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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

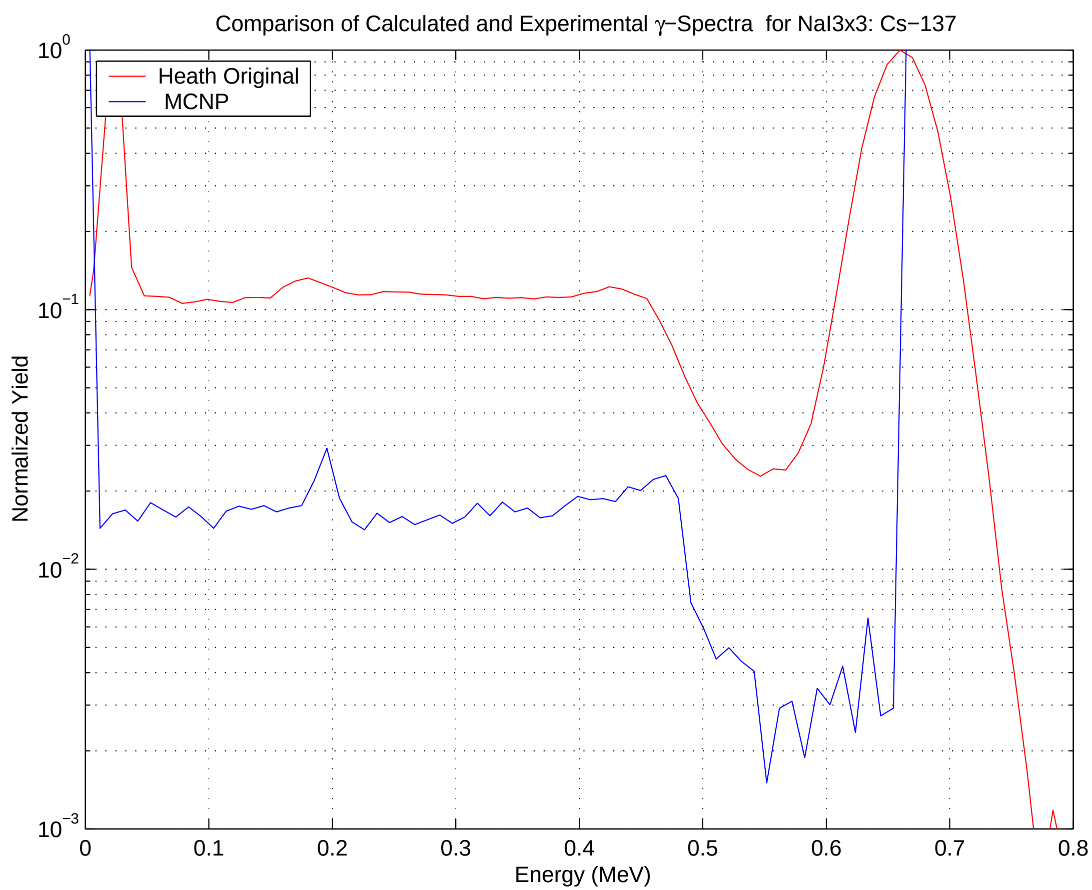
Introduction

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)

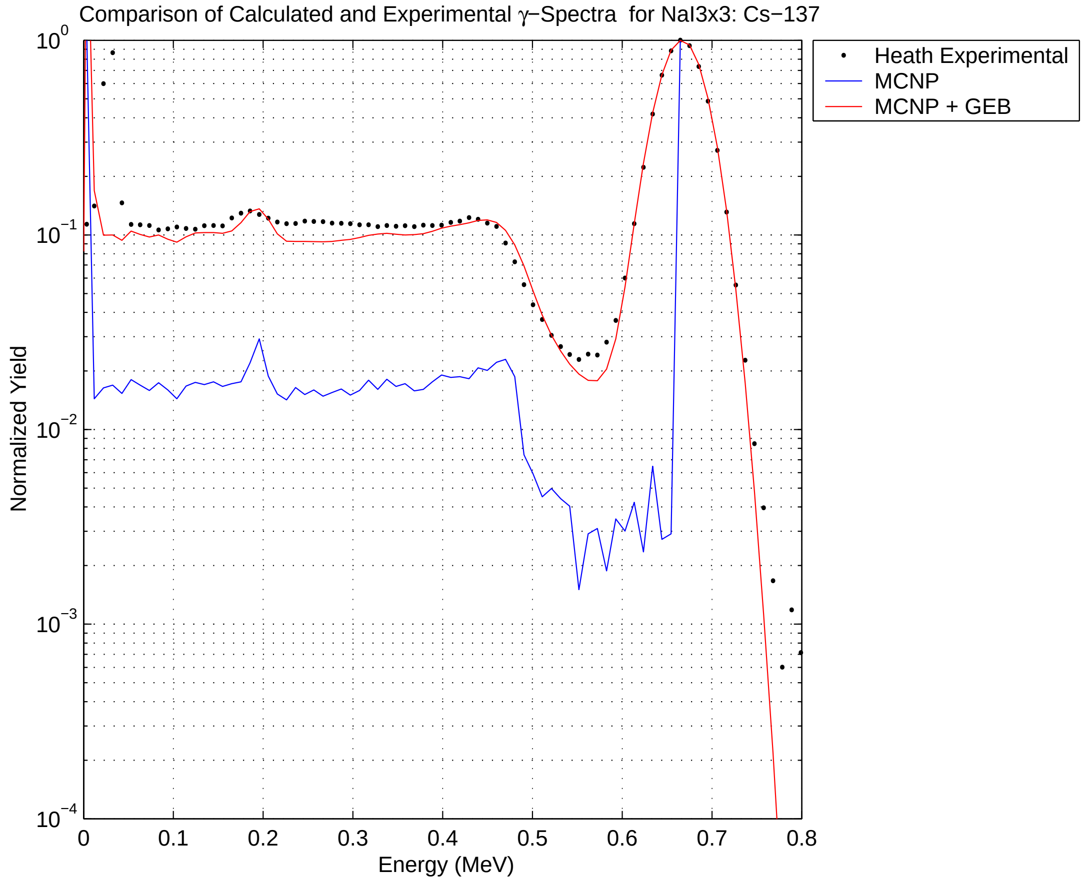


Summary of Deficiencies between Calculated and Measured Spectra

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)

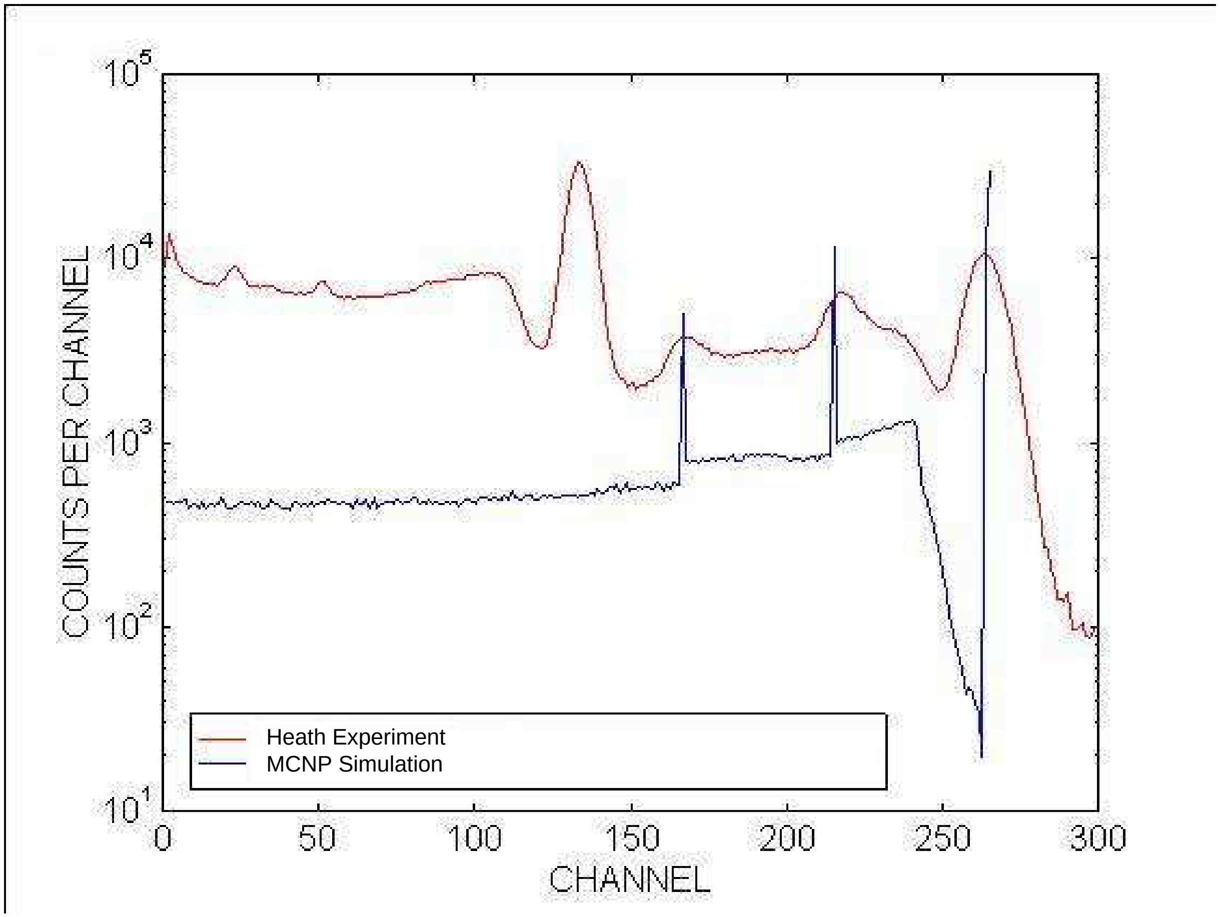


Summary of Deficiencies between Calculated and Measured Spectra

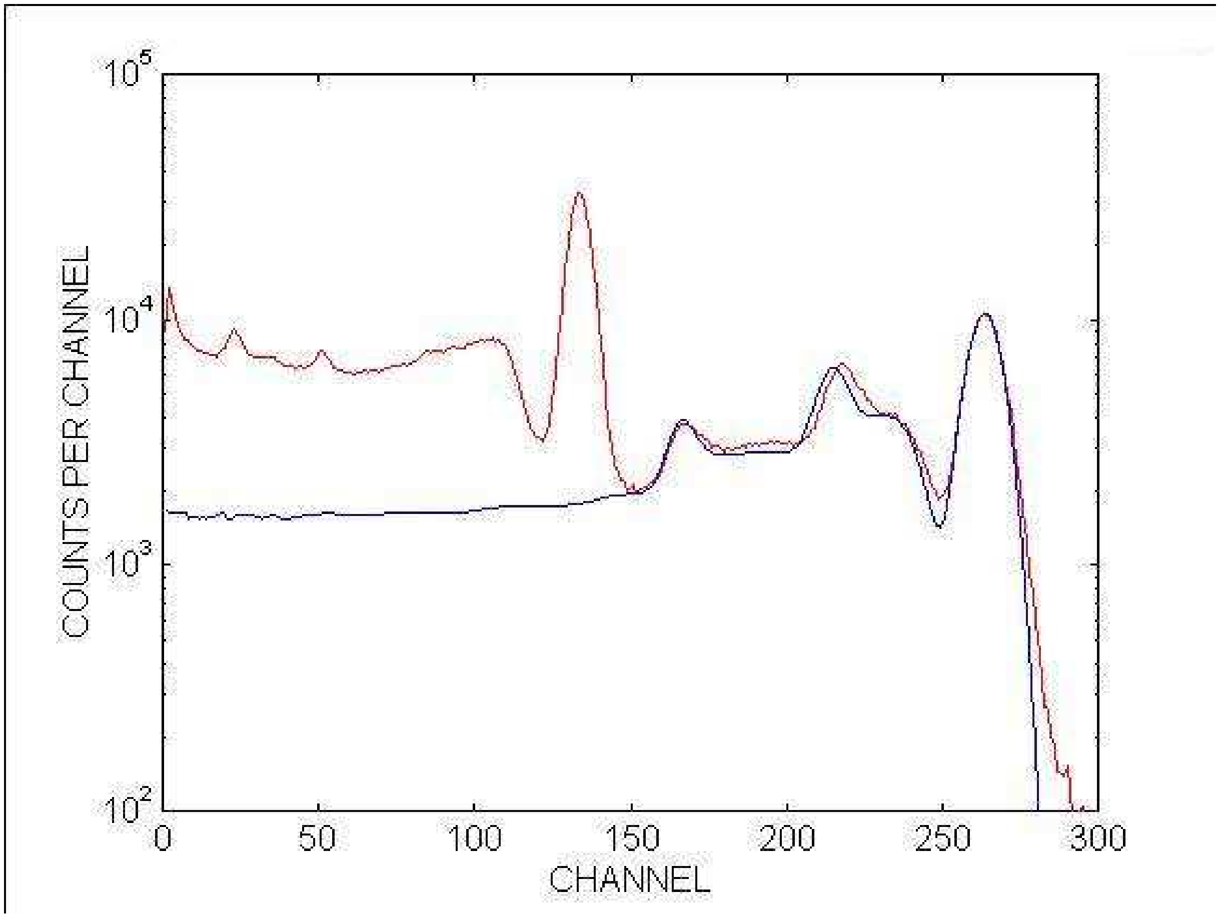
FLAT CONTINUUA

- **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

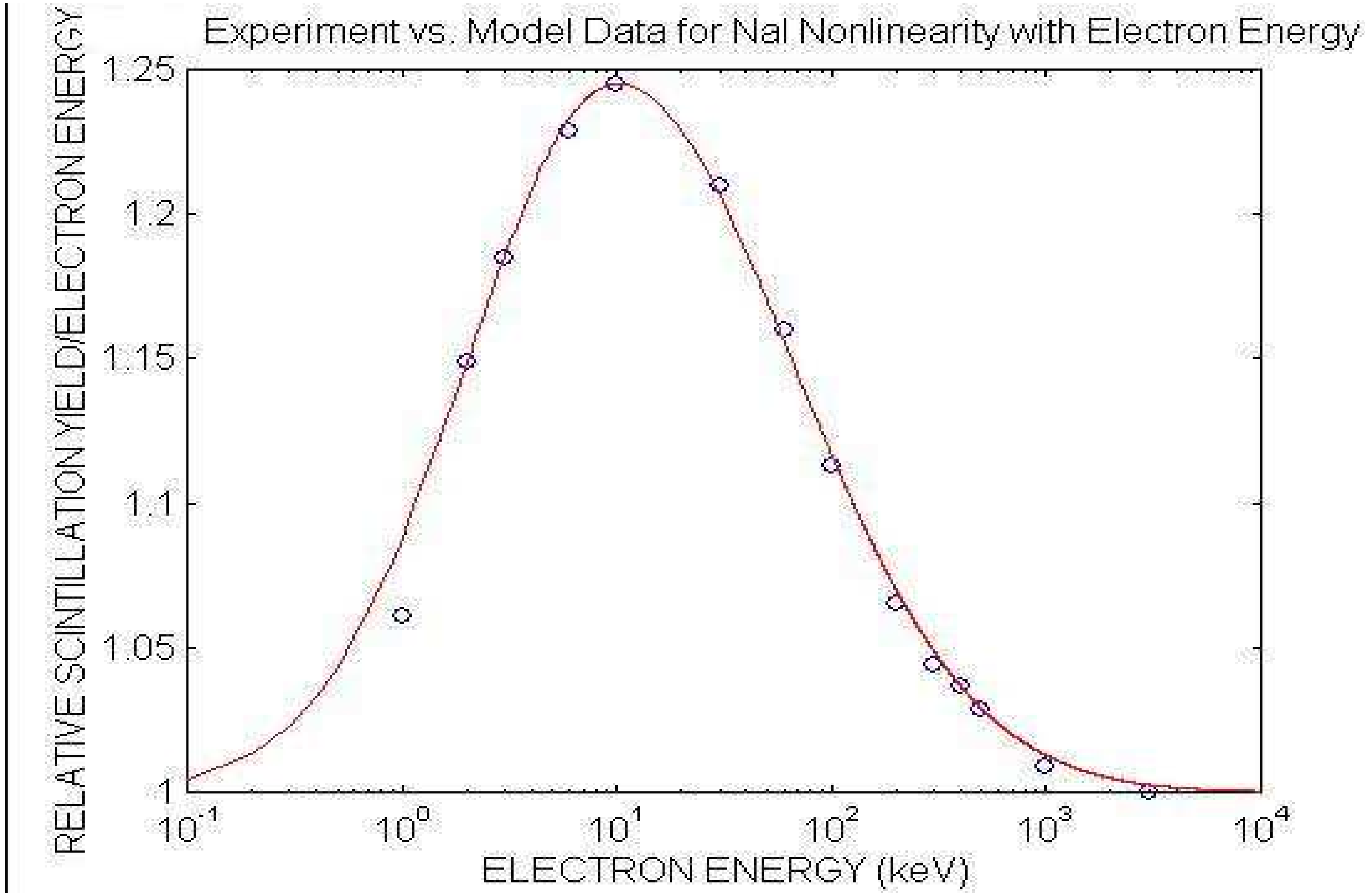


Non-linear energy deposition

- **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*:**

$$S(E_e) = 1 + k_1 \exp\left[-(lnE_e - k_2)^2/k_3\right] \quad E_e \geq 10\,keV$$
$$S(E_e) = 1 + k_1 \exp\left[-(lnE_e - k_2)^2/k_4\right] \quad E_e \leq 10\,keV$$

Gardner, R.P. and A. Sood, Nucl. Inst. and Meth. in Phys. Res B 213 (2004) 87-99.


Experiment vs. Model Data for NaI Nonlinearity with Electron Energy
RELATIVE SCINTILLATION YIELD/ELECTRON ENERGY
1.25
1.2
1.15
1.1
1.05
1
10^-1
10^0
10^1
10^2
10^3
10^4
ELECTRON ENERGY (keV)

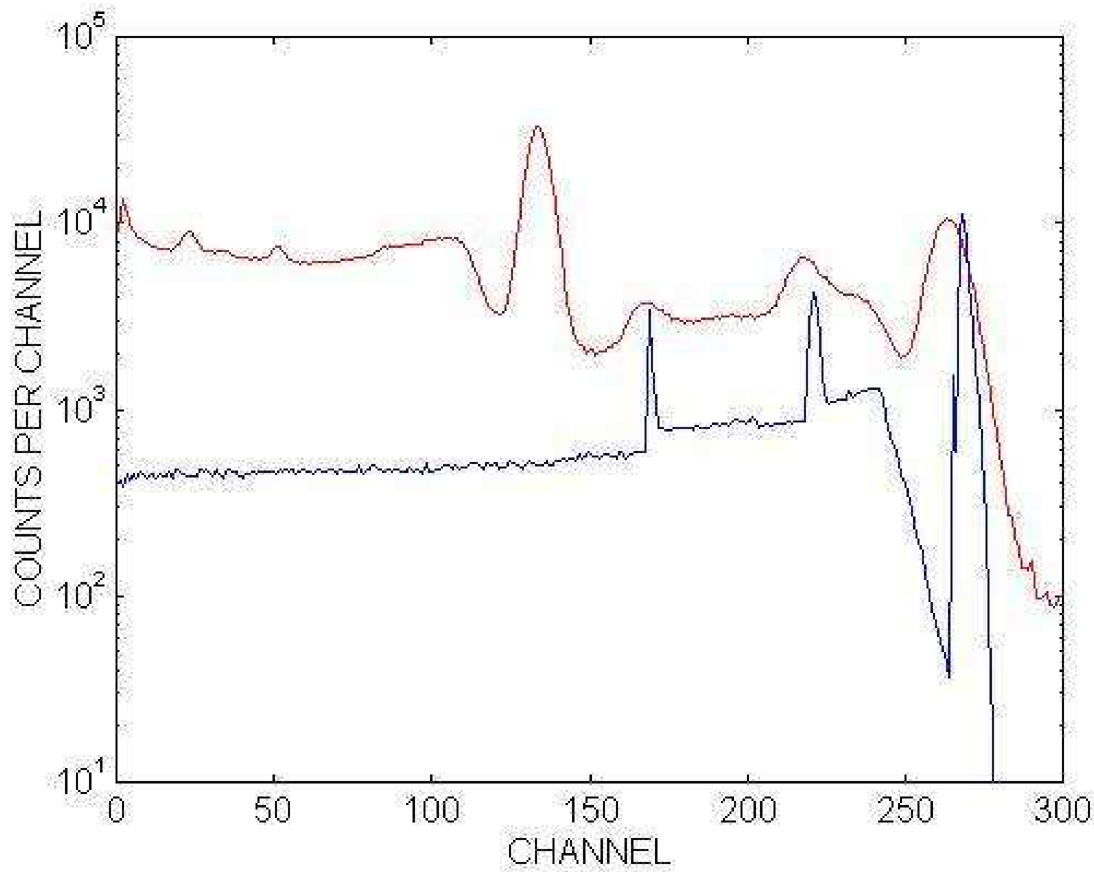
MCNP Simulation of NaI DRFs

- **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**

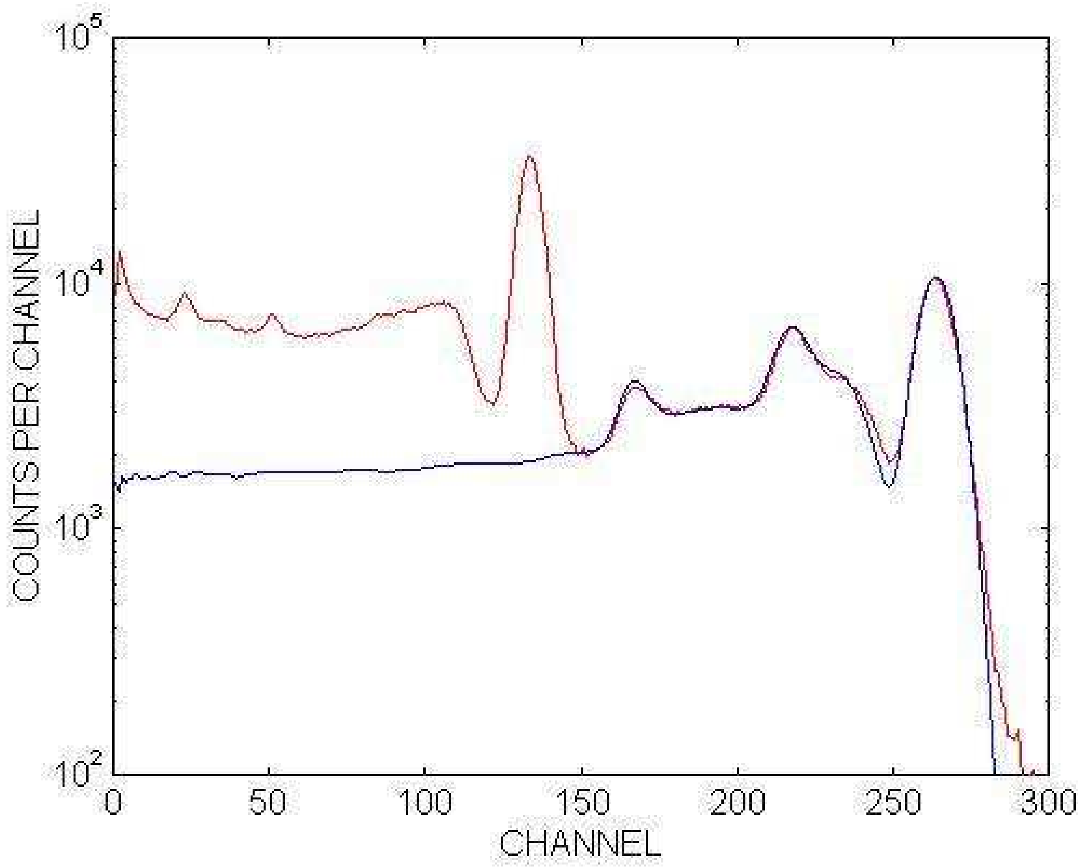
Experimental Comparisons

- Benchmark quality experiments performed by Russ Heath (1964)
- NaI 3x3 γ-spectra taken with single energy isotopes under standard laboratory conditions
- Detector shield designed to minimize impact from surrounding environment

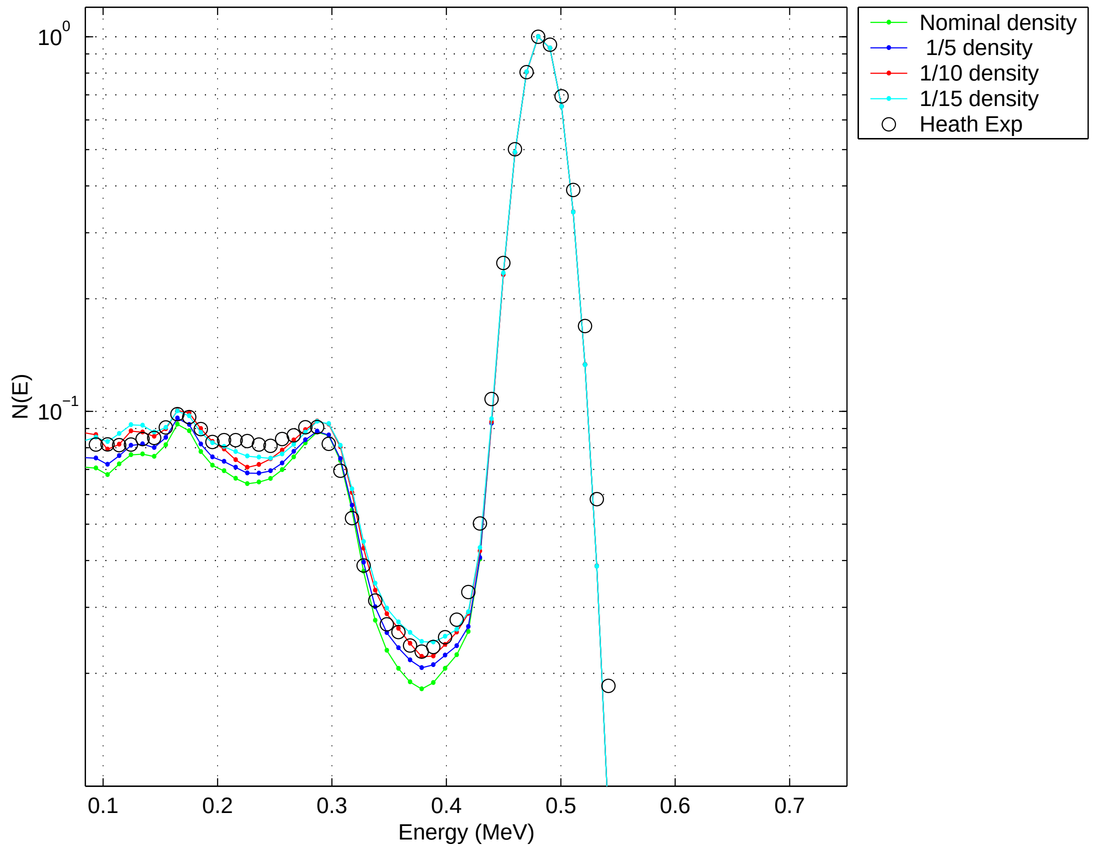
Non-linear Gaussian Spread



Gaussian Energy Broadening



Flat Continuum: Decreased density for electron transport



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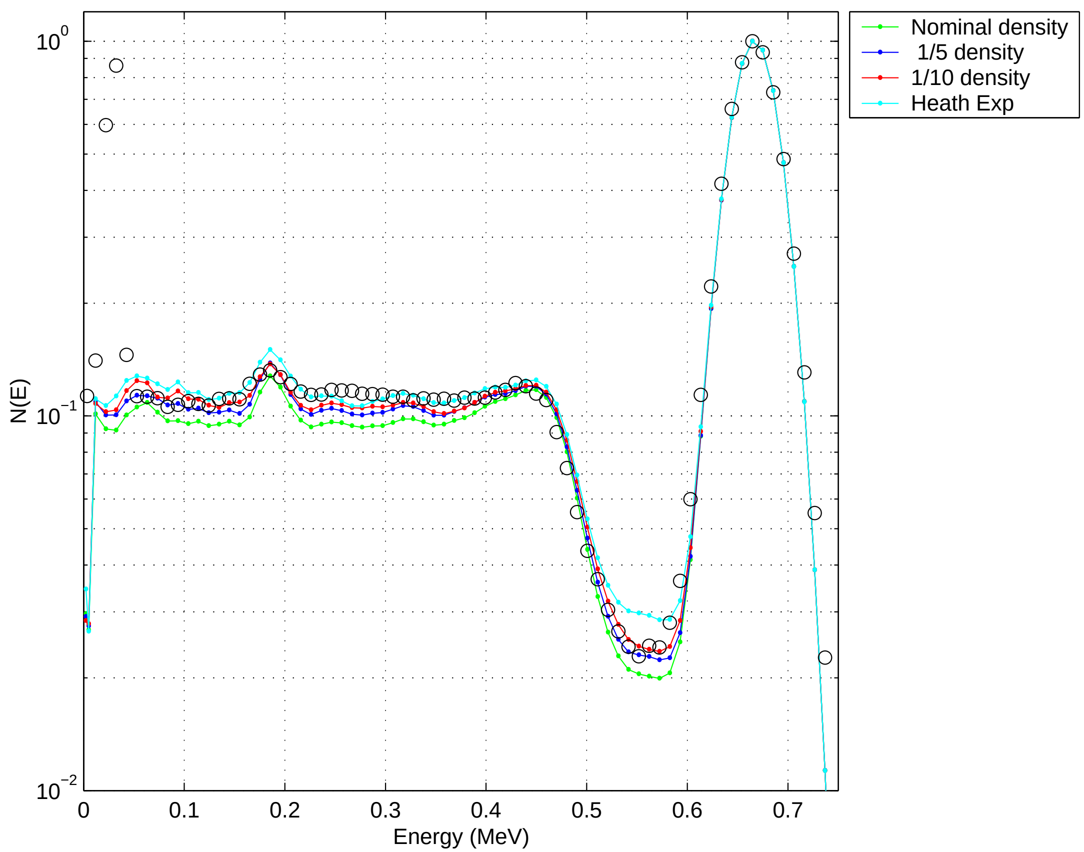

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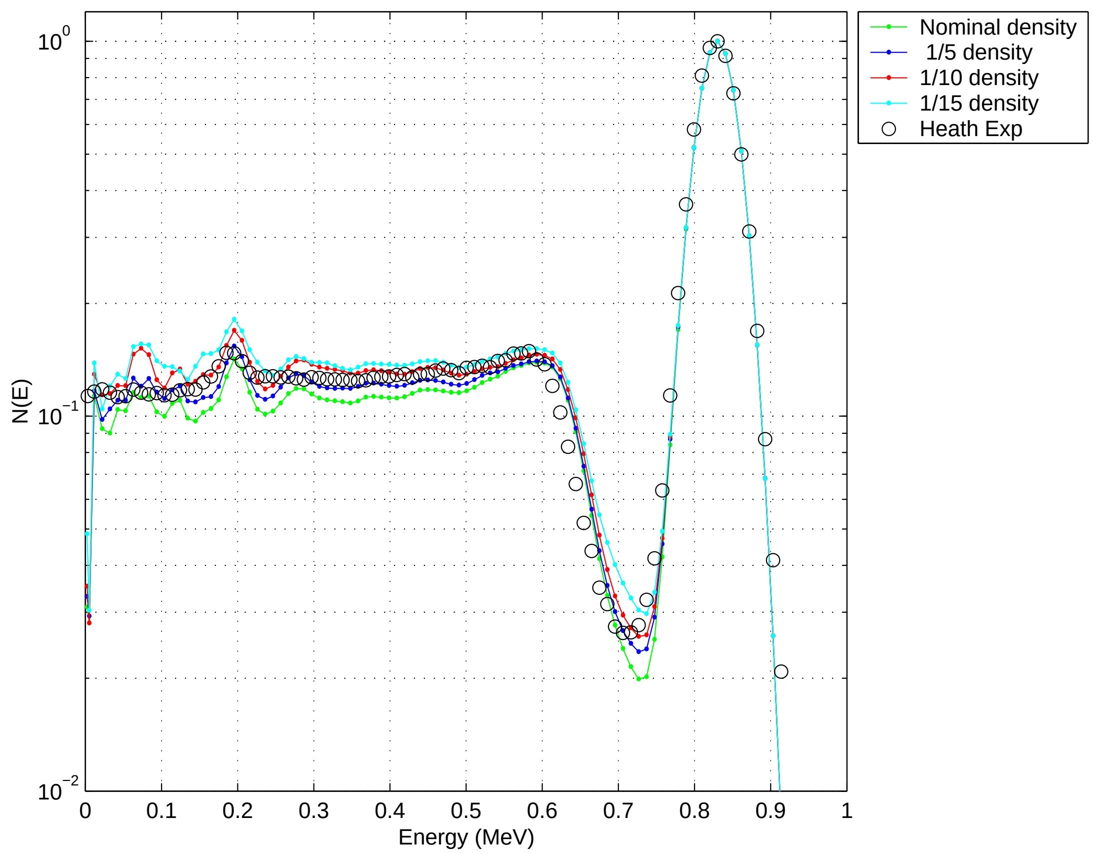

Summary of Work Presented

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