Title: MCNP5 Simulation of NaI Detector Response Functions

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Intended for: MCNP reference
MCNP5 simulation of NaI detector response functions

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Overview

- Introduction
  - Uses of detector response functions (DRFs)
  - Deficiencies in Monte Carlo simulation of DRF’s
- Non-linear energy deposition
- Simulation of flat continuum
- MCNP Simulation of NaI DRF
  - Experimental benchmarks
  - MCNP calculations
- Summary
Introduction

DRF’s are used with Monte Carlo simulation to predict incident photon pulse-height spectra. Translates photons incident on detector surface to a pulse-height spectrum.

- Allows advanced VR to transport photons to detector surface – VERY EFFICIENT!
- Produces very accurate gamma-ray spectra
Deficiencies between Calculated and Measured Spectra (Gaussian Broadening)

Comparison of Calculated and Experimental $\gamma$-Spectra for NaI3x3: Cs–137

Energy (MeV) vs. Normalized Yield

Heath Original vs. MCNP
Summary of Deficiencies between Calculated and Measured Spectra

GAUSSIAN ENERGY BROADENING

- Spectrum broadening is attributed to scintillation process, detector nonlinearity, electronics, etc, and is characteristic to each detector system.

- Thus every detector’s resolution must be characterized using well-known sources.

- Spectrum broadening is NOT part of normal particle transport calculation, but can be included as part of the detector simulation.
Deficiencies between Calculated and Measured Spectra (Flat Continuua)

Comparison of Calculated and Experimental γ-Spectra for NaI3x3: Cs–137

- Heath Experimental
- MCNP
- MCNP + GEB

Energy (MeV)

Normalized Yield

10^0
10^-1
10^-2
10^-3
10^-4

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
Summary of Deficiencies between Calculated and Measured Spectra

**FLAT CONTINUA**

- MC simulation previously shown that shape is due to electron leakage before full energy deposition
- Intensity predicted is much smaller than experimentally observed
- Possibly due to crystal imperfections or electron trapping mechanisms
- Effects of processes cannot be determined *a priori*
Deficiencies between Calculated and Measured Spectra (Non-linear Energy Dep.)
MCNP: Non-linear Energy Deposition
Non-linear energy deposition

- Previously noticed by many researchers
- Non-linear energy deposition occurs at energies below 3 MeV
- Asymptotically approaches constant at higher electron energies
- Characterized by *scintillation efficiency*:

\[
S(E_e) = 1 + k_1 \exp \left[ -\left( \ln E_e - k_2 \right)^2 / k_3 \right] \quad E_e \geq 10 \text{ keV}
\]

\[
S(E_e) = 1 + k_1 \exp \left[ -\left( \ln E_e - k_2 \right)^2 / k_4 \right] \quad E_e \leq 10 \text{ keV}
\]

Experiment vs. Model Data for NaI Nonlinearity with Electron Energy
MCNP Simulation of NaI DRFs

- MCNP modified to account for:
  - Non-linear energy deposition: multiplying electron energy by $S(E)$ just before pulse-height tally is collected
  - Flat continuum: increasing electron leakage artificially by decreasing NaI density when electrons produced

- Use of MCNP allows:
  - General geometry capabilities
  - Accurate photon, electron transport
Experimental Comparisons

- Benchmark quality experiments performed by Russ Heath (1964)
- NaI 3x3 $\gamma$-spectra taken with single energy isotopes under standard laboratory conditions
- Detector shield designed to minimize impact from surrounding environment
Non-linear Gaussian Spread
Gaussian Energy Broadening
Flat Continuum: Decreased density for electron transport

![Graph showing energy distribution for different densities](image)
Flat Continuum: Decreased density for electron transport
Flat Continuum: Decreased density for electron transport
Summary of Work Presented

- Approach seems to work
- Need high energy $\gamma$ spectra for further testing
- Characterize other detector sizes and types (eg. BGO)