Photon Transport and Photonuclear Reactions

Nuclear Security and Nonproliferation Nondestructive Assay Application Ideas
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Photon Reaction Phenomena (that I've thought about)

In order of increasing *maturity*

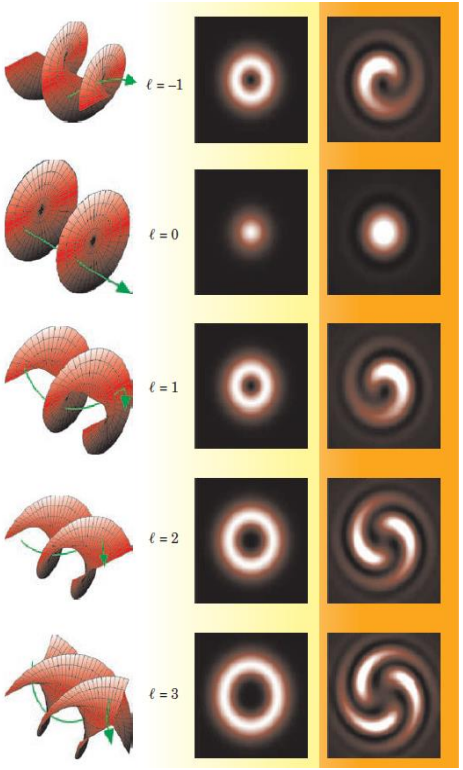
- OAM nuclear interactions
- Nuclear Resonance Fluorescence
- Elastic/coherent photon scatter

Application

- Non-destructive assay
  - Cargo scanning
  - Object characterization
  - Material accountancy
  - New signatures?

Nuclear Physics with OAM photons?

- Photons with orbital angular momentum (OAM) have been created using photon optics
- These photons have been observed to interact with atoms differently than L=0 photons
- Could laser-Compton scattering produce *twisted* γ-rays*?*
  - If so, how would they interact with nuclei?



Padgett et al., Physics Today 57, 5, 35 (2004), DOI: 10.1063/1.1768672

Nuclear Resonance Fluorescence

- *Unique* isotope-specific signatures for non-destructive assay
  - Attractive because inducing γ-radiation is *highly* penetrating (~20 g/cm^2 mean free path)
  - Challenge is cross sections are typically small when compared to measurement system resolution
    - 'Witness foil' concept
    - Better photon sources?
- Can be used for transmission and back-scatter assays
  - Manipulation of witness foil temperature / chemistry *should* expose different signatures. (No data to support this)

Nuclear Resonance Fluorescence – data needs

- Abilities to simulate NRF are:
  - Still rudimentary:
    - Graduate students developed GEANT NRF package and hacked ENDF/ACE formats to insert phenomenon into MCNPX/6
  - Based foremost on theoretical extrapolation of limited measurements:
    - Angular correlations/distributions, Voigt profiles, Debye temperature effects, bremsstrahlung interpolation between 2 and 50 MeV endpoint energies
    - Unresolved resonances, e.g., missing ‘scissor-mode’ strength not included but could affect integral measurements
- Can nuclear photon sources be used to stimulate NRF?
  - Beyond Mossbauer effect... are there chance overlaps from other photon transitions and how strong are they?

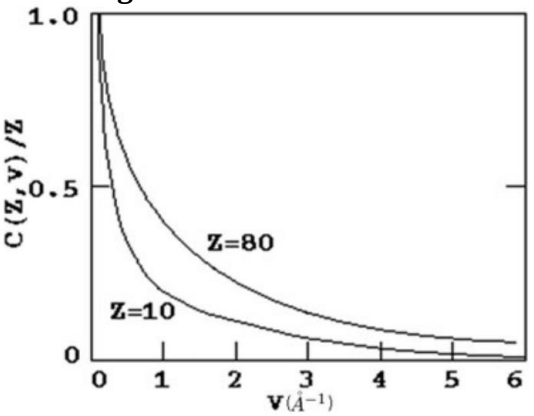
Elastic Photon Scattering

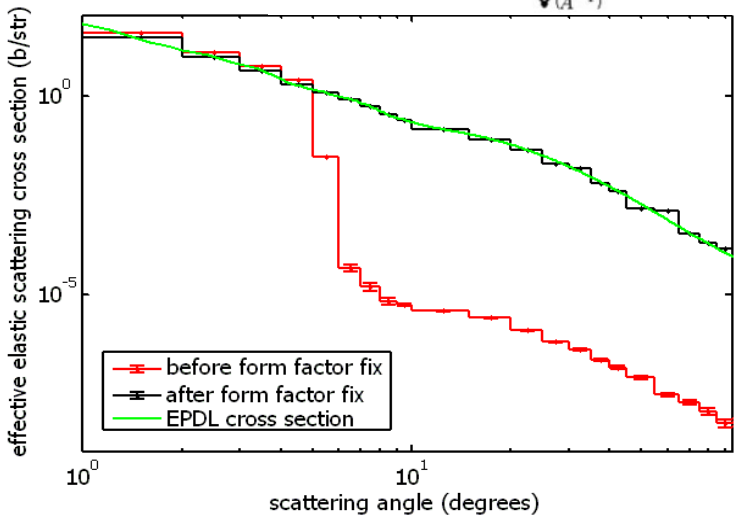
- MCNP versions prior to MCNPX v2.7.0 had hardcoded non-physical truncation of photon scattering form factors
  - Most MCNP photo-atomic libraries have propagated this legacy truncation
- Discovered by XRF Pb studies

$$\sigma_{Ray}(\theta) = \sigma_{Th}(\theta)\,[F(q,Z)]^2$$

$$\sigma_{Th}(\theta) = \frac{r_e^2}{2}(1+\cos^2\theta) = \frac{r_e^2}{2}(1+\mu^2)$$

Image from MCNP4C manual



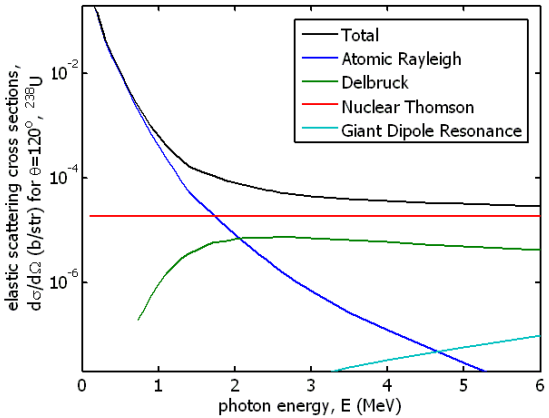


MCNPX simulations of photons incident upon U

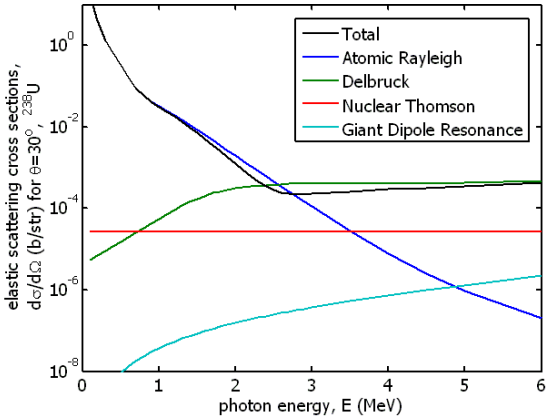
John S. Hendricks & Brian J. Quiter (2011) MCNP/X Form Factor Upgrade for Improved Photon Transport, Nuclear Technology, 175:1, 150-161, DOI: 10.13182/NT10-17
LA-UR-11-02295

Elastic Photon Scattering

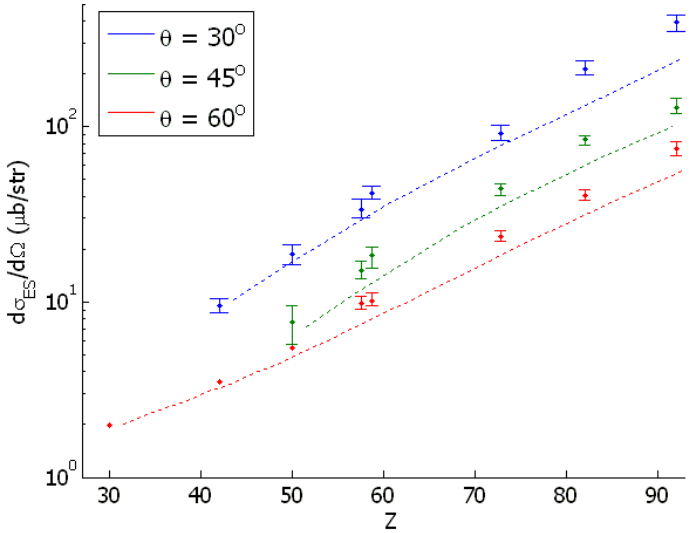
- ENDF supports form factors exclusively
- EPDL97 – LLNL compilation of coherent scatter amplitudes.



EPDL cross section Photons on ^{238}U@120°



EPDL cross section Photons on ^{238}U@30°



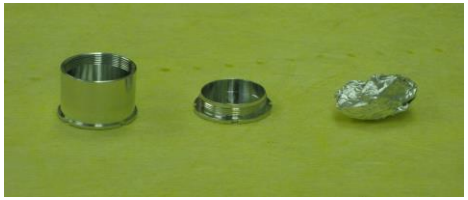
Scatter cross sections for 2.754-MeV photons. Data from B. Kasten, et al. Phys. Rev. C 33, (1986) pp. 1606. with EPDL97 theory

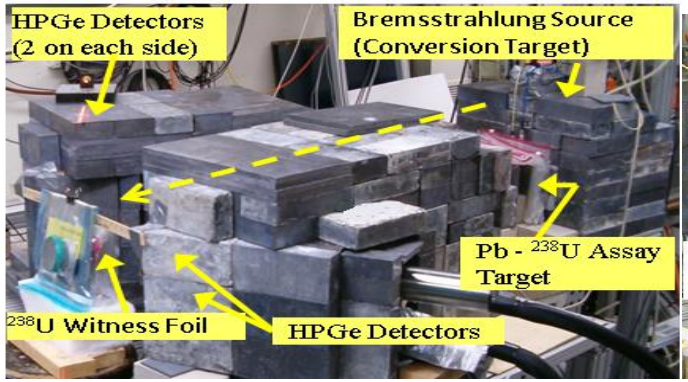
Conclusions

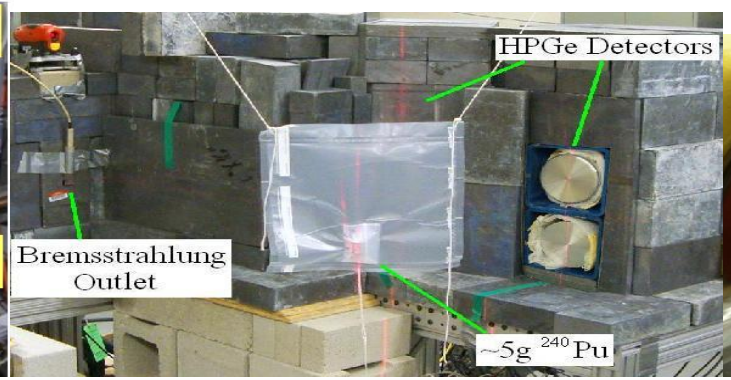
- New generations of photon sources are becoming available.
  - Source development continues with an eye to deployable systems
  - Ultra-fast photon pulses could create novel signatures, but detector systems to observe them remain a challenge
- Phenomena such as NRF that were seen as too impractical may become practical
  - Data and evaluation are still rudimentary
- Improved sensitivity will make the precision/accuracy of *old unglamorous* phenomena relevant again

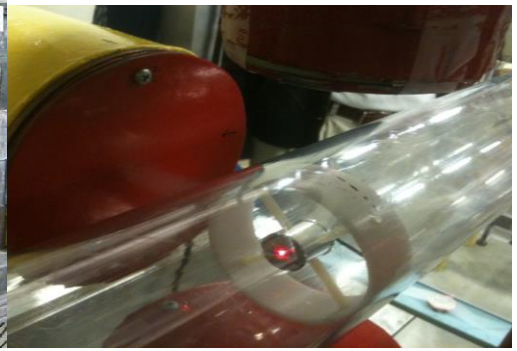
Thank you!!!
Questions/comments?

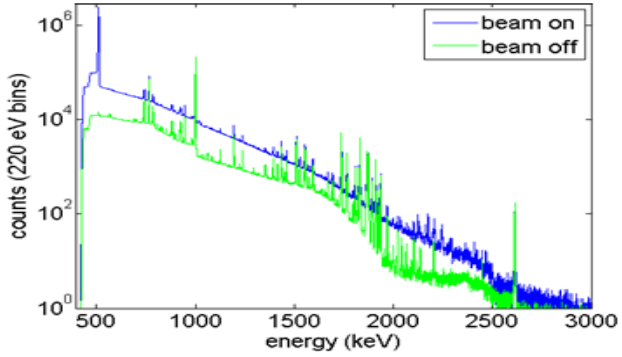
6g of $^{240}PuO_2$



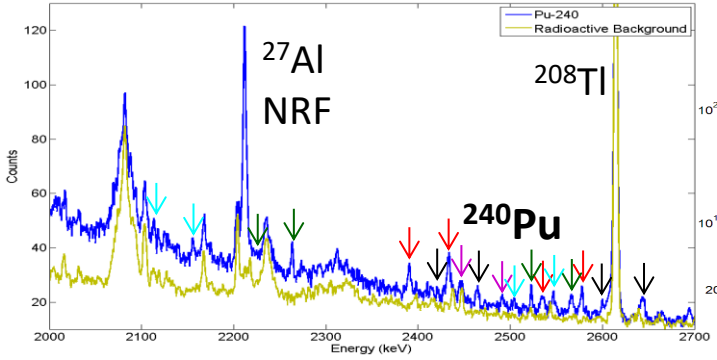




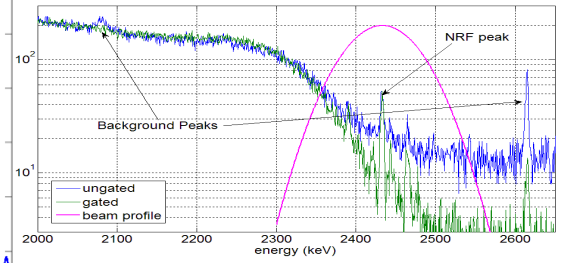




First Actinide transmission NRF measurement



First measurement of ^{240}Pu NRF



^{240}Pu @ HIγS