# *Advanced Gas Reactor Fuels Program Review*

# AGR-2 PIE Gamma Scanning Results

**Jason M. Harp Ph.D.**
**Idaho National Laboratory**

**July 15-16, 2015**

www.inl.gov

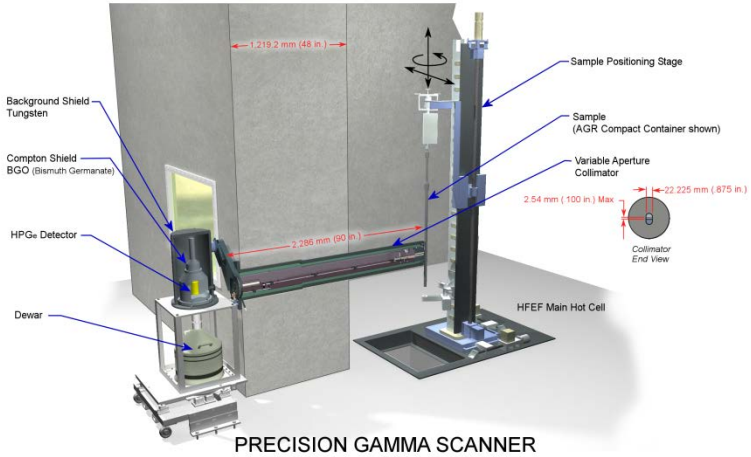
Idaho National Laboratory

# *Outline*

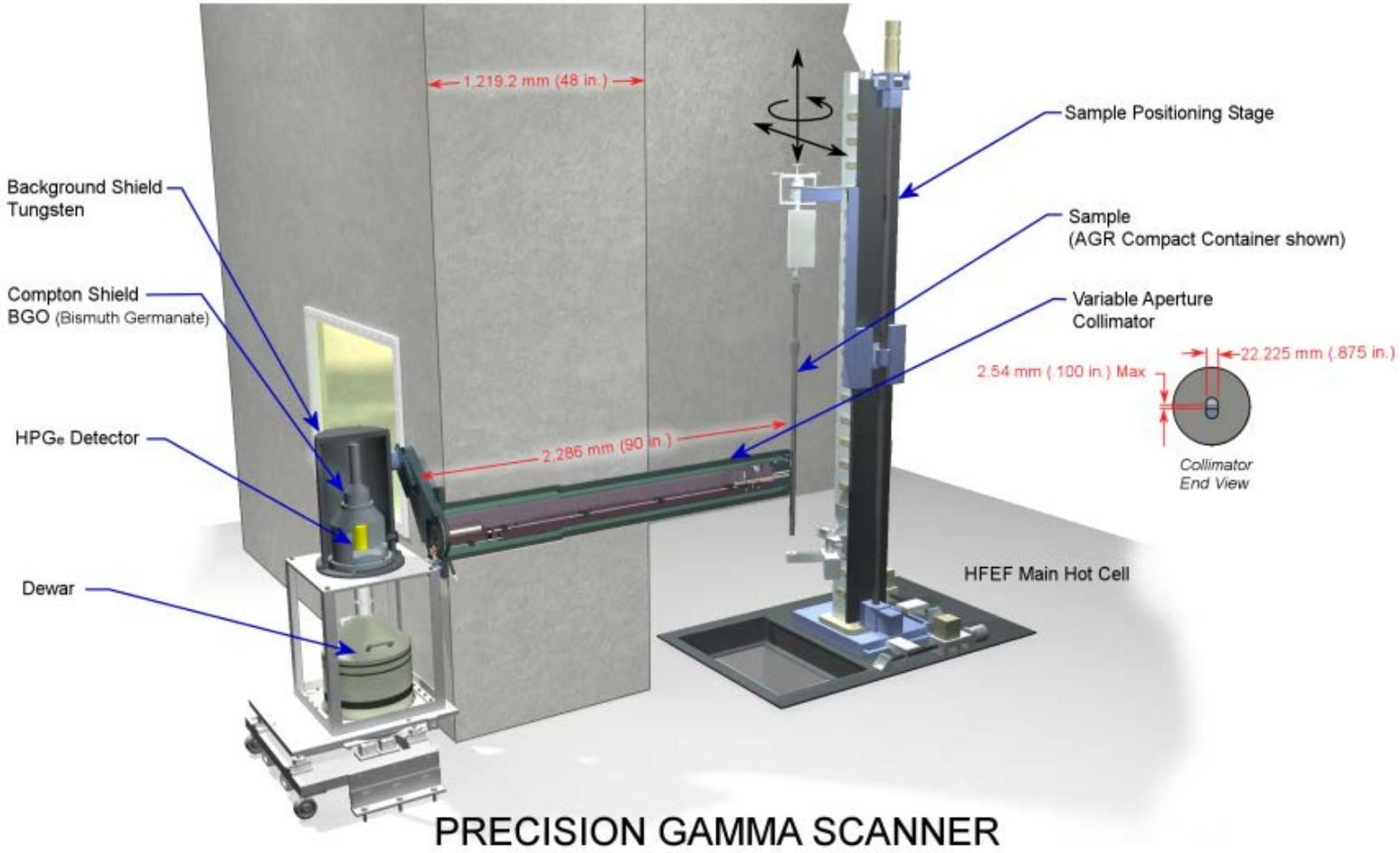
- PGS Introduction
- Test Train scans
- Compact scans
- Holder scans
- Future scans

# Precision Gamma Scanner

- Located in the Hot Fuel Examination Facility (HFEF)
- Three major components
  - Detector System
  - Collimator
  - Sample positioning apparatus
    - Control Software automatically adjusts sample position after a set live time and saves spectra
    - Movement in x, y, z, Φ directions
- Designed originally for pin type fuel
- Typically used for qualitative fission product distribution in irradiated fuels
  - Initial non-destructive step in PIE
  - Burnup
- Quantitative measurements are possible in specific cases (i.e. TRISO fuel)
  - Efficiency calibration
  - Geometry correction

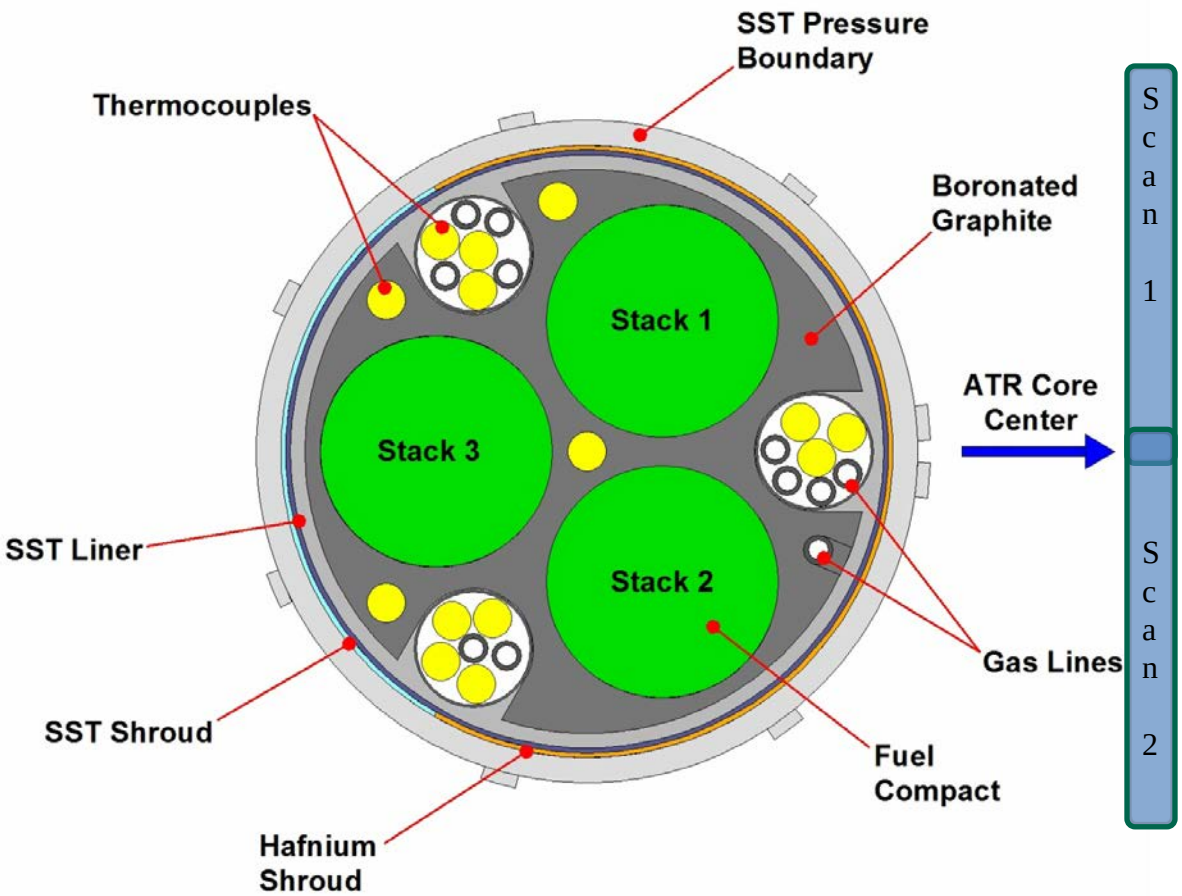


# PGS at Window 7M

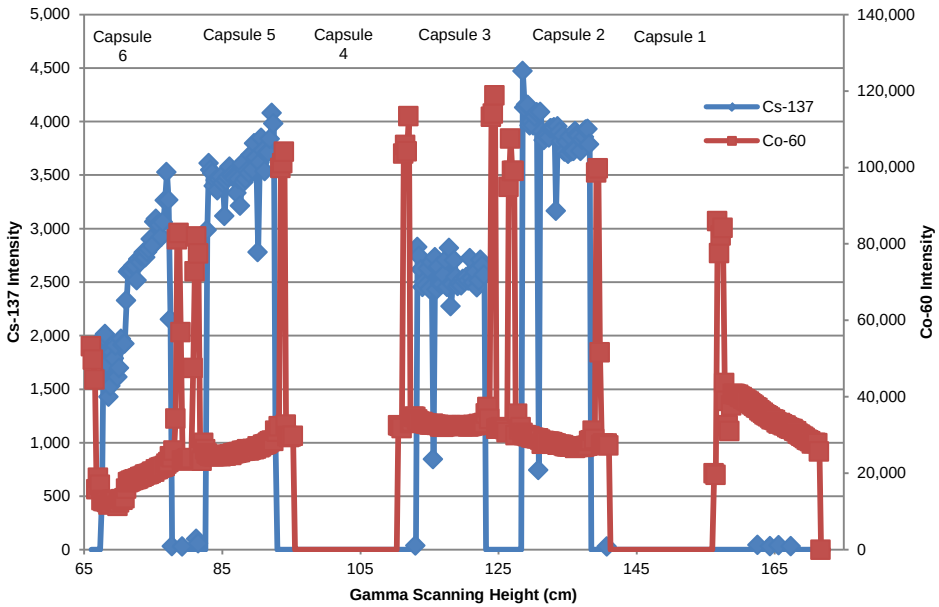


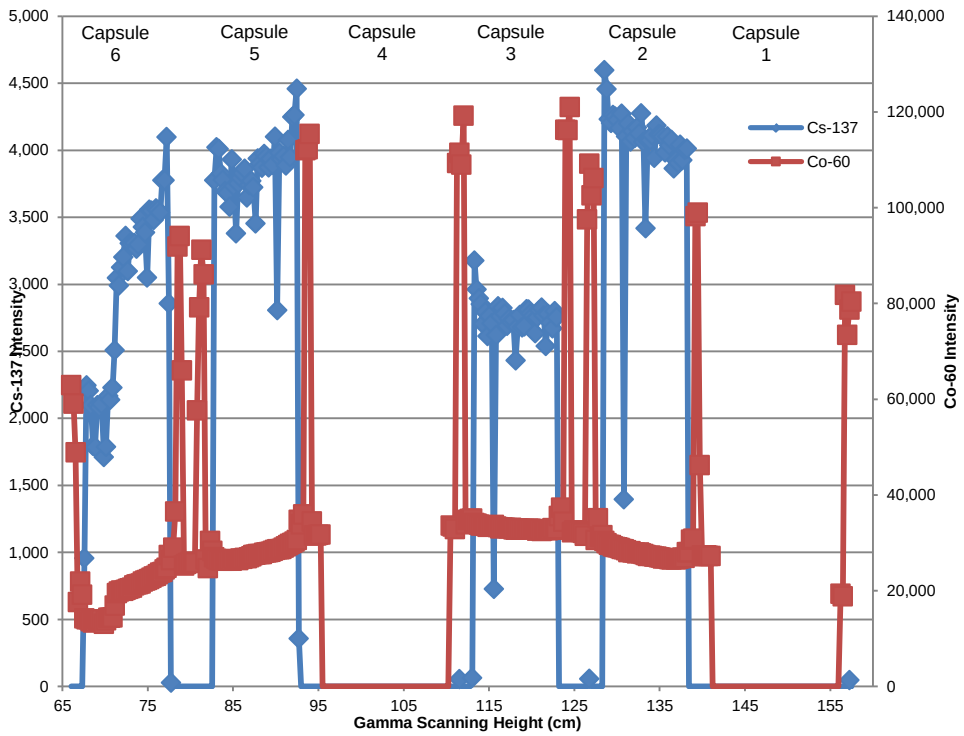
# Test Train Gamma Scan

- Examined to identify interior components, including the fuel compacts, and determine if any damage or shifting of components within the capsules had occurred.
- The test train was scanned in two off-axis sweeps
- Scans were performed with the collimator closed down to 0.025 cm wide, but scans were still taken every 0.254 cm.
- The scans were analyzed for fission products adjacent to the nominal fueled regions which might indicate whether deterioration of graphite spacers allowed fuel compacts to shift axially.
- Spectra from the scans were analyzed for activation products and fission products
- Nothing unusual was observed in the fission product distribution. In general the fission products appeared to be retained in approximately 10.16 cm long sections of the test train at regular intervals indicating no shifting of the compacts during irradiation.



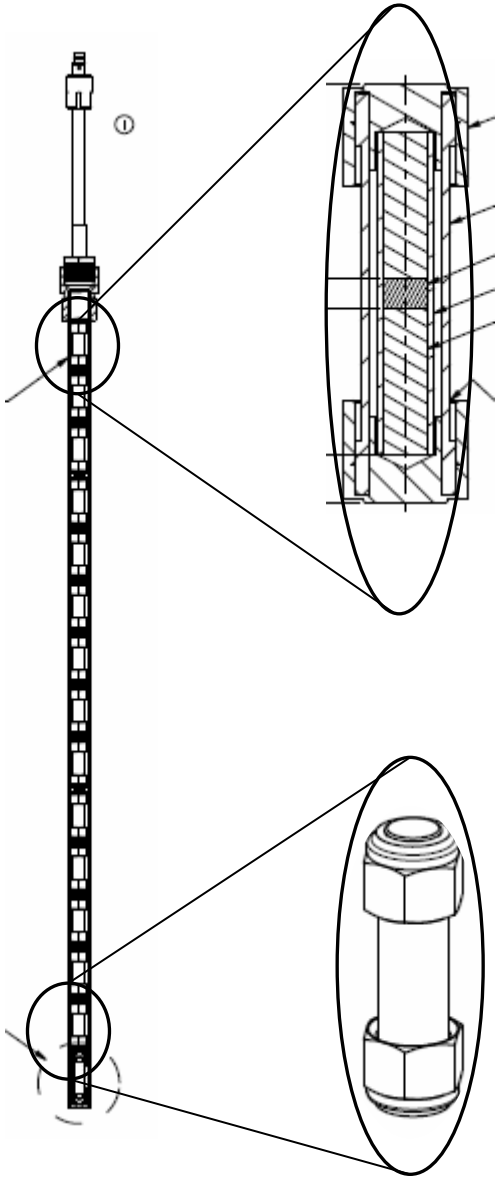
# Test Train Gamma Scan



# Compact Gamma Scans

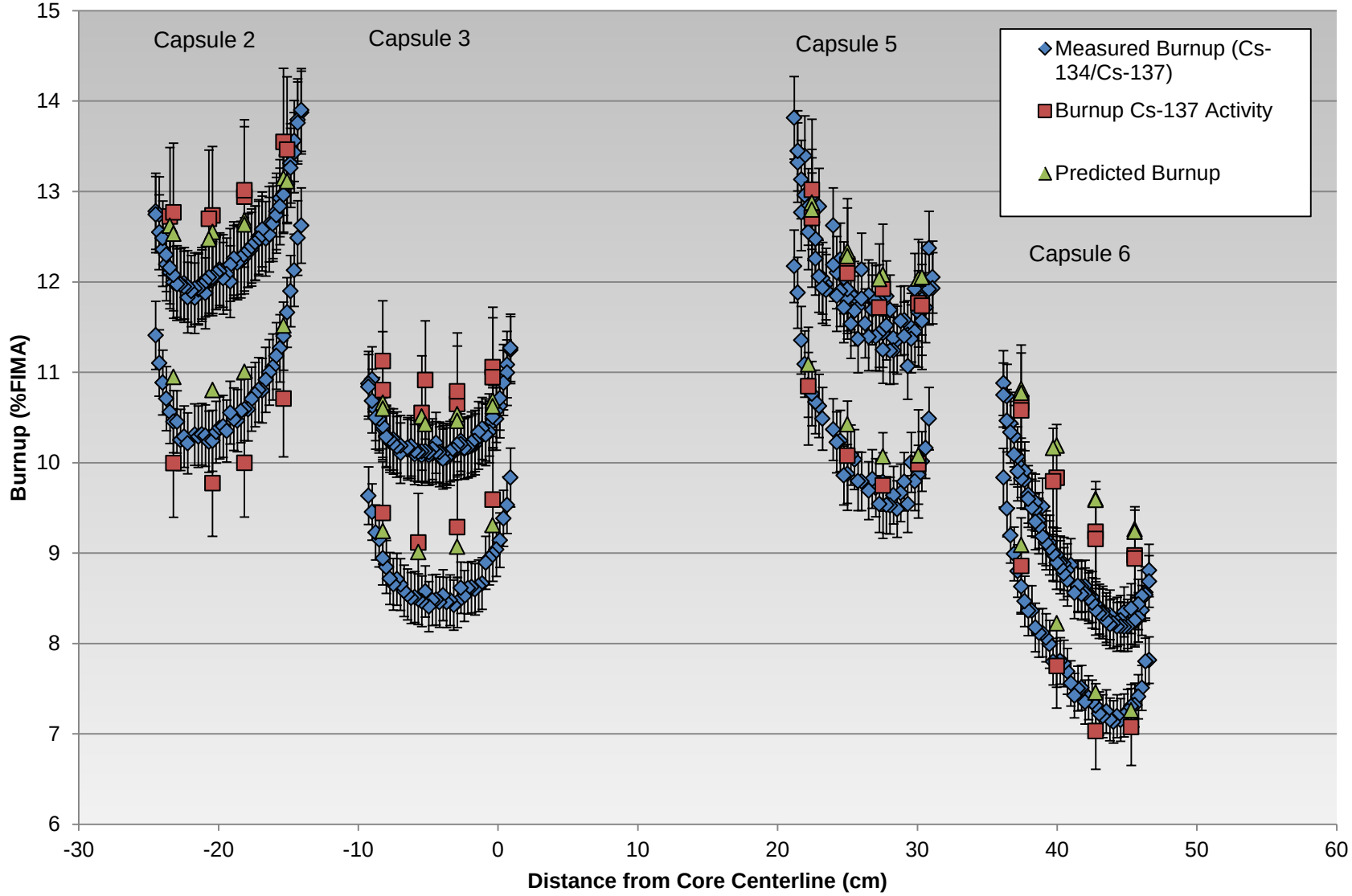
- Gamma-ray scans of all the AGR-2 compacts will be completed (36 so far)
- Compacts are scanned in 0.254 cm steps with the collimator set to 0.254 cm
- Non-destructive burnup evaluation using gamma spectrometry has been performed using two techniques
  - Direct fission product inventory
  - Ratio of shielded to direct fission product inventories (Cs-134/Cs-137)
- The Ag-110m inventory is also evaluated for retention
- Variety of other fission products detected (Ce-144, Eu-154)



# Conversion of Measured Activities to Burnup

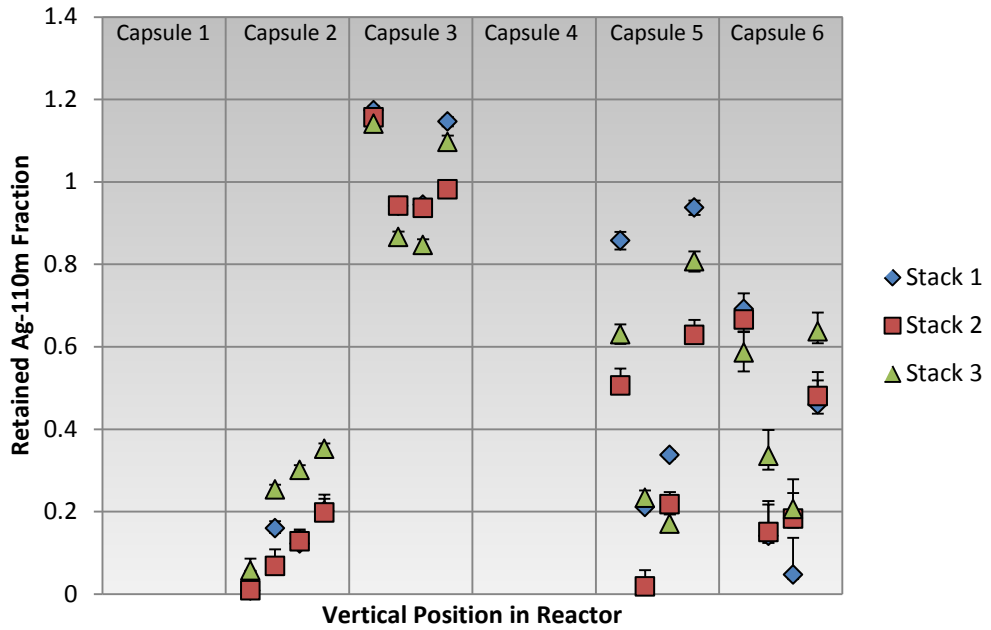
- Relationships between final burnup and final fission product activity or activity ratio were developed to predict burnup from the PGS measurements
- Both gamma-ray spectrometry burnup analysis methods have challenges
  - Direct activity: Efficiency calibration, local variations not captured
  - Activity ratio: Neutron energy spectrum shifts, tracking cross sections
- C/E results suggest an optimum indicator for both methods
  - Direct activity: Cs-137
  - Activity ratio: Cs-134 / Cs-137 (shielded FP) / (direct FP)
- Linear Regression relationships between the final predicted burnup and the final predicted Cs-137 Activity and Cs-134/Cs-137 ratio were used to derive burnup from the AGR-2 Compact Gamma Scans
  - Capsules 2, 5, and 6 used one set of relationships
  - Capsule 3 had its own relationships

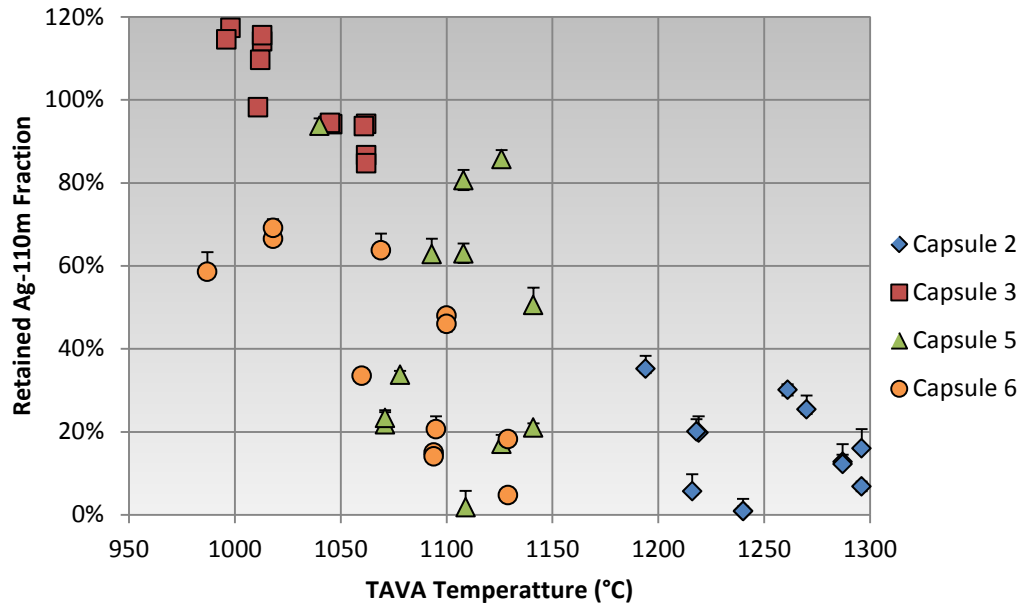
# Preliminary Burnup Estimates



# Ag-110m Inventory

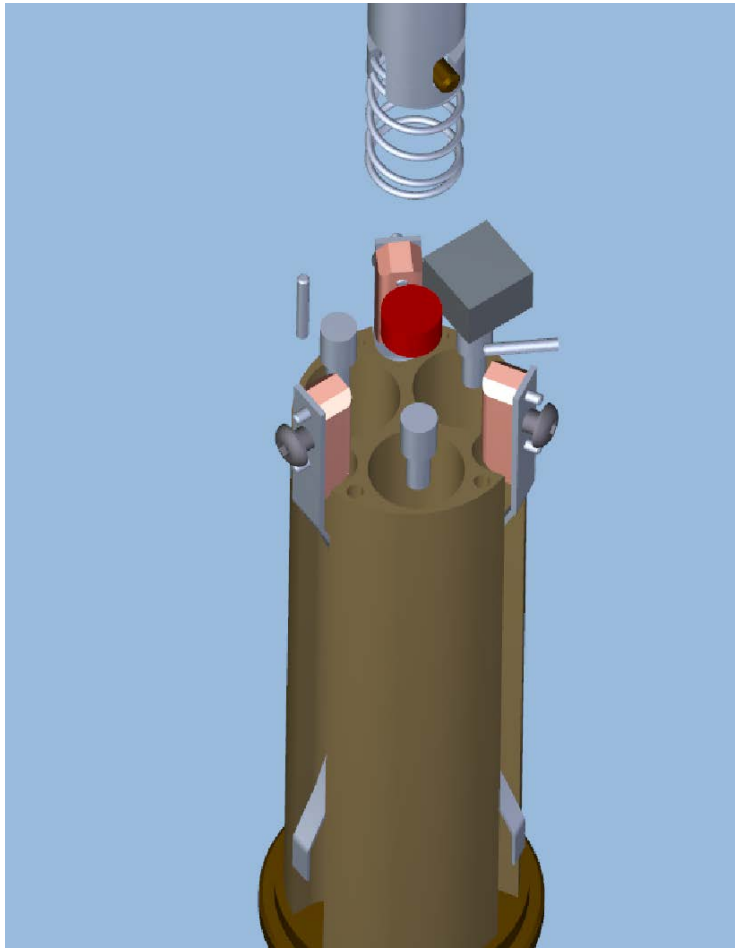
- The Ag-110m activity from all the scans of a compact are summed to find the total inventory
- This value is compared to the predicted inventory
- For all capsules the lower uncertainty band is based on measured activities and the upper band is base on measured activity and/or MDA
- TAVA Temperature is an incomplete metric, burnup, time at temperature, and isotopic mix at a temperature all likely play a role in Ag release



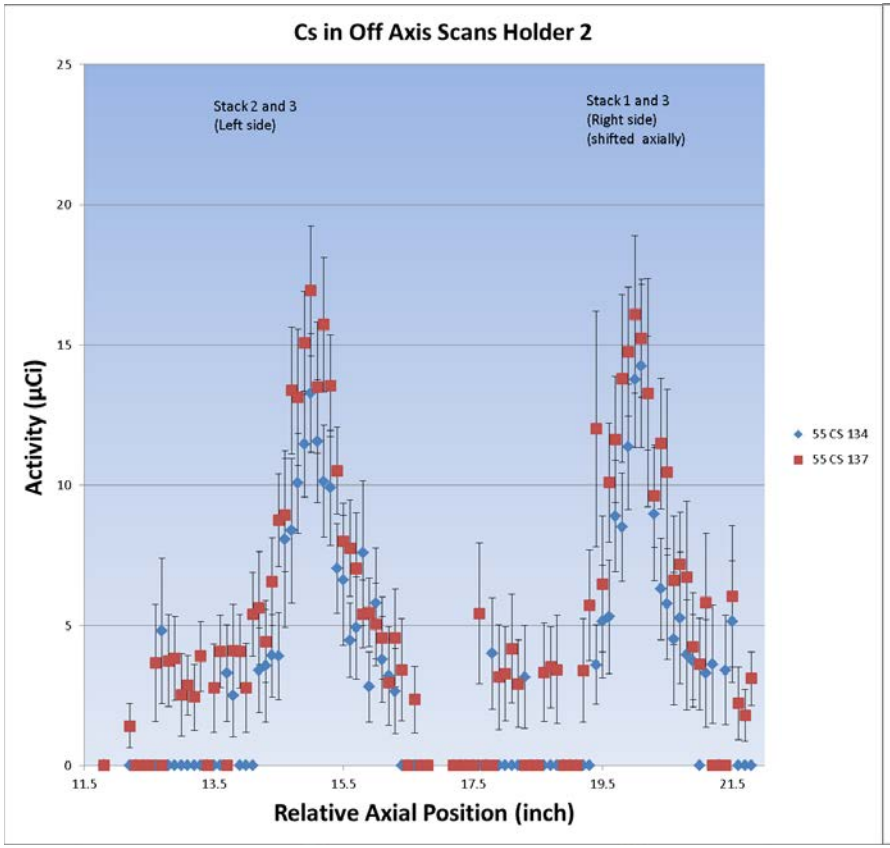



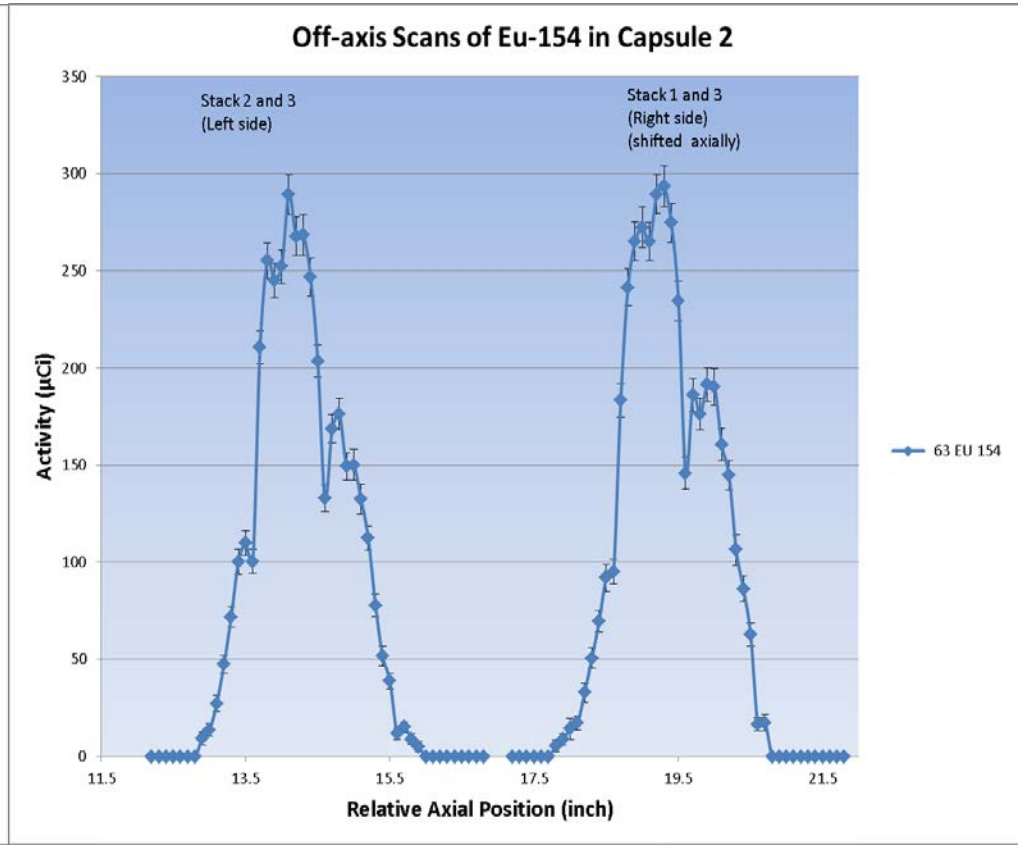
# Holder Gamma Scans

- Holders are scanned with tomography in mind
- Each holder is scanned with two off axis scans to identify levels to map
- The new fixture has improved mapping
- Source to fix coordinate system
- Test PGS GECT capabilities for AGR-3/4

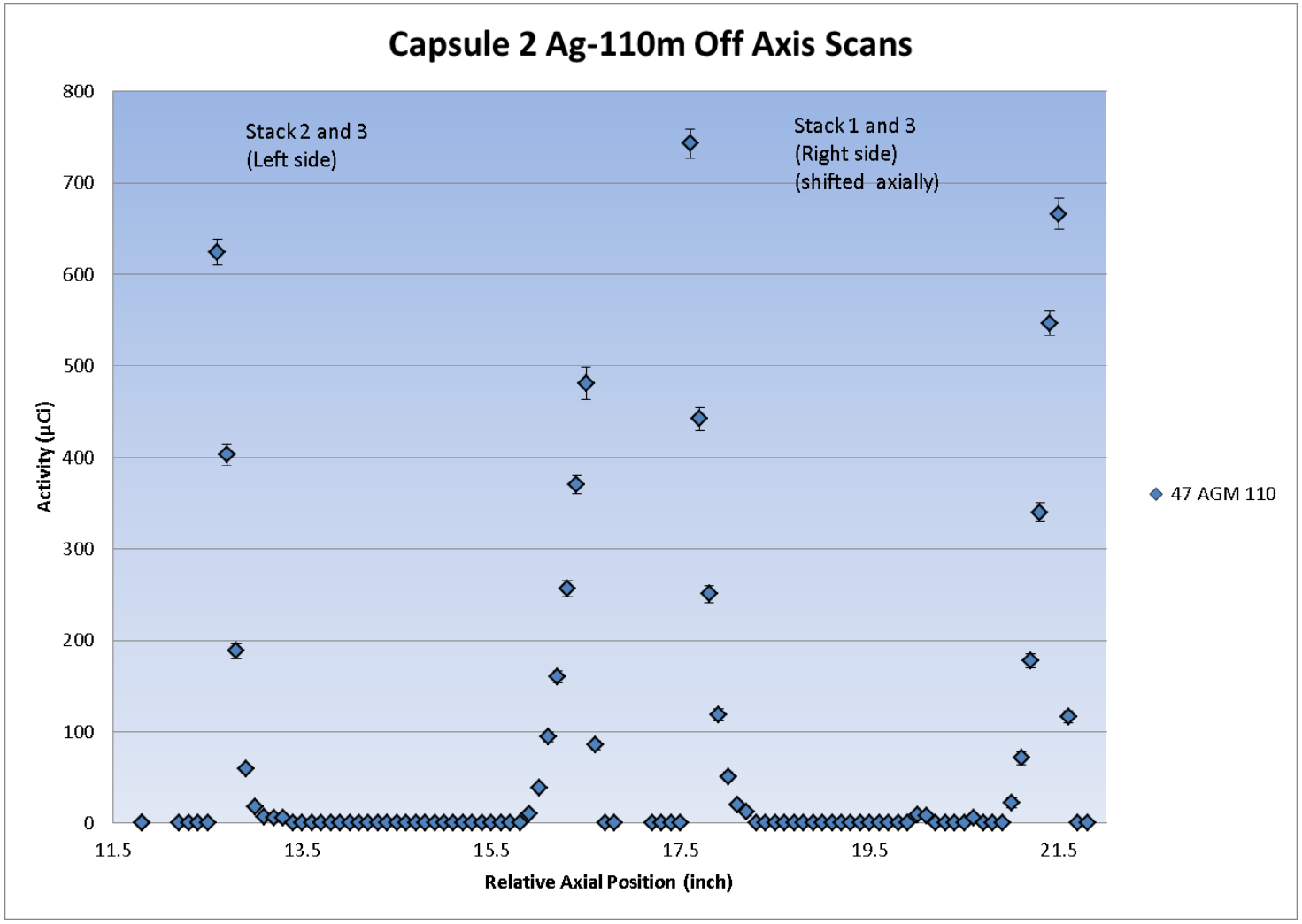


# Off-axis Scans

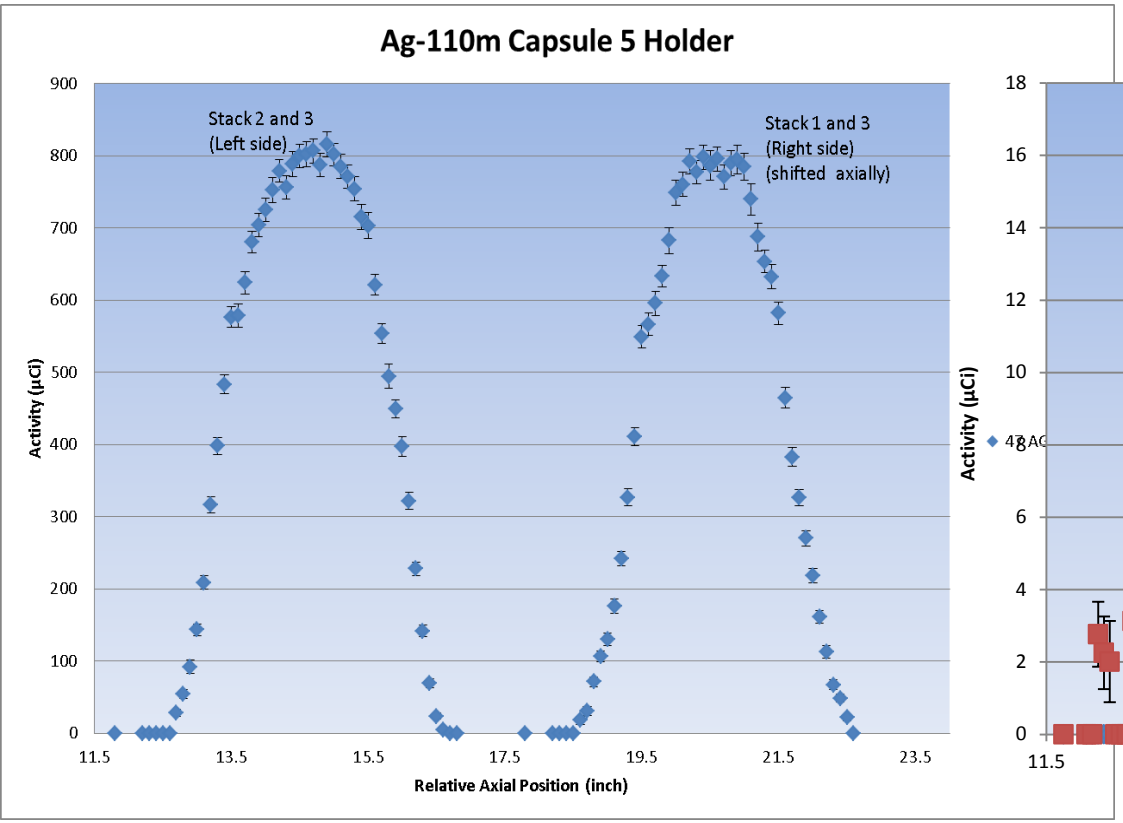


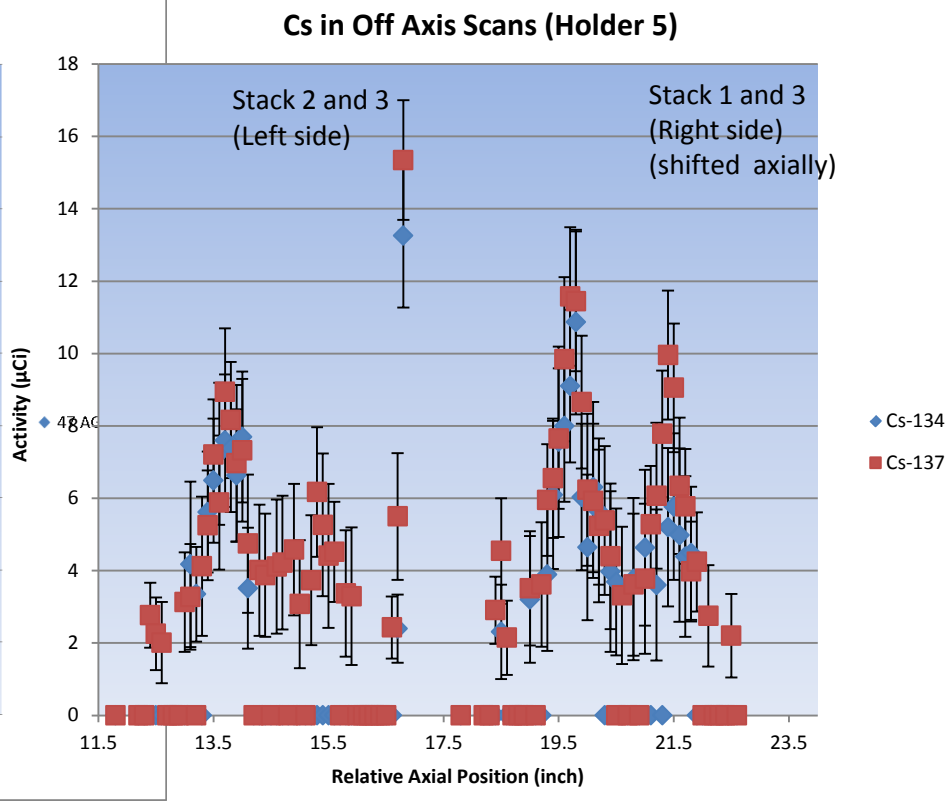



# Holder 2 Ag-110m off-axis scans

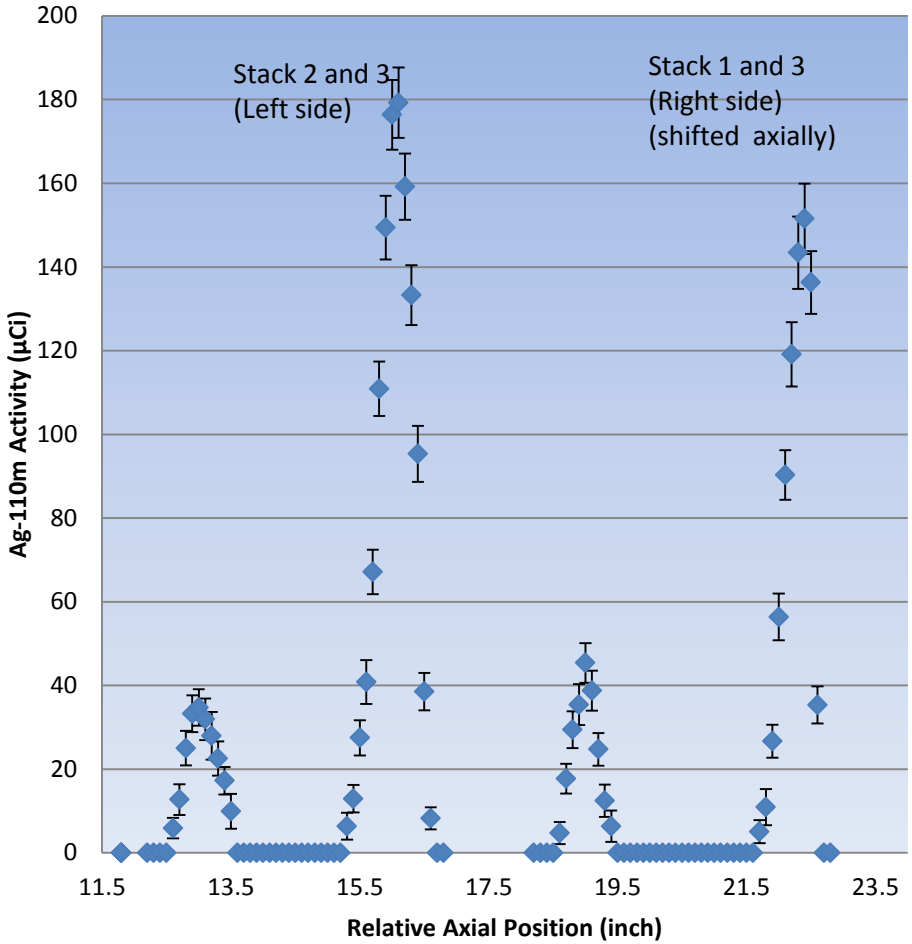


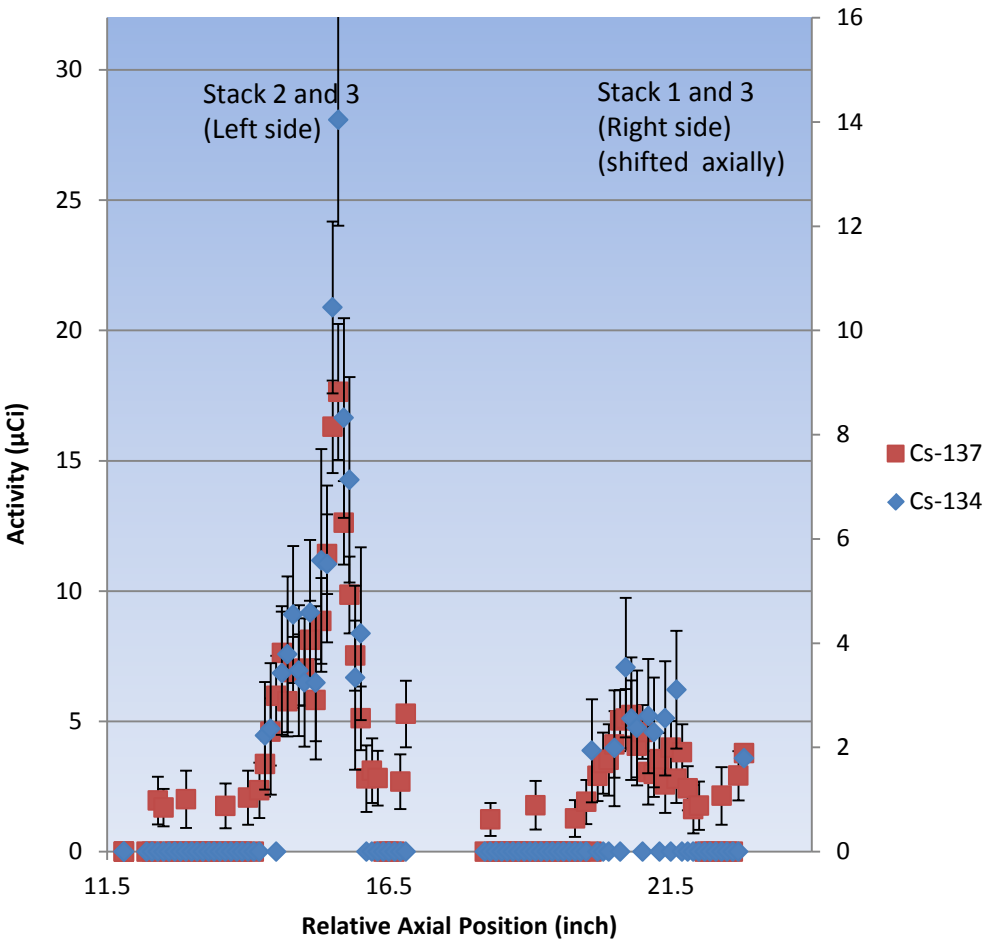
# Off-axis Scans Capsule 5



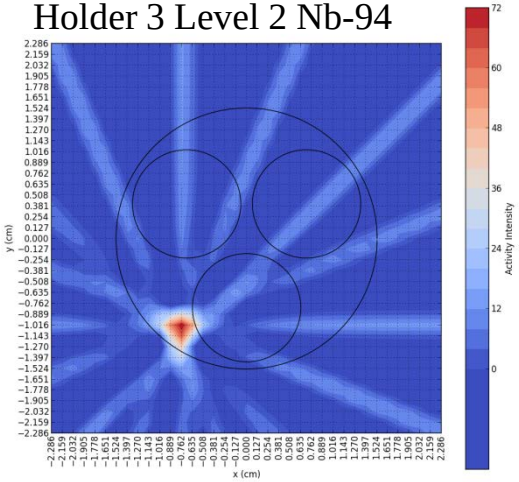
# Off-axis Scans Capsule 6



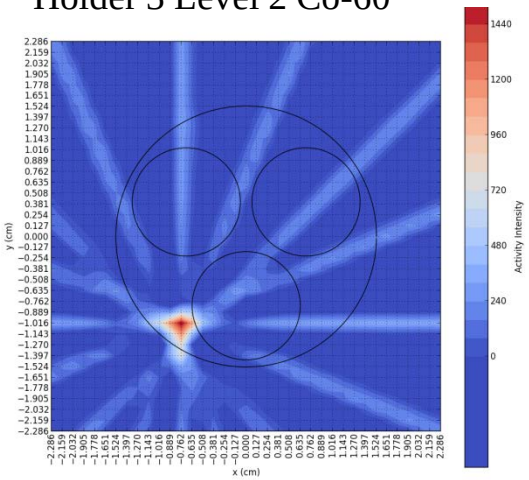



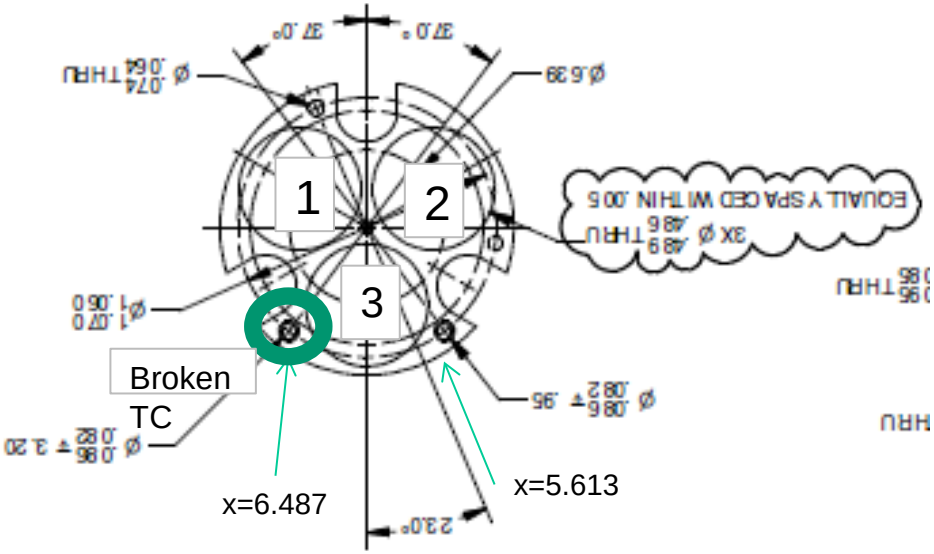
# Thermocouples and Gas Lines

Holder 3 Level 2 Nb-94

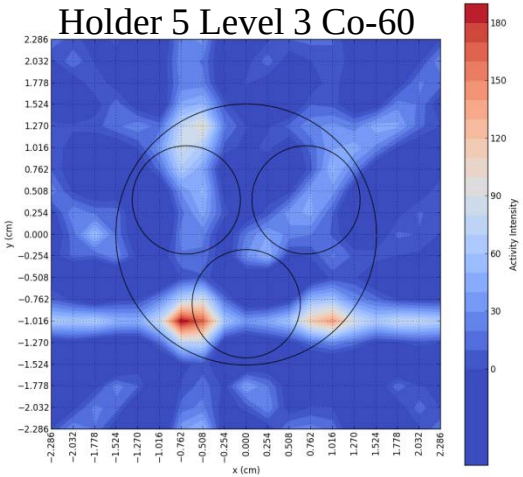



Holder 3 Level 2 Co-60



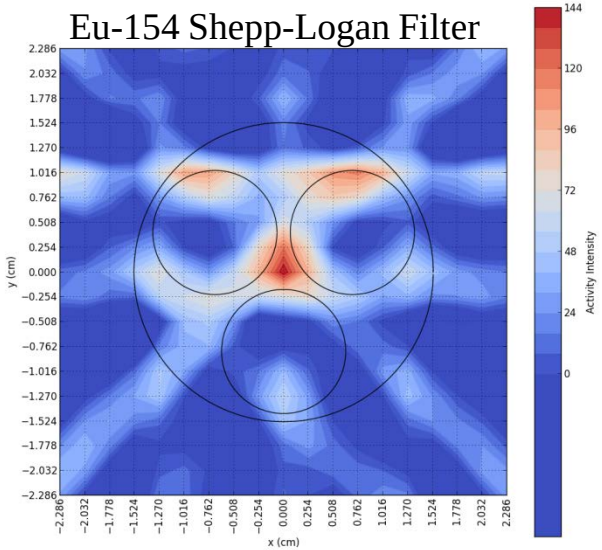



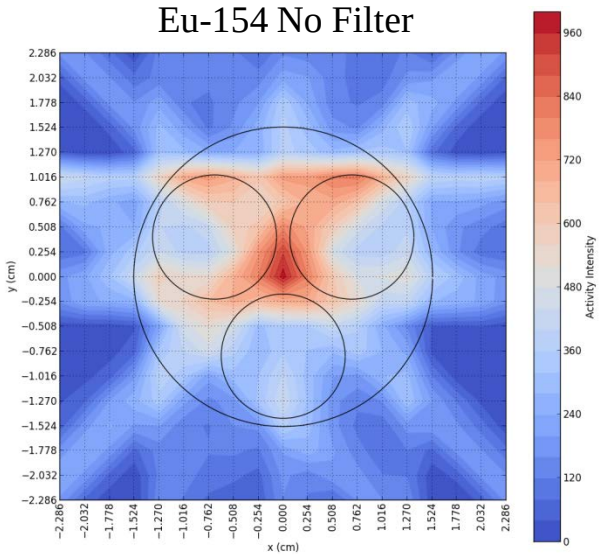

Holder 5 Level 3 Co-60



# AGR-2 GECT Results

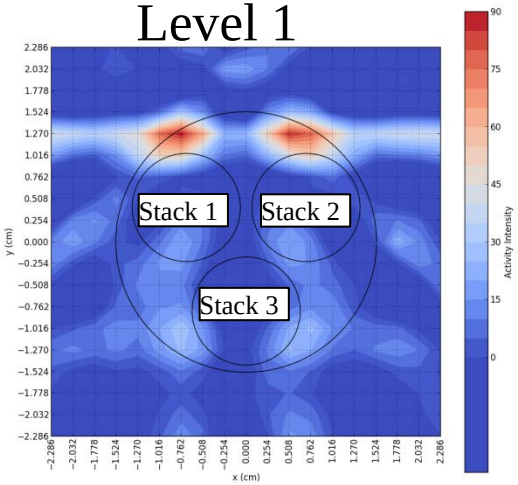
- A large amount of Eu-154 was released to the AGR-2 Capsule 2 holder ($3.7\times10^{-2}$ holder, $1.4\times10^{-2}$ Level 2)
- Tomography scans have been completed on Holders 2, 3, 5, and some work on Holder 6
- The Eu-154 distribution has been mapped at Level 1 and 2
- Cs-134 and Cs-137 was detected at Level 2 of the Capsule 2 holder and was mapped
- Ag-110m was located at the ends of the holder and was mapped after the Level 2



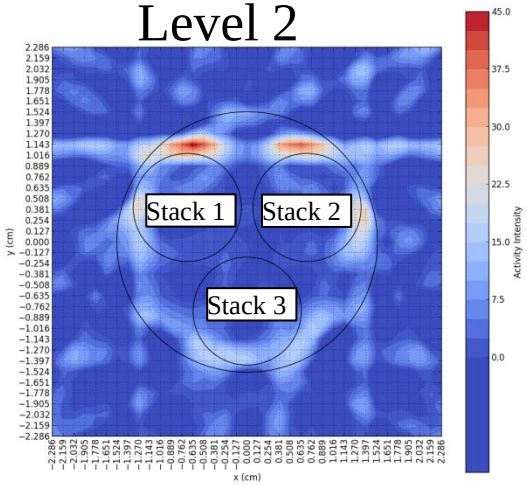
# Holder Gamma Tomography Ag-110m

Holder 2
Level 1



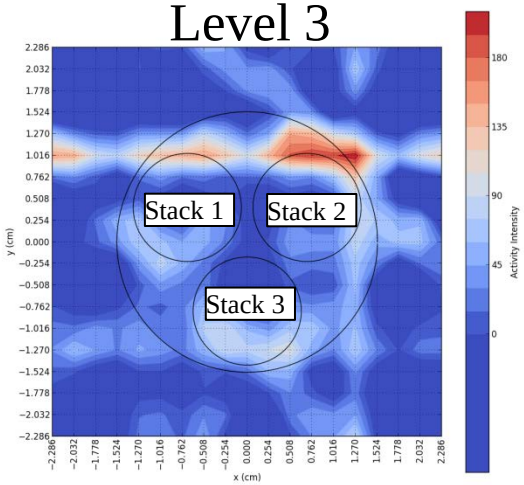

8 Angles
0.254 cm steps

Holder 3
Level 2




16 Angles
0.127 cm steps

Holder 5
Level 3

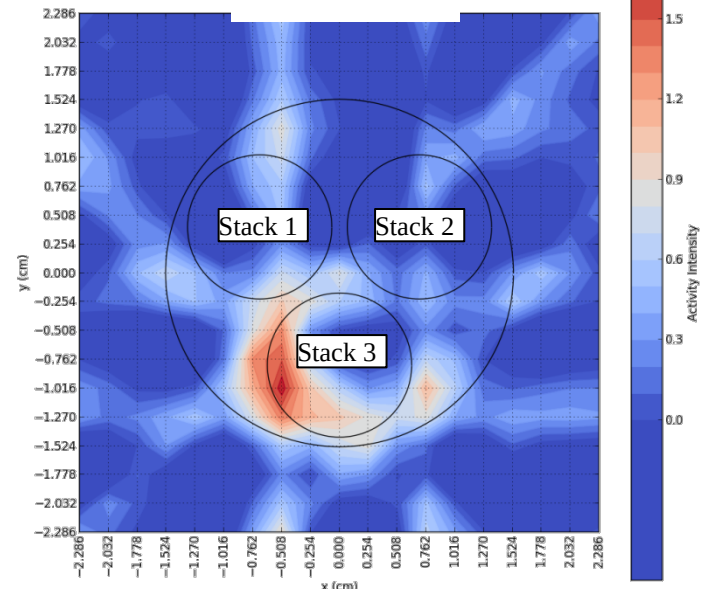



7 Angles
0.254 cm steps

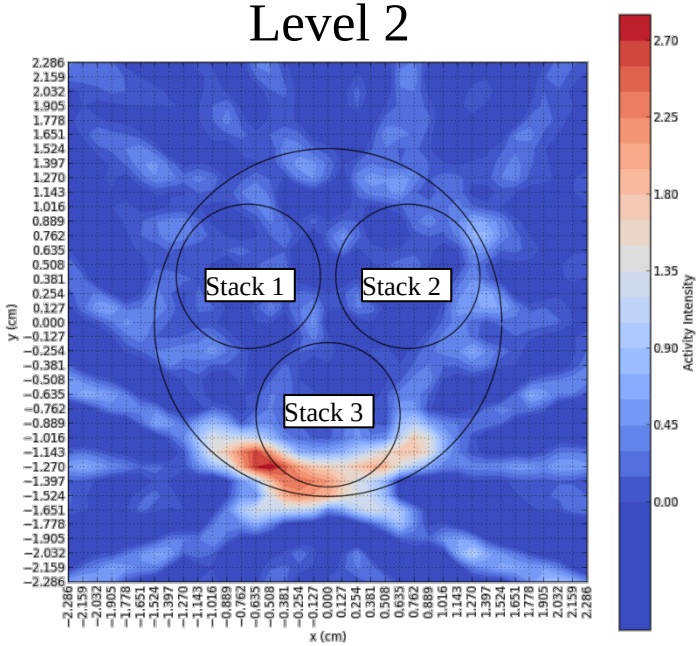
# Cs Hot Spots

- Likely Failed SiC Particles in Compacts 223, 523, and 533
- No Cs in Capsule 3
- Cs is present in Holder 6, but it has not been mapped in detail

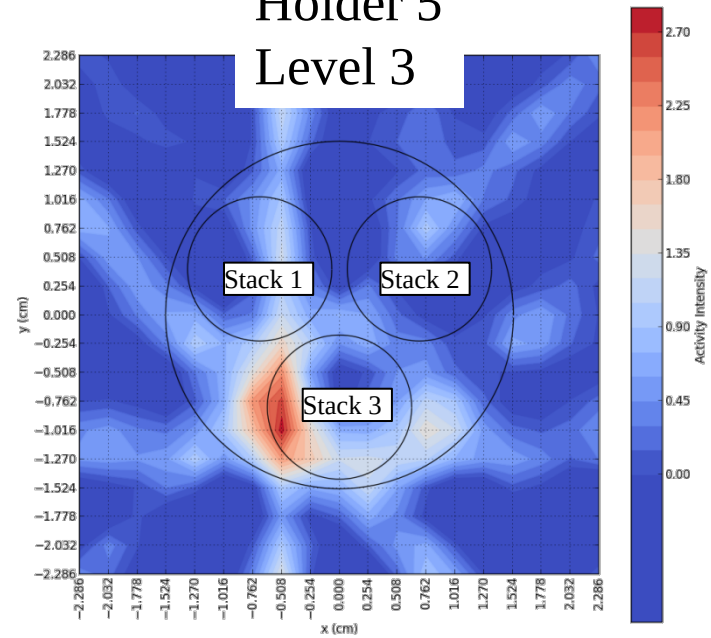
Holder 5
Level 2




Holder 2
Level 2

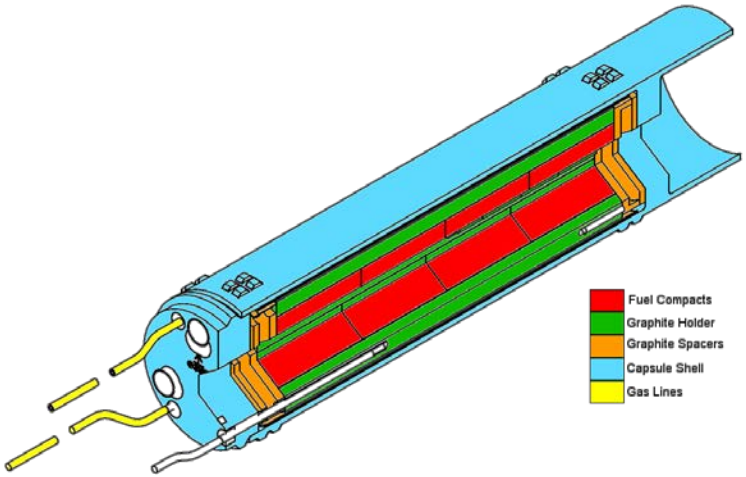



Holder 5
Level 3



# *Future Exams*

- Capsule 1 and 4 Compacts and Holders
  - Pending PGS conflicts with AGR-3/4 and other programs
- Capsule Shells at AL
  - Completed
- Graphite Spacers at AL
  - In progress
- Additional Capsule 1 and 4 exams FY16




**AGR-2 Irradiation Capsule**

# Summary

- Burnup
  - Good agreement with predictions
- Ag-110m Retention
  - UCO Similar to AGR-1
    - temperature and burnup effect
  - $UO_2$ had lower releases
    - 10.4% of predicted in Holder 3
    - temperature and burnup effect
- Holder data Similar to AGR-1
- No evidence of massive failure
  - Only a few failed SiC per Capsule

# Questions?

**Jason Harp**

jason.harp@inl.gov

**Idaho National Laboratory**

(208) 533-7342