T2.2-P9

On-Site Inspection Capabilities -- Examination of Laboratory Detector Response

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A modeling utility has been developed to simulate acquired gamma spectra from any user defined source to meet on-site inspection (OSI) threshold during in-field laboratory analysis of plutonium fission products

Goals and Motivation

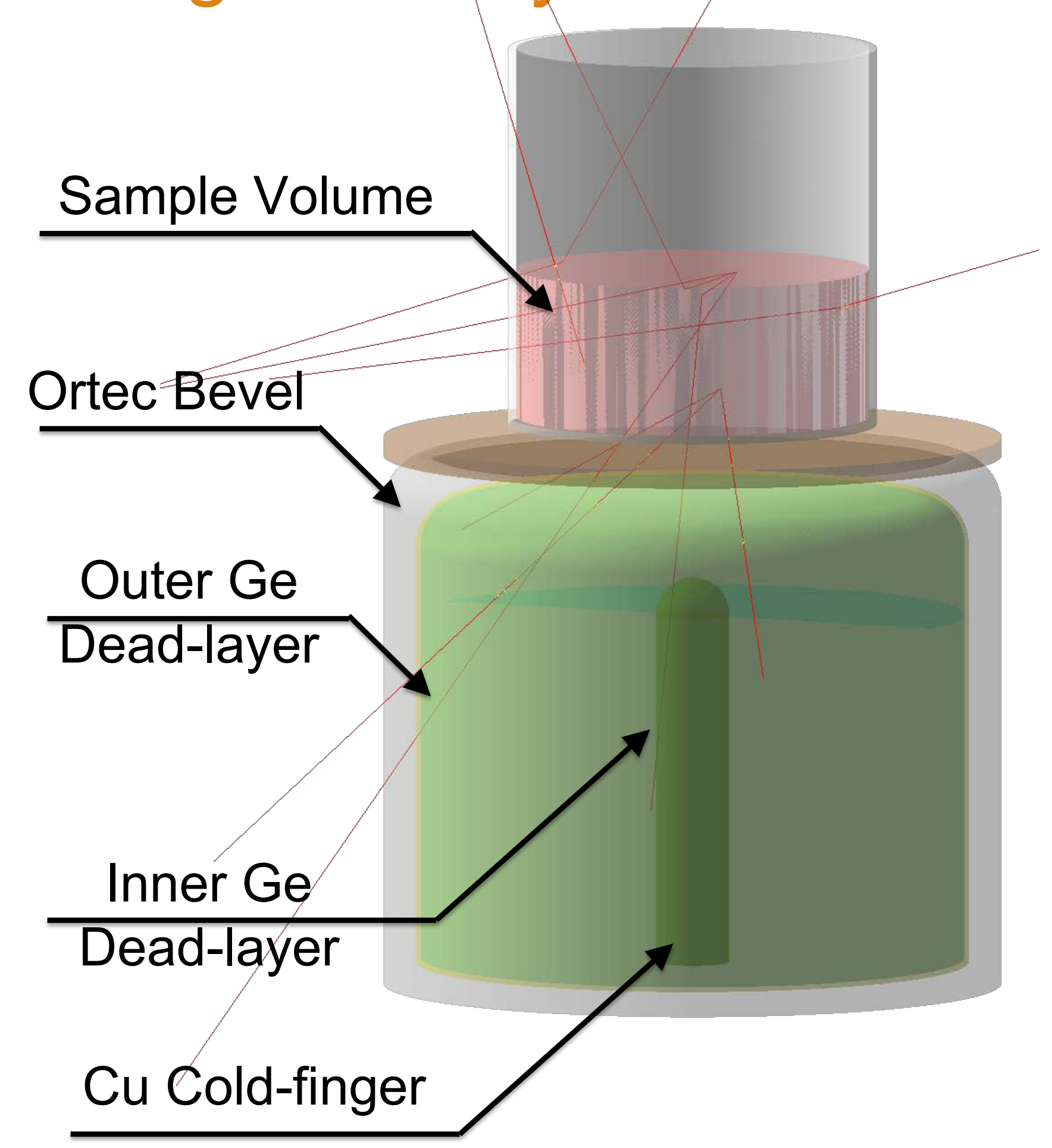
Achieving the maximum sensitivities for detection of Comprehensive Nuclear Test-Ban Treaty relevant radionuclides during an on-site inspection (OSI) using gamma spectroscopy in-field is difficult. Detector sensitivity to relevant radionuclides varies based on the operational conditions such as environmental background and equipment performance [1-3]. The motivation of this work was to examine the impact of crystal design parameters on a germanium detector's (HPGe) sensitivity to a sample representative of an unfractionated nuclear detonation sample.

A modeling utility built using the GEANT4 C++ framework has been developed to simulate acquired gamma spectra from any user defined source and HPGe detector. Several detector responses were simulated for a sample containing a mixture representative of a fast-fission sample of ^{239}Pu. The simulations were conducted at several times (2, 10, 15, and 30 days) post-detonation for OSI relevant radionuclides. Simulations were conducted for HPGe systems from: the Integrated Field Exercise in 2014, Pacific Northwest National Lab, and a crystal from a spectroscopic portal monitor system.

Method & Analysis

GEANT4 was selected because of its versatility in constructing user specific tallies and a complete physical simulation of nuclear decay. A high-fidelity detector construction routine was developed that captures minor design differences between Canberra and Ortec HPGe crystals.

High Fidelity Model



Jar Soil Geometry

Crystals were exposed to 2oz and 4oz soil jar samples in simulation space containing varying concentrations of ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{105}Rh, ^{106}Rh, ^{127}Sb, ^{129}Te, ^{132}Te, ^{131}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{141}Ce, ^{143}Ce, ^{144}Ce, and ^{147}Nd. A detector tally designed to include the effect of true-coincidence summing was used in the simulation to assure accurate estimation of the impact of sum events on the MDA at higher energies.

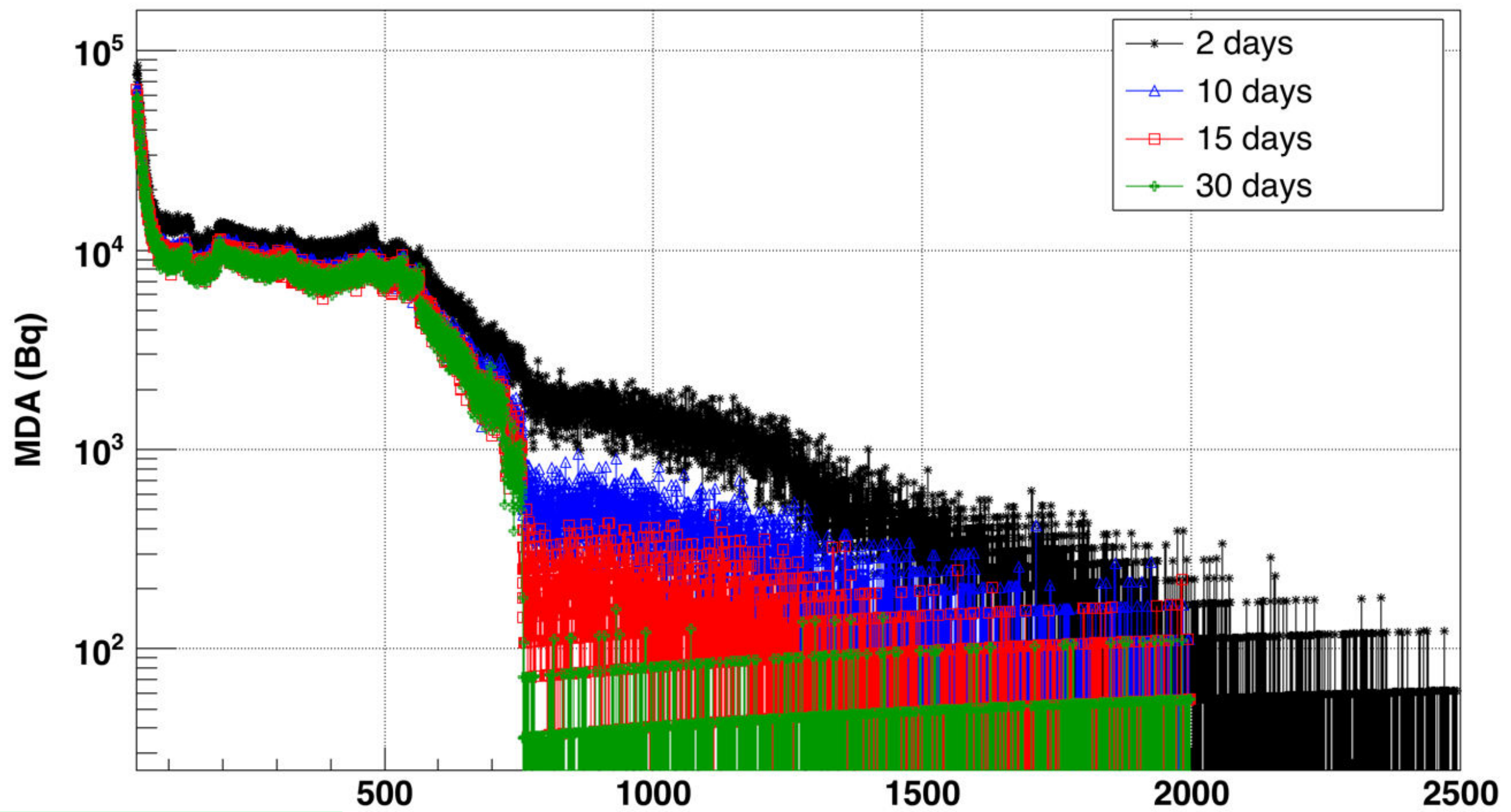
Results & Discussion

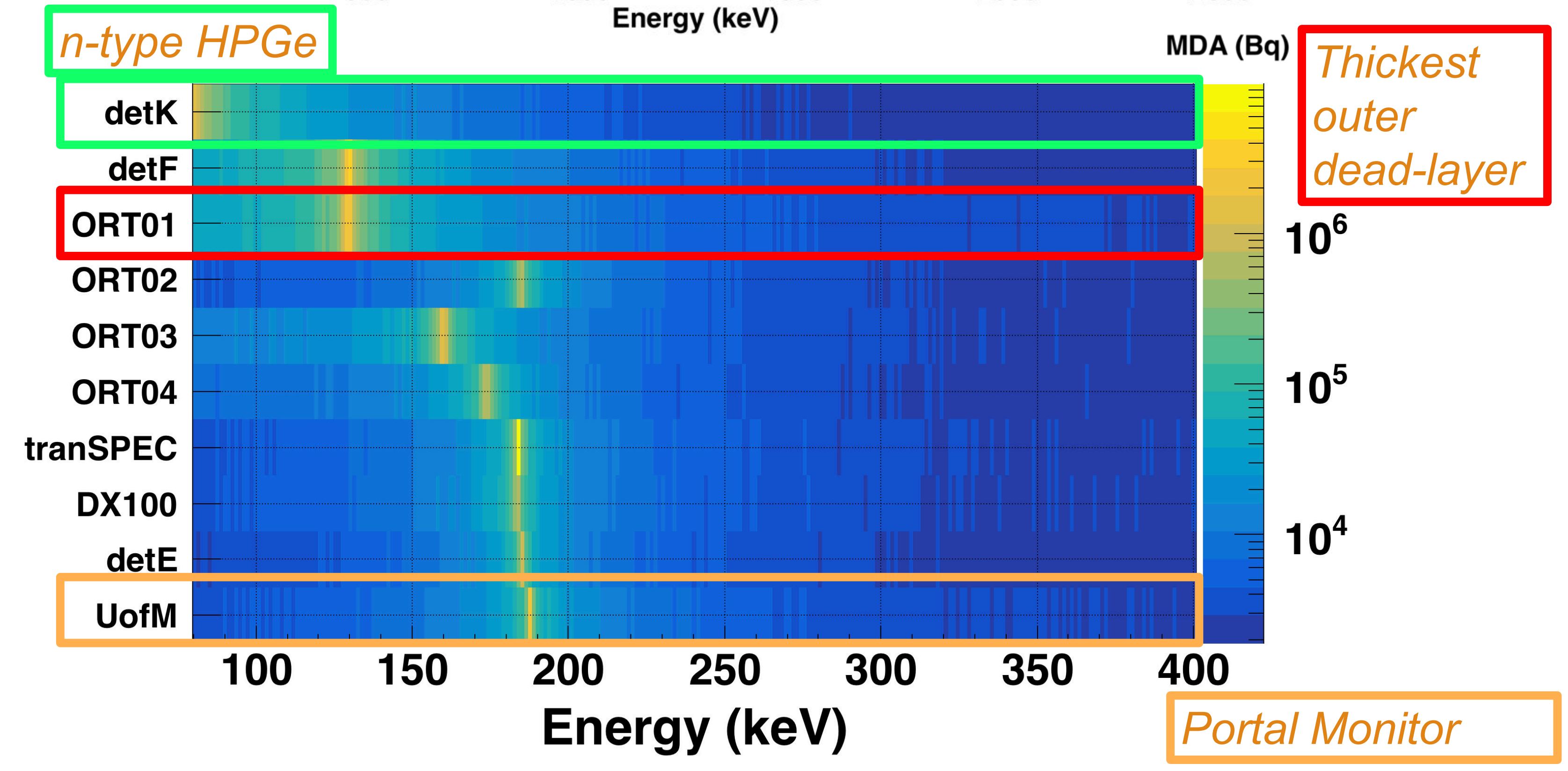
Radionuclide non-specific Minimum Detectable Activity (MDA) spectra were simulated using the high fidelity model for each of four post-event time intervals. Decay of ^{140}La/Ba over the 30 day interval can be inferred from the increasing sensitivity between 765-1596 keV. The most significant difference over time can be seen in the lobe feature at ~100 keV and the increase in the non-specific MDA from about 400-765 keV between the 2 and 30 day post-event spectra. The energy-dependent MDA is also ~40% lower at 100 keV for the 30 day interval relative to the 2nd day.

The most interesting observation from this experiment was the dramatic difference in the full-energy range MDA of the thickest dead-layer crystal in comparison to the n-type detector.

Radionuclide Non-specific MDA

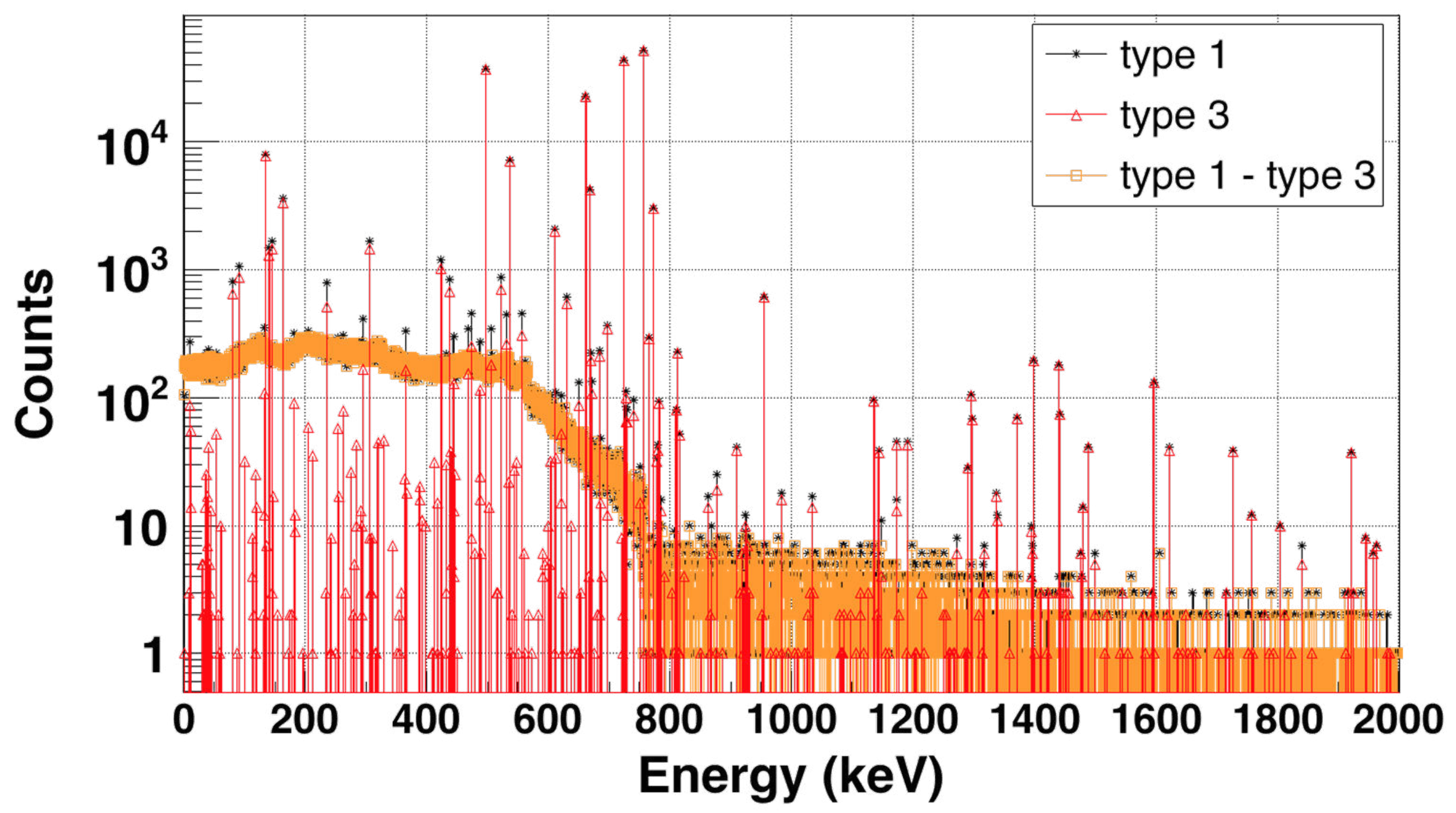
$$\frac{\Gamma_a \cdot \mathrm{MDA}_a \cdot (1 - e^{-\lambda_a t_c})}{\lambda_a t_c} = \frac{(4.65\sqrt{\mathrm{bkg}} + 2.71)}{\varepsilon}$$





Plutonium Fission Spectrum

Simulated nuclide inventory of a 2-hour count following pulsed fast-fission of ^{239}Pu at 2 days post irradiation.



			(mm)				
Det.	**Type**	**Manuf.**	**dia.**	**hgt.**	**DL**	**Can Thick.**	**Can Material**
detK	n	PGT	71	71	0.003	0.5	304 Stainless
100% eff.	p	Canberra	80.2	80.6	0.61	1.5	Aluminum
ORT01*	p	Ortec	87.9	98.1	0.7	3.6	Aluminum
ORT02*	p	Ortec	85.6	105.1	0.7	1.5	Aluminum
ORT03*	p	Ortec	89.4	76	0.7	1.5	Aluminum
ORT04*	p	Ortec	82	105.5	0.7	1.0	Aluminum
tranSPEC*	p	Ortec	66.2	50.5	0.7	1.0	Aluminum
DX100*	p	Ortec	67	52.3	0.7	1.0	Aluminum
detE	p	Ortec	81	83.5	0.7	1.5	Magnesium
40% eff.	p	Ortec	84.7	32.4	0.7	1.6	Aluminum

The above table is a simplified description of the detectors modeled in this work. Detectors with an asterisk were used during the IFE 2014 exercise. These simulations covered a moderate range of diameters and wide range of heights and can thicknesses.

Conclusions & Future Work

Based on this review, the ideal detector was actually not the largest volume detector. The best performing p-type detector was the spectroscopic portal monitor detector with a width of 82mm and thickness of 32mm. This detector provided comparable sensitivity to the larger volume detectors within the poorest sensitivity region of the spectra below the ^{95}Zr 765-keV gamma where gamma-ray down-scatter dominates the spectrum.

The most sensitive detector, however, was the n-type HPGe detector. This crystal type is difficult to work with in-field because of x-ray summing effects. Nevertheless, advanced simulation utilities capable of accurately estimating true-coincidence summing paired with n-type detector assay is a promising method for obtaining significant (~50%) improvements in detector sensitivity for OSIs.

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[1] J. L. Burnett, H. S. Miley, and B. D. Milbrath, "Radionuclide observables during the Integrated Field Exercise of the Comprehensive Nuclear-Test-Ban Treaty," *Journal of Environmental Radioactivity*, vol. 153, pp. 195–200, Mar. 2016. https://doi.org/10.1016/j.jenvrad.2016.01.002

[2] J. L. Burnett and A. V. Davies, "On-site inspection for the radionuclide observables of an underground nuclear explosion," *Journal of Radioanalytical and Nuclear Chemistry*, vol. 303, no. 3, pp. 2073–2079, Mar. 2015. https://doi.org/10.1007/s10967-014-3739-0

[3] R. Britton, J. L. Burnett, A. V. Davies, and P. H. Regan, "Maximising the sensitivity of a γ spectrometer for low-energy, low-activity radionuclides using Monte Carlo simulations," *Journal of Environmental Radioactivity*, vol. 134, pp. 1–5, Aug. 2014. https://doi.org/10.1016/j.jenvrad.2014.02.018

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