Performance Evaluation of Multi-Array Plastic Scintillation Detector

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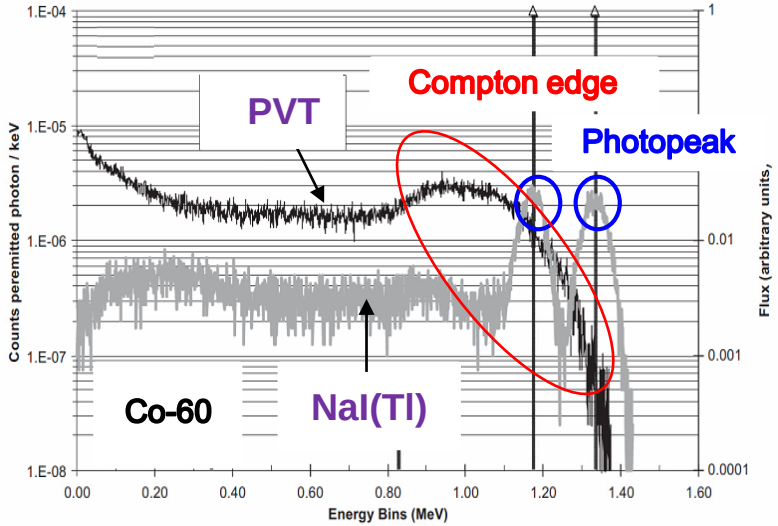
Introduction

Radiation Portal Monitor (RPM) Systems

- RPM systems perform **radiation monitoring** on border crossings.

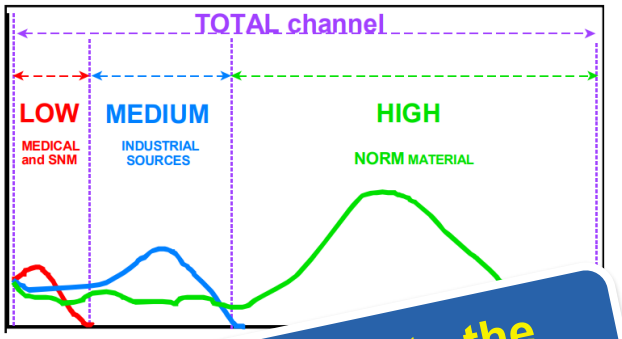
Large-sized
plastic scintillator



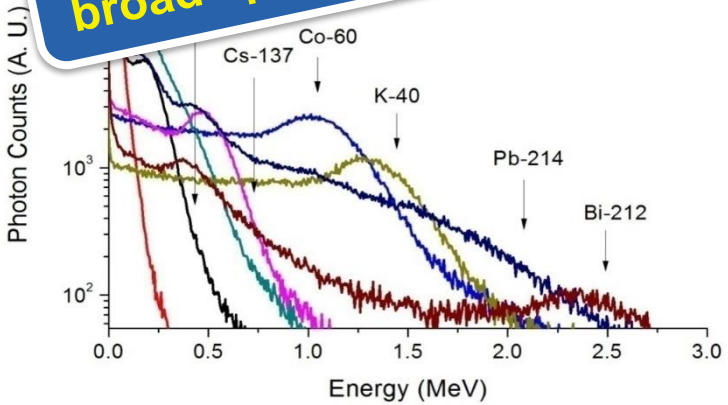
- Gamma ray and neutron detection
- Large detectable area
- Easily manufactured with reasonable price

- Low Z-number material
- Dominant Compton scattering probability
- Poor energy resolution
- Frequent nuisance alarms.

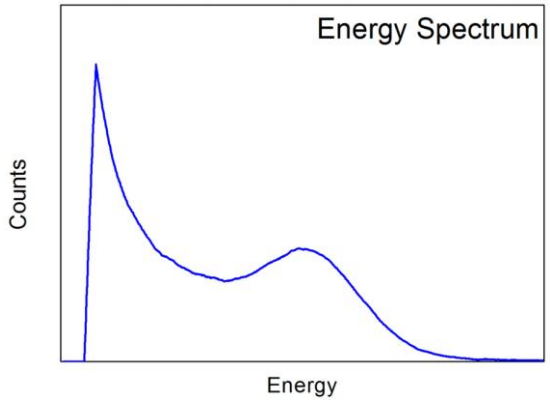
Classification Algorithm for RPM System



Limitations due to the broad spectra distribution



Energy weighted algorithm



$$C_{EW} = C \times E$$

C_i : Photon counts i^{th} bin

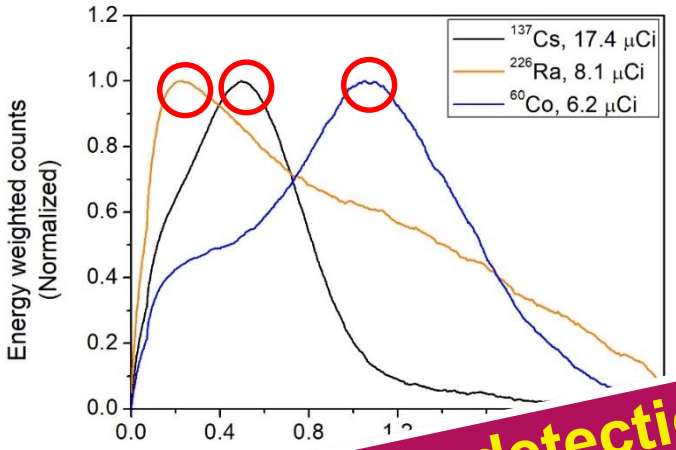
E_i : Energy of i^{th} bin [MeV]

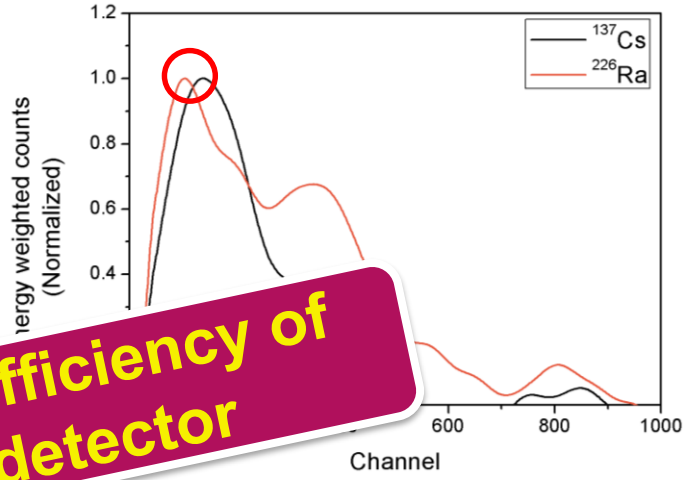
C_{EW} : Energy weighted count

- The energy weighted algorithm is that the **counts per channel of energy** spectrum are **multiplied by the energy of each channel**.

Spectral Distribution by Source Condition

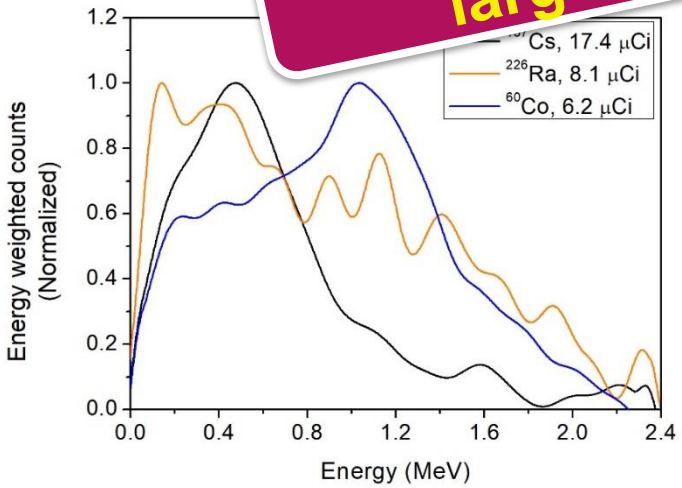
Static conditions

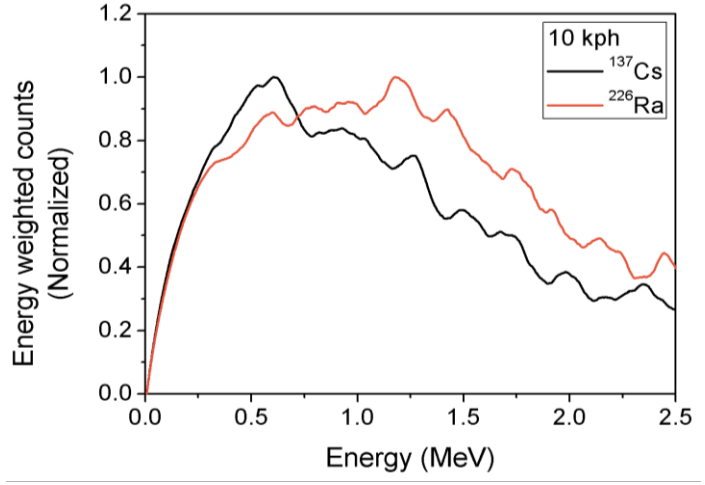




Low detection efficiency of large-sized detector

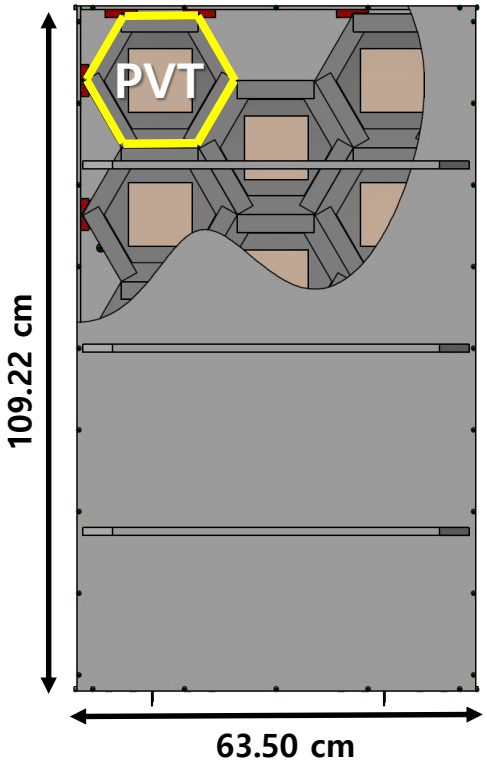
Dynamic conditions

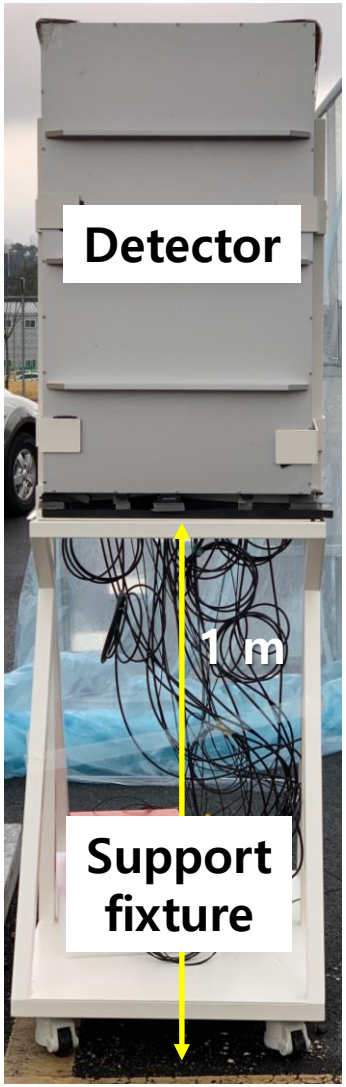




Multi-Array Plastic Scintillation Detector

- **Detector design**
  - Multiple hexagonal pillar shaped polyvinyl toluene (PVT) plastic were arranged in certain area.
  - Total 14 PVTs were arranged and each PVT was coupled with photo-multiplier tube (PMT).





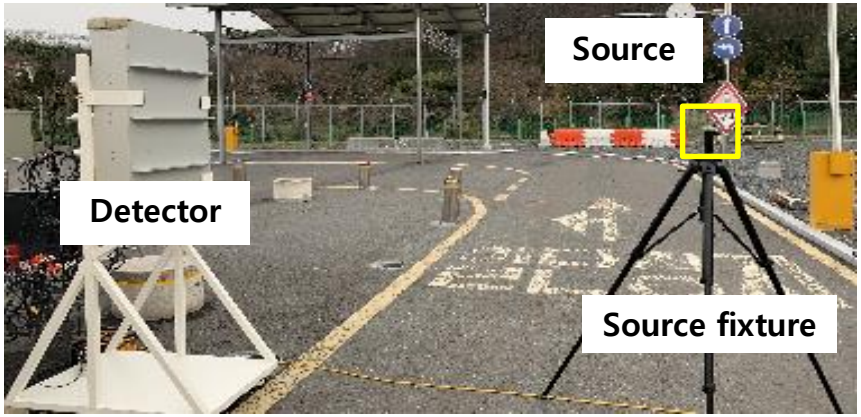
Purpose of the Study

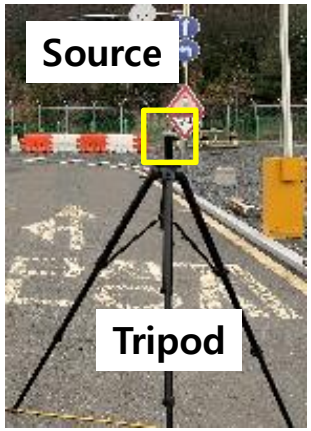
- The purpose of this study is to evaluate the performance of the multi-array plastic scintillation detector, which was designed to improve detection efficiency of conventional RPM system.

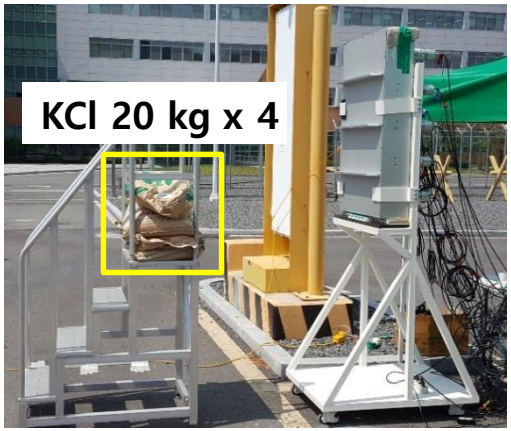
Materials and Methods

Practical Measurement Conditions

■ Static condition







- Radionuclides

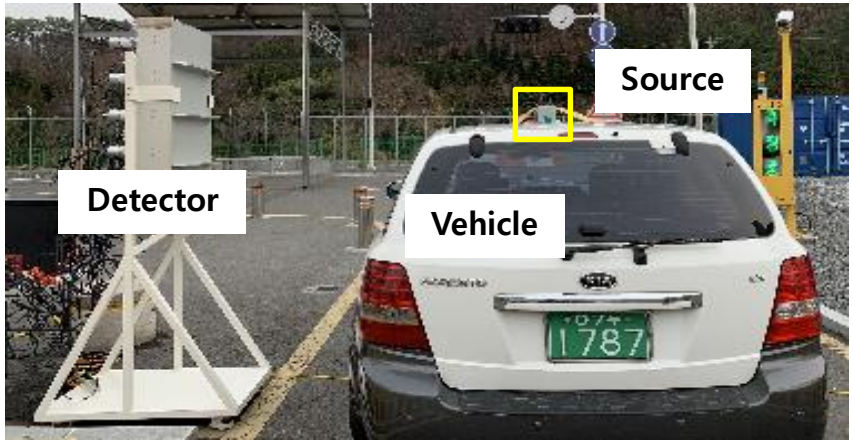
Source	^{137}Cs	^{60}Co	^{226}Ra	^{22}Na	^{54}Mn	^{40}K
Activity (μCi)	74.6	51.3	6.6	13.2	14.5	80 kg
Distance	2.5 m					0 m
Time	1-10 sec. 60 sec		60 sec			
Number of trial	5 (60 sec), 20 (1-10sec)					

* Background count was also measured.

- Nuclide to detector: 2.5 m
- Nuclides fixture materials
  - Tripod (disc sources, 2.5 m)
  - Additional stand (^{40}K, 1.0 m)

Practical Measurement Conditions

■ Dynamic condition



<Vehicle movement during experiment>

- Radionuclides

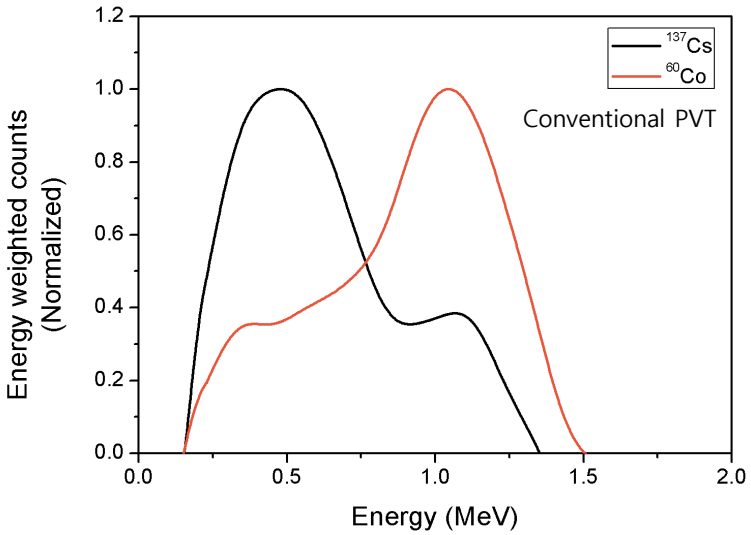
Source	^{137}Cs	^{60}Co	^{226}Ra	^{40}K
Activity (μCi)	4, 8, **16**, 32, 64	1, 3, **6**, 12, 24	14.1	80 kg
Speed (km/h)	10, 20, 30			
Number of trial	30			

* Background count was also measured.

- Vehicle speed: 10 km/h, 20 km/h, 30 km/h.
- Source is located to pass the center of the detector.

Performance Evaluation of the Detector

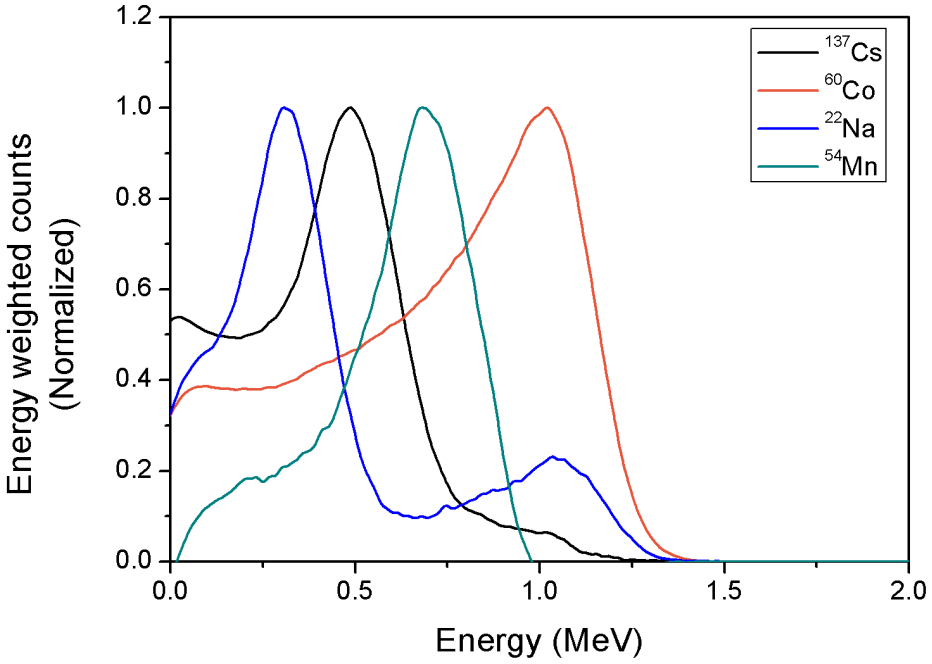
- **Static condition spectra**
  - The energy weighted spectrum of ^{137}Cs and ^{60}Co were measured previously.
  - The peak width was compared with full width at half maximum (FWHM).
  - Total count comparison.
  - Spectra by measurement time (1 to 10 sec)

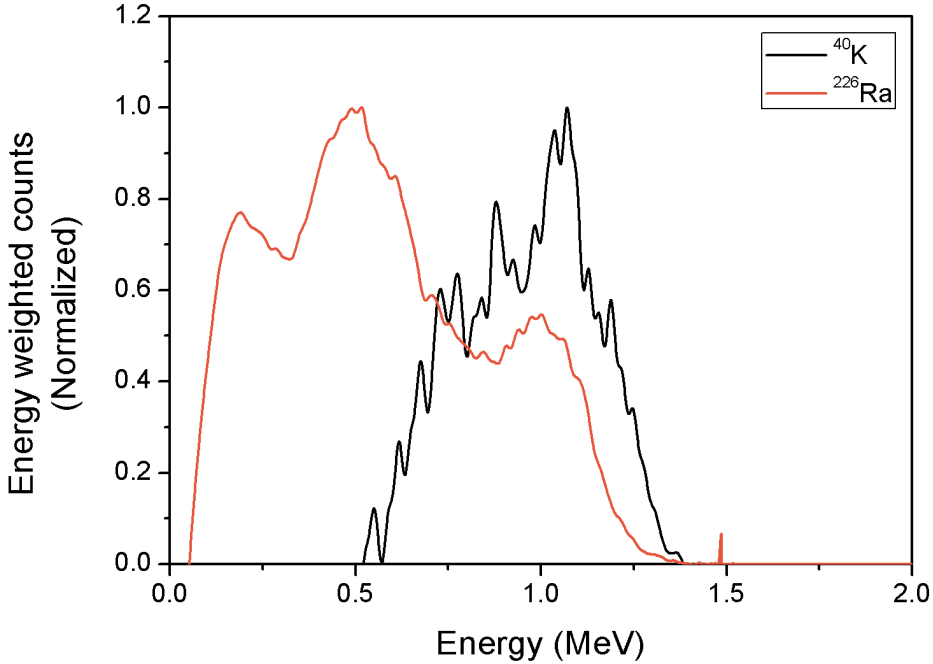


- **Dynamic condition spectra**
  - Spectra by the speed of the vehicle and the activity of the sources.
  - Speed: 10, 20, 30 km/h
  - Activity: 5 different activities for ^{137}Cs and ^{60}Co

Results and Discussion

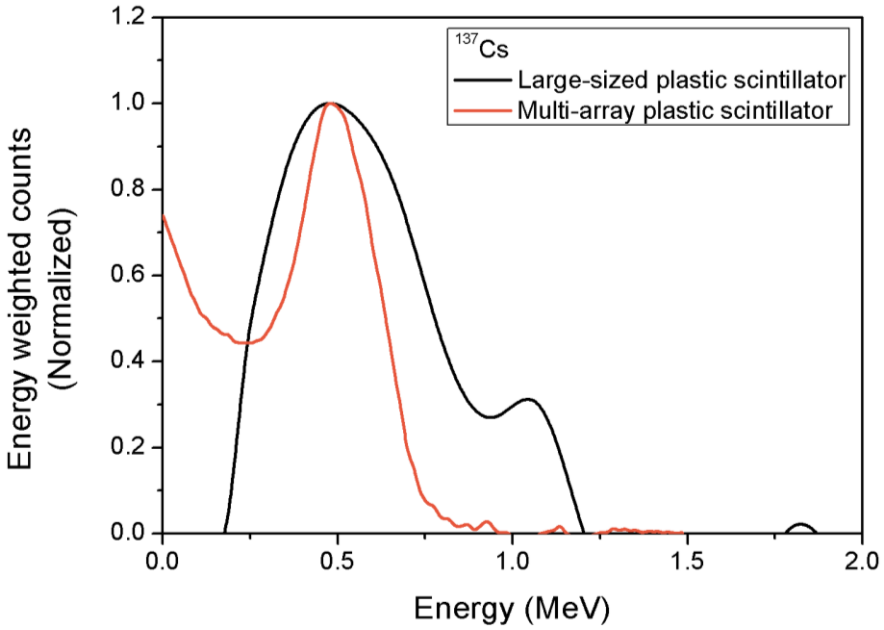
Energy Weighted Spectra Under Static Condition

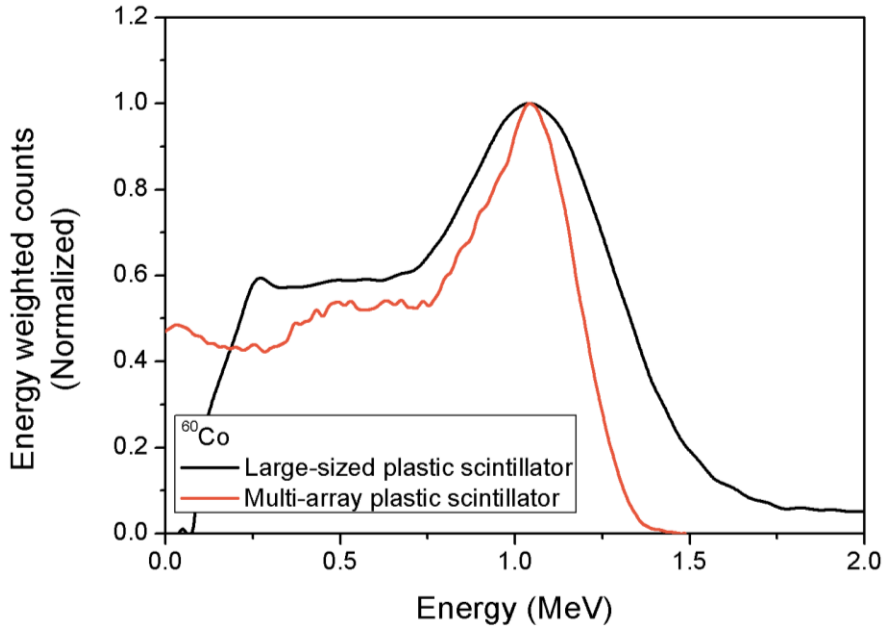




Energy Weighted Spectrum Comparison

- Energy weighted spectrum under static condition

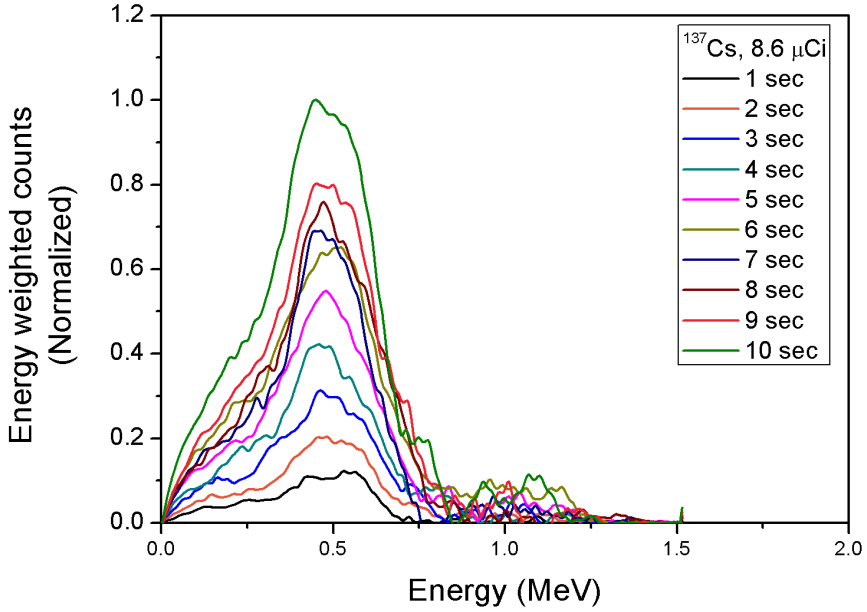




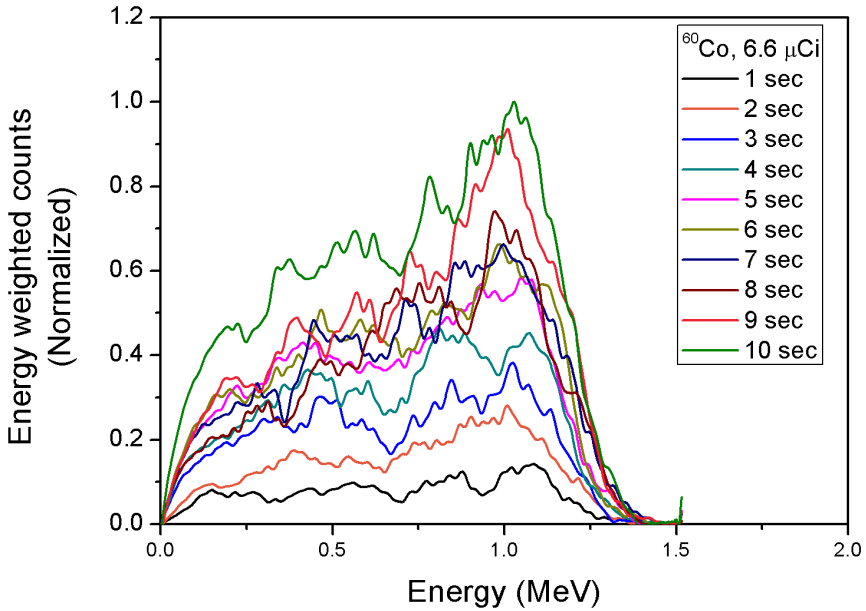
- The full-width at half maximum of the peak for the multi-array PVT was decreased by **26.30%** and **29.78%** for ^{137}Cs and ^{60}Co, respectively.
- The total count was increased with multi-array detector by **25.19%** and **11.46%** for ^{137}Cs and ^{60}Co respectively.

Energy Weighted Spectra by Measurement Time

■ ^{137}Cs



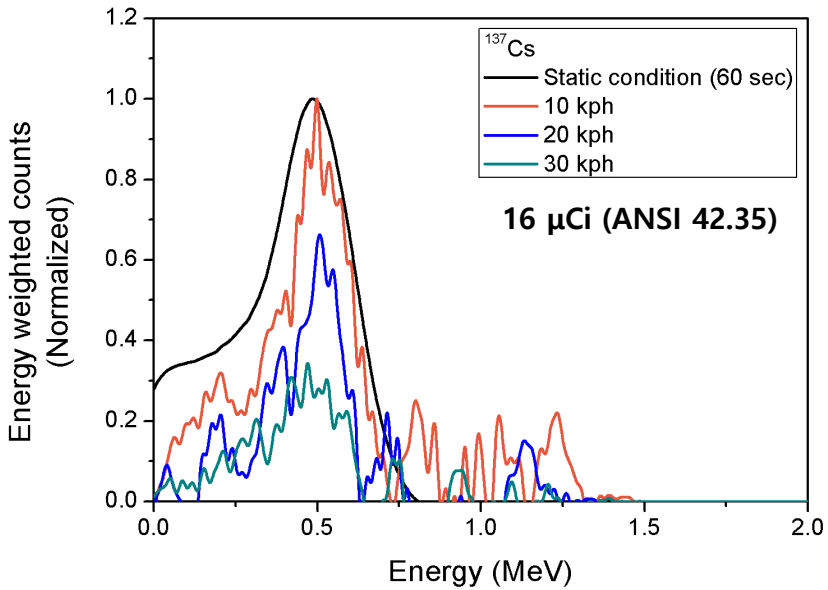
■ ^{60}Co

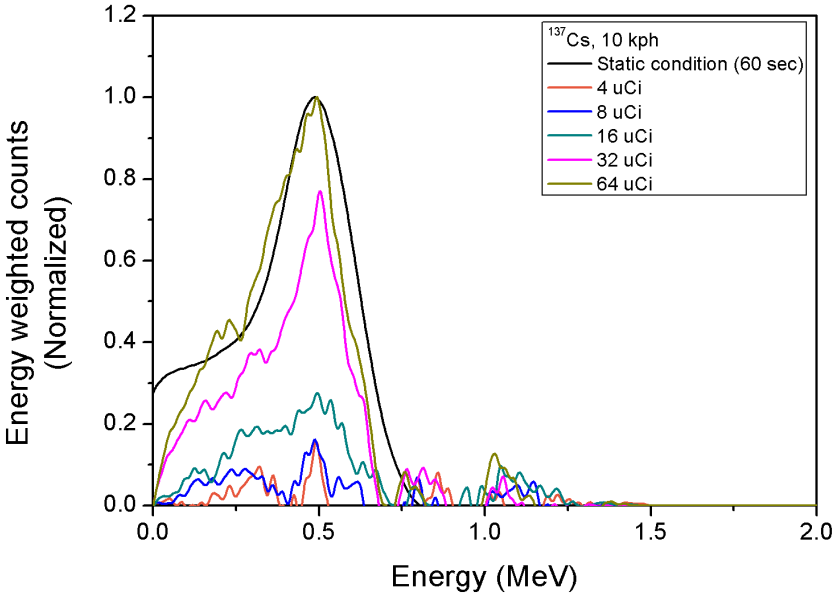


- For both nuclides, the spectra showed a single peak for all cases, even though the measurement time was decreased from 10 sec to 1 sec.
- The peak location was within 0.5% (0.002 MeV) and 3.5% (0.037 MeV) of the theoretical Compton edge energy of ^{137}Cs and ^{60}Co respectively.

Energy Weighted Spectra with Various Speed

■ ^{137}Cs

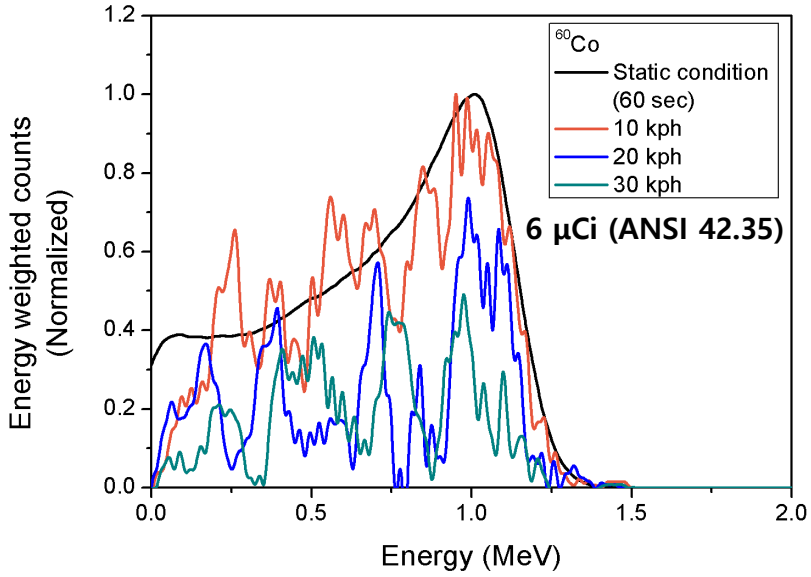


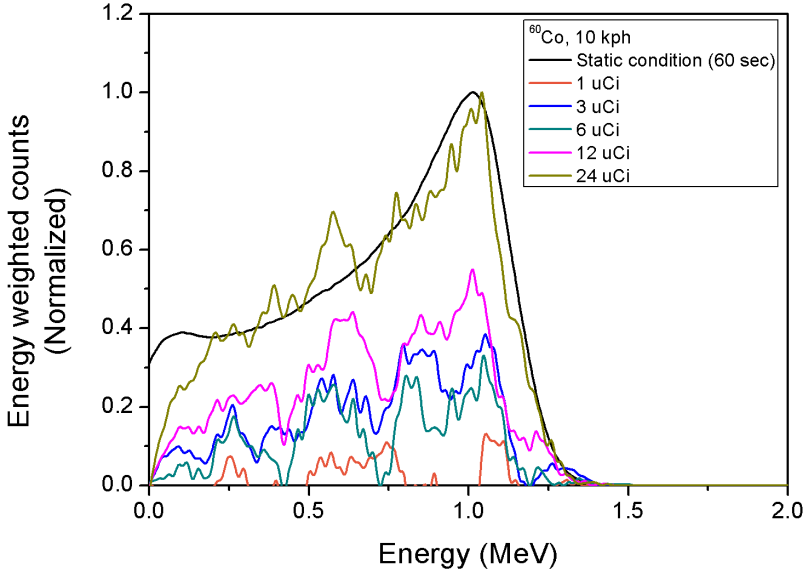


- As the speed of the vehicle was increased, the total count was decreased. However, the peak was located in ±**13.16%** range of the theoretical Compton edge energy.
- The statistical fluctuation of the spectrum was increased as the activity of the source was decreased, but the peak was observed.

Energy Weighted Spectra with Various Speed

■ ^{60}Co





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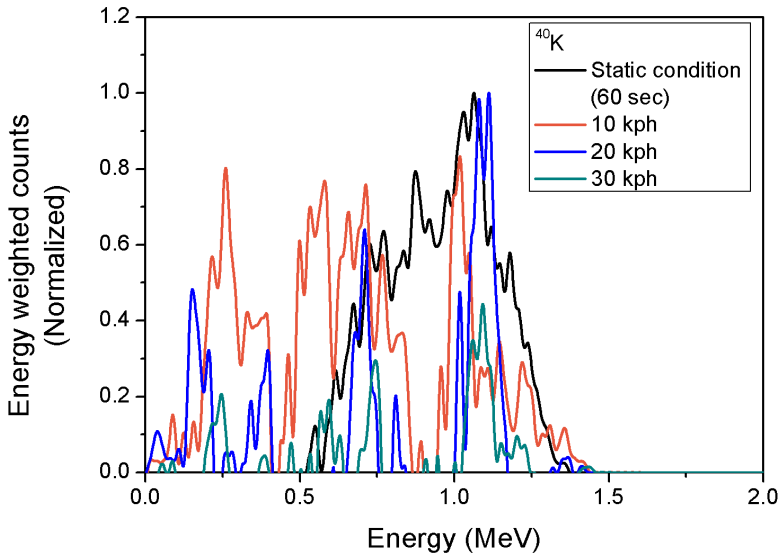
Energy Weighted Spectra of NORM Sources

Energy (MeV)

■ ^{40}K



- The Compton edge peak of ^{226}Ra was shown in the spectra, but the peak of daughter nuclide was not clear unlike the static condition.
- Some of ^{40}K spectra showed a peak at Compton edge energy, but with high statistical fluctuation.

Conclusion

Conclusion

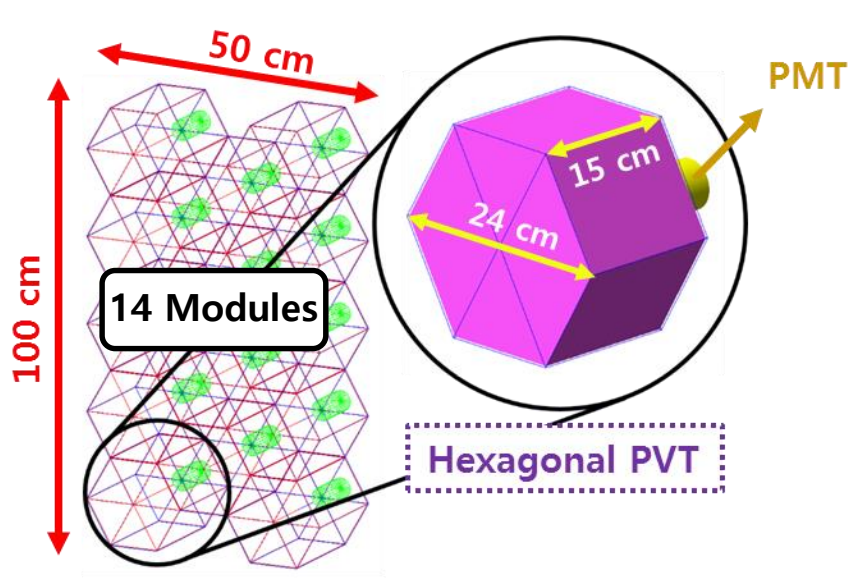
- In this study, the **performance evaluation** of multi-array plastic scintillation detector was proceeded.
- Multi-array plastic scintillation detector showed **sharper peak** and **abundant counts** than conventional detector.
- Additionally, the detector showed the **possibility of classification** with short time measurement or low activity of the source.
- With this results, **the classification between nuclides with similar theoretical Compton edge energies** is expected with higher accuracy than conventional detector.

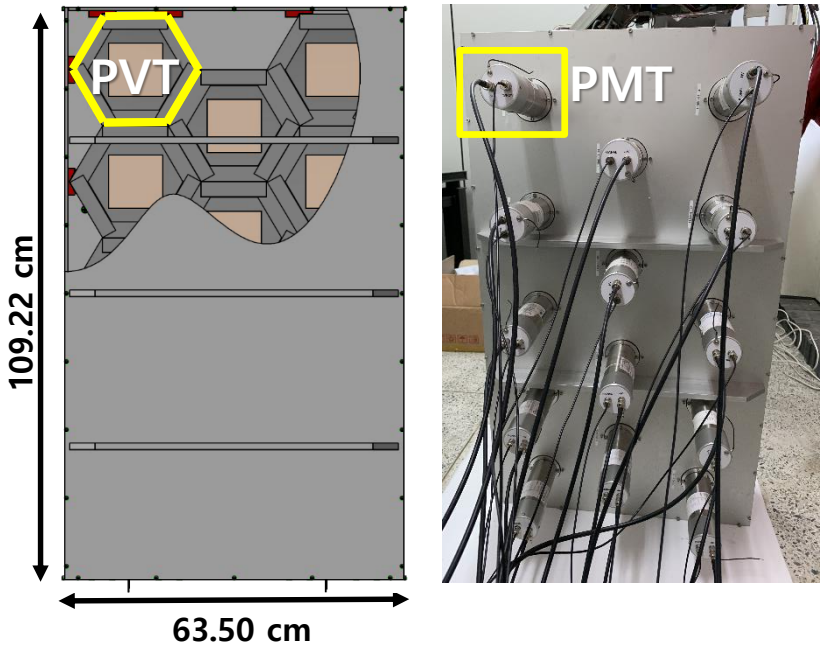
THANK YOU

Q & A

Multi-Array Plastic Scintillation Detector

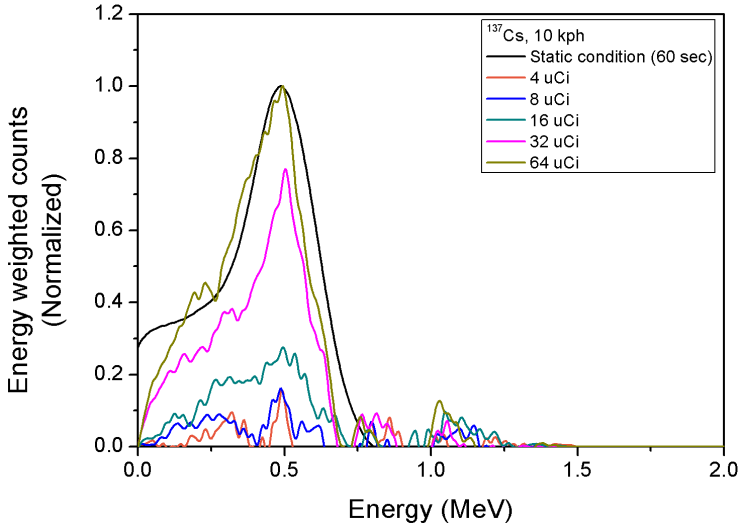
- Modeling the multi-array plastic scintillation detector
  - Optimal size of the detector was selected with the amount of produced and collected optical photons inside the detector.
  - Hexagonal pillar shaped PVT was multiply arranged with single PVT coupled to each PVT.

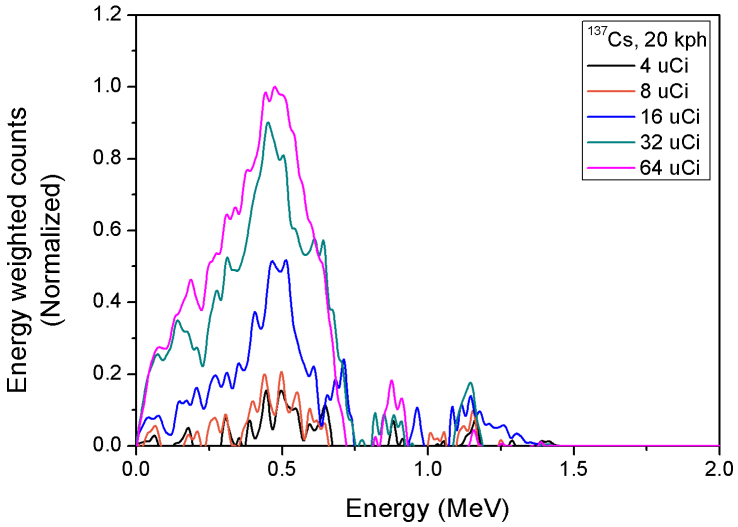


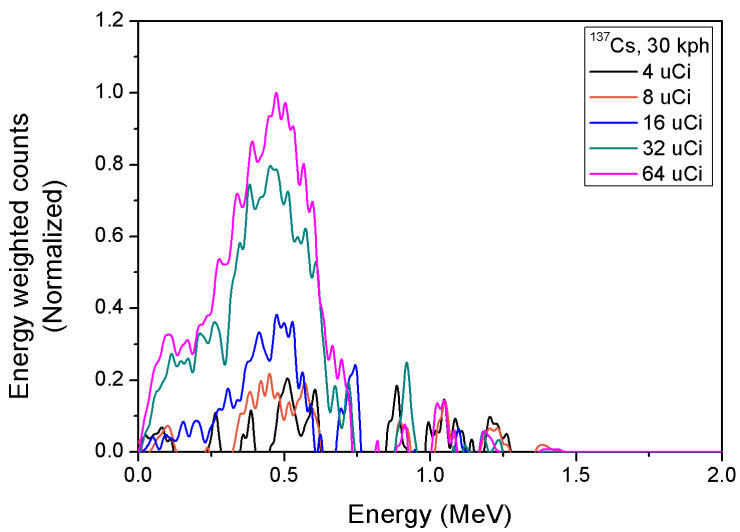


Multi-array plastic scintillation detector models. (Left: Geant4, right: practical model)

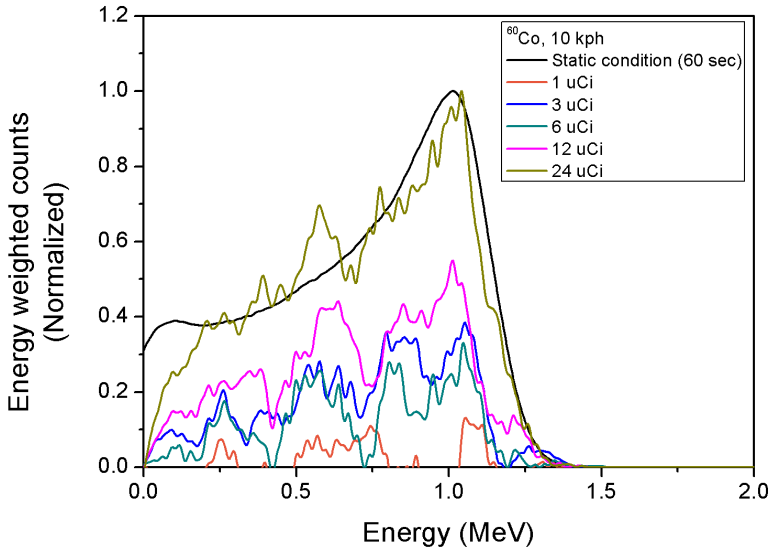
^{137}Cs 5 activities

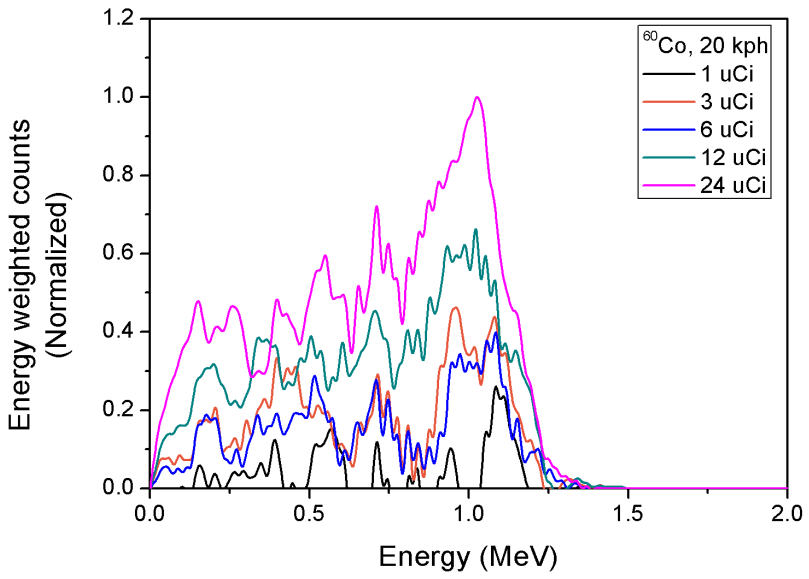


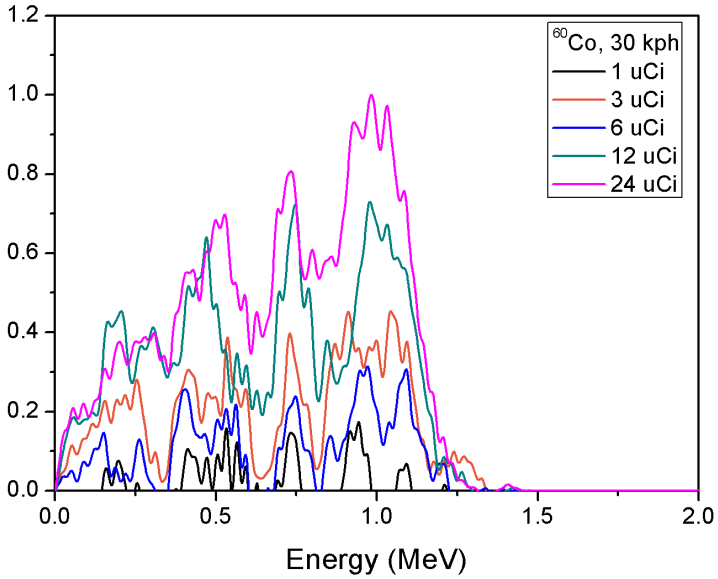




^{60}Co 5 activities







Energy Weighted Spectra Under Static Condition

- Energy calibration
  - ^{137}Cs (0.478 MeV), ^{60}Co (1.041 MeV), ^{22}Na (0.340 MeV), ^{54}Mn (0.639 MeV)
  - E (MeV) = 0.0008 * Ch – 0.1082

- Spectra of naturally occurred radioactive materials (NORM)
  - The energy weighted spectrum of ^{40}K showed high statistical fluctuation, but a single peak was located at Compton edge energy.
  - In case of ^{226}Ra, the Compton edge peak was shown, along with the peak of daughter nuclide after 1 MeV.