Development of a phoswich detector for radioxenon field measurements

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Background
Many radioxenon detector systems used in the International Monitoring System (IMS) and in related applications employ beta/gamma coincidence detection to achieve high sensitivity. While very sensitive to small amounts of radioxenon, the existing systems require careful calibration and gain matching of several detectors and photomultiplier tubes. Most systems are also designed for stationary operation and are heavy and bulky. Having previously developed the PhosWatch detector [1], we improved key aspects of the design to develop it into a field radioxenon detector. The PhosWatch is a CsIC404 phoswich detector and uses pulse shape analysis to detect beta/gamma coincidences, requiring only a single photomultiplier tube and electronics readout channel. After Monte Carlo simulations to study the detection efficiency, the light collection and resulting energy resolution, and the background in various geometries [2,3], two prototypes most promising design were manufactured, assembled in the rugged portable package, and tested with a variety of test sources, including 222Rn and 133Xe.

Sample Spectra (PPW201)

2D energy spectra are shown in Figure 2. The spectra are equivalent to those from a typical beta/gamma radioxenon detector, such as SAUNA, ARSA, or the PNNL quad detector. Subtle differences exist due to the detector geometry and the pulse shape analysis processing. For example, the “Compton line” from 137Cs does not have a sharp cutoff at ~480 keV since the scattering process can take different paths. Additional low energy counts are visible in the coincidence background spectrum, attributed to noise processed by the pulse shape analysis. However, these differences can be accommodated in existing spectrum analysis programs by slight adjustment of ROI.

Figure 2. 2D coincidence spectra with PPW201 (Cs, 137Xe, 85Rb) and energy resolution as a function of energy.

Reducing Background Through Geometric Partitioning

Further reduction in background can be achieved using 2 principles:
- minimizing detector mass and/or volume
- geometric partitioning: detect coincidences in a detector array

Thus a design of 12 detectors (forming a dodecahedral shell) will have lower ambient background due to the smaller detector size, and be able to distinguish most triple coincidences (3 particles from beta emitting Xe isotopes interacting in 3 different detectors) from double coincidences (2 particles from metastable Xe isotopes). This concept was studied in a test design with 3 phoswich detectors. Counted 10 seconds with 5 thickness of Pb shielding (0.25, 0.50, 0.75, & 2.0).

Detector Design and Assembly

The PPW detector consists of a 2in CsI crystal, cut in half along its axis, and combined with a Xe cell made from 2in x 2in x 1.5mm beta scintillator plates mounted on a Cu frame. It is attached to a photomultiplier tube and encapsulated in a 2in Cu housing. In the first prototype (PPW201), the beta scintillator was BC-404 covered with a thin aluminized mylar layer to mitigate the memory effect. In the second prototype (PPW202), the beta scintillator was crystal stilbene, shown to have negligible memory effect [4]. The detector is designed to be operated with a Minirion PSM power supply module that incorporates an LED pulse for gain stabilization against temperature drifts.

Stilbene beta detector

In a first test, a planar Stilbene/CsI test detector was assembled – approximately half of a PPW. It was compared to a BC-404/CsI test detector in the same geometry. Results show a significantly reduced memory effect, similar light output, and slightly better CE energy resolution.

Alpha Rejection PSA with Stilbene (PPW202)

Stilbene generates different pulse shapes for different particles, and so the pulse shape analysis to detect betas and gammas can be extended to detect alphas. This allows removal of all alpha events from the measurement data.

Conclusion and Outlook

In summary, we developed a portable version of the PhosWatch radioxenon detector and evaluated the design with test sources. The detector is smaller and requires less shielding than existing radioxenon detectors used in nuclear explosion monitoring. Using a single PMT minimizes setup and gain calibration, and makes for a more robust system. Reduced complexity of the detector design lowered production costs by about a factor 3 compared to the older 3 inch PhosWatch detectors. Overall, the Portable PhosWatch has good energy resolution and lower background than the 3 inch PhosWatch. Considering only the changes in detector background and shielding, preliminary estimates place its 133Xe MDC about 30% higher than that of previous PhosWatch detectors, but still below 1 mBq/m

Using stilbene crystal as the beta detector significantly reduces the memory effect, and allows advanced pulse shape analysis to remove alphas from the 214Rn decay chain. However, the material is very brittle and even after repeated rework, PPW202 is not sufficiently gas tight to allow quantitative radioxenon measurements. A third detector will be assembled with AlO3-coated BC-404.

References and Acknowledgments