Advanced Gas Reactor Fuels Program Review

AGR-3/4 Graphite/Matrix Ring Analysis

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Outline

• AGR-3/4 Test Train Gamma Scan
• GECT Introduction
• Sample Problem and Application to Fission Product Distribution
AGR-2 Compact 522 Tomography Burnup

Compact

Compact 522 Burnup

137
AGR-3/4 Test Train Scans (Capsule 1 to 6)
AGR-3/4 Goals and Nomenclature

- Generate data for fission product transport models
  - Diffusion coefficient
  - Activation energy
  - Cs, Ag, Eu, Sr, others
- AGR-3/4 rings
  - Inner Ring (ID 0.491”, OD 0.961”, 0.235” thick)
  - Outer Ring (ID 0.966”, OD 1.574”, 0.304” thick)
  - Nominal dimensions
  - Graphite Sink
- Gamma Scanning of Rings for hotspots and total activity is planned
Gamma Emission Computed Tomography Background

• Gamma Emission Computed Tomography (GECT)
  – Gamma ray signals emitted from a distributed source
  – Collected by a well collimated detector
  – The source is progressively moved past the detector in a regular pattern
  – Rotated through several different angles
• The collected scans can then be used to reconstruct the original source distribution through the use of an inverse Radon transformation.
Inverse Radon Transformation

- The input of the inverse Radon transformation consists of a $n$ by $m$ matrix of line integrals
  - Simulation response or counts
  - Created by the $m$ evenly spaced, ordered measurements for each $n$ angles of collected information.
- The transformation creates a $n$ by $n$ Radon matrix that is representative of the intensity of emitted particles
GECT Applied to AGR-3/4

- The potential exists to analyze AGR-3/4 diffusion rings using GECT using the Precision Gamma Scanner (PGS)
- The results of GECT can be translated into radial fission product distributions as an alternative/complement to coring and lathing techniques
- Off axis vertical scans of the inner and outer rings would
  - Identify “heights of interest” for GECT similar to the technique used in AGR-1 holder scans
  - Quantify the total fission product inventory
- GECT scans would use several horizontal scans of an AGR-3/4 ring at different angles
- Examples of similar GECT application to fission product distribution exist in literature for LWR fuel and TRISO experiments (HFR-B1)
MCNP Simulation of GECT on PGS

• A representative MCNP model was created of the PGS collimator and detector system to represent gamma rays emitted from both inner and outer rings from AGR-3/4.
• The rings and gamma sources were sequentially moved a set distance each step past the collimator opening in the simulations as illustrated in the sketch.
• The simulated system response for each step was recorded and compiled as input for the inverse Radon transformation.
• Two different source distributions were simulated:
  – A source with a constant radial distribution
  – A source that decayed logarithmically over 2 orders of magnitude radially
  – These distributions are based on the predictions in the AGR-3/4 Irradiation Test Plan
  – Depending on the temperature conditions of the capsule, the test plan predicts a fission product distribution varying from constant to dropping two orders of magnitude across the inner ring.
**MCNP Simulation of GECT on**

- Step size 0.635 mm, Collimator size 2.54 mm
- 8 angles
- Rounded edges
- Ghosting from Fourier Analysis
  - Low number of angles
  - Filtering
- The fidelity of the scans improves with
  - Smaller step sizes
  - Additional angles
  - Smaller collimator
  - Optimize for time and resolution
Azimuth Integration of GECT Image

![Graphs showing azimuth integration of GECT Image with Activity Intensity vs. Radius (cm) plots.](image)
Relating Derived Distributions to a Physics Model

- Assuming some sort of physics that can be related to a distribution in the rings

\[ A(r) = A_0 e^{-Qr} \]

- An exponential factor \( (Q) \) can be recovered from the integrated distribution
  - Fit is 4.4% different than original input
- Exponential Factor goal is a factor of 2
- Pre-exponential \( (A_0) \) goal is a factor of 10
  - Normalize image to total measured activity
Expected Activity and GECT Feasibility

- PGS limits of detection
  - 1 μCi Cs-137, Cs-134
  - 1 μCi Ag-110m
- Expected Activity in Inner Ring
  - 1 to 387 μCi per slice Cs-137
  - 0.02 to 10 μCi per slice Ag-110m
  - Range based on coldest and hottest capsules
- Cs-137 Should be detectable by GECT
- Ag-110m may be difficult to detect
  - Release from intact TRISO should make Ag-110m detectable
- The Outer Ring is more challenging
  - 0.03 to 3 μCi per slice Cs-137, 4E-4 to .4 μCi per slice Ag-110m
  - Lower temperature capsules (1, 3, 12) doubtfully detectable
  - The 5 capsules run at 1100°C and one run 1300°C should have adequate activity concentrations for mapping.
  - The 3 capsules run at 1000°C will most likely be borderline acceptable for GECT application.

- Timing
  - Approximately 7 days for Inner Ring (0.025” steps, 42 scans per angle, 8 angles, 30 min scan)
  - Only scan select levels identified by axial scanning
  - Outer Ring Scans – approximately 11 days (same parameters)
  - Software Upgrades should speed process
Physical Ring Sampling

- Physical Ring Sampling is still necessary
  - Sr-90 emits no gammas
  - Some radial sampling and dissolution is still needed for Sr-90 measurement
  - Very little is predicted beyond the compacts
- Eu-154 mapping may provide insight to Sr-90 diffusion
  - No current predictions on Eu diffusion
- Benchmark of GECT
- Test coring of unirradiated graphite and matrix material worked well.
  - Each core can then be sectioned and analyzed
AGR-3/4 Fission Product Distribution Status

• The designs and fabrication of the AGR-3/4 PGS fixtures and physical ring samplers are complete
• Sources for AGR-3/4 fixtures are in HFEF
• Cores have been drilled from surrogate AGR-3/4 rings
  – Appropriate drill bits identified
  – Machining parameters established
  – Sectioning of cores still needs to be resolved
Lathing as an Alternative to Coring

- Ideally 10 quantitative measurements would be taken across the thickness of a ring (Cs, Ag, Sr)
- Concentrations are likely too small for coring to be successful in many capsules while still meeting the desired measurement resolution
- Lathing and collecting of the machine fines is another approach
- Cyclone separators have very high collection efficiencies (>99%) for graphite machined fines (10 to 300 µm particle size)
- ~100 nCi per sample is required
  - Lathing the central region of a ring (center 25 mm)
  - Hot rings look promising
  - Cold rings look challenging
Summary

- GECT has the potential to map fission product distributions in the AGR-3/4 diffusion rings
- A similar technique directly benefited AGR-1 and AGR-2 by finding a compact with TRISO leaking Cs
- Monte Carlo Simulations have been performed to evaluate the feasibility of applying GECT to PGS and AGR-3/4
- The simulations produce radial distributions and some quantifiable data for diffusion
- There should be adequate Cs-137 and Ag-110m to apply GECT to most AGR-3/4 capsules
- Physical Ring Sampling is necessary to evaluate Sr-90 and will help benchmark GECT measurements
- The first rings are now out of the capsules and available
  - AGR-3/4 gamma scanning should begin in August