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Sensitivity Analysis of Activity Concentrations to Effective Sample Position in IDC products using Monte Carlo Simulation

CTBTO PREPARATORY COMMISSION

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INTRODUCTION

Manual system is part of the particulate monitoring technology used in the CTBT's IMS. It involves a sample holder to maintain the measurement repeatability. This study aims to emphasize the importance of the sample holder.

METHODS/DATA

Four detectors with different crystal sizes and shapes were simulated using Monte Carlo simulation. For each detector, efficiency curves with varying radial positions were determined, and their impact on the detector efficiency was evaluated.

START

RESULTS

Photo-peak efficiencies decreased when radial position biases were introduced. The decreased efficiencies consequently affected the quantification of activity concentrations of commonly observed natural isotopes at IDC products such as Pb-212, Be-7 and K-40.

CONCLUSION

The result exemplifies the importance of the sample holder to improve the accuracy in reported activity concentrations.

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Introduction

- Comprehensive Nuclear-Test-Ban Treaty (CTBT)’s International Monitoring System (IMS) operates airborne particulate monitoring systems to identify any indications of a nuclear test.
- For the particulate monitoring, the IMS utilizes three systems, Radionuclide Aerosol Sampler/Analyzer (RASA), CINDERELLA/Automatic Radionuclide Air Monitoring Equipment (ARAME) and manual.
- While sample placement for measurements is an automatic process in RASA and CINDERELLA/ARAME, the manual system requires human intervention.
- At manual stations, a sample holder is used to maintain the measurement repeatability.
- This study investigates potential efficiency changes, which originates from the sample radial position bias since it can affect the quantification of activity concentrations in International Data Centre (IDC) products.

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Objectives

1. Simulate HPGe detector efficiencies at default sample positions with detectors having different crystal sizes and shapes. Four detectors used at the IMS manual stations were randomly selected as tabulated below.

Detector ID	Crystal Shape	Crystal Radius [mm]	Crystal Height [mm]	End-Cap Radius [mm]
DET 1	Planner	40.5	30	51
DET 2	Coaxial	40.8	83.5	48.5
DET 3	Coaxial	33	66	42.8
DET 4	Coaxial	32	64	44.8

2. Simulate detector efficiencies, while varying radial positions in increments of 5 mm up to 20 mm (radial position bias).

3. Calculate efficiency differences for commonly observed natural isotopes in IDC products, Pb-212 (238.6 keV), Be-7 (477.6 keV) and K-40 (1460.8 keV).

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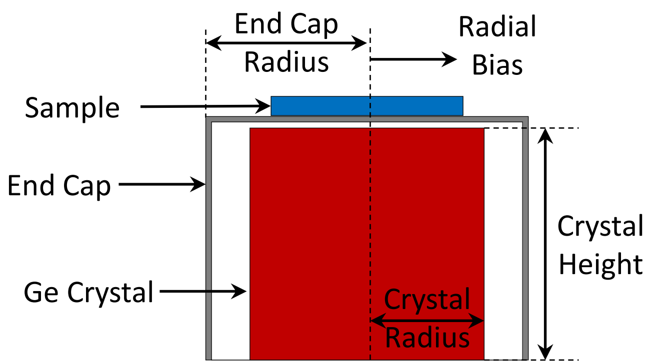
Methods

- The sample is a cylindrical compressed filter with a radius of 25 mm and thickness of 5 mm.
- The default sample position is the calibration geometry, that sample and detector crystal are concentric as shown below.
- This study used VGSL (Virtual Gamma Spectroscopy Laboratory) software package for Monte Carlo simulation [1].
- Each simulation ran until the statistical uncertainty in the efficiency is less than 0.5% in all energy bins.
- VGSL-simulated efficiencies under default geometries were validated using experimental data from calibration measurements. The calibration sources contain a standard mix of isotopes, as tabulated in the right table.
- Using the VGSL-simulated efficiency pairs, least-square fitting to the empirical efficiency curve was performed with only non-TCS (True Coincidence Summing) peaks [2].
- Mean (μ) and standard deviation (σ) of differences between experimental and VGSL efficiencies were calculated.
- Difference = (Experimental Eff. - VGSL Eff.) / Experimental Eff.
- After the validation of default efficiency curves, efficiencies with radial position biases were simulated in a step-by-step approach.
- Efficiency differences at the selected energies were then calculated.

Isotope	Energy [keV]	Non-TCS
Am-241	59.54	Y
Cd-109	88.03	Y
Co-57	122.06	Y
Ce-139	165.85	N
Sn-113	391.70	Y
Cs-137	661.66	Y
Mn-54	834.83	Y
Y-88	898.04	N
Zn-65	1115.55	Y
Co-60	1173.24	N
Co-60	1332.50	N
Y-88	1836.06	N



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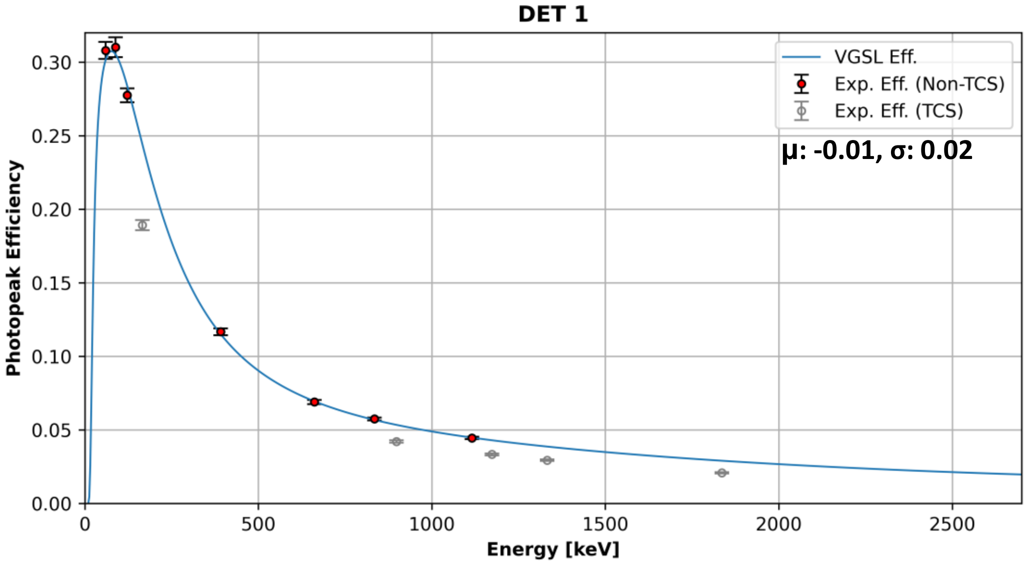
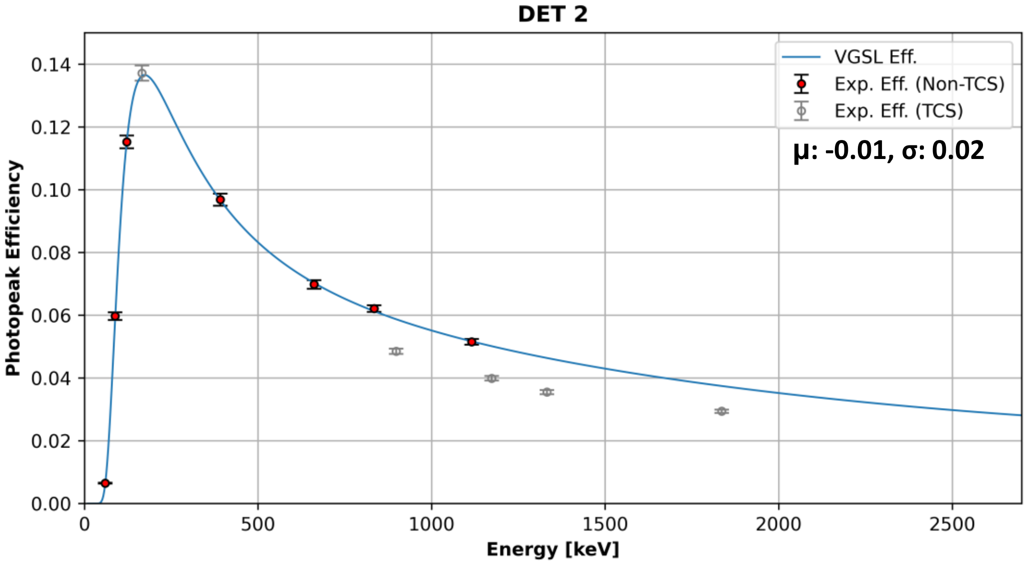
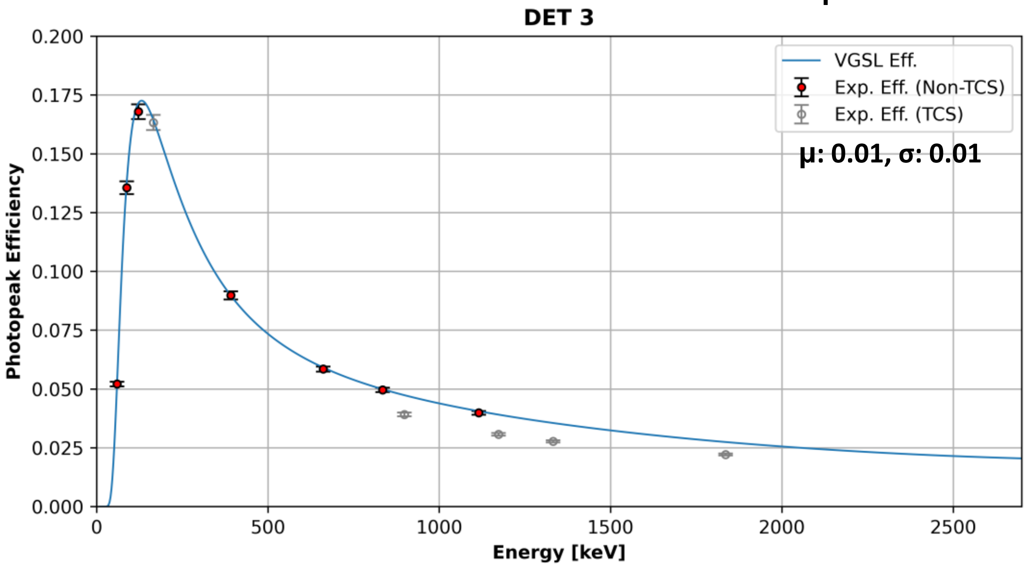
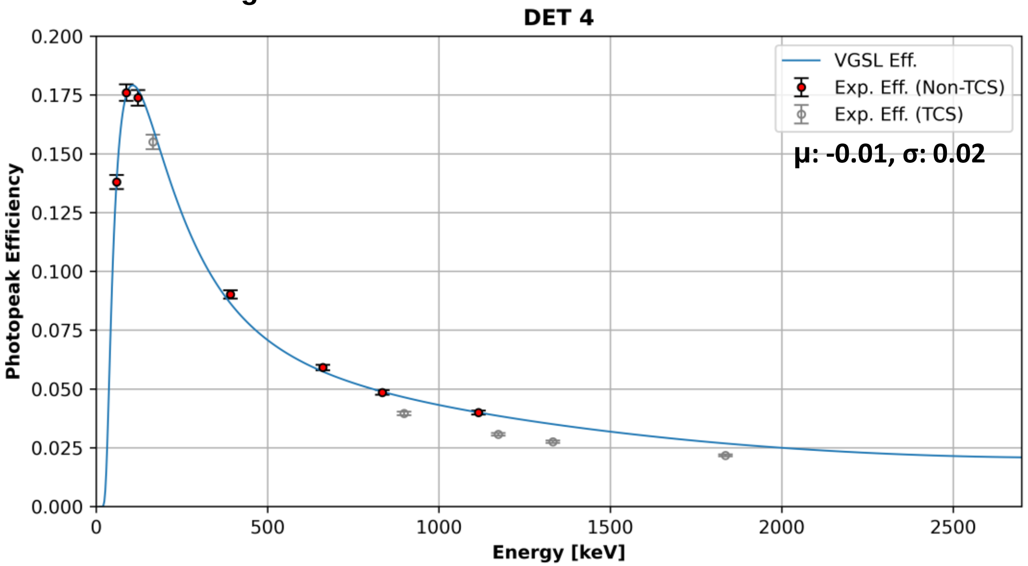
Results:
VGSL-Simulated Efficiency at Default Sample Position





TCS peaks are not included in the fitting.





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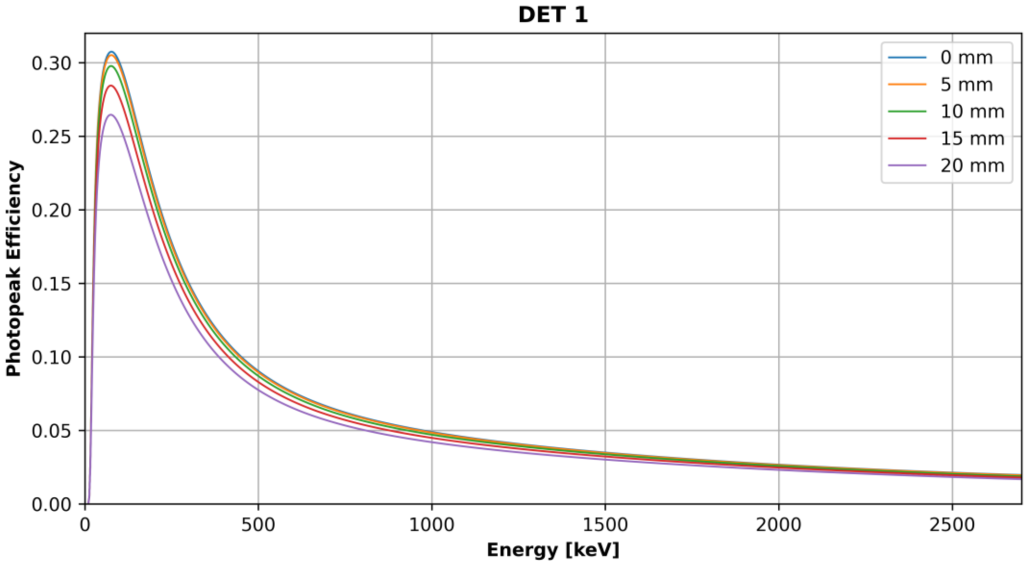
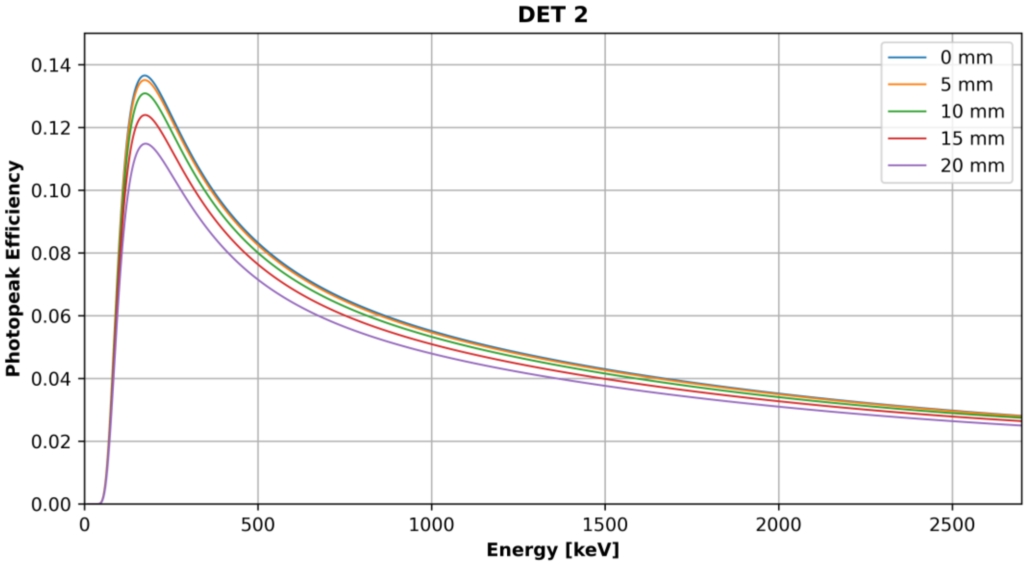
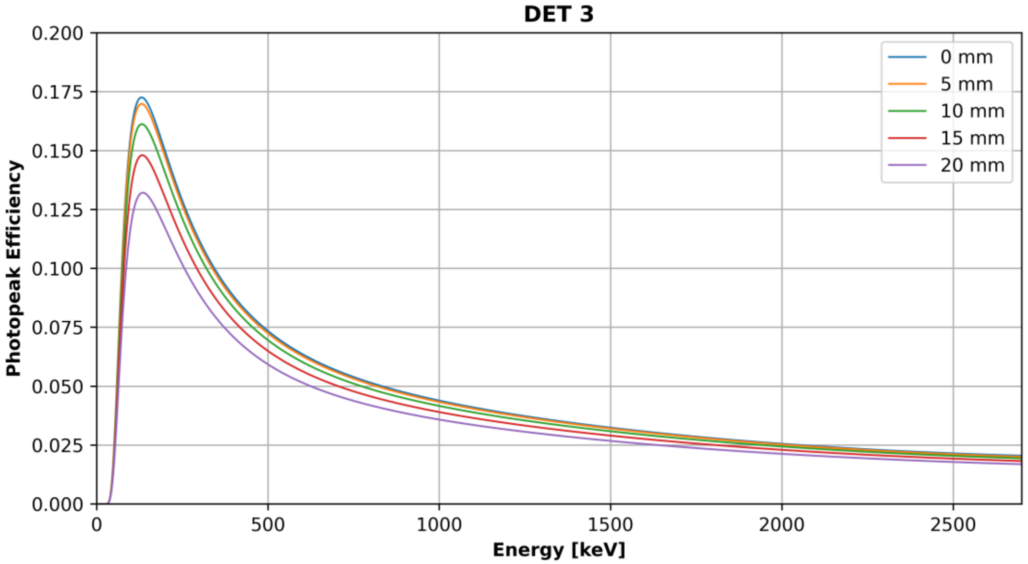
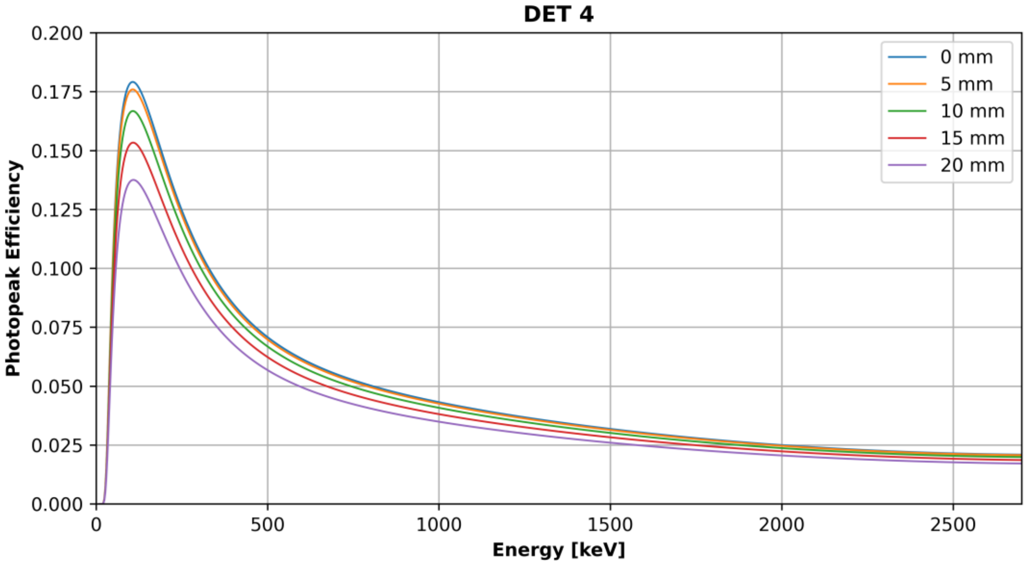
Results:
Simulated Efficiency Curves with Radial Position Bias









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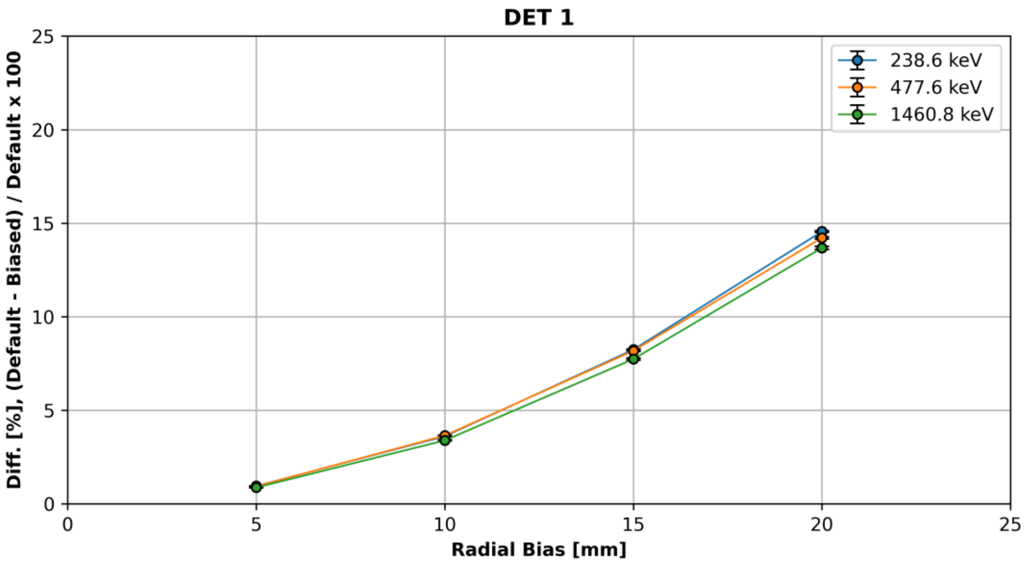
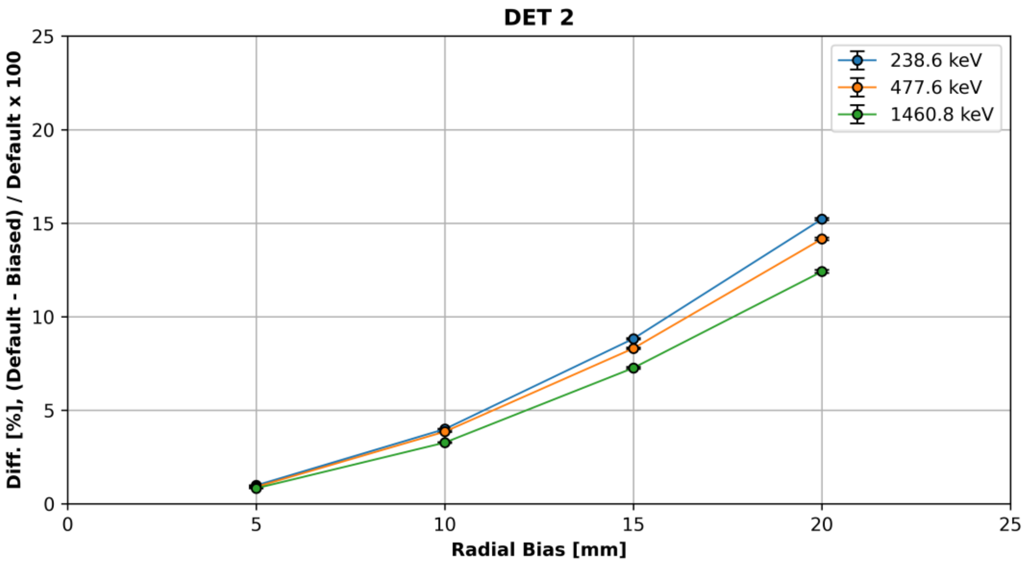
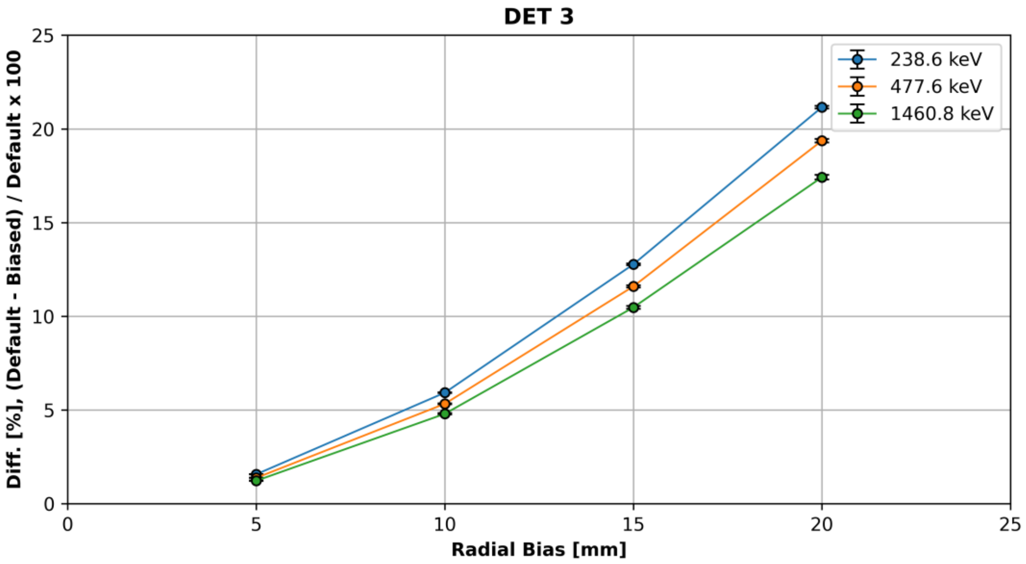
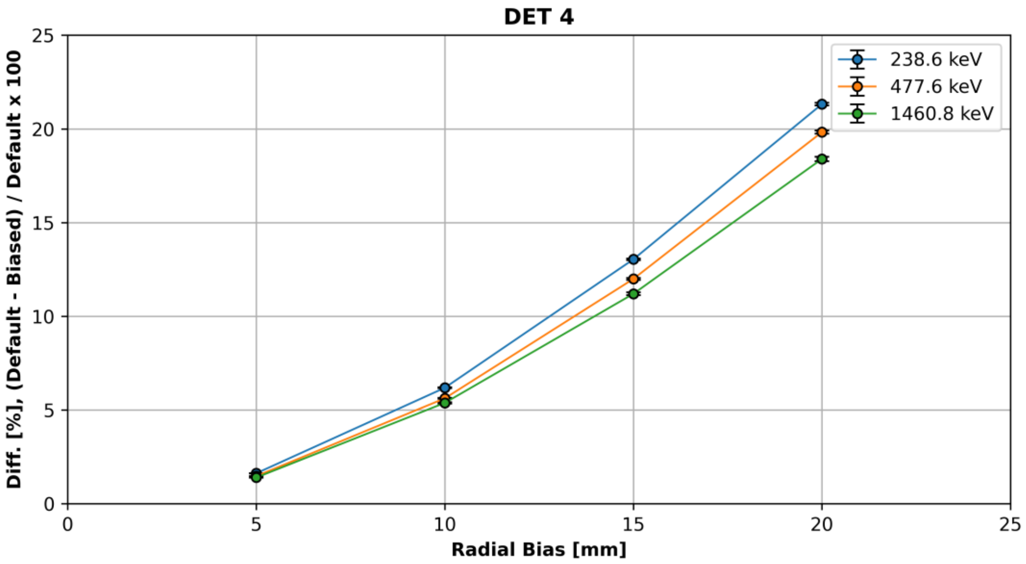
Results:
Efficiency Differences at Selected Energies









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Conclusion

- The results confirmed efficiency decrease when the radial position bias was introduced as also shown by *Helmer* [3]. The smaller the crystal radius was, the larger the efficiency because off-center bias is greater for smaller radius crystals.

- As the sample was located farther from the center position, efficiency decreased further in all energy range. The radial bias of 20 mm led to around 15 to 20% efficiency drops.

- The efficiency at 238.6 keV (Pb-212) was more affected by the position bias than that at 1460.8 keV (K-40), which infers that the quantification of Pb-212 activity concentration is affected to a greater extent.

- The use of sample holder plays an important role to maintain the measurement repeatability, as evidenced by the results.

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References

[1] R. Plenteda, 2002. “A Monte Carlo Based Virtual Gamma Spectroscopy Laboratory”, PhD diss., Atominstitut der Österreichischen Universitäten

[2] Canberra Industries, “Genie™ 2000 Spectroscopy Software Customization Tools V3.4 “

[3] Helmer, R. G., 1983. “Variation of Ge-Detector efficiency with source diameter and radial source position”, Int. J. Appl. Radiat. Isot. 34, 1105-1108.

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