Russell Goff REU work with Dr. Koltick on Neutron Induced Gamma Ray Spectroscopy for Elemental Analysis
Associated Particle Imaging

- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively
Power of Elemental Analysis

Fraction of Counts Detected

- CW Simulants
  - Tap Water
  - Bleach
  - Shampoo
  - Vitamins

- Food Items

Elements:
- H
- O
- Na
- Si
- Cl
Associated Particle Imaging

- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively
Neutron generator

- Mf Physics- A-920
DT Fusion Reaction

100keV D in
14.1 MeV neutron & 3.5 MeV alpha out
Neutron Generator Specs.

- D + T → α + n
- 14.5 MeV neutrons at around $1 \times 10^8 \text{ neutrons second}^{-1}$
- Operator exposed to roughly $0.2 \text{ mRem hour}^{-1}$ (compared to $0.1 \text{ Rem year}^{-1}$ NRC general population exposure limit)
Penning Trap

[Diagram of a Penning Trap with labeled parts: Cathode Plate, Cylindrical Anode, Trapped Electron Cloud, and an illustration of electric and magnetic fields.]
Associated Particle Imaging (API)

- Creates 3-D image of object non-invasively
Scintillation Screen

Energies:

\[ ^{7}\text{Li} \quad 30-70 \text{ keV} \]
\[ \alpha \quad 3.5 \text{ MeV} \]
\[ n \quad 14.1 \text{ MeV} \]
- $\alpha$ particle & neutron from D-T Fusion travel opposite directions
- Time of flight recorded & used to create image. Estimated by time difference between $\gamma$ detection and start of $\alpha$ particle logic gate. [Neutron=5cm/ns $\gamma$=30cm/ns].
Coupling PMT to A-920
$\alpha$-Detector

Beam Spot

Sample

Interrogation Region at 1 meter
~10 inches cube

Neutron Generator
Deuterium/Tritium Source

Target

14.1 MeV neutron

Sealed Tube

Accelerator

ZnO(Ga) Coating w/ Ni overcoat

Imaging PMT Module

3.5 MeV Alpha
Inelastic Scattering

- Lifetime of excited state is in range of picoseconds
- Incoming neutron must exceed unique threshold
Thermal Capture

- De-excitation occurs in picoseconds
- Cross section increases with decreasing energy
**Inducing Gamma Rays**

- **Activation**
  - Not as useful since due to seconds long half lives there can be no alpha gating for imaging.
Associated Particle Imaging

- Associated Particle Neutron Elemental Imaging (API)
  - Creates 3-D image of object non-invasively
Different Gamma ray energies are uniquely associated with different isotopes.
Need for Good Energy Resolution

- Energy Resolution: FWHM over the mean pulse height of the photopeak
- 10% compared to 0.1%
HPGe Detectors

- Benefit of great energy resolution
  - 1.07keV resolution with 1.173MeV source
- However...
  - High Maintenance
  - Lower counting efficiency
  - Fragile
  - Operate around 100°K
  - Expensive
Detector cooling & vacuum systems

- Alternative to liquid nitrogen
- Kept at vacuum

Citation 4
Must be pumped out and annealed occasionally to “erase” neutron damage and renew vacuum
- Annealing helps vacancies and interstitials, created from neutron damage, recombine
Putting the Pieces Together

- Used $\alpha$ particle and beam spot of neutron generator to tell where gamma was born
  - Used gamma ray to deduce what element was at that position
Counting system with Logic pulse
40mV Discriminator Setting Data

PMT on A-920 7-29-2011

Counts per 100 seconds

Beam Current (mA)
Coincidence
Why didn’t that work?
Where did that piece go?
This is too expensive to be broken
Creating documentation on
- Neutron generators
- HPGe detectors & associated equipment
- Data processing tools
- Maintenance Procedures
Bibliography

1) Simpson, American Institute of Physics “Compact accelerator neutron generators” (2002)
2) Thermo-Scientific.com (06/28/11)
3) Kane, “Detection of special nuclear materials using prompt gamma-rays from fast and slow neutron induced fission” (2010)
4) ORTEC X-Cooler II Owners manual
3 Main Gamma-Ray Interactions

- Photo-Electric Effect (PE)
- Compton Scattering (CS)
- Pair Production (PP)
- A gamma-ray may take multiple interactions to deposit its full energy in a detector.
- Photon is traveling speed of light through small distance.
- Output response from detector will be same for multiple interactions as it would have been had the photon deposited all its energy in a single interaction due.
Causes of different peaks

- Escape of x-ray from PE- A few keV
- Annihilation Radiation-Positron and an electron annihilate and send two 511keV photons in opposite directions. This Results in no shift, a single escape peak, or a double escape peak
- Backscatter peak- Compton scattering in surrounding materials before reaching detector. Creates peak around 200keV.
More examples

- Pair production in surrounding material: Creates 511keV peak
- $^{40}K$ in background: Causes 1460keV peak
- Sum peak from pile-up: Two peaks at close enough time that detector system combines them into peak equal to sum of their energies
Likelihood of each Interaction

- Photo Electric Effect Dominant
- Pair Production Dominant
- Compton Scattering Dominant

hv in MeV
Shifts in energy peaks

- Occur when energy carrier escapes from detector
Exploring feasibility of API in medical Diagnostics

- Currently in very infant stages of process
- Would require PPM precision
- Cross sections may be too small for prompt gamma’s in elements of interest
- Dose to patient must be kept relatively low
  - Currently PET & CT scans give 1-2 REM dose
Potential Future Uses

- Hypoxia-Deficiency of Oxygen in tissue
- Promotes growth of tumors
- Promotes malignancy
- Greater resistance to treatment
Current Diagnosis Procedure

- Biopsies which spread tumors
- Invasive $O_2$ needle electrode’s
  - $pO_2 = 40\text{mmHg}$ normal cell
  - $pO_2 < 10\text{mmHg}$ generally hypoxic
- Oxygen reduced pharmaceuticals
- Anesthetization & other factors throw results