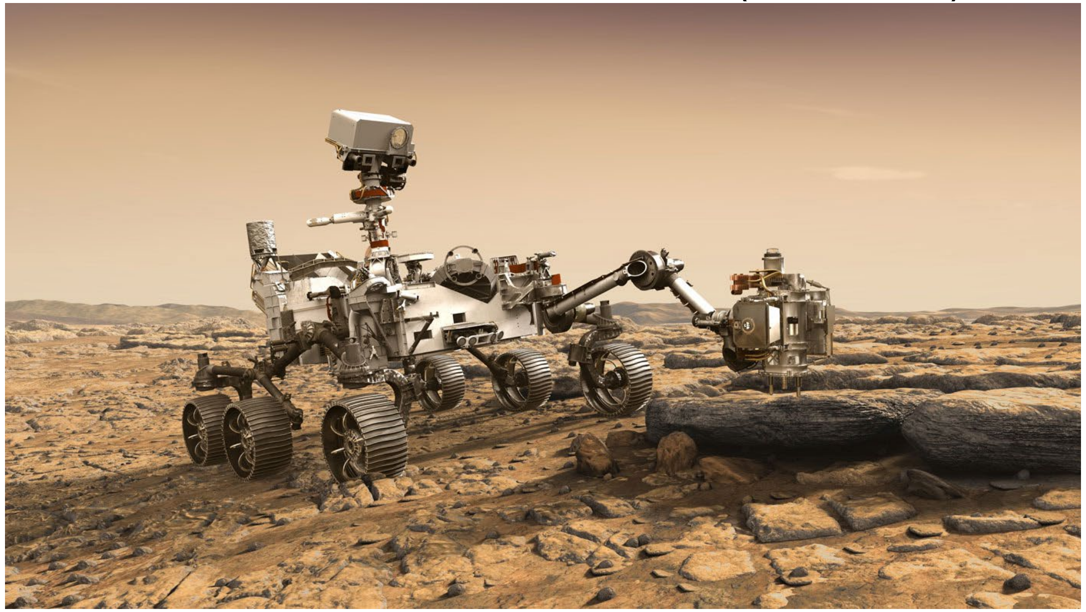


Pt = Platinum
Rh = Rhodium
PG = Pyrolytic Graphite

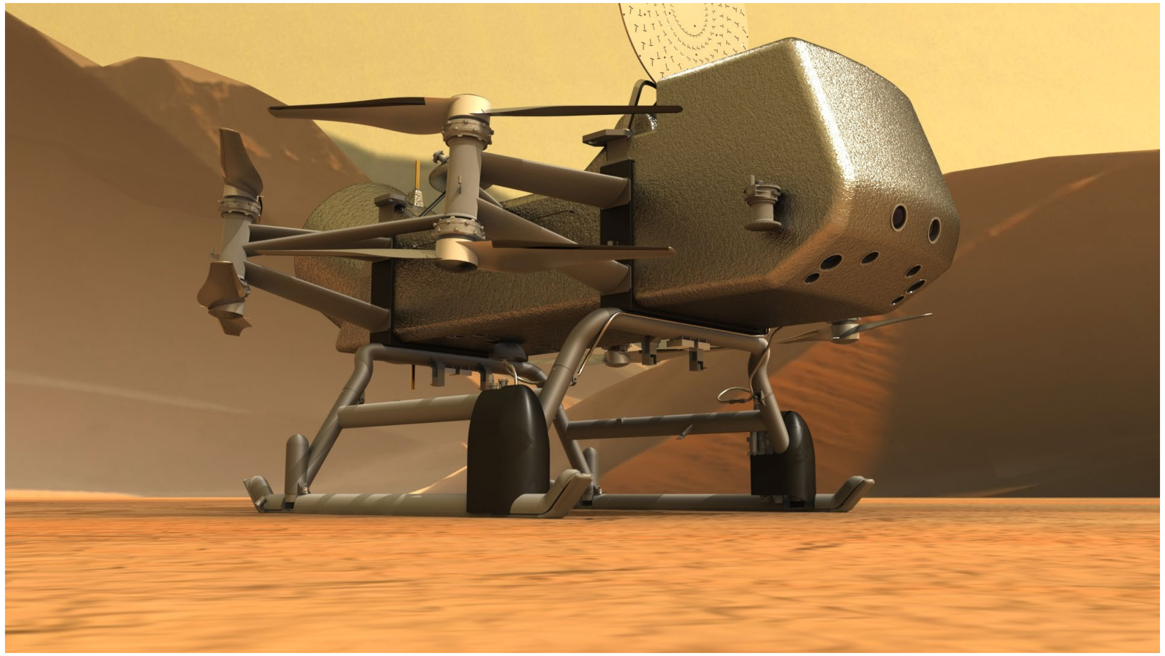
$^{238}PuO_2$ = Plutonium Dioxide
FWPF = carbon-carbon composite woven with perpendicularly oriented graphite fiber

Future Missions

Mars 2020 Perseverance Rover (2021 to ?)



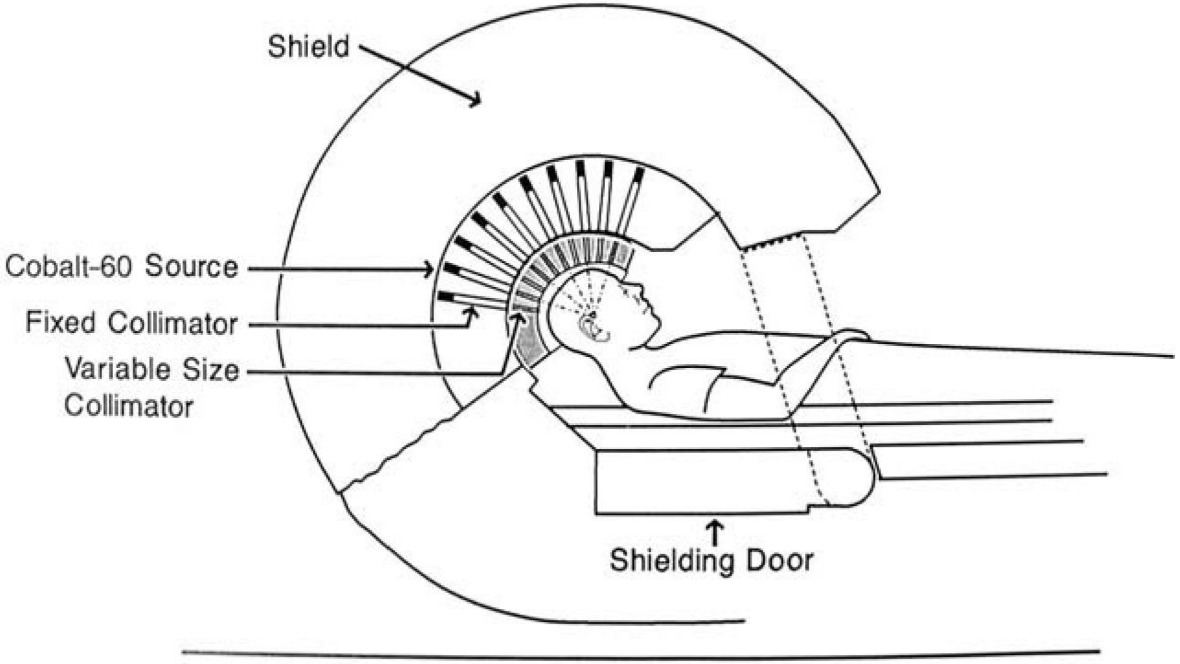
Dragonfly Octocopter to Saturn's Moon Titan (Launch 2027)



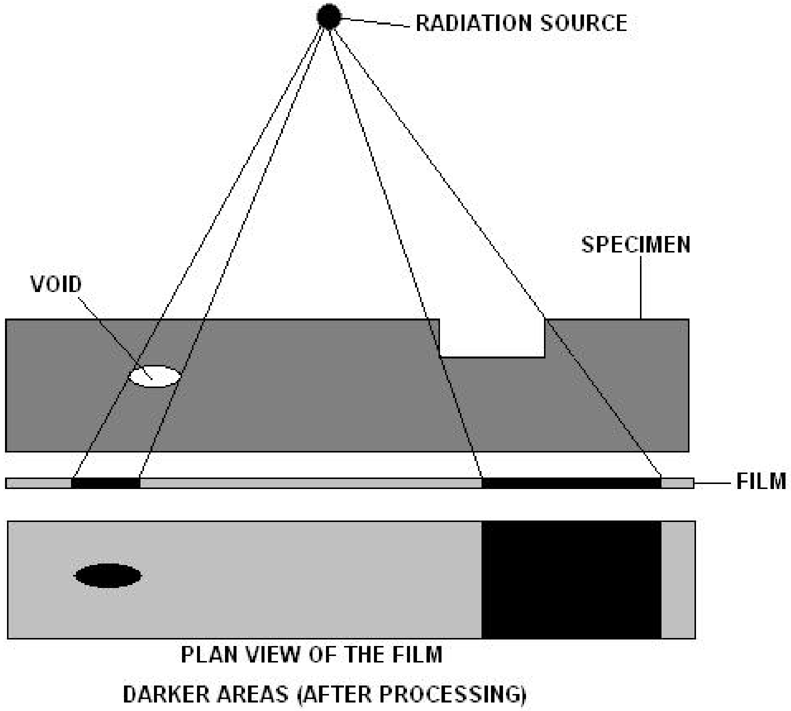
Overview of Co-60 Production at INL

What is Co-60 Used For?

Gamma Knife Cancer Treatment



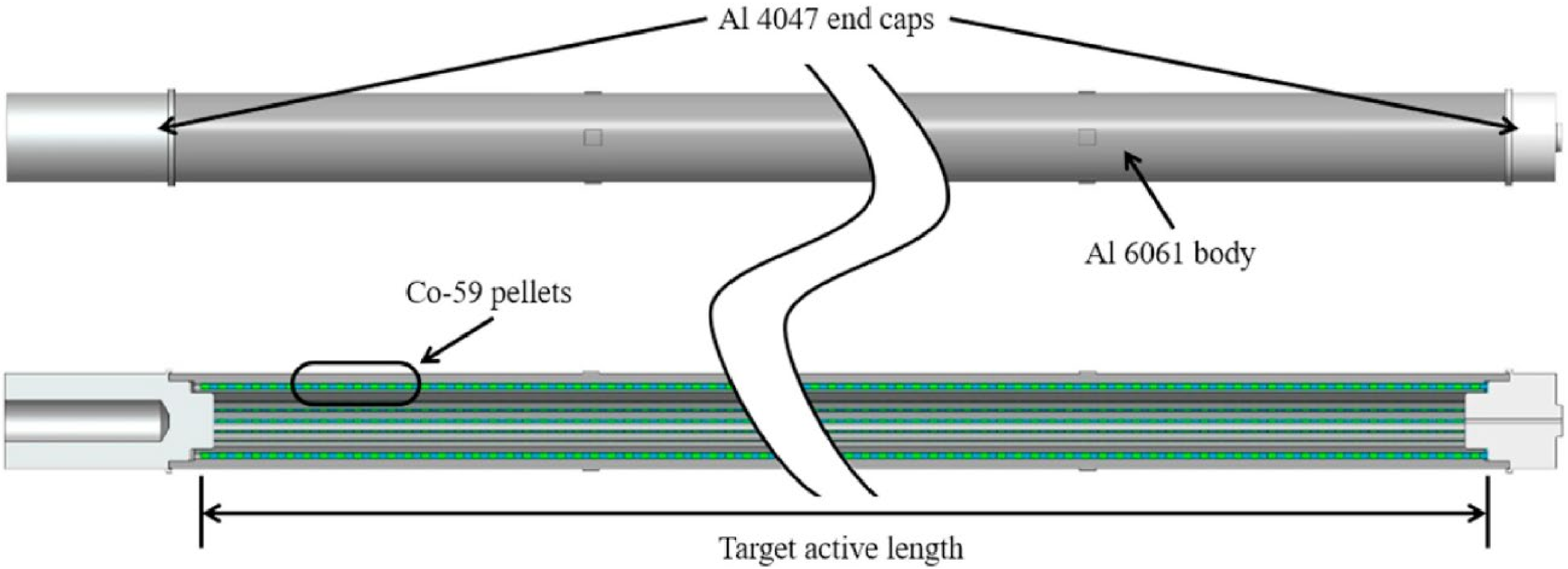
Non Destructive Testing



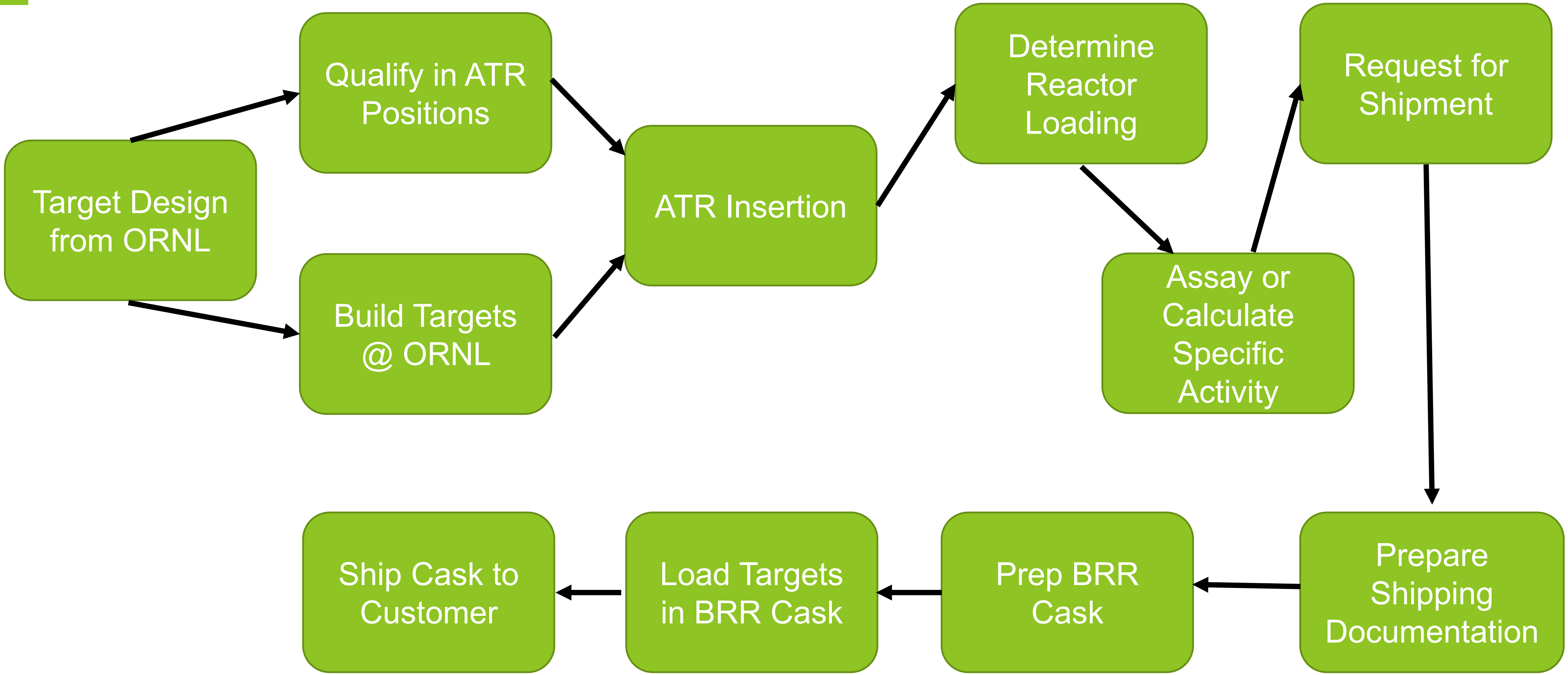
Co-60 Production Overview

- High Specific Activity (HSA) Cobalt-60 is produced in ATR for the DOE Isotopes Program (DOE-IP)
- Targets contain thousands of tiny pellets of Cobalt that are enclosed inside aluminum packaging
  - Pellets are designed to be removed from the target at the end user and re-encapsulated
- Legacy Cobalt targets were irradiated in ATR until 2012
  - Target suffered creep rupture in 2012 during cask loading process and use was discontinued
  - Legacy Cobalt targets are stored in the ATR canal
  - New target design was developed for irradiation in ATR
- New HSA Cobalt targets were designed and fabricated
  - 66 targets were built
  - ATR irradiation began in 2015
  - Specification at shipping of 250 +/- 25 Ci/g

Co-60 Target Design

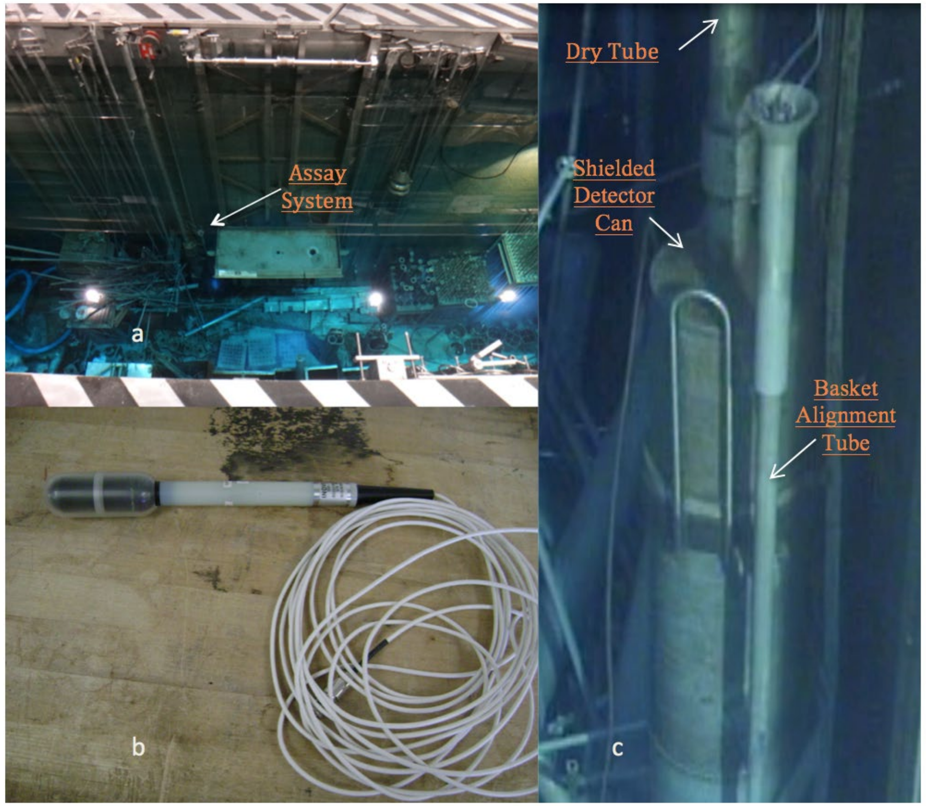


Co-60 Workflow at INL



Co-60 Target Assays

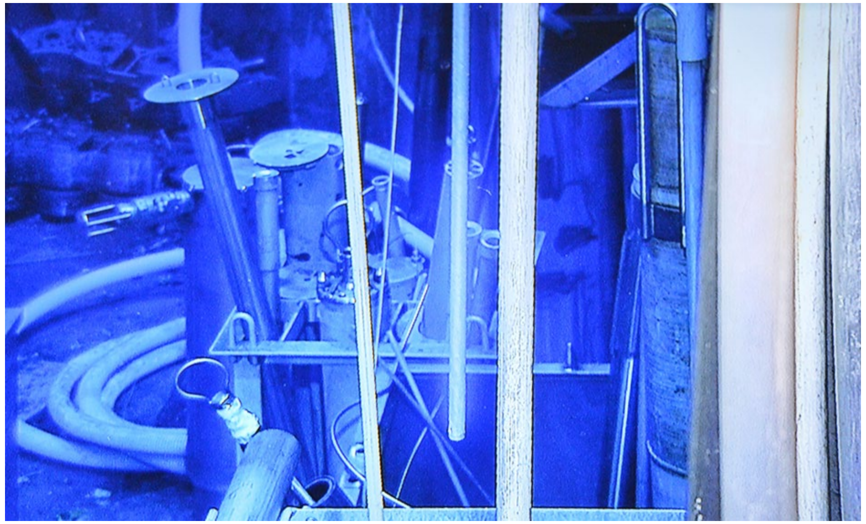
- Assays have 2 primary uses
  - Verifies projection and production analysis
  - Provides non-export control data to DOE Source Database
- Assays are performed in the ATR canal
  - Targets are moved to the canal area
  - Ion chamber is used to measure the source strength



Assay system: a) Location of assay system in canal, b) Victoreen 550-4 ion chamber, c) Close up of assay system

Co-60 Progress To Date

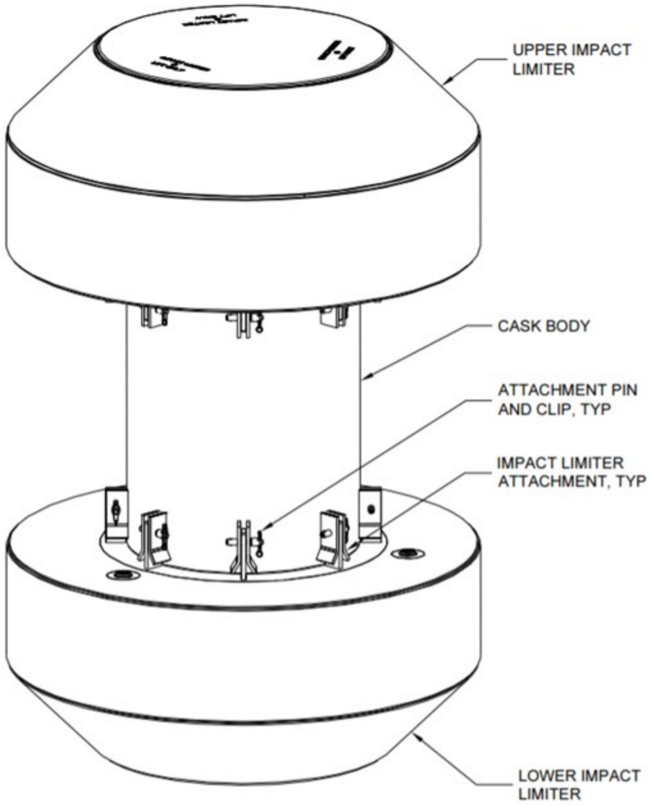
- Irradiation of 66 targets began in 2015
- INL has completed multiple Co-60 shipments as of April 2023
- Multiple assays have been completed to improve production estimates
- Future irradiation and production plan is in under development
- Currently irradiating Co-60 production targets in ATR

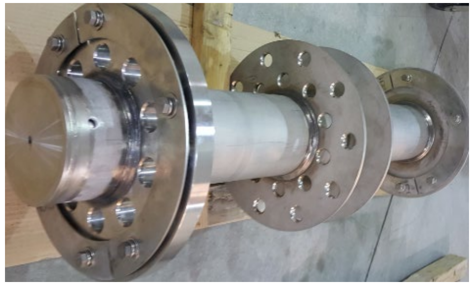


Isotope Transportation Using the BRR Cask Shipping

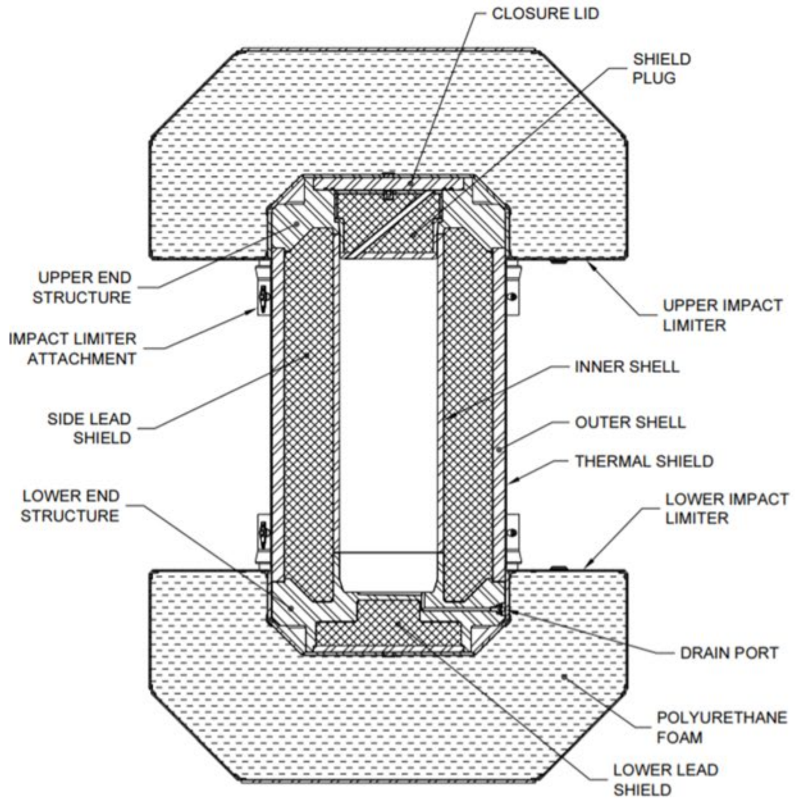
BRR Cask Overview

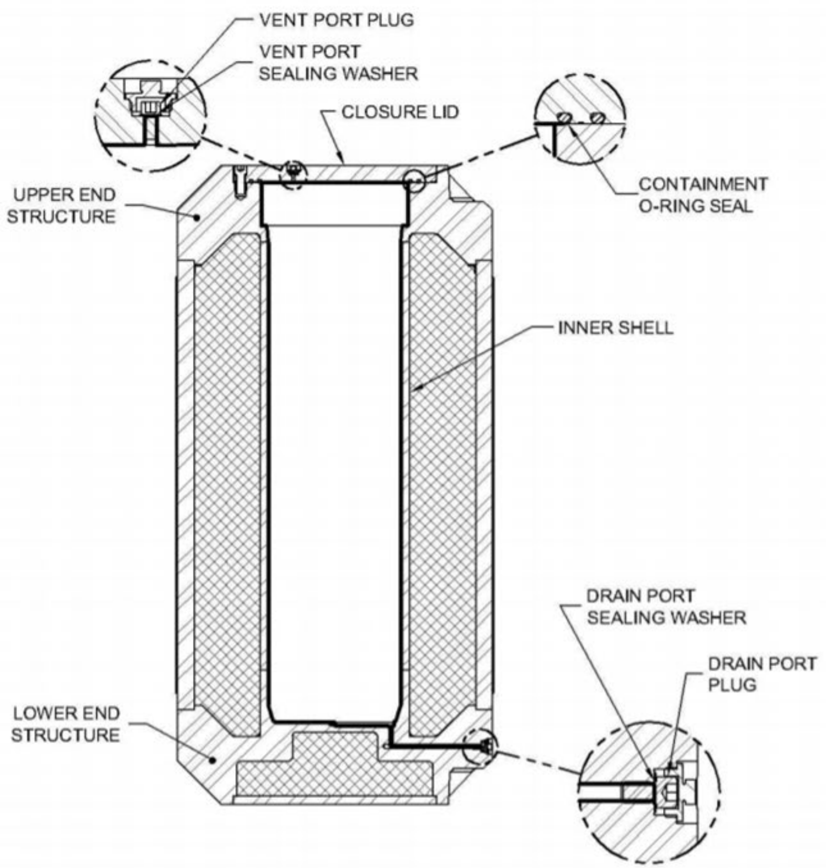
- BRR was originally developed to transport irradiated fuel elements or loose plate of a square fuel element from various test and research reactors
- The cask is composed of:
  - lead–shielded package body
  - payload basket
  - square loose plate box
  - upper shield plug
  - a closure lid
  - upper and lower impact limiters





BRR Cask Overview





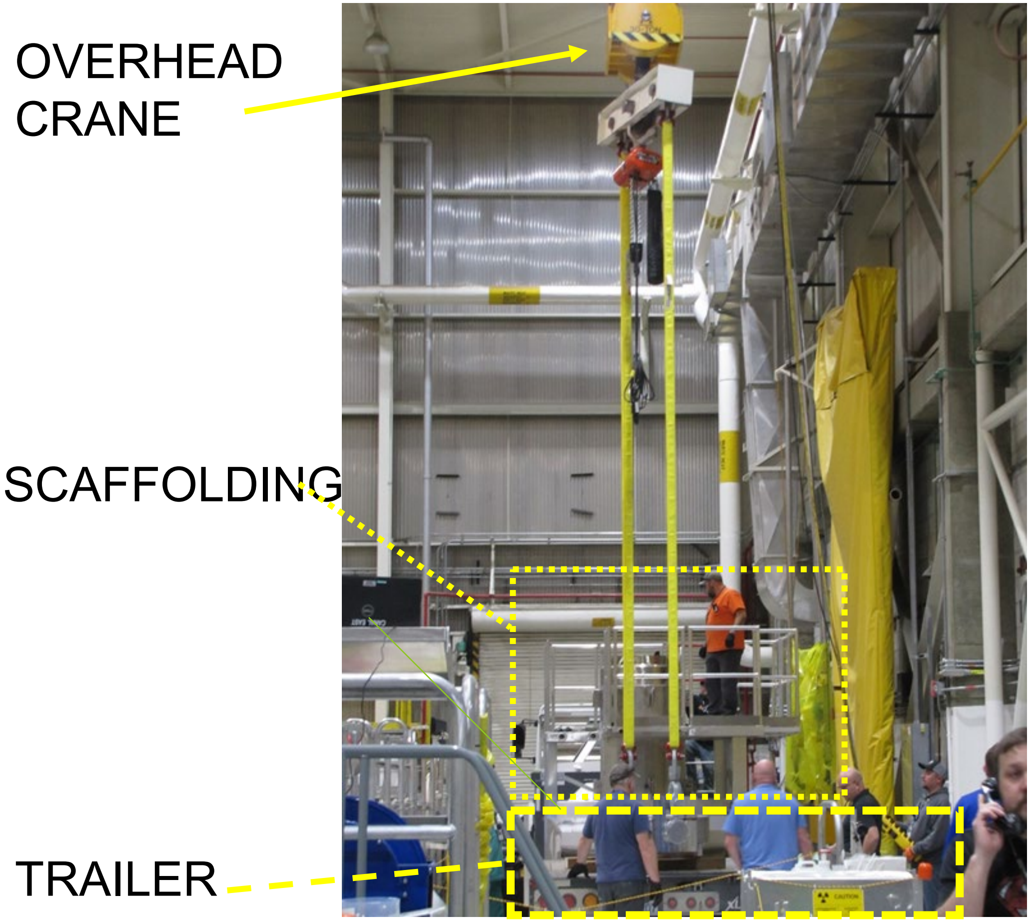
The BRR Cask has multiple features that enable the shipment of nuclear fuel and radioactive material in a U.S. Department of Transportation compliant cask

Shipping Co-60 in the BRR Cask

- Shipping schedule is highly dependent on how smoothly operations go
- Day 0
  - Move trailer to ATR from CFA
  - Survey equipment at ATR
  - Prep support equipment and paperwork
- Day 1
  - Install cask platform (scaffolding)
  - Move trailer inside ATR Canal
  - Install platform extensions
  - Survey cask trailer
  - Remove tie downs and upper impact limiter
  - Lift and place next to canal
  - Vent and remove lid from cask
  - Verify/install correct cask insert
- Day 2
  - Lift cask to canal
  - Load targets
  - Remove cask from canal
  - Place lid on cask
  - Racon survey
  - Begin overnight nitrogen purge
- Day 3
  - Vacuum dry the cask
  - Helium leak test
- Day 4
  - Move cask to trailer
  - Install upper impact limiter and tie downs
  - Tractor and trailer radiation survey
- Day 5
  - Inspection by state troopers
  - Leave ATR complex

BRR Cask – Setup and Unloading in ATR Canal Area

- The BRR Cask has external scaffolding and supports to provide for worker safety and access to the cask
- Trailer is moved to the canal area
- Additional safety platforms are installed by hand
- The overhead crane is used to disassemble the BRR cask
- Upper impact limiter and tie downs are removed
- Cask is lifted from the trailer and placed beside the canal by the overhead crane
- Cask is vented and lid is removed



BRR Cask - Loading

- Cask is lifted by the overhead crane and slowly lowered into the canal
- Co-60 targets are loaded into the cask
- Cask is slowly raised from the canal
  - Allows water to drain from the cask
  - Radiation monitoring is performed to confirm levels are as expected

BRR Cask –Vacuum Drying

- BRR Cask is placed next to the canal
- Cask lid is installed
- Nitrogen purge performed to remove liquid
- BRR Cask is dried using a vacuum drying system
  - Vacuum pumps and liquid nitrogen are used to pull a vacuum on the cask
  - Low pressure causes water to sublimate and be drawn out by vacuum pumps
- For DOT shipments no liquid can be inside the cask
- After pressure in the cask stabilizes, a leak check with helium is performed to verify that the cask is sealed

BRR Cask – Loading & Inspection

- The cask is lifted by the overhead crane and placed on the trailer and impact limiter is placed on top of the cask
- Cask is chained down to the trailer and safety platforms are removed
- Expanded metal barriers are placed around the BRR cask
- Radiation and contamination surveys are performed on the tractor, trailer, and cask prior to release
- Cask is moved out of the fenced ATR area
- Idaho state trooper inspection of the tractor and trailer is performed outside the ATR complex prior to release for traveling on highway

Conclusions

- Isotope production at INL involves organizations across the lab
- Qualification of positions ensures safe irradiation and gives production estimates
- Co-60 produced in ATR is used for cancer treatments
- Pu-238 produced in ATR will be used to power future NASA deep space missions

Acknowledgements

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- Co-60 production portions of this work was funded by the US Department of Energy Isotope Program and was performed under US Department of Energy Contract DE-AC07-05ID14517.