AN INVESTIGATION OF PROMPT GAMMA ACTIVATION ANALYSIS AND COMPTON IMAGING

Ben Riley
Mentor: Heather Chen-Mayer
Overview

- Prompt Gamma Activation Analysis
  - What is Prompt Gamma Activation?
  - Composition Analysis
  - 3D Filament Composition

- Compton Imaging
  - Compton Scattering and Compton Camera
  - Geant4 Simulation
  - Image Reconstruction
Prompt Gamma Activation

- Incident neutrons: pass through, scatter, or capture
- Capture events excite elemental nucleus
- Characteristic gammas emitted at de-excitation.
- Emission spectra characterize sample
Motivation

- PGAA and Compton Imaging
  - Bulk Composition Analysis
  - Non-destructive technique
  - Potential to detect impurities and corrosion: need spatial resolution
PGAA Beam Line

- Located on NG-D
- Polychromatic beam: average at 6 Å; Flux: 5E9 n/cm²-s

Credit: Danyal Turkoglu
Prompt Gamma Activation Analysis

- Compare spectral intensities
- Calculate mass ratios

\[
\frac{m_H}{m_X} = \frac{A_H/\varepsilon_H \sigma_{\gamma,H}/M_X}{A_X/\varepsilon_X \sigma_{\gamma,X}/M_X}
\]

- \(A_X\) is the net peak area, \(\varepsilon_X\) is the detector efficiency at the peak energy, \(\sigma_{\gamma,X}\) is the gamma production cross section, and \(M_X\) is the atomic mass.
3D Printing Filament Analysis

- Three common filaments were examined: PLA, ABS, and Nylon

- Four disks for each plastic:
  - 2cm diameter
  - 0.5mm-2mm thickness in 0.5mm increments
Filament Properties

- PLA
  - Bioplastic: $C_3H_4O_2$
- Nylon
  - Overall class of polymers with different stoichiometry
- ABS (Acrylonitrile Butadiene Styrene)
  - Three part composition: $(C_8H_8)_x(C_4H_6)_y(C_3H_3N)_z$
Comparison

- Prompt gamma yield: Depth Dependent; Atom ratio: constant
- Linear behavior with increased thickness: No self-shielding effects
- Slope: Stoichiometric ratios
- ABS: x:y:z => 2:2:3
- Nylon: Blended Filament; primarily nylon 6,6

Atom Ratios of Various Materials Determined From PGAA
PGAA and Compton Imaging

■ Current PGAA
  - *Bulk analysis only*
  - *Limited spatial resolution*

■ Proposed For PGAA
  - *Use Prompt Gammas to image sample*
  - *Utilize Compton imaging techniques*
  - *Give spatial resolution*
Compton Scattering

- Intermediate-High Energy Regime
- Photon scatters off electron
- Angle determined by

\[
\frac{1}{E'} - \frac{1}{E} = \frac{1 - \cos(\theta)}{m_e c^2}
\]
Compton Camera

- Multistage pixelated detector
  - Scatters in first stage
  - Absorbed in second stage
  - Pixilation gives positional data
- Generates Compton cones
  - Energy deposited gives angle
    \[
    \frac{1}{E'} - \frac{1}{E} = \frac{1 - \cos(\theta)}{m_e c^2}
    \]
  - Positional data gives placement and orientation
- Volumetric reconstruction from single scan
Simulation

- Geant4: Monte-Carlo simulation for radiation transport
- Models 5 meV neutron beam interacting with sample
- Detectors output spectra and Compton events

Nylon Spectra

![Graph showing simulated and real nylon spectra with energy on the x-axis and counts on the y-axis.](image)
### Geant4 Information

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<th>Step#</th>
<th>X(mm)</th>
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<th>Z(mm)</th>
<th>KinE(MeV)</th>
<th>dE(MeV)</th>
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List of 2ndaries - #SpawnInStep= 2 (Rest= 0, Along= 0, Post= 2), #SpawnTotal= 2

- 16.1 -8.22 -19.5 2.22 gamma
- 16.1 -8.22 -19.5 0.00132 deuteron

EndOf2ndaries Info

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* G4Track Information: Particle = deuteron, Track ID = 3, Parent ID = 1

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* G4Track Information: Particle = gamma, Track ID = 2, Parent ID = 1

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List of 2ndaries - #SpawnInStep= 1 (Rest= 0, Along= 0, Post= 1), #SpawnTotal= 1

- 71.8 26.6 53 0.353 e-

EndOf2ndaries Info
Event Tracking

- Geant4: Tracks particle events sequentially
- Events track parent and daughter particles
- Simulate ~1E10 Events, 3 hrs
- High event counts allow for image reconstruction
Back Projection Reconstruction

- Cones projected onto plane through sample
- Conic sections plotted
- Heat map generated
Statistical Reconstruction

- Alternative Reconstruction Method
- UMD School Of Medicine
- Computationally Faster
  - 4 min vs 3 hrs
- Smoother

Credit: Jerimy Polf
Simulation

- Material Filtering: Water vs Titanium
- Spatial Resolution and Composition

Disks: 0.5 mm depth
2.0 cm radius
Statistical Reconstruction

H

Ti

\[ y = 0.0 \text{ mm} \]

\[ z \text{ [mm]} \]

\[ x \text{ [mm]} \]

Gamma Emission

\[ z \text{ [mm]} \]

Gamma Emission

\[ z \text{ [mm]} \]
Conclusion

- **PGAA**
  - Nondestructive
  - Accurately determine chemical composition
- **Compton Imaging**
  - Spatial Resolve Prompt Gamma emission
  - Distinguish based on element
- **Together**
  - Complimentary techniques
  - Composition and position
Special Thanks

- Heather Chen-Mayer, Mentor
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- Jeremy Polf and Haijian Chen, UMD Proton Therapy Center
- SURF Directors