Comparison of Point Kernel Radiation Shielding and Monte Carlo Radiation Transport Methods in Support of Decommissioning Gamma Surveys

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Overview

- Examine the effects of gamma radiation spectrum on NaI(Tl) detector response.
- Examine the actual gamma spectrum from volumetric contaminated soil source geometry (i.e., primary and secondary gammas).
- Compare calculated NaI(Tl) detector responses based on point kernel radiation shielding methods with those for Monte Carlo radiation transport methods.

Regulatory Guidance

- MARSSIM (NUREG-1575, Rev. 1):
  - "A gamma scintillation detector (e.g., NaI(Tl)) provides data in counts per minute and conversion to mSv/h is accomplished by using site-specific calibration factors developed for the specific instrument."
- NUREG-1507:
  - "For a particular gamma energy, the relationship of NaI scintillation detector count rate and exposure rate may be determined analytically (in cpm per μR/h). … Correlation requires two steps – first, the relationship between the detector's net count rate to net exposure rate (cpm per μR/h) is established; and second, the relationship between the radionuclide contamination and exposure rate is determined."

Compton Scatter Influence of Correlation

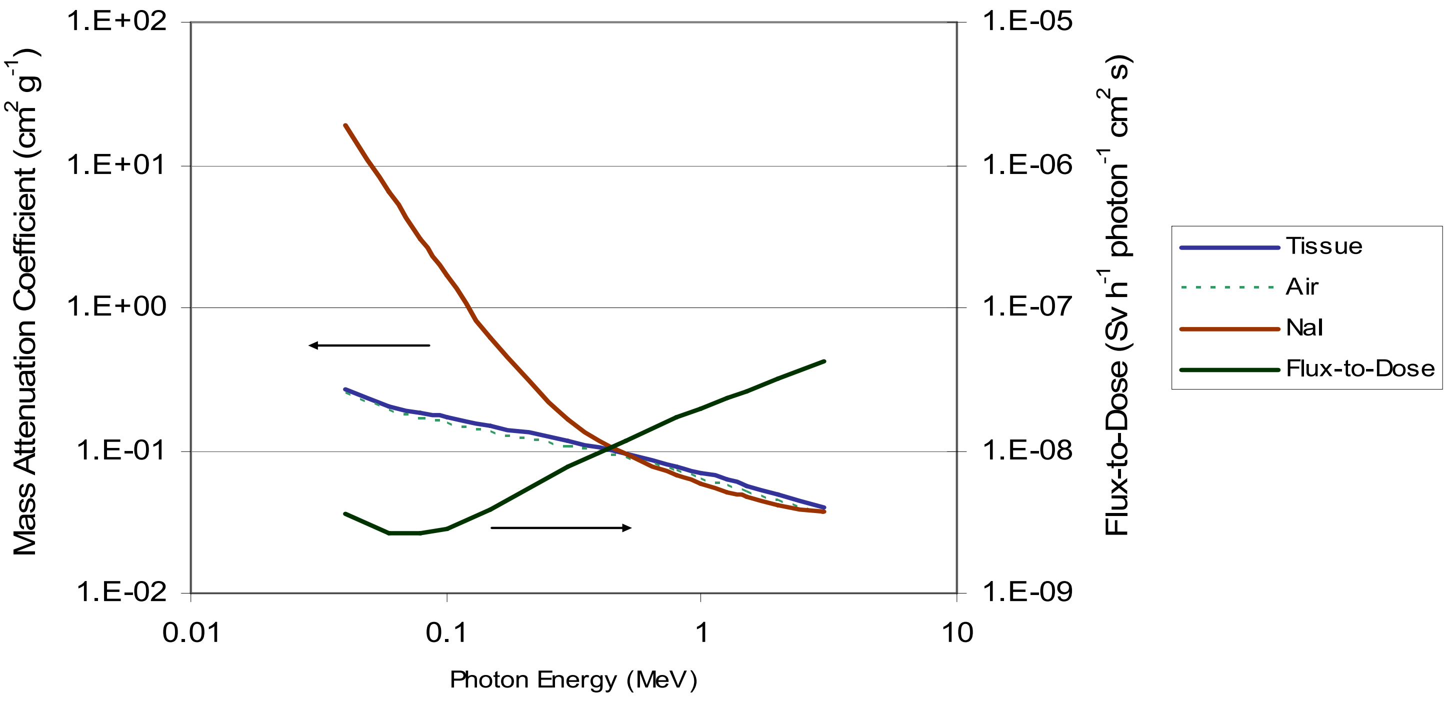
- Detector should be calibrated to gamma energy spectrum.
  - But, spectrum highly dependent on Compton scatter component.
  - For volumetric sources, Compton scatter can contribute greater than 50% of the gamma flux.
  - Spectrum changes with source and shielding geometries.

Point Kernel versus Transport Code Modeling

- Point kernel methods rely on buildup factor to increase calculated dose rates.
  - Energy spectrum beyond initial gamma energy not considered.

- Radiation transport methods (e.g., MCNP) model particle path, absorption and scatter interactions, and resulting energy spectrum.
  - Actual primary and scatter spectrum calculated at point of interest (i.e., detector location).

Gamma Attenuation and Flux-to-Dose Comparison



Relative Attenuation and Dose

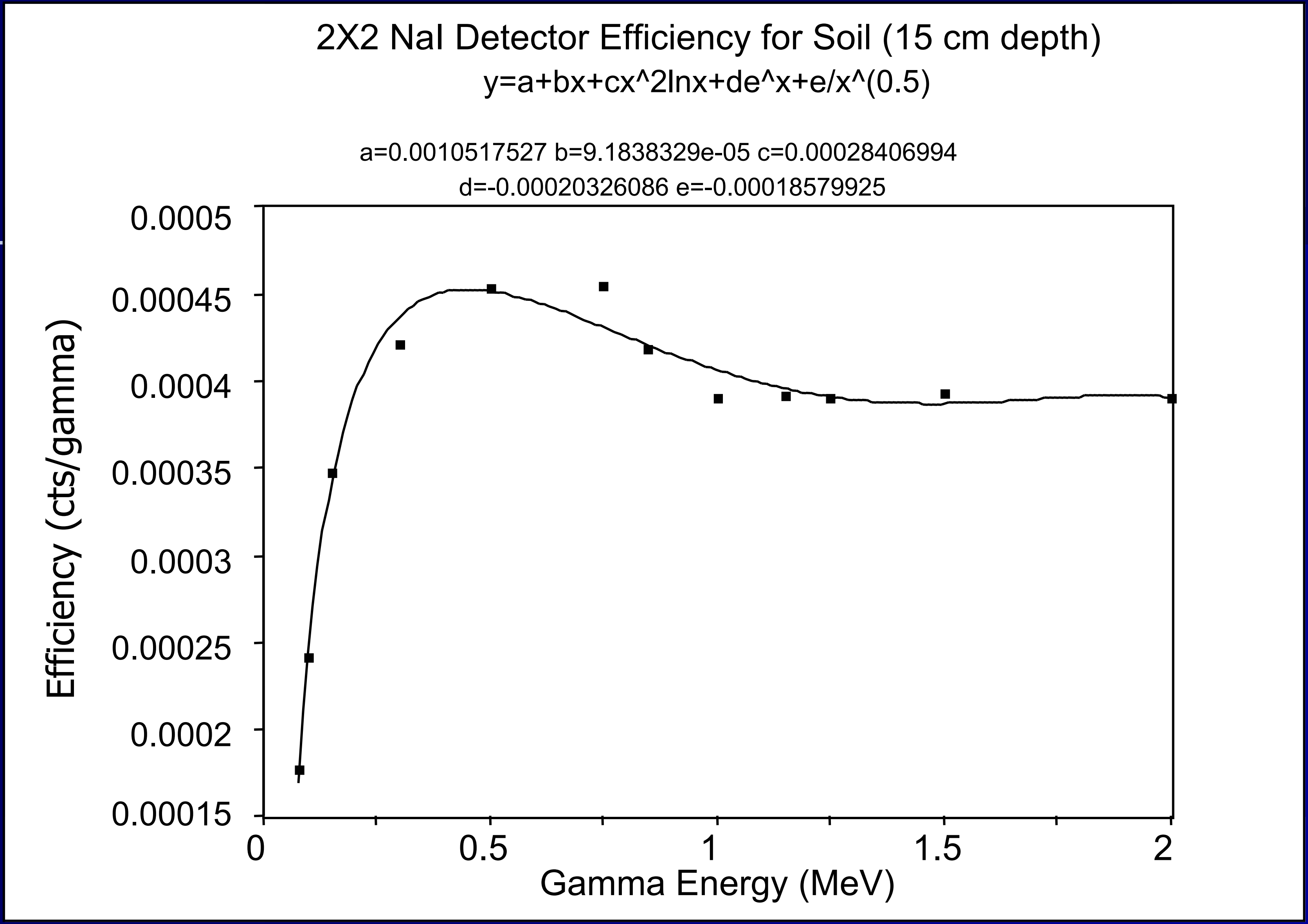
Gamma Energy (MeV)	NaI Atten X Flux-to-Dose	Relative Ratio to Cs-137
0.1	4.73E-09	4.2
0.3	1.26E-09	1.1
0.662 (Cs-137)	1.13E-09	1.0
1.0	1.16E-09	1.0
2.0	1.33E-09	1.2
3.0	1.54E-09	1.4

2X2 Inch NaI Count Rate versus Exposure Rate (from NUREG-1507)

Gamma Energy (MeV)	cpm per µR/h
0.060	13,000
0.2	4,230
0.4	1,700
0.6	1,010
1.0	540
2.0	260

Relative Contribution to NaI Detector Count Rate (15 cm contaminated soil depth)

Gamma Energy (MeV)	Primary (uncollided)	Compton Scatter
0.1	65%	35%
0.3	29%	71%
0.6	14%	86%
1.0	10%	90%
2.0	7%	93%



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2X2 Inch NaI(Tl) Detector Relative Response to Th-232 + Progeny w/15 cm Contaminated Soil Depth

Gamma Energy (MeV)	Primary Gamma Abundance	Frac. Abun. of Total Count Rate
<0.1	14%	7%
0.1 - 0.3	22%	25%
0.3 – 1.0	49%	56%
1.0 - 2.0	3%	3%
> 2.0	12%	9%

Comparison of 2X2 Inch NaI Detector Response – 15 cm Contaminated Soil Depth

Nuclide	NUREG-1507 (cpm/μR/h)	MCNP (cpm/μR/h)	Ratio (NUREG/MCNP)
Am-241	13,000	8,100	1.6
Cs-137	900	1300	0.7
Co-60	430	670	0.6
Th-232	830	960	0.9

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Applications

- Scanning volumetric materials for controlled disposal or release
- Sub floor contaminated soil investigation/screening
- Underground sewer line modeling
- Harvard cyclotron activated shield block modeling

Conclusion

- NaI detector response highly dependent on gamma energy spectrum – at the detector
- Compton scatter can be major contributor to the response, especially for volumetric or shielded sources
- NUREG-1507 method appears to over estimate NaI response for low energy gammas and under estimate where Compton scatter important
- MCNP type modeling needed to account for Compton scatter
- Use detector counts not a correlated dose rate