Characterization of NORM Using HPGe Measurements and MCNP6 Simulations

ANS Annual Meeting

San Francisco, CA

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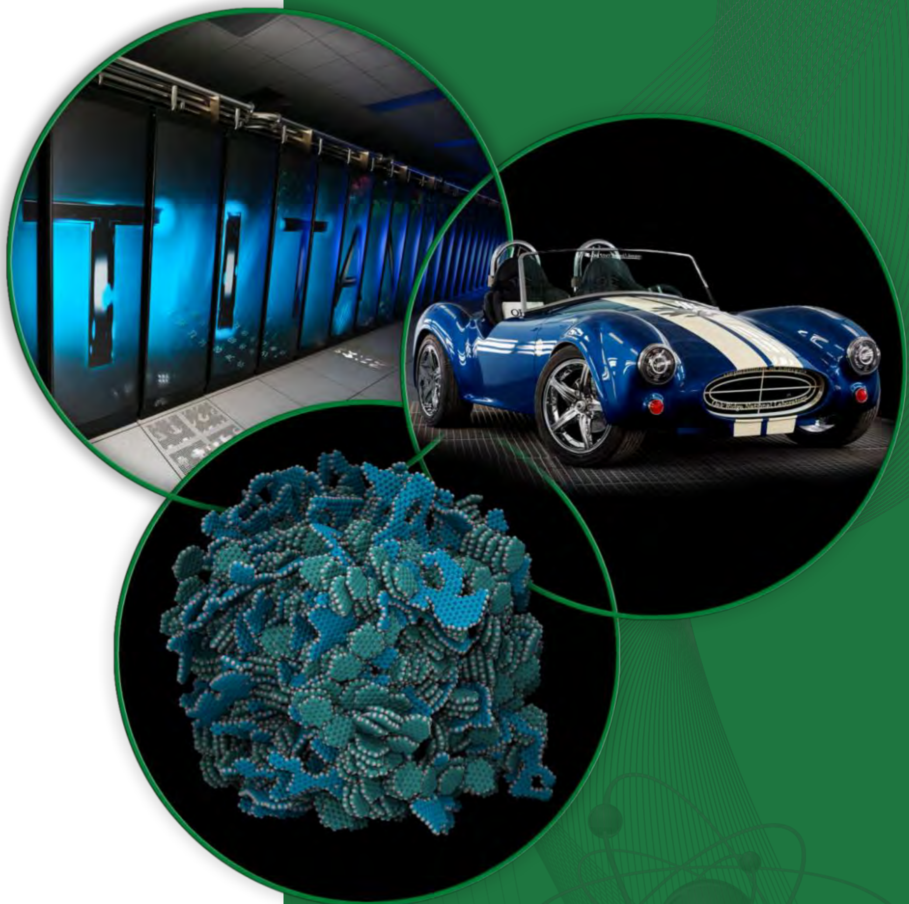

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Outline

- Why?
- What?
- How?
  - Measurement
  - Simulation
- Results/Discussion
- Future Work

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Introduction

- Part of an NNSA project focused on urban search
  - Collect “benchmark quality” data at a representative but controlled urban environment
    - Fort Indiantown Gap National Guard site in Pennsylvania
  - Generate radiation transport models (MCNP/SCALE-MAVRIC/Shift) to serve as a “virtual” test bed

Military Operations on Urbanized Terrain (MOUT) Site

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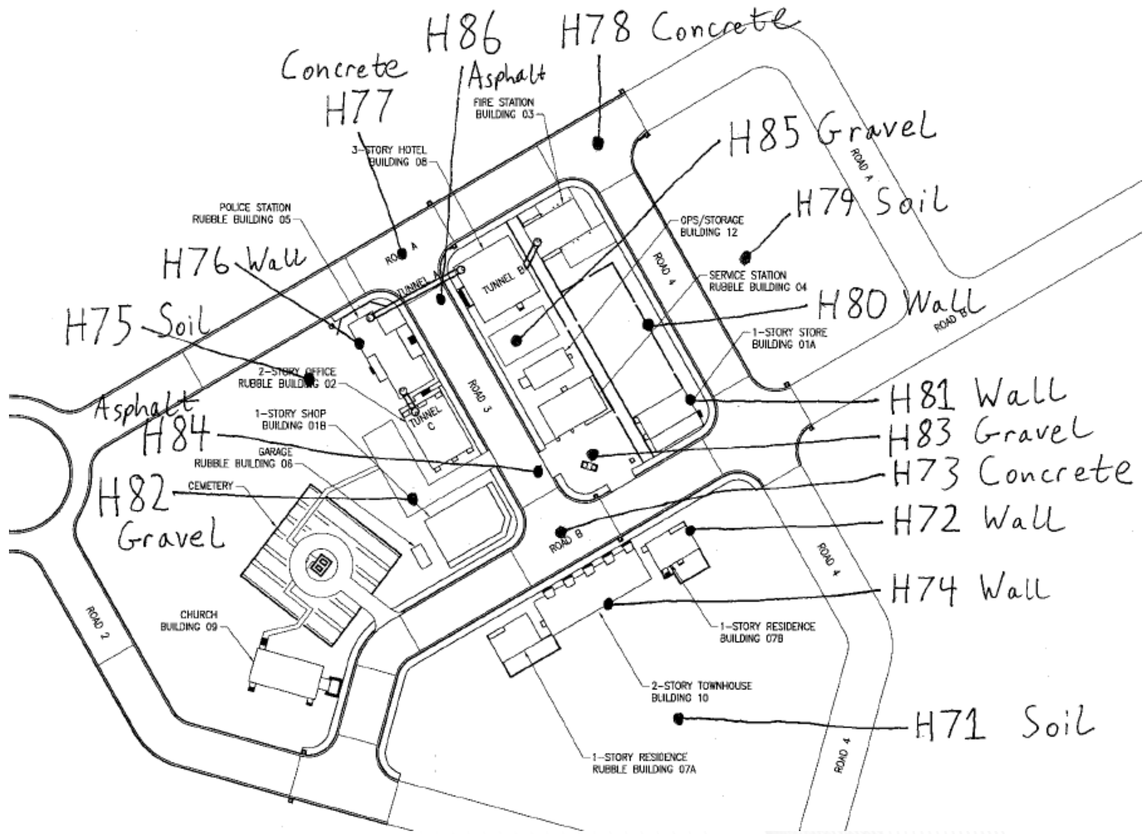
Measuring Background

- Detection over background is critical
  - Must characterize and understand various sources
  - Background can then be incorporated into large-scale simulation used to produce representative synthetic data
- How to best measure background?

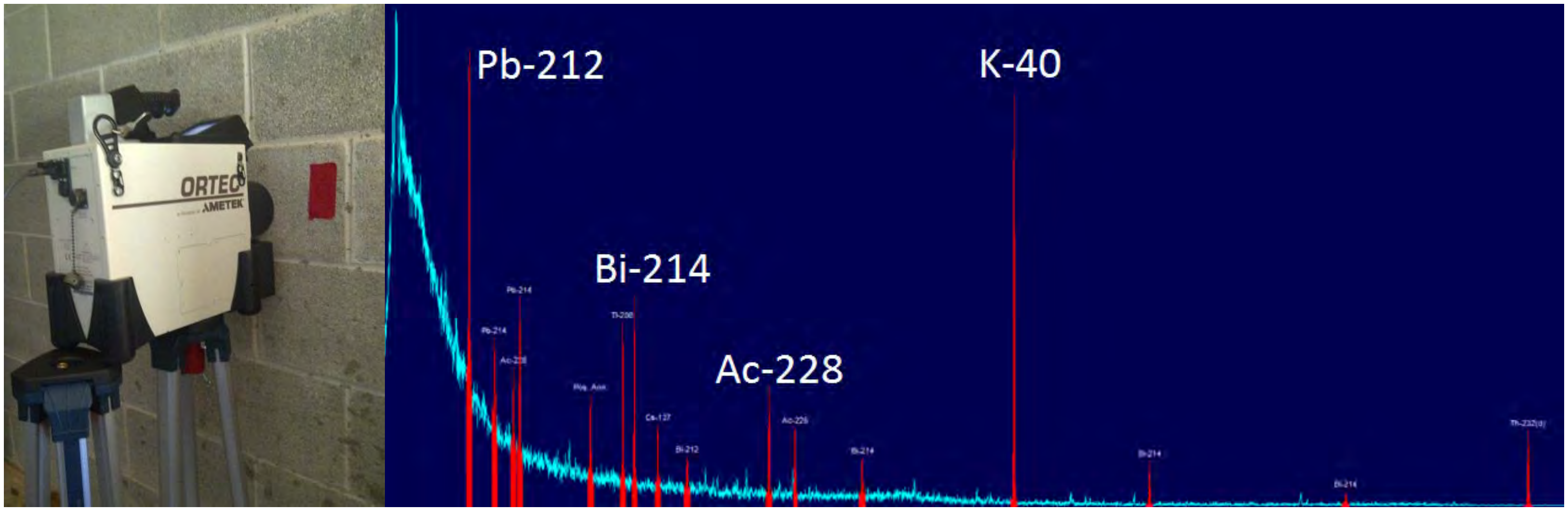
Shielded HPGe detector measuring various sources of background

HPGe Data Collection



Locations for NORM measurements at FTIG site for last measurement campaign

Determining NORM from Measurement



- Counts in detector a function of:
  – Activity concentration of NORM (Naturally Occurring Radioactive Material) (Bq/kg)
  – Gammas per decay (Branching Ratio)
  – Detector response (Counts per gamma/kg)

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Method for Determining NORM

$$C(E) = K * g * R(E)$$

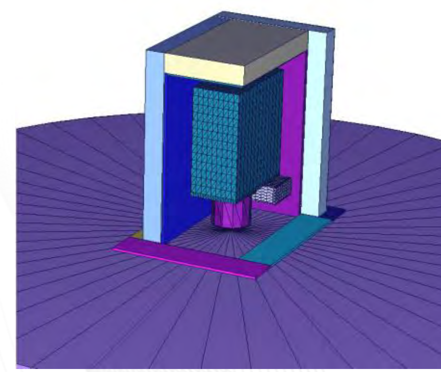
- $C(E)$ Count rate at energy E (counts/sec)
- K Activity concentration (Bq/kg)
- g Branching ratio (γ/decay)
- $R(E)$ Detector response at E (counts per γ/kg)

Method for Determining NORM (cont.)

- Careful measurement of each material using a shielded HPGe detector (ORTEC Detective EX-100T)

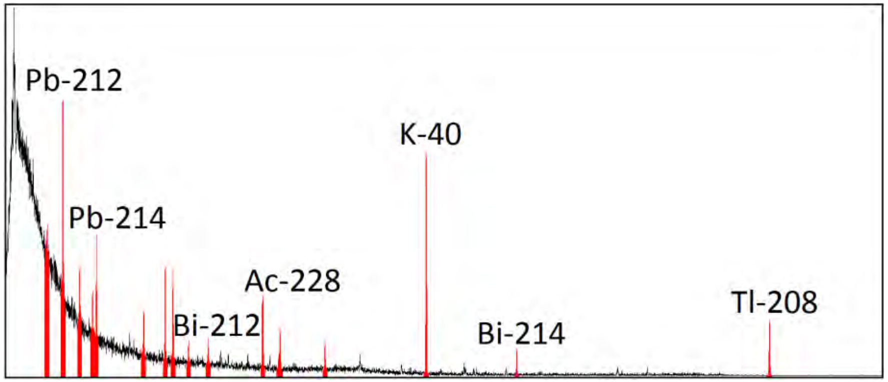
- Nuclear data (ENDF/B-VII.1)

- Detailed Monte Carlo radiation transport simulations with MCNP6 to estimate detector response



Measurements – Gamma Spectroscopy

- Typical NORM constituents (K,U,Th) (^{137}Cs in soil)
- 20 gamma lines used for NORM calculation
- Used variance weighted average to estimate activity

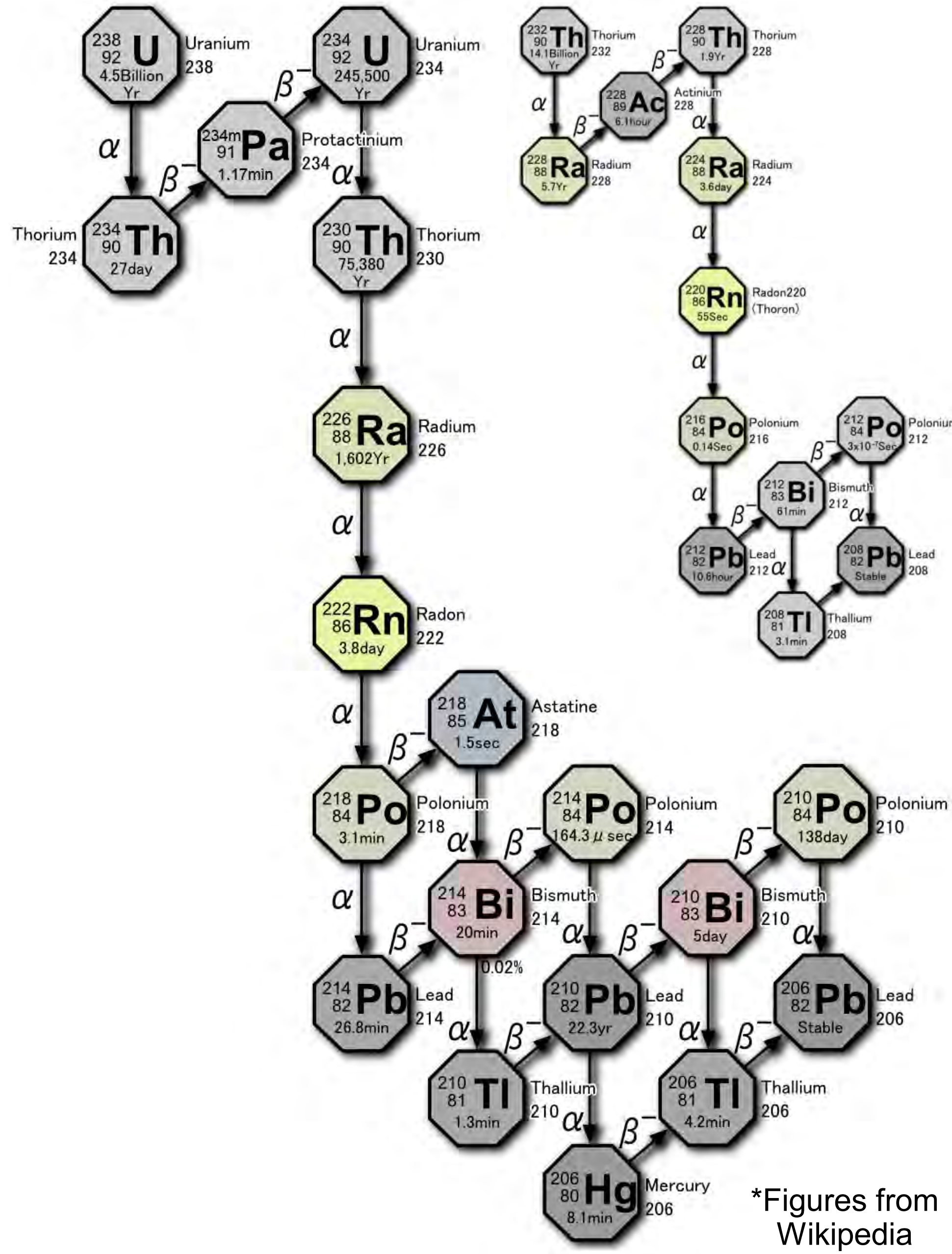


Nuclear data for NORM constituents

Nuclide (parent)	Half-Life (yrs)	Energy (keV)	Branching Ratio
^{40}K	1.248E+09	**1460.8**	0.10662
^{137}Cs	3.008E+01	**661.66**	0.8513
^{226}Ra (^{238}U)	1.600E+03	**186.21**	0.0359
^{214}Bi (^{238}U)	3.784E-05	**609.32** **1764.5** **1120.3**	0.4549 0.153 0.1492
^{214}Pb (^{238}U)	5.095E-05	**351.93** **295.22** **242.00**	0.356 0.1842 0.07251
^{228}Ac (^{232}Th)	7.016E-04	**911.20** **968.96** **338.32**	0.262 0.159 0.114
^{212}Bi (^{232}Th)	1.151E-04	**727.33** **1620.5** **785.37**	0.06669 0.01467 0.01102
^{212}Pb (^{232}Th)	1.214E-03	**238.63** **300.09**	0.436 0.03301
^{208}Tl (^{232}Th)	5.805E-06	**2614.5** **583.19** **860.56**	0.99754 0.85 0.125

Other Considerations/Assumptions

- Assumed secular equilibrium for U and Th decay chains
- 186 keV peak– assuming sec. eq.:
  - 42.3% ^{235}U & 57.7% ^{226}Ra
- Several nuclides with only 1 peak
  - ^{212}Bi, ^{212}Pb, ^{226}Ra, ^{137}Cs, ^{40}K
- ^{208}Tl represents only 0.3594 of parent activity due to BR

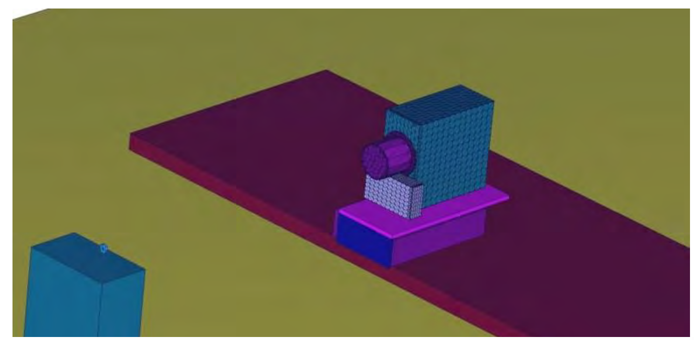


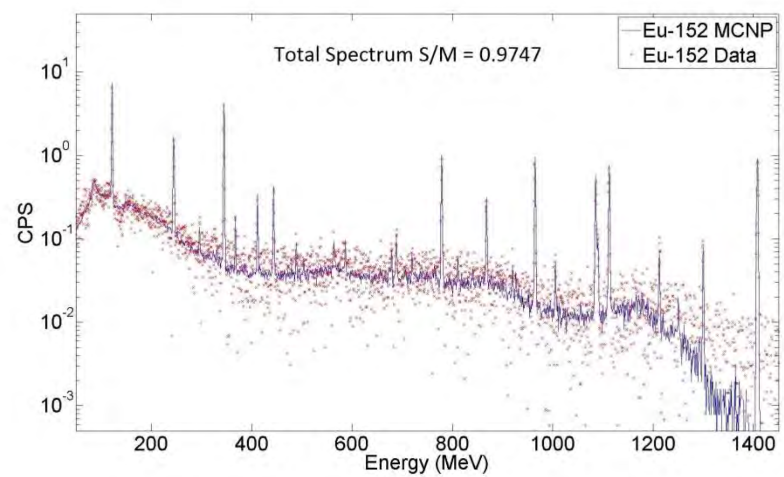
*Figures from Wikipedia

Simulation – ORTEC Detective

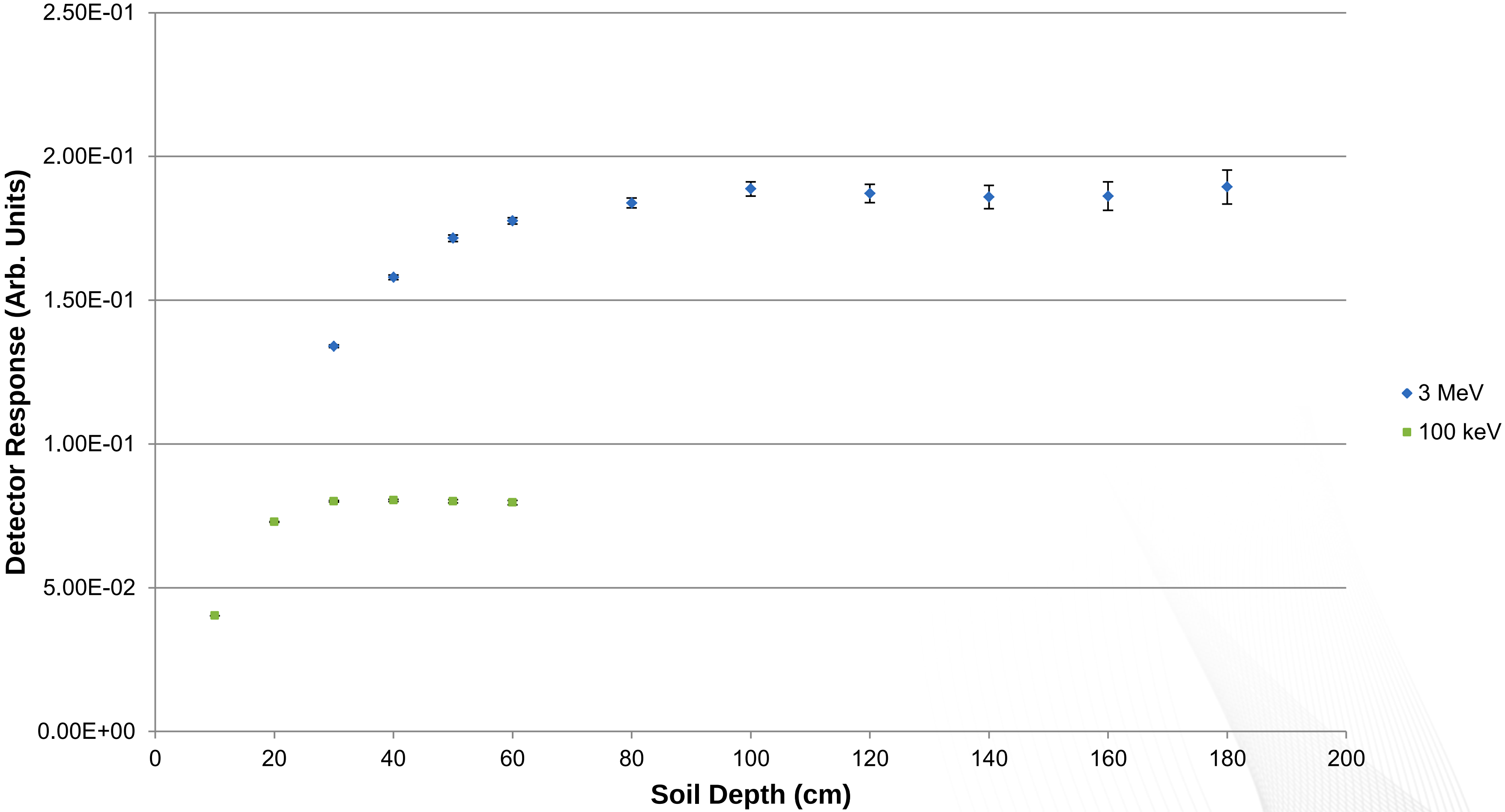
- Specs from ORTEC Detective EX100T
- Used accepted material definitions
  - PNNL-15870
- ORIGEN for creating source spectra
- Relative efficiency – Comparison
  - 3” x 3” NaI @ 25 cm from ^{60}Co
  - 48.34% modeled vs. 48.87% reported
- Experimental validation with ^{137}Cs, ^{60}Co, and ^{152}Eu :
  - S/E = 0.98, 0.96, and 0.97, respectively

Validation experiment and model



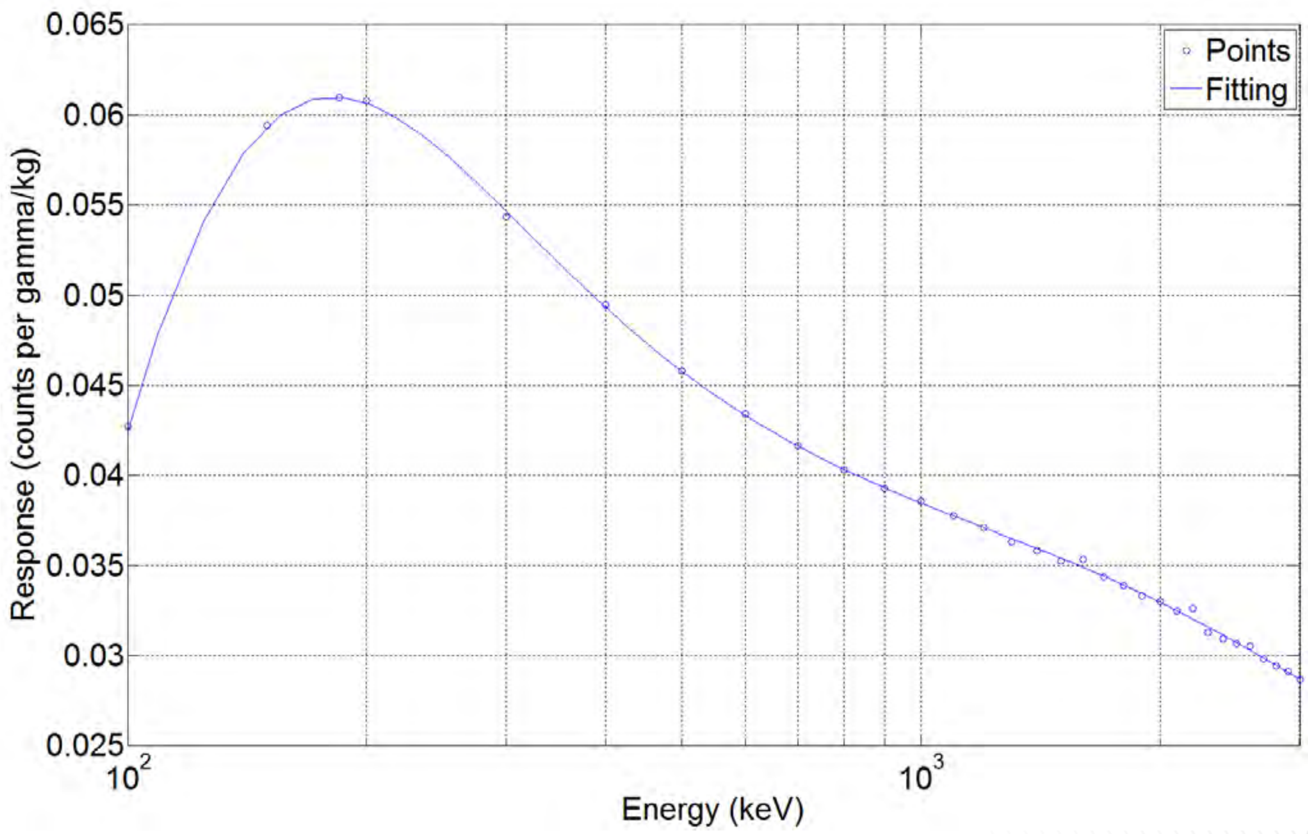


Simulation – Ground Depth Study



Simulation – Response Curve

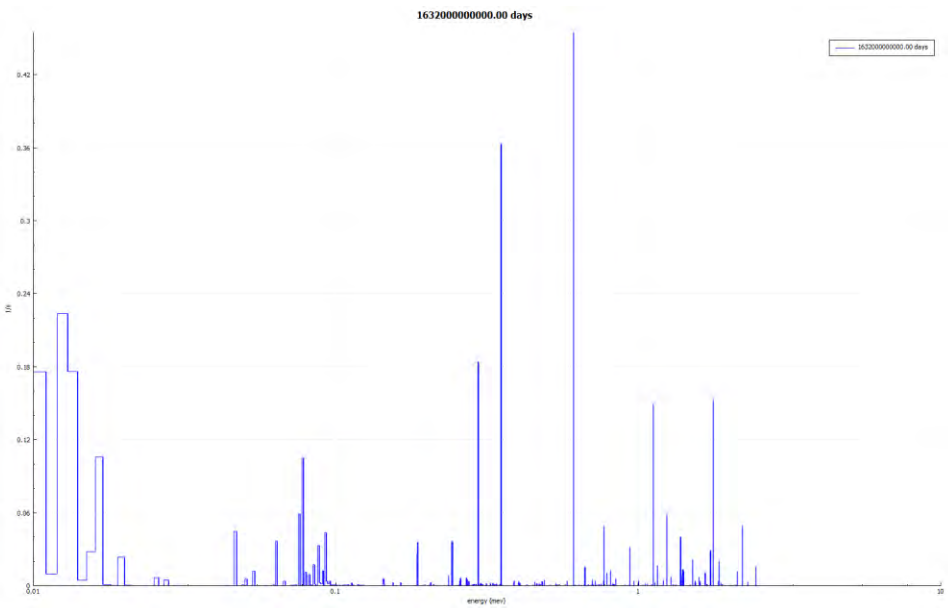
- Simulate response for 1 Bq/kg concentration
  - Compute number of full-energy counts for mono-energetic distributed gamma emitter at 1 gamma/s/kg



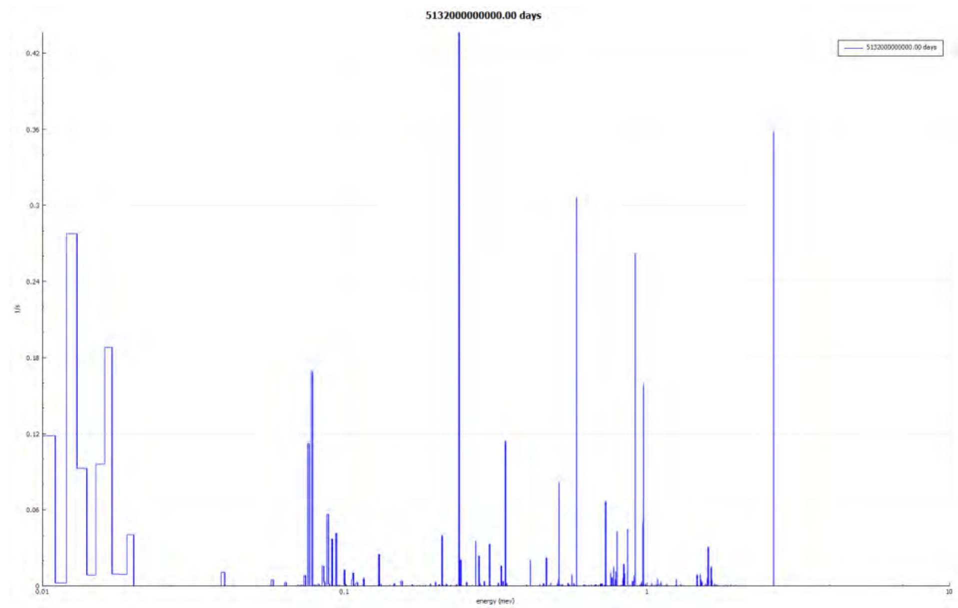
Simulation – Source Spectra

- Used ORIGEN to generate appropriate spectra
  - Assuming secular equilibrium
  - Spectra for entire series (U (235 & 238) and Th)
  - Decayed for ~1 half-life of parent to 1 Bq

U-Series Spectrum

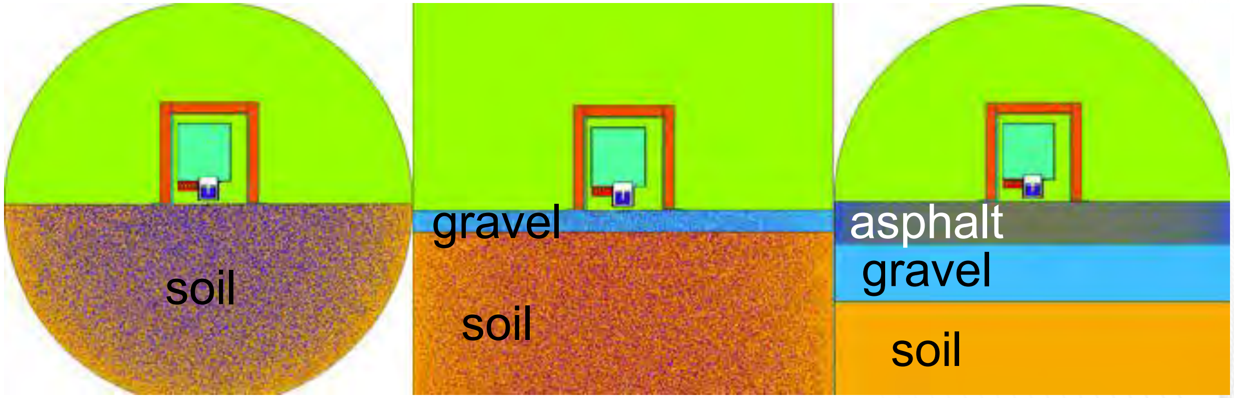


Th-Series Spectrum



Simulation – Iterative Approach

- Estimated and subtracted soil contribution
  - Attributed remaining spectra to source in gravel
- Repeated for asphalt, concrete, etc.
  - Small differences for all cases except gravel and sidewalk
  - Agreement of the activity predicted from various peaks originating from the same nuclide used as check
    - (i.e., ^{208}Tl 583 keV and 2614 keV peaks)



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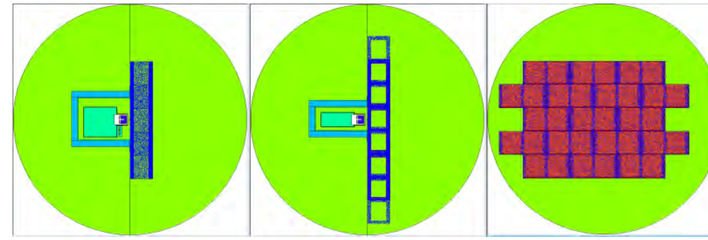
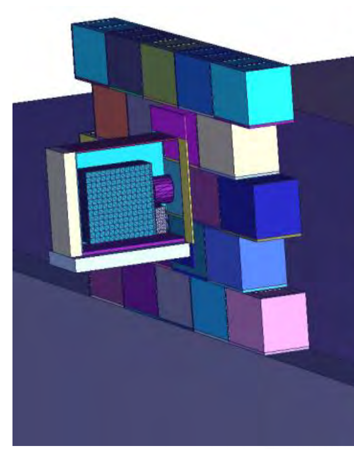
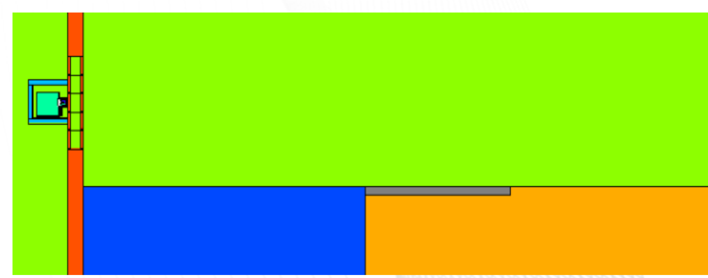
Simulation – Wall Source Attribution

- Had to account for contribution coming thru wall
- Used cases where wall faced a field or street
  - Computed soil/sidewalk/asphalt contribution to spectrum using ADVANTG code
  - Subtracted this contribution and assigned remaining component to wall







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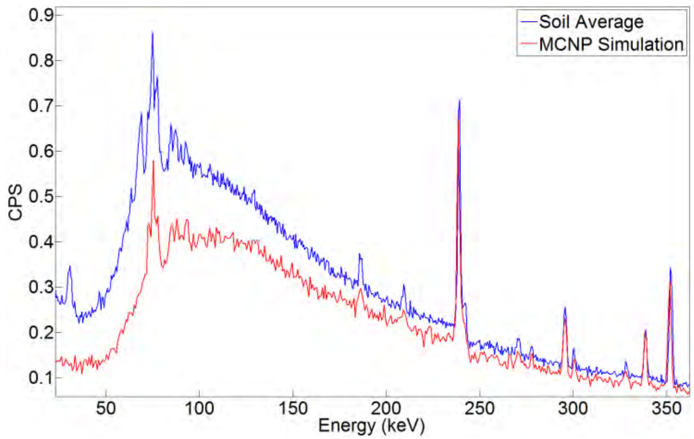
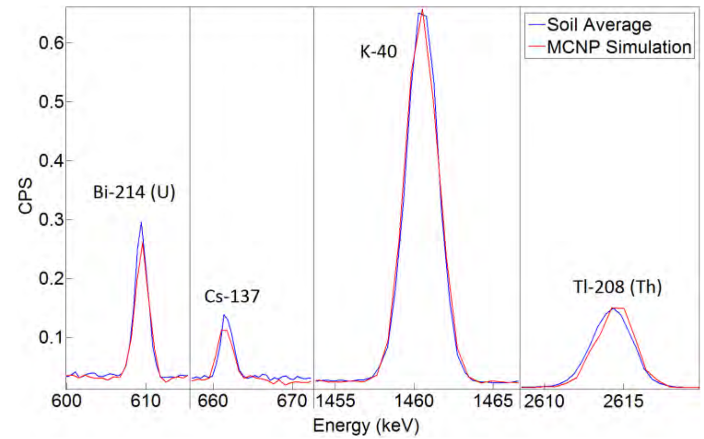
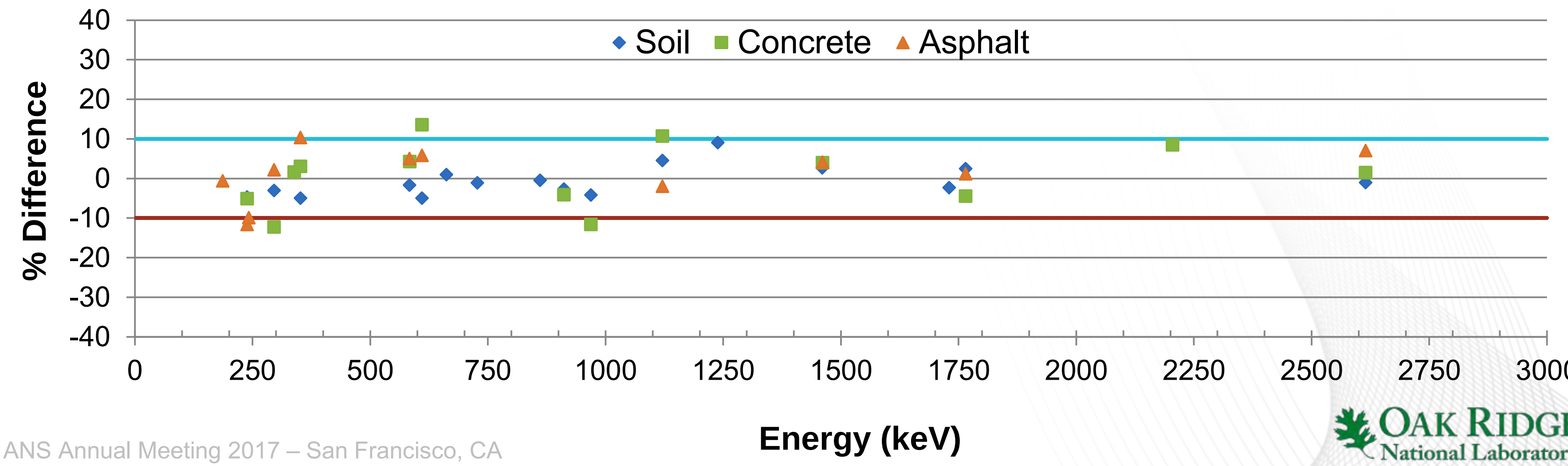
Measured Spectra vs. Synthetic Data

- Low end of the spectrum matches less well than full-energy peaks





- Percent difference between peak areas across energy spectrum



Determining Sources of Error

- Needed to attribute low-energy difference in both shielded HPGe and unshielded NaI cases

- Conducted sensitivity study using model
  - Lead gaps, dead layer size, simulated battery, density changes, wet soil, etc.

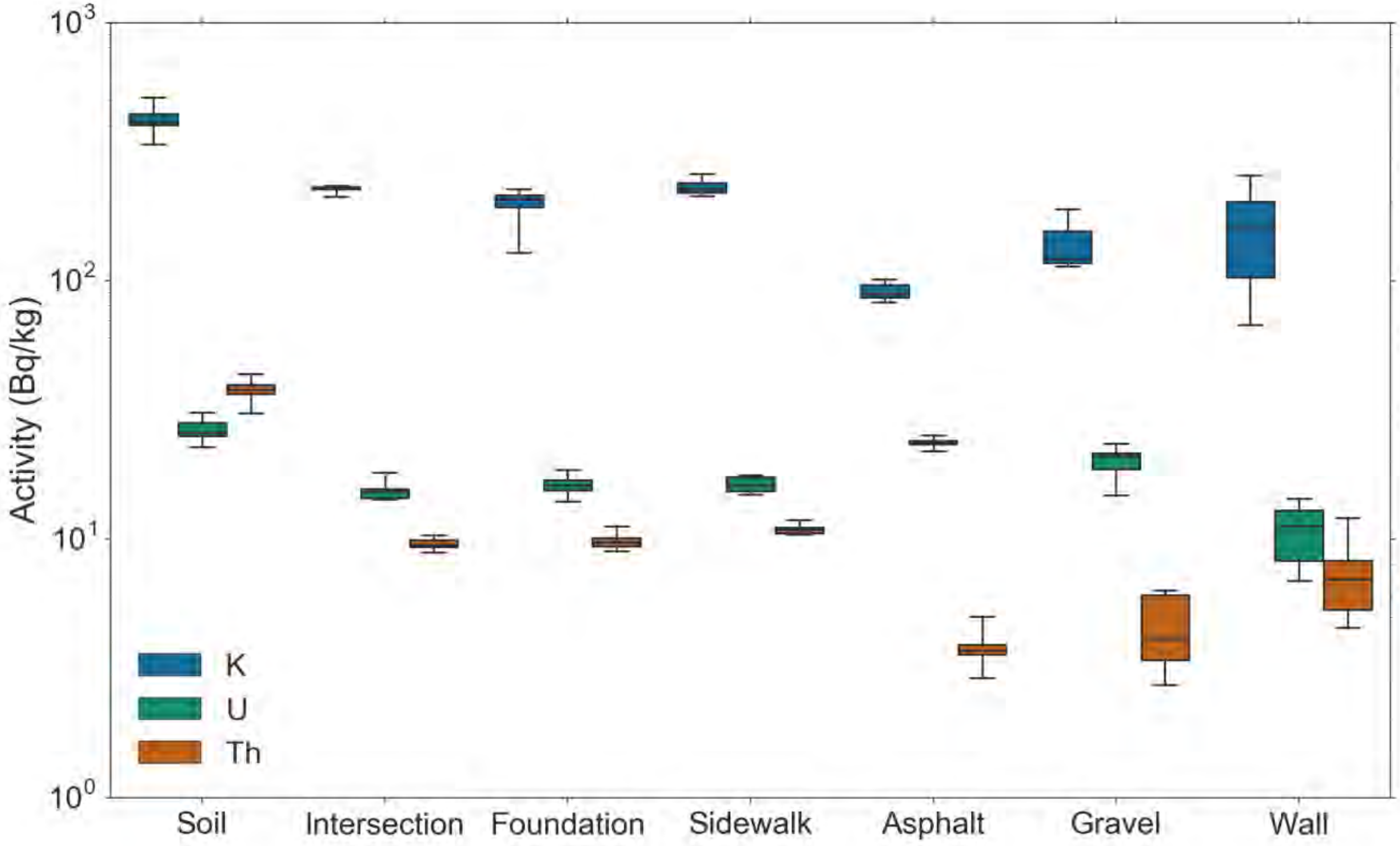
- Possibilities:
  - **Sky shine**
  - Cosmic rays and/or interactions with lead
  - Nearby sources streaming through/around/under lead
  - Small NORM concentrations in shielding/detector

Calculated NORM Concentrations

Material (No. of Measurements)	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{137}Cs* (Bq/kg)
Soil (12)	420 ± 55	26.5 ± 2.4	37.7 ± 3.4	5.4 ± 2.1
Intersections (5)	227 ± 8	15.5 ± 1.5	9.6 ± 0.6	-
Sidewalks (9)	230 ± 15	16.2 ± 1.2	10.9 ± 0.4	-
Foundations (11)	200 ± 26	16.3 ± 1.4	9.8 ± 0.6	-
Asphalt (13)	91 ± 6	23.7 ± 0.8	3.7 ± 0.5	-
Gravel (7)	139 ± 34	20.0 ± 2.9	4.6 ± 1.5	-
Light Tan CMU (4)	239 ± 25	13.4 ± 0.9	9.3 ± 1.6	-
Dark Tan CMU (4)	122 ± 55	9.2 ± 2.0	8.0 ± 3.0	-
White CMU (2)	72 ± 5	8.2 ± 0.3	4.7 ± 0.3	-
Grey CMU (2)	165 ± 8	12.8 ± 0.4	5.7 ± 0.5	-
Red CMU (1)**	103 ± 9	10.2 ± 0.6	5.7 ± 0.5	-

* Detectable amounts of ^{137}Cs were only found in soil
** Uncertainty represents a single measurement, not uncertainty in value across the FTIG site

NORM in the FTIG Environs



Ticks are not error bars but represent the bounds of the determined NORM values for each material based on individual measurements (70 in total).

Conclusions

- A method was developed and implemented for characterizing NORM for various materials in the FTIG environment
  - Agreement with worldwide values
  - Internal consistency
  - Validation with experiment
- These NORM concentrations have been implemented in full-scale model with promising results
  - Preceding talk by Douglas Peplow

Future Work

- Inserting various representative threat sources

- Use “virtual” test bed to test different detector suites, detection algorithms, create training data, etc.

- Further development and validation with Shift