Efficient System for Small Waste Containers Activity Estimation

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INTRODUCTION

We are developing a high efficiency system for accurate activity quantification of spatially distributed gamma-emitting isotopes ('hot spots') in homogenous content of waste containers. As a proof of concept, we first implement it for small waste containers.

Preliminary simulation results show high efficiency and good accuracy of the position and activity estimation

The purpose of this work is to improve, using Monte-Carlo simulations, the activity estimation accuracy by advanced algorithm that make use of the detectors pixelization and spectrum measurements.

The proposed measuring system

- The measurement system is shaped as a rectangular box made of 32 plates of scintillator detectors – 6 per side and 4 at the top and bottom caps (see Fig. 1).
- The waste-container is placed inside the scintillators box to capture almost all of the emitted Gamma-photons. This detection configuration is highly efficient due to the nearly 4π coverage of the radioactive material with scintillators (81% coverage).
- The pixelization of the box sides gives additional spatial data that we use for better source position estimation, hence better activity estimation.

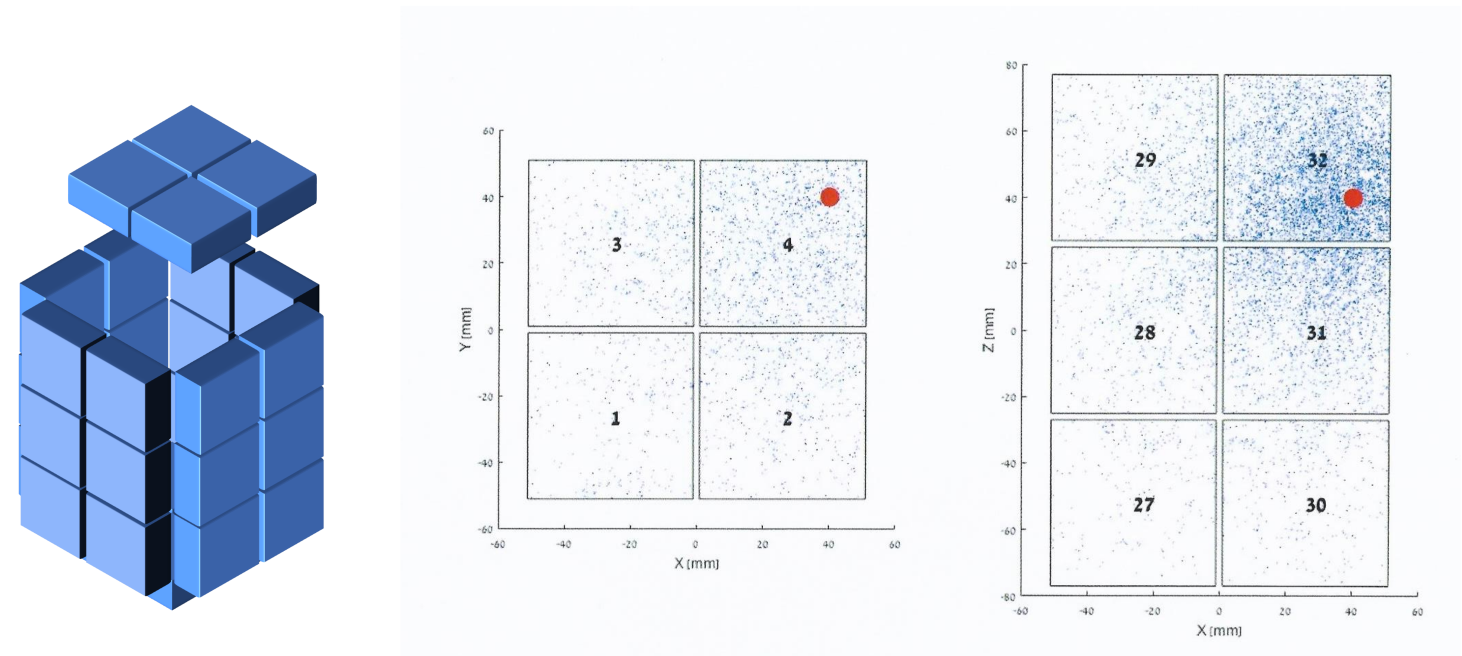

Figure 1: Scintillators Layout – 3D (left), top and bottom (middle) and sides (right). The events (blue) from a single ^{137}Cs source (red) through a concrete matrix.

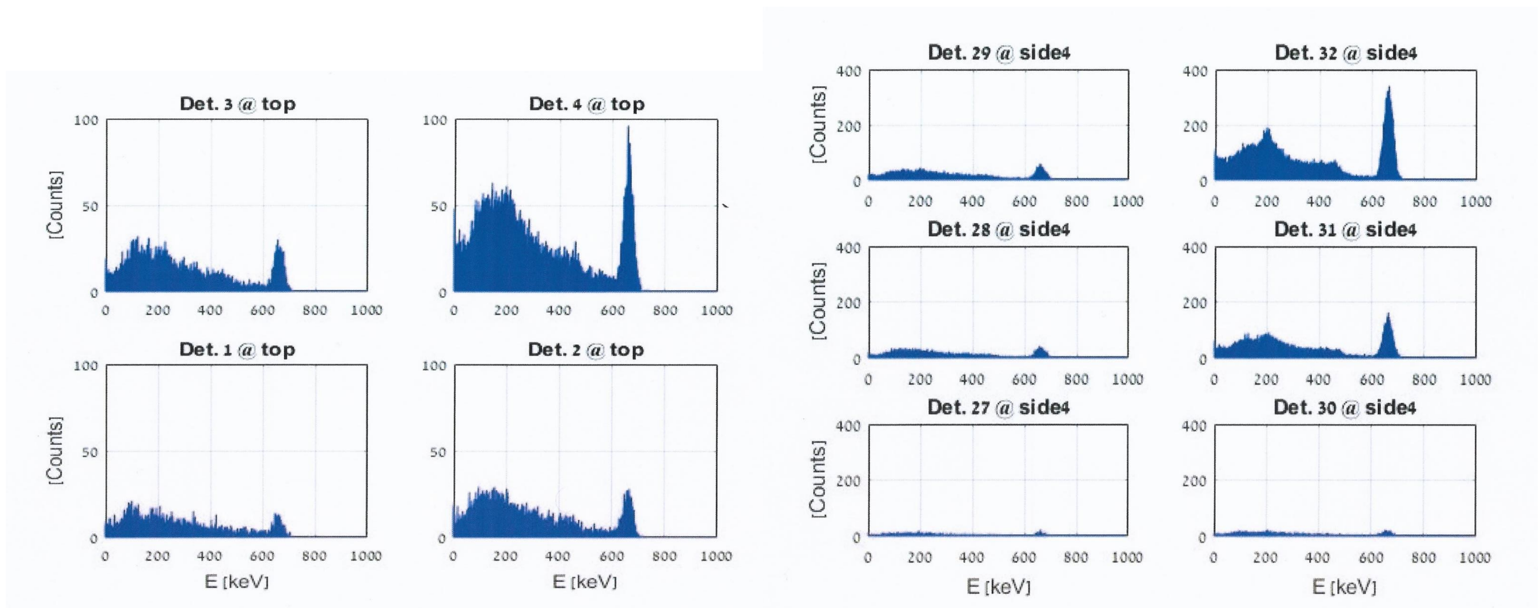

Figure 2: Spectrum readings of the single source in the respective detectors from Figure 1.

- The measured spectrums form the 32 scintillators plates is needed for the attenuation at different energy bands μ(E).
- To reduce the data
  - We sum the spectrum into bins of 50 keV/bin
  - We get 15-30 bins with sufficient counts (0.75 to 1.5 MeV, depending on the source maximum energy)
  - This create a total of 500-1000 data points for all spectrums in all the detectors for every source position, matrix material and type of source.

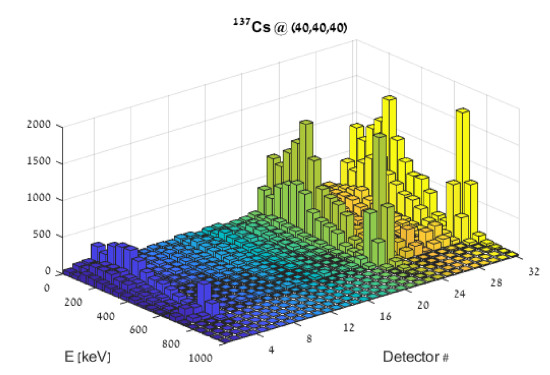

Figure 3: Full data set - 16 bins spectrum of 32 detectors for a ^{137}Cs positioned at (40,40,40)

Method

- The count of the peak bin is used to estimate the source activity.
- The whole spectrum range is used to estimate the number of hotspots and their positions, exploiting the fact that each source position has a different spectral signature in the detectors (Figure 3).

In this work the following steps are taken:

1. Build a database of simulated low resolution spectrums of the 32 detector plates. In each simulation we use only one source with different parameters:
   a) The source is located in a grid of possible positions
   b) Choose a different type of source with different energy emissions, e.g. ^{137}Cs, ^{60}Am, ^{60}Co etc.
   c) Different materials of the matrix, e.g. concrete, sand, plastic etc.
2. Measure / simulate several test cases with Different number of sources of the same type randomly spread in the container, in a few different matrix materials
3. Evaluate the attenuation by density and/or gamma transfers
4. Search the most probable positions for N hotspots using the Alternating Projection (AP) procedure developed by [1] and demonstrated in [2]:
   a) Each step we add a source and search for its optimal position while keeping the previous sources fixed
   b) Calculate the activities according to the ratio of the peak energy.
   c) Calculate the distance between the estimated spectrums to the measurements.
   d) After N sources, we randomly pick a source and search for a better position, and recalculate the activities and distance.
   e) Every few iterations, we randomly change the number of total sources to (N+1) or to (N-1) sources.
   f) Stop condition uses the distance of the reconstructed spectrums from the original measurements.

Preliminary Results and future work

❖ We compare the results to the basic method of Whole Body Count (WBC), where the source position is assumed at the center of the container.

❖ For known and homogenous matrix attenuation, the activity estimation maximum error of the WBC is 80% while with the new system it is 20%

❖ High accuracy (<10%) for low number of sources (hot spots) at any configuration in the waste container.

❖ Ongoing and future Work:
- Increase the database for different matrix materials.
- Check the influence of attenuation error on the activity.
- Add an iterative step to estimate better the attenuation.
- Use Principle Component Analysis (PCA) to shrink the number of data points important for the database position search.

❖ We are currently building a small model to test the proposed system.

Conclusions

❖ For homogenous and known attenuation the system maximal activity estimation error is reduced to 10% which allows to take a much smaller tolerance from the allowed activity of each waste level.

❖ Due to the high coverage of scintillators the system is very efficient and expected to reduce the measurement time by an order of magnitude Vs. a single detector and even more from a single collimated detector.

Bibliography

[1] Ziskind, I. and Wax, M. , "*Maximum Likelihood Localization of Multiple Sources by Alternating Projection*" ASSP-36, 1988, IEEE Transactions on ASSP, pp. 1553-1560.

[2] E. Vax, E. Marcus, T. Mazor, Y. Kadmon and A. Osovizky, "*Collimator-Less Passive Gamma Scanning for Radioactive Waste Drums*", IEEE Transactions on Nuclear Science, vol. 67, no. 4, pp. 544-551, April 2020

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