INL/MIS-22-65565-Revision-0

# Isotope Production at the Idaho National Laboratory (INL)

January 2022

Changing the World's Energy Future

Andrew John Zillmer

Idaho National Laboratory

*INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC*

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**January 2022**

**Idaho National Laboratory**
**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

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**Andrew Zillmer**
**Deputy Division Director Space Nuclear Power & Isotope Technology**
**Program Manager Isotope Technology**

# 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

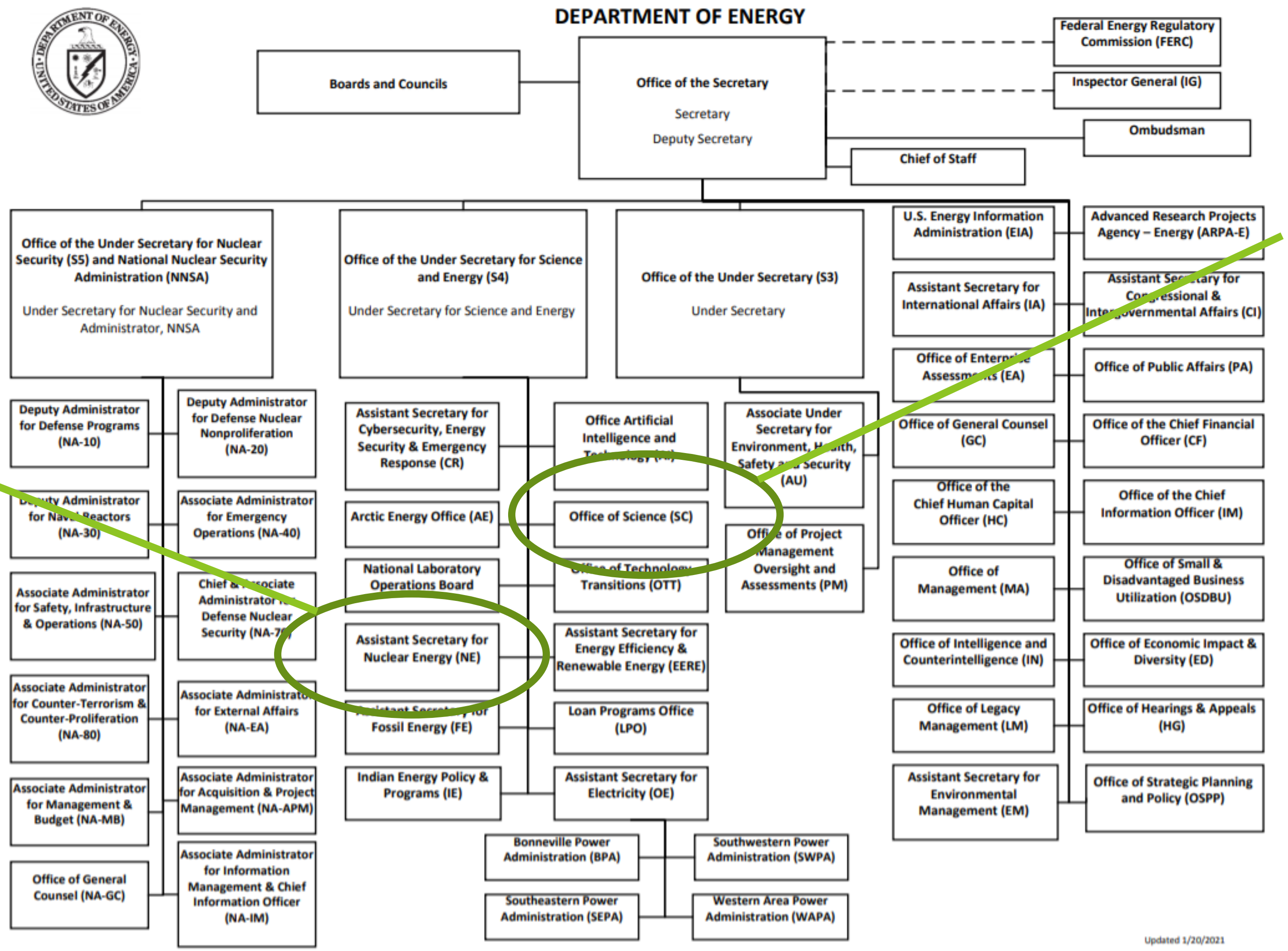
- Targets need to be qualified for irradiation and evaluated for production efficacy
  - Analysis to show that neutronics, thermal, and structural limits are not exceeded
  - Estimated production yields are calculated
  - Hardware needs to be fabricated to specifications
  - Safety review and analysis 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

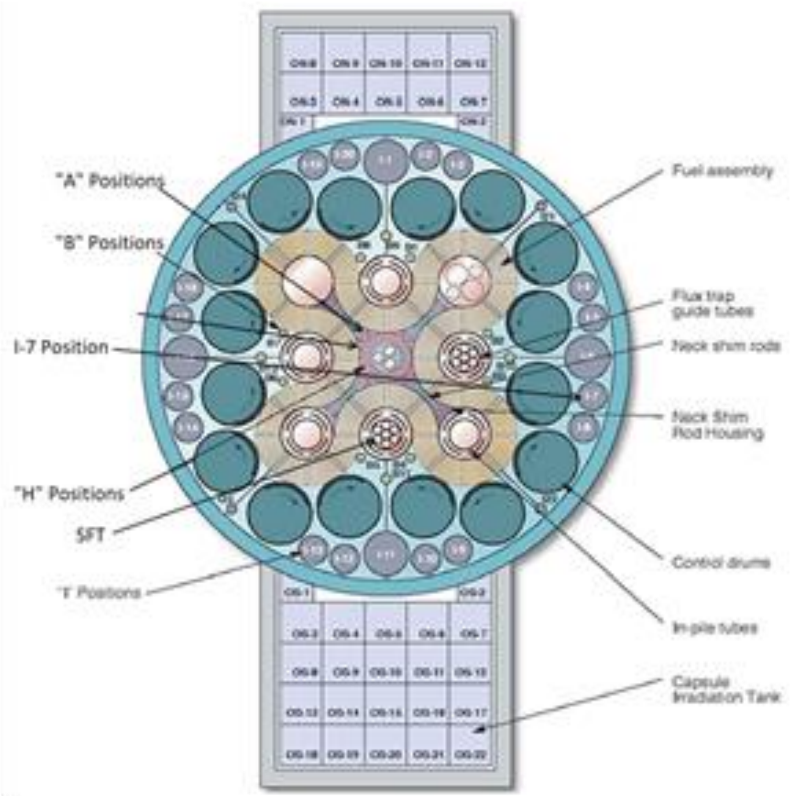
ATR and Pu-238 funding comes through DOE NE-3




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

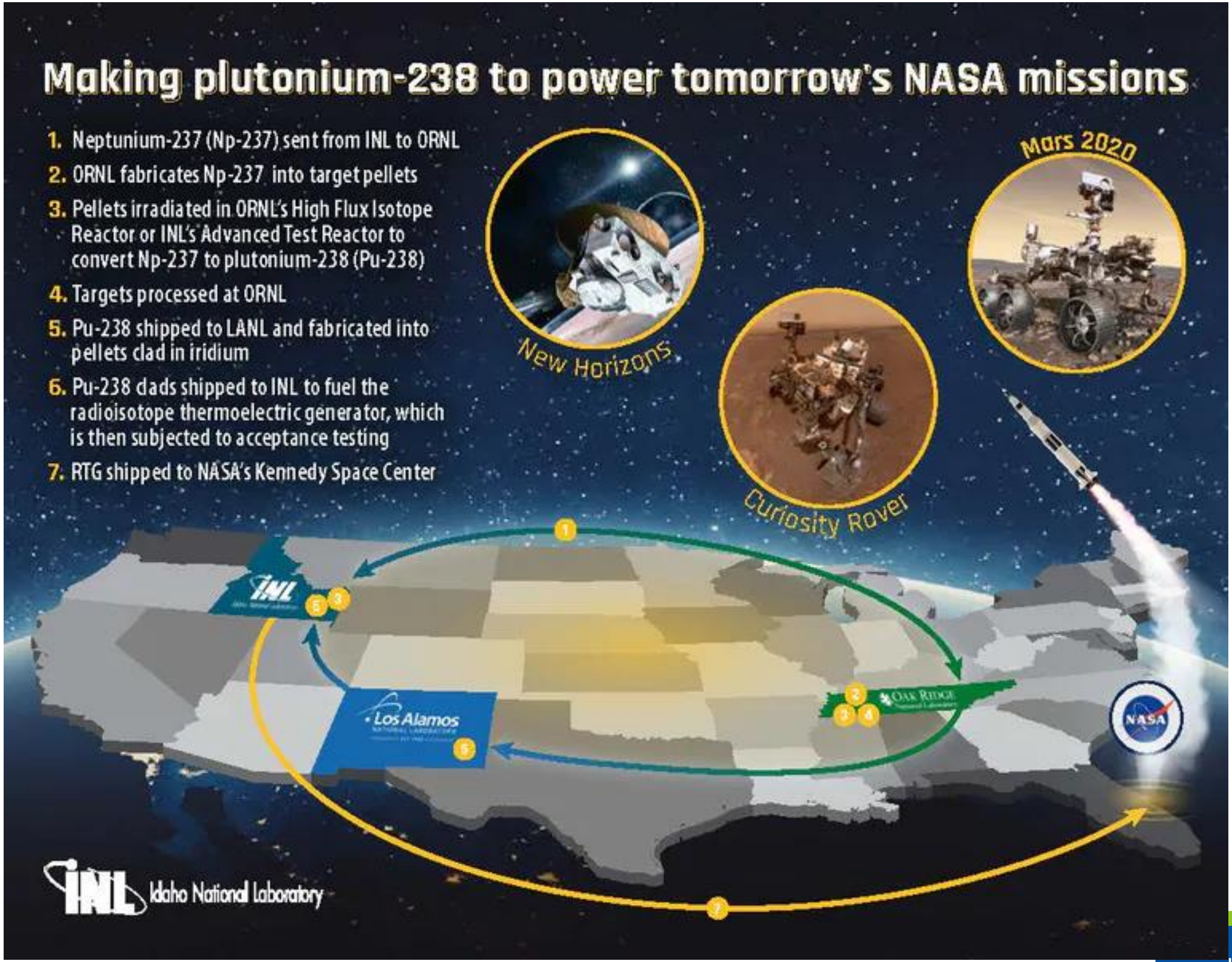
# Advanced Test Reactor Irradiation Positions

- 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


Making plutonium-238 to power tomorrow's NASA missions
1. Neptunium-237 (Np-237) sent from INL to ORNL
2. ORNL fabricates Np-237 into target pellets
3. Pellets irradiated in ORNL's High Flux Isotope Reactor or INL's Advanced Test Reactor to convert Np-237 to plutonium-238 (Pu-238)
4. Targets processed at ORNL
5. Pu-238 shipped to LANL and fabricated into pellets clad in iridium
6. Pu-238 clads shipped to INL to fuel the radioisotope thermoelectric generator, which is then subjected to acceptance testing
7. RTG shipped to NASA's Kennedy Space Center
New Horizons
Curiosity Rover
Mars 2020
INL
Los Alamos
Oak Ridge
NASA
Idaho National Laboratory

# 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

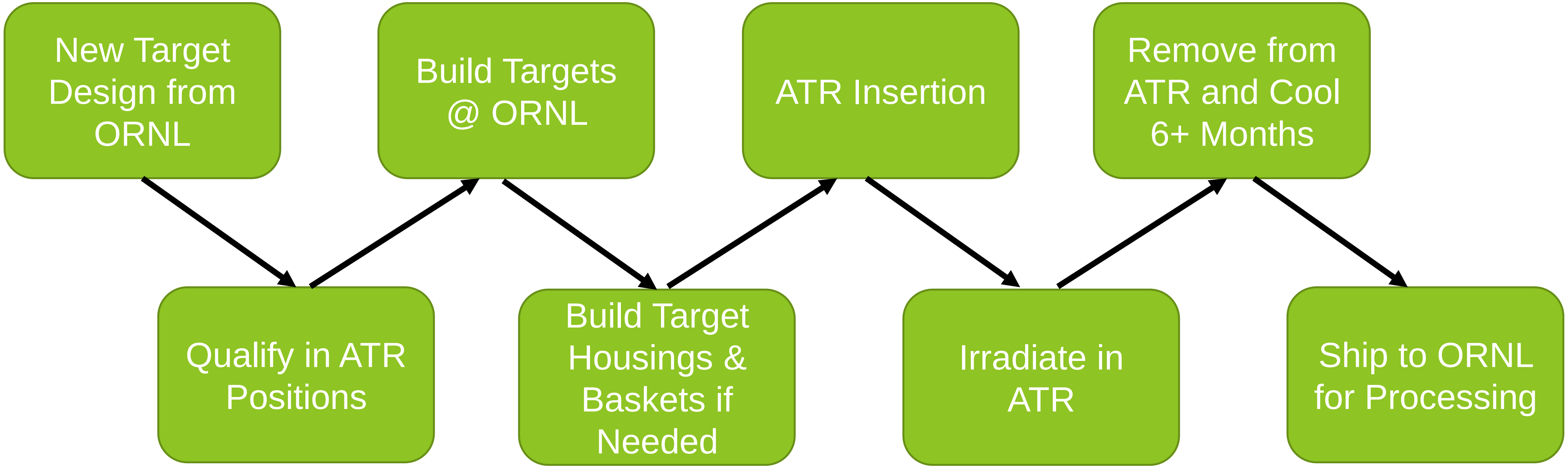
Los Alamos National Laboratory EST. 1943

- 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

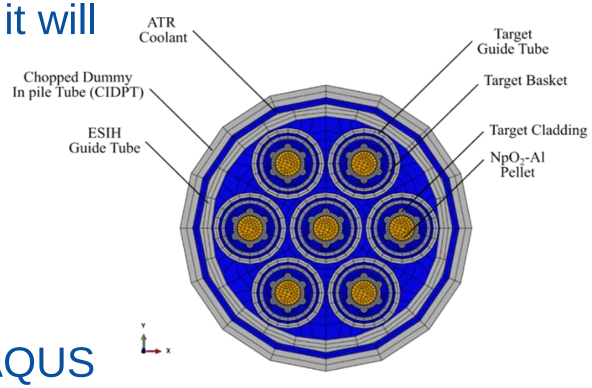
- Manufactures clads for Pu-238
- Produces Pu-238 in HFIR
- Processes irradiated targets to separate Pu from Np
- Manufactures Np targets for irradiation in HFIR and ATR
- Sends clads and Pu-238 to LANL

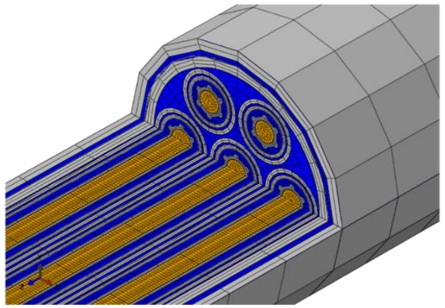
# PFS Workflow at INL

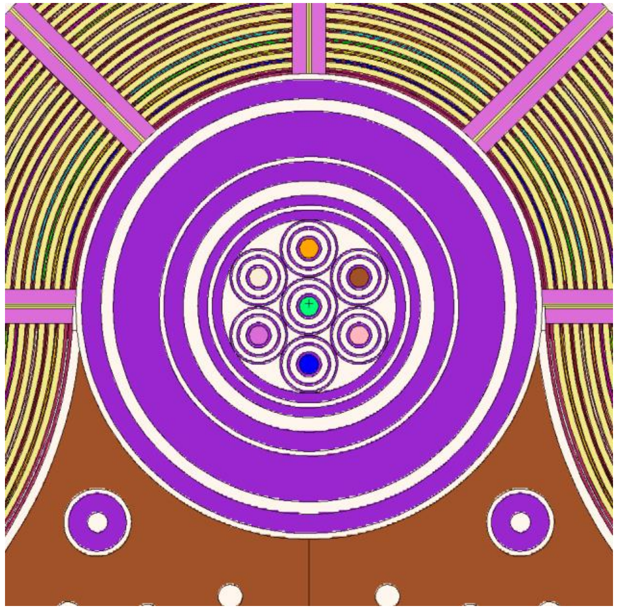


# Target Qualification

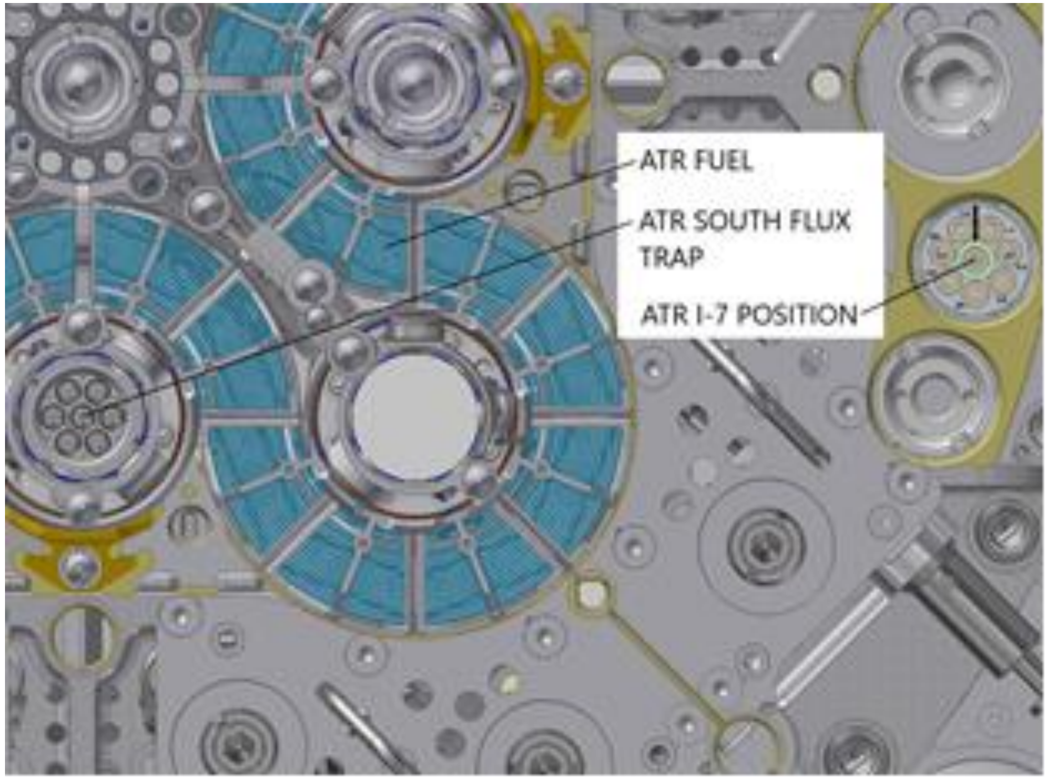
- CAD drawings are created for the target as well as baskets and handling equipment
- Each model of target is qualified for each position that it will be irradiated in
  - Neutronics Analysis with MCNP
    - Reactivity worth
    - Axial flux perturbation
    - Neuron and gamma heating
  - Thermal Hydraulic 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

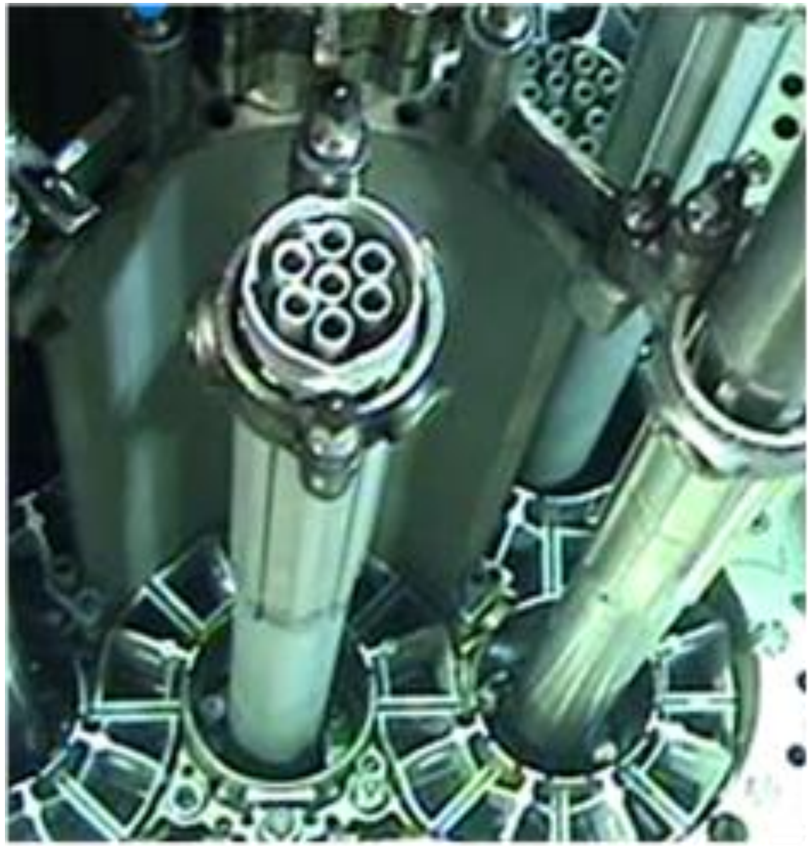




# Insertion Into ATR

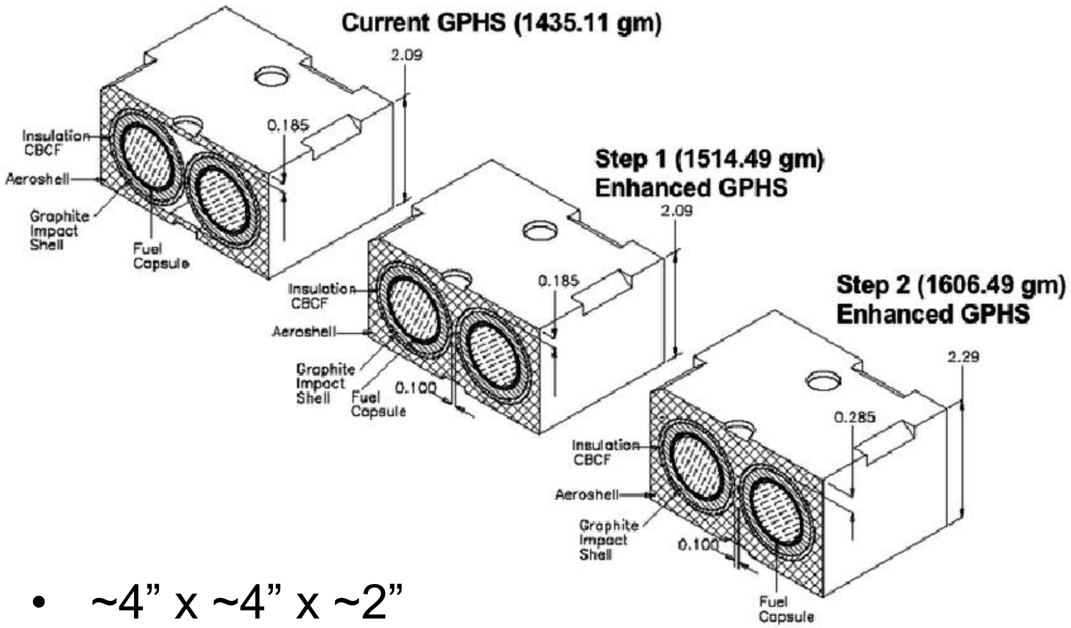


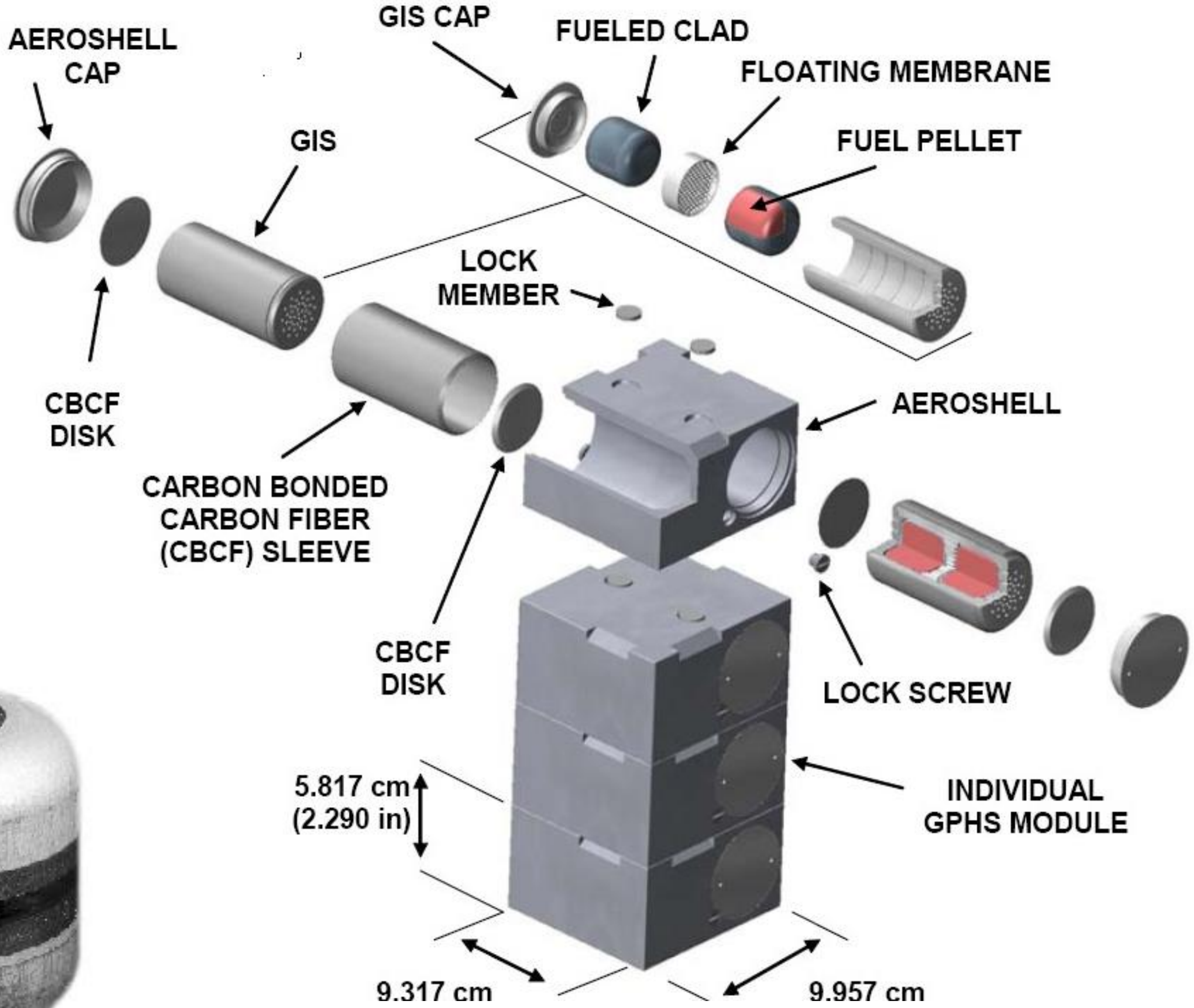
# After Irradiation

- 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

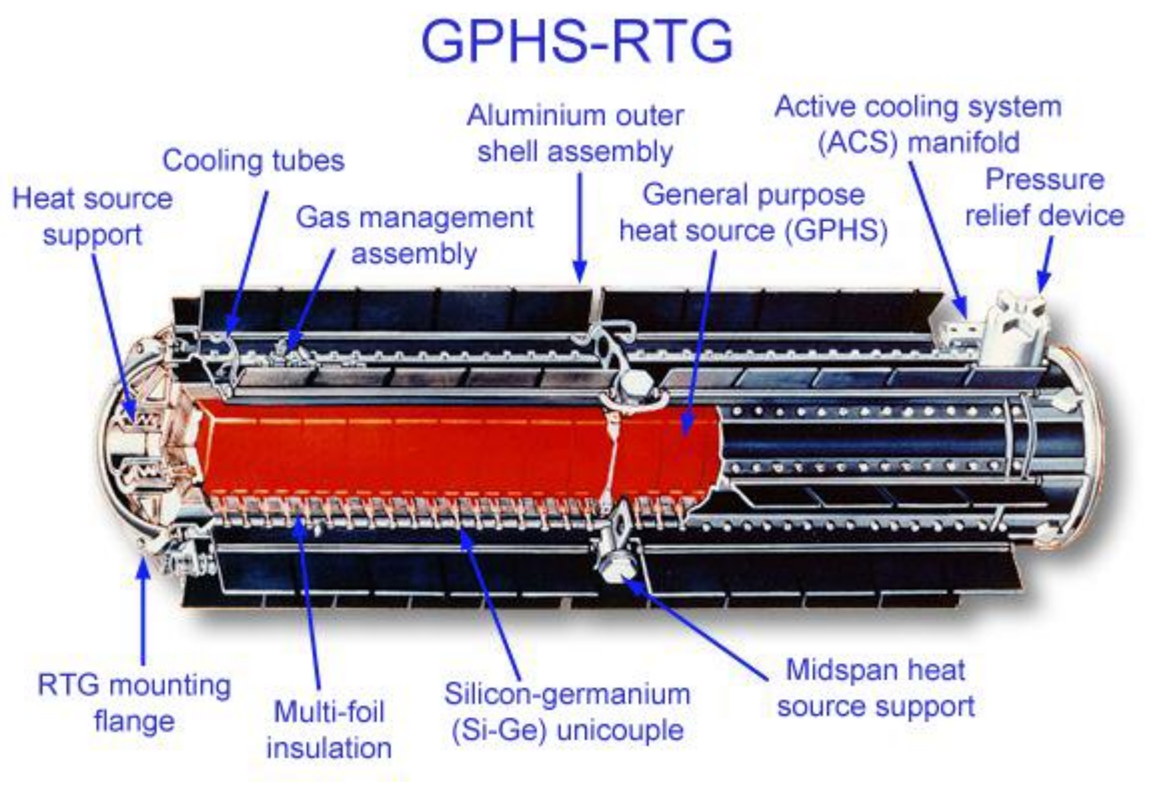
# General Purpose Heat Source (GPHS) Assembly

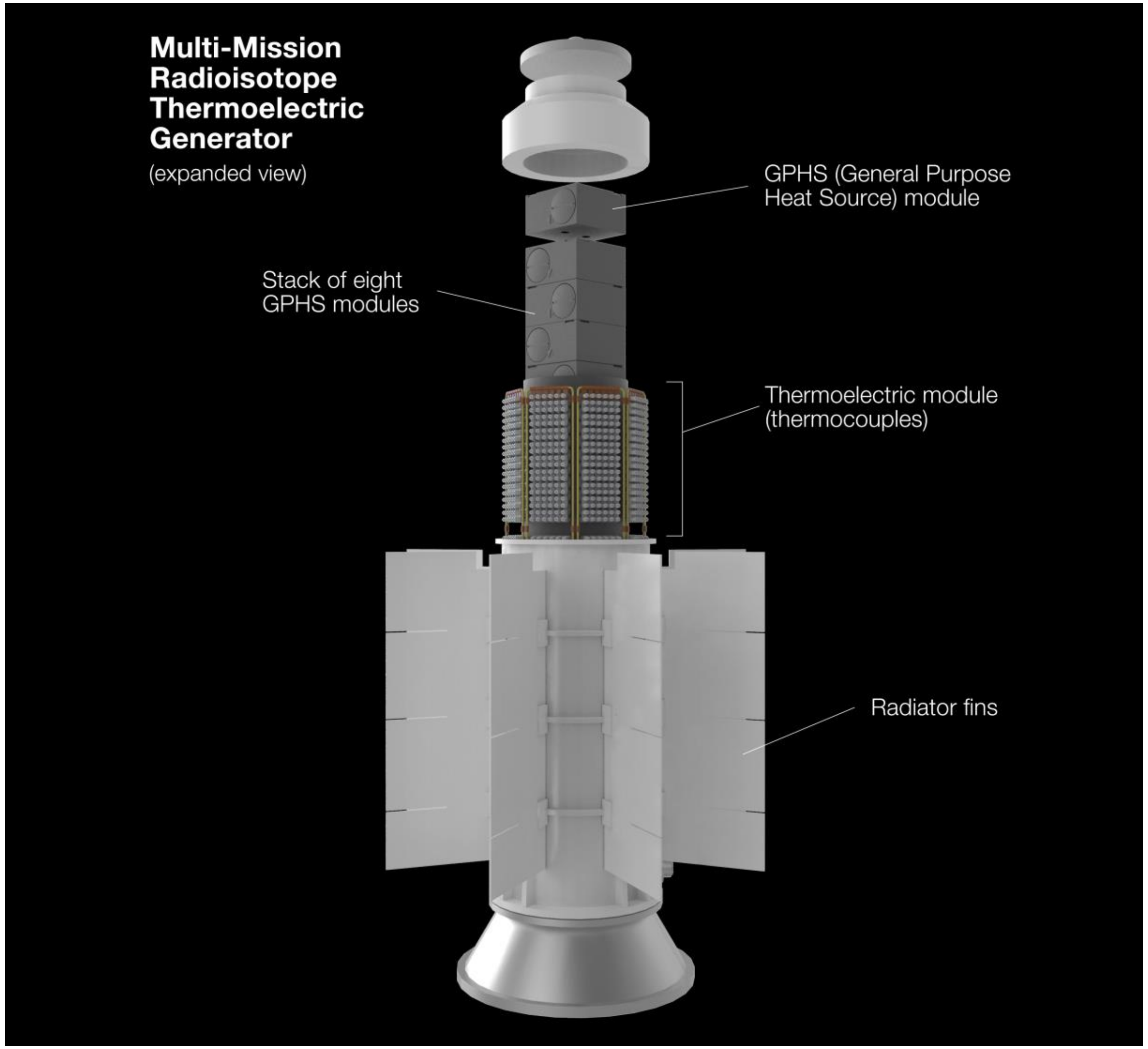



- ~4" x ~4" x ~2"
- Weighs ~3.5 pounds (~1.5 kg)
- Thermal output of 250 watts



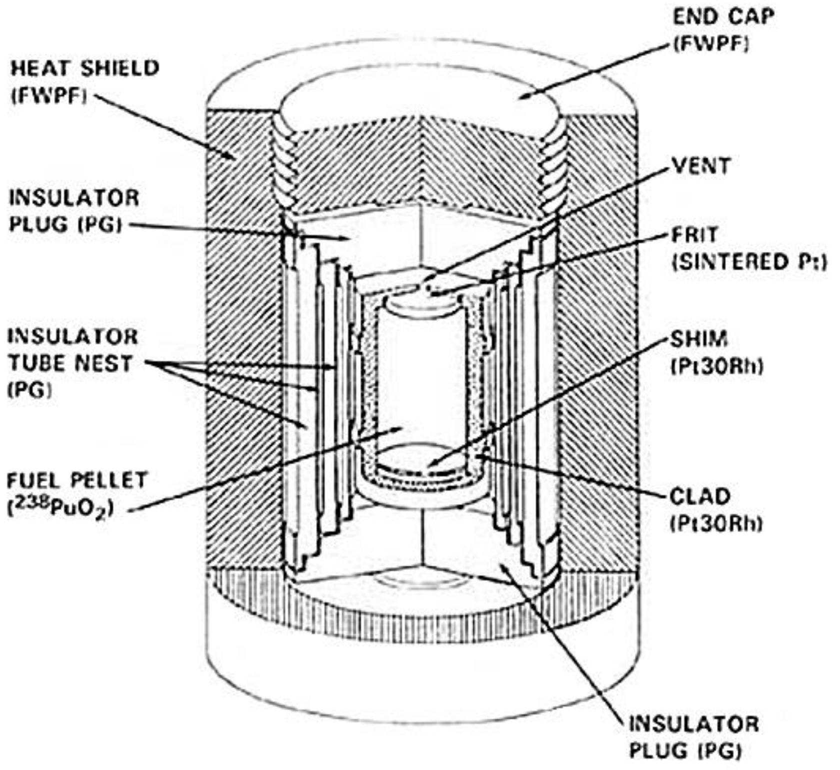
# Radioisotope Thermoelectric Generator (RTG) Assembly



# Radioisotope Heating Unit (RHU)


## LIGHTWEIGHT RADIOISOTOPE HEATER UNIT

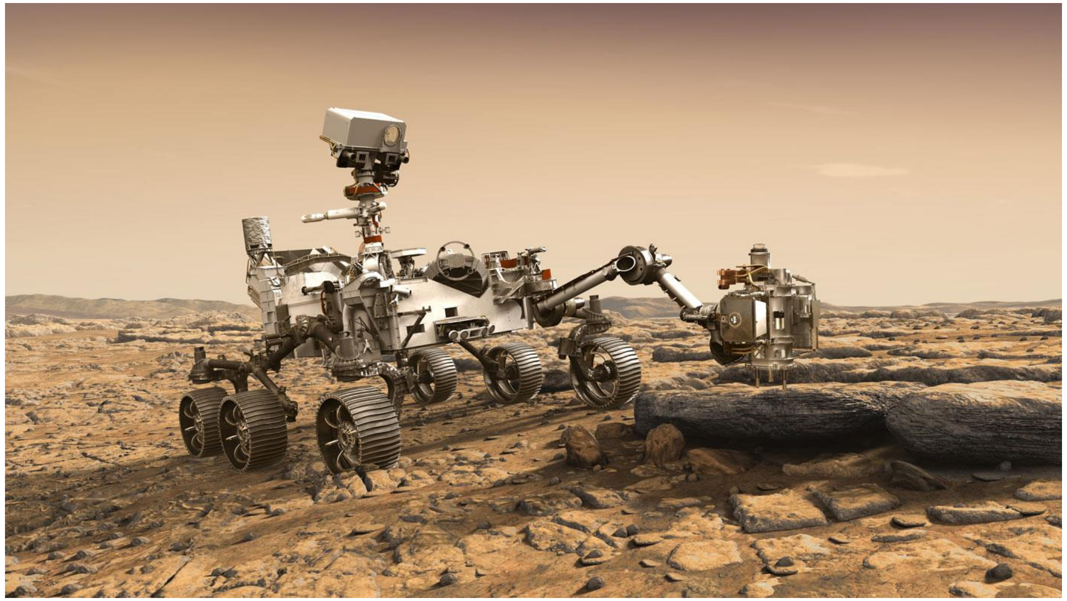



Pt = Platinum
Rh = Rhodium
PG = Pyrolytic Graphite

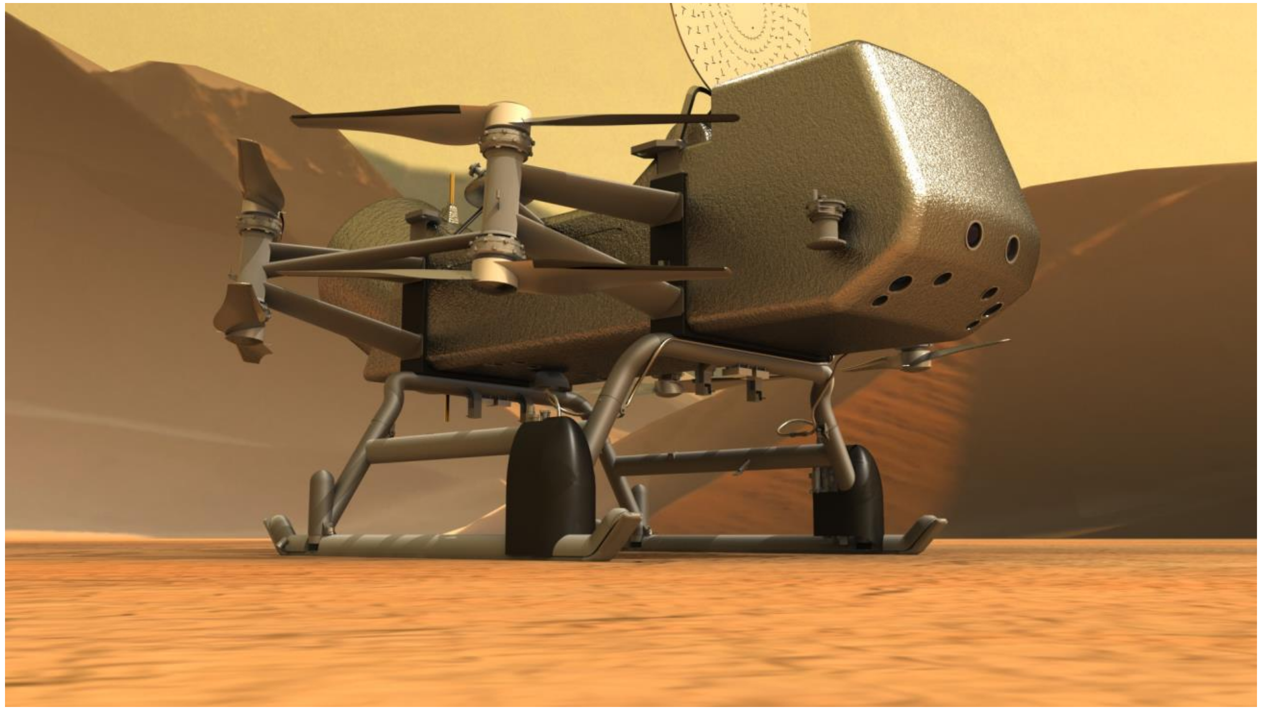
$^{238}PuO_2$ = Plutonium Dioxide
FWPF = carbon-carbon composite woven with perpendicularly oriented graphite fiber

# Future Missions

Mars 2020 Perseverance Rover (2021 to ?)



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



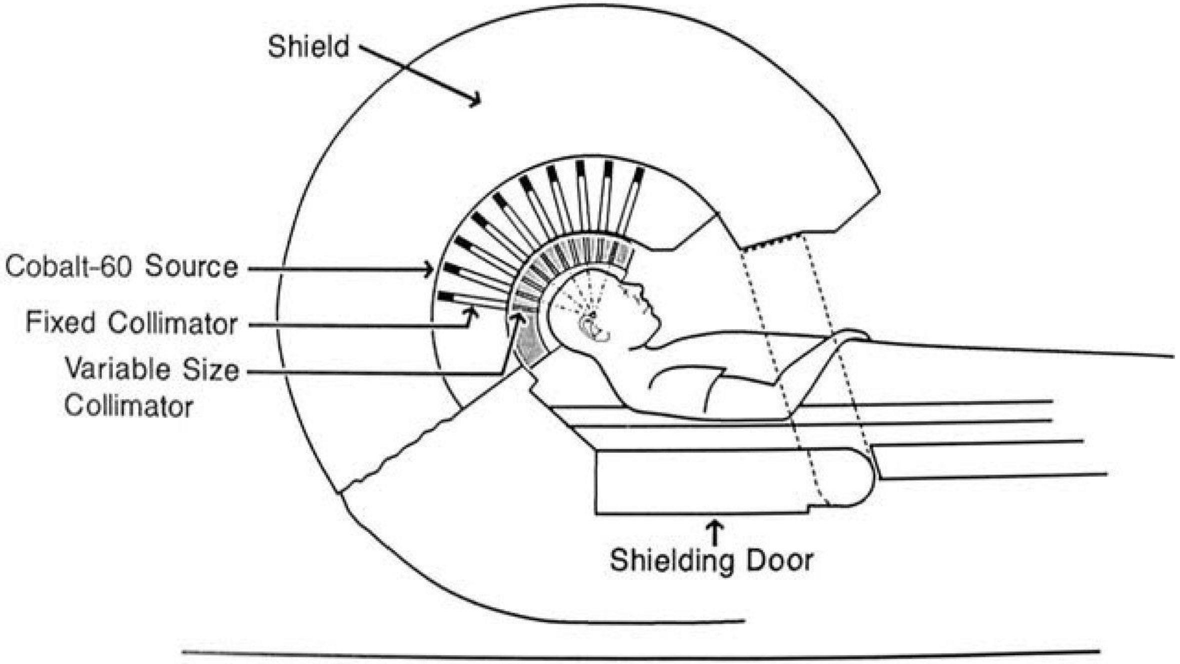
# Pu-238 Production Progress to Date

- Qualified and irradiated targets in I7 and South Flux Trap (SFT)
  - Targets completed irradiation in April 2021
- Nearing completion of qualification of a full length target
- Future concepts will look at increasing the amount of Np-237 in the targets
  - Increases production yield of Pu-238
  - More difficult to qualify due to higher irradiation heating, increased breeding of fissile materials, and higher decay heat after discharge
- Pu-238 that INL has made in the last year will power future NASA missions to outer planets

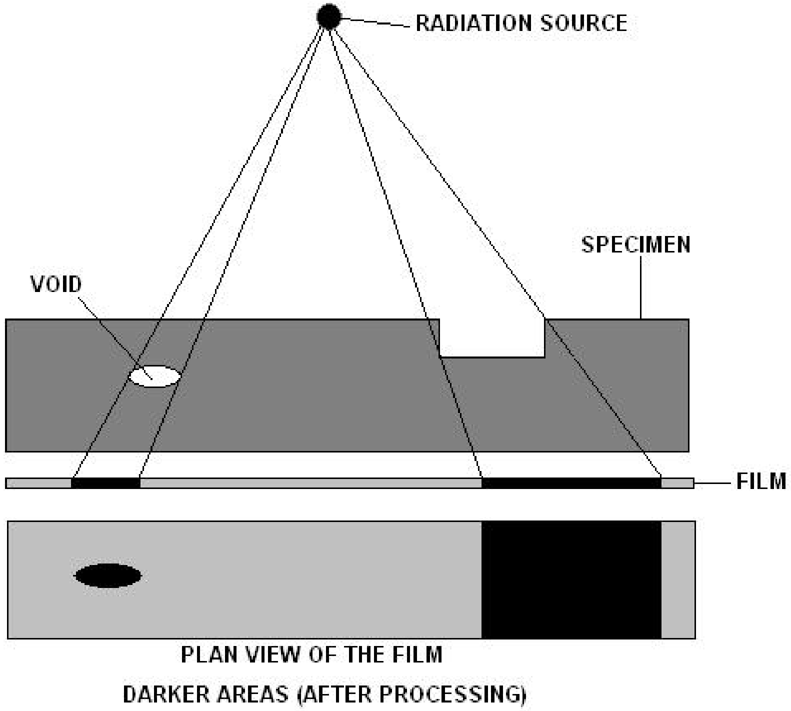
# Overview of Co-60 Production at INL

# What is Co-60 Used For?

Gamma Knife Cancer Treatment

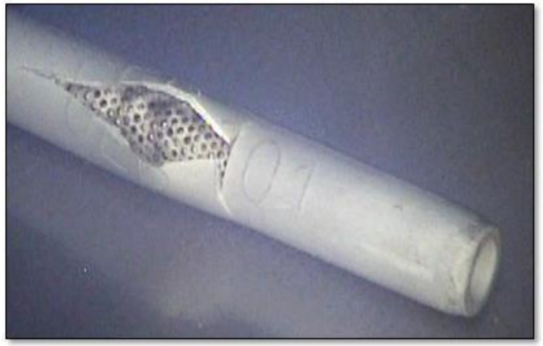



Non Destructive Testing

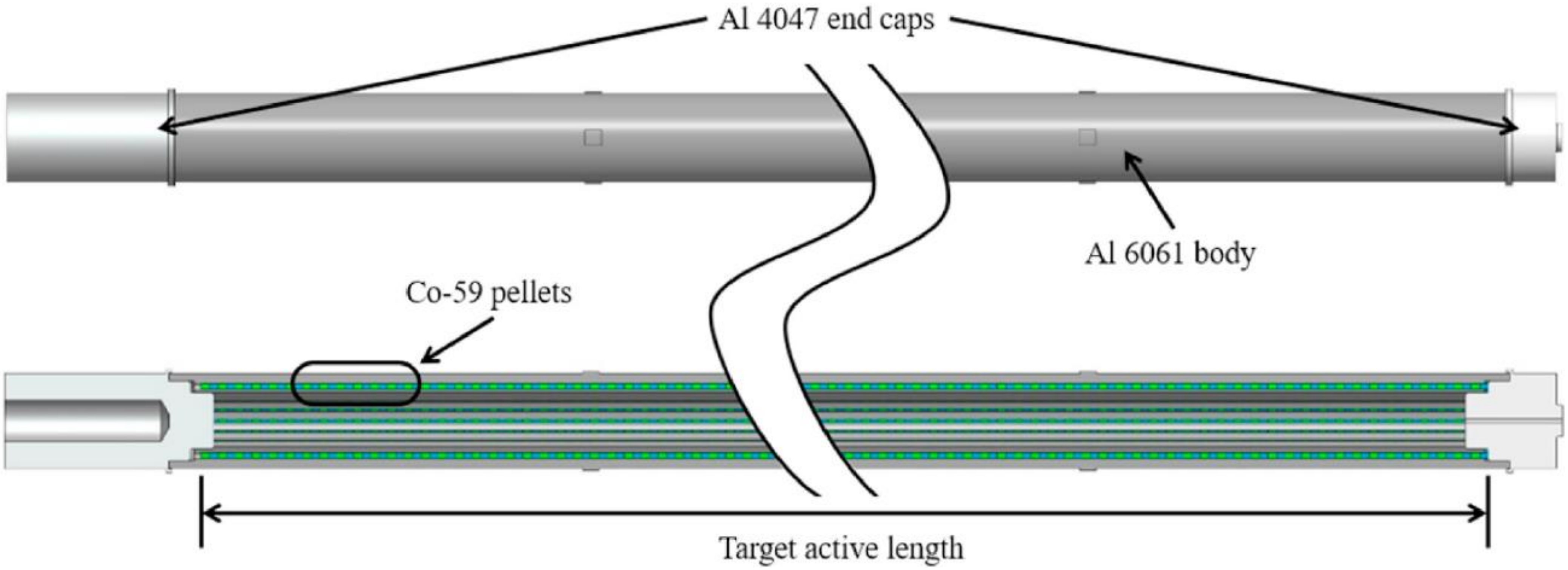


# Co-60 Production Overview

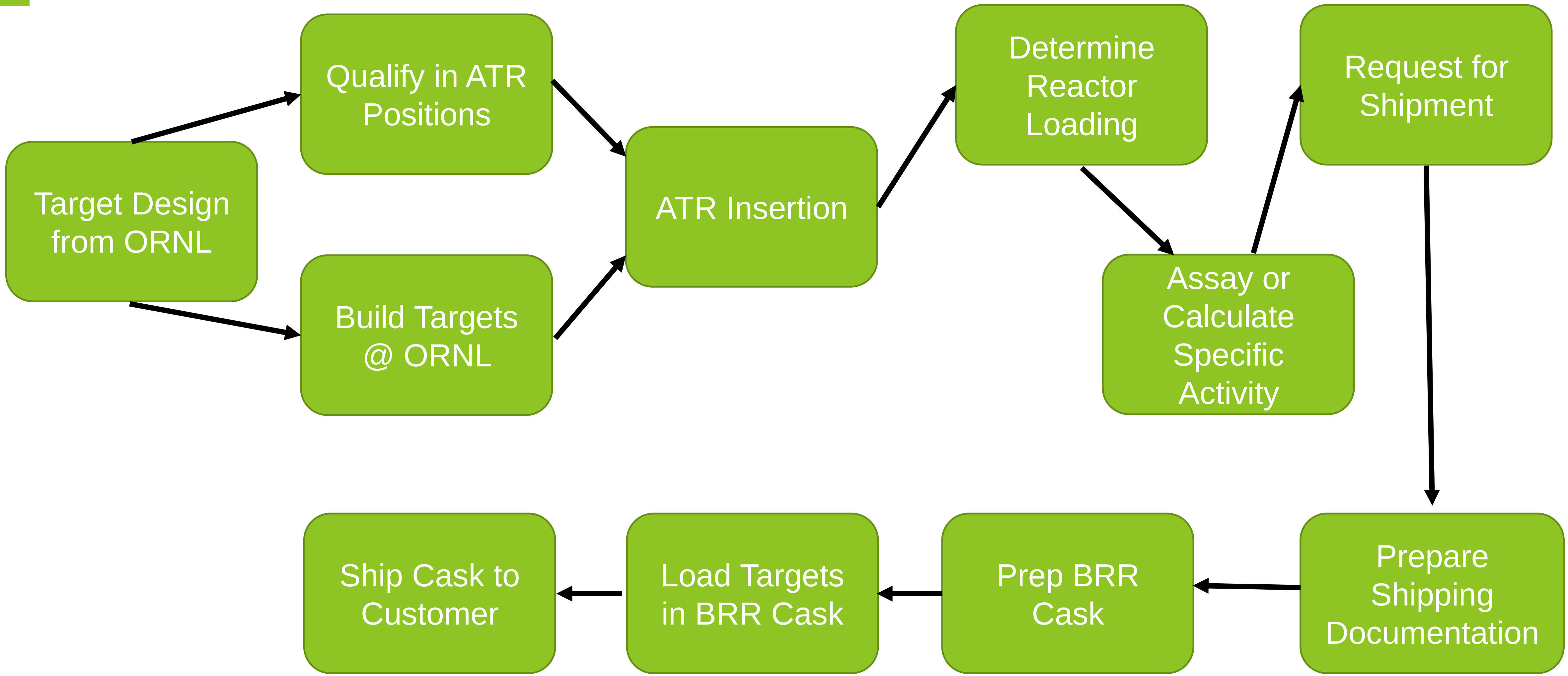
- High Specific Activity (HSA) Cobalt-60 is produced in ATR for the DOE Isotopes Program (DOE-IP)
- Targets contain thousands of tiny pellets of Cobalt that are enclosed inside aluminum packaging
  - Pellets are designed to be removed from the target at the end user and re-encapsulated
- Legacy Cobalt 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

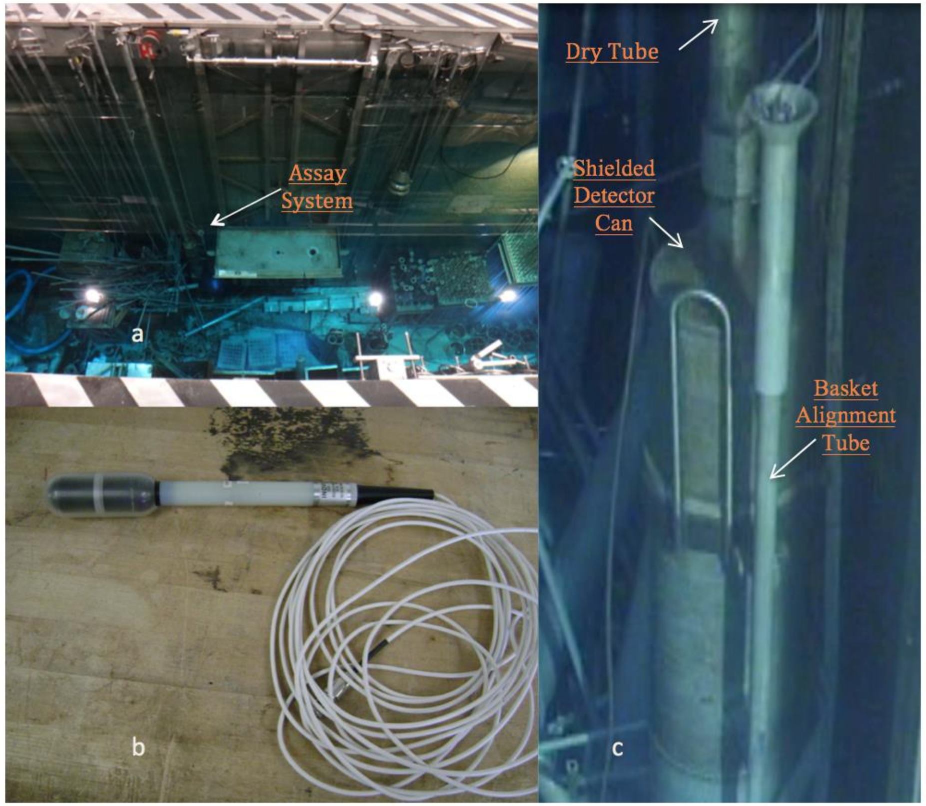


# Co-60 Workflow at INL



# 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**

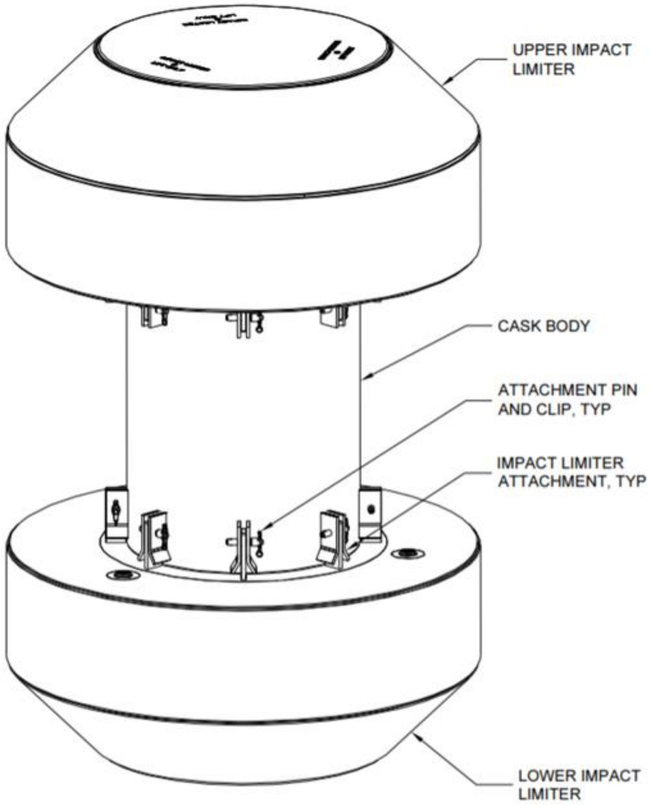
# Co-60 Progress To Date

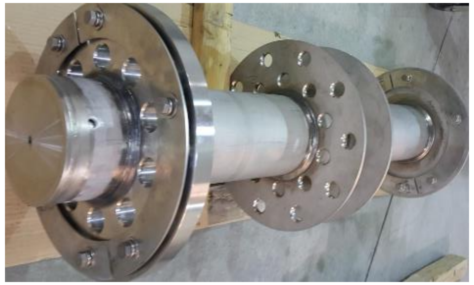
- Irradiation of 66 targets began in 2015
- INL has completed several Co-60 shipments as of January 2022
- Multiple assays have been completed to improve production estimates
- Future irradiation and production plan is in under development
- Earliest future irradiation in ATR is once the Core Internal Changeout (CIC) process is complete and Cycle 171A begins in April 2022

# Isotope Transportation Using the BRR Cask Shipping

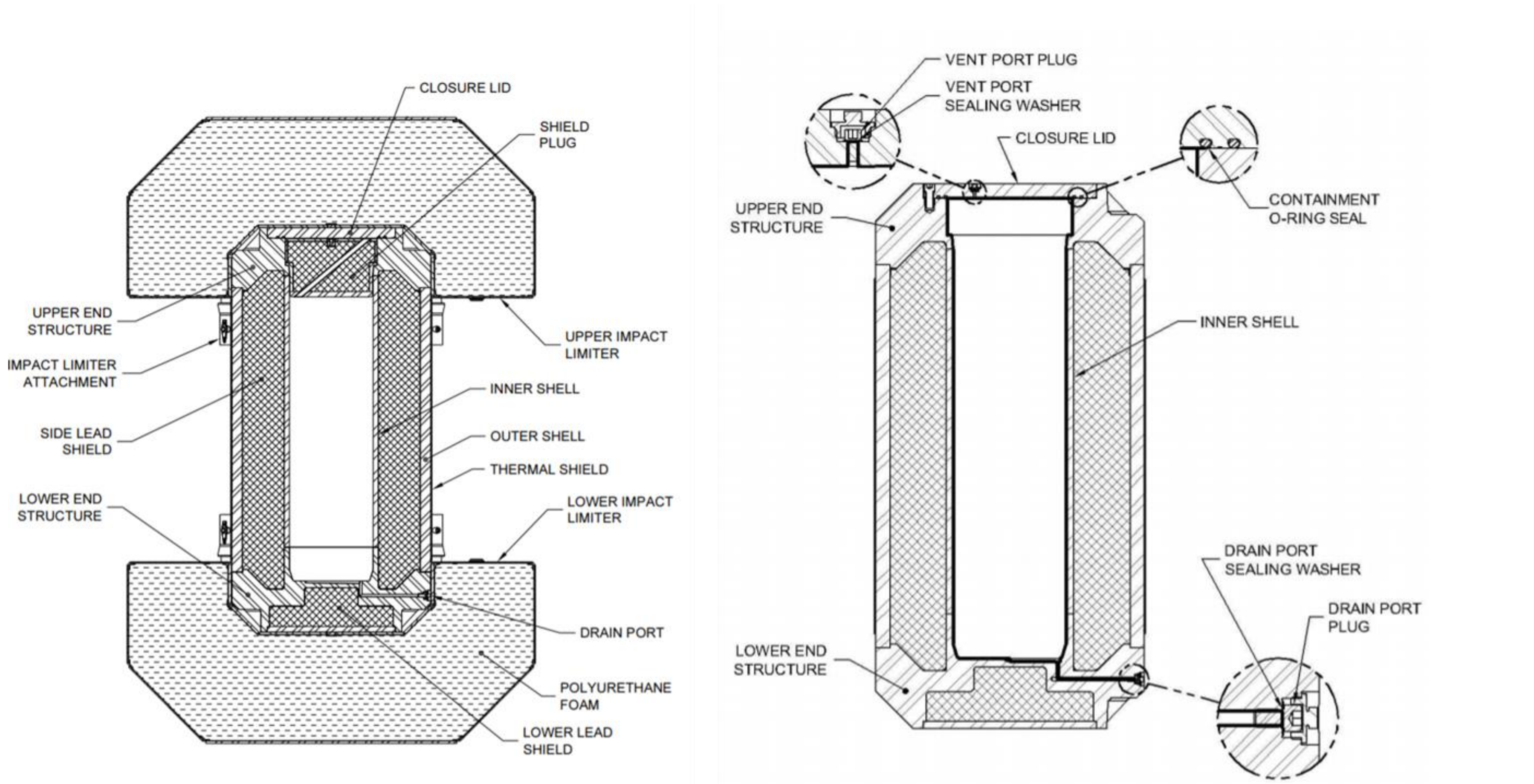
# BRR Cask Overview

- 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



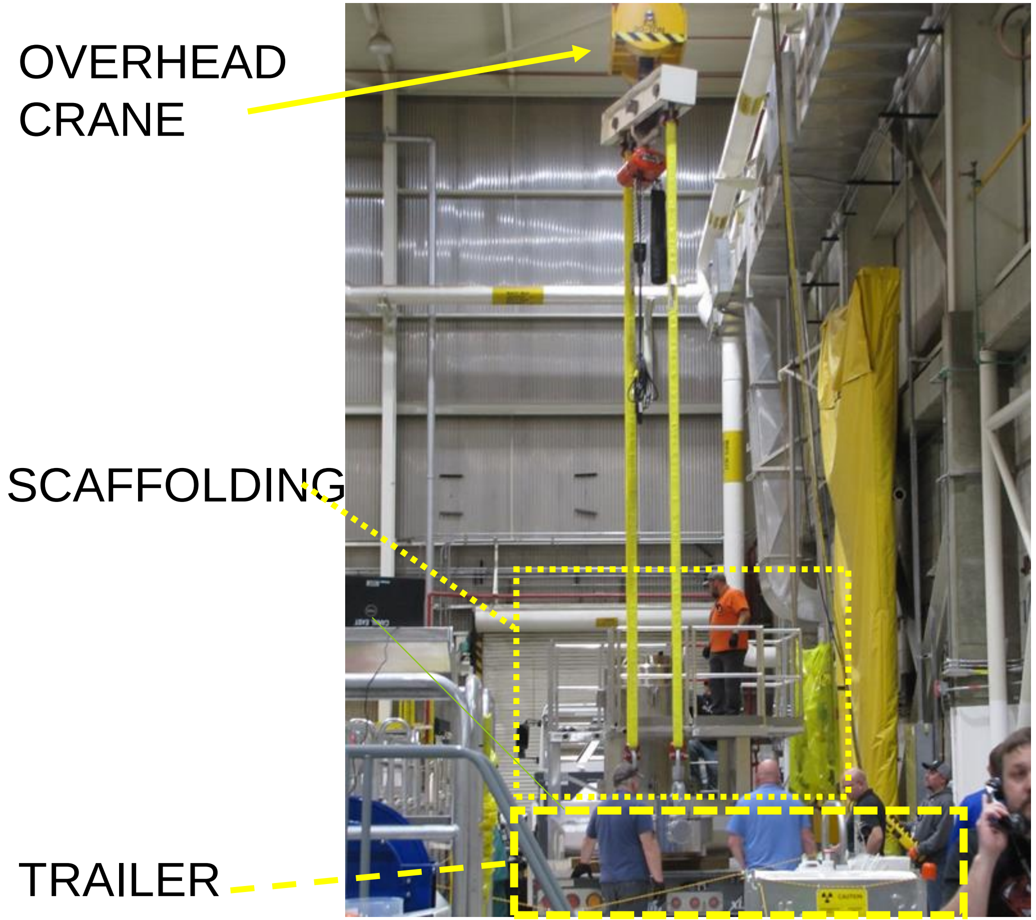

The BRR Cask has multiple features that enable the shipment of nuclear fuel and radioactive material in a U.S. Department of Transportation compliant cask

# 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

- Pu-238 production portions of this work was funded through DOE & NASA Interagency Agreement # NNH19OB05A and DOE contract DE-AC05-00OR22725.
- 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.