Many Radioxenon detector systems used in the International Monitoring System (IMS) and in other 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 and their organic scintillators show a memory effect from previous measurements.

We present in this paper a novel detector designed for field measurements such as those performed during On-Site Inspections (OSI). The design is based on a simple poinch design, where beta/gamma coincidences are detected by digital pulse shape analysis. Size, weight, and complexity have been reduced and the memory effect has been mitigated while still achieving the minimum detectable concentration required by IMS stations. Since a single photodetector is used to read the combined scintillation light of the beta and gamma detectors, this configuration also simplifies the calibration processes. Built-in gain stabilization addresses varying environmental field conditions such as temperature changes. This in turn reduces the instrument setup time and maximizes the utilization of the short-lived radioxenon isotopes.

The detector design is studied by both GEANT4 and MCNPX modeling, and preliminary measurement results are reported.

Material and Methods

Detector geometry

The baseline detector chosen was the Phoswatch detector [1]. It is nearly 40% efficient photodetector comprising an 8 cm spherical glass cell made out of BC-404 and surrounded by a 3 cm cylindrical CsI(Tl) crystal. The compound scintillation light is read out by a photomultiplier tube (PMT) and processed digitally. Pulse shape analysis is performed for beta-gamma coincidence identification [2]. The purpose of this work was to optimize the geometry for better manufacturability. Out of many geometries considered, four geometries based on 2” CsI(Tl) scintillators were considered (fig. 1) for simulations through GEANT4.

Detection efficiency summary for the simulated geometries (GEANT4):

Table 2: Probabilities (in %) for photon full energy and partial energy deposition in BC404 and CsI for photon and electron deposition (table 2 & 3).

Memory effect

BC404 is notorious for having a so-called xenon memory, where Xe gas stays entrained within the plastic scintillator for a period of time that exceeds collection intervals. As a result there is a hysteresis effect and a new calibration must be done before the start of the next collection period to account for this entrainment. As proposed in [3], 0.5 mm of YAP matches the electron stopping power of 2 mm of BC-404, however X-ray transmission factors are 5% and 75% respectively at 30 keV and 80 keV respectively, thus reducing considerably the overall detector sensitivity. AGS-03 coatings [4] showed promising results, though challenging to industrialize.

Alternatively, one possible method to circumvent this is to place a thin but impermeable interface between the BC404, which would be assembled using conventional planar industrial methodologies. MCNP was used to simulate the effect of such interface using the following parameters (table 1):

Table 1: MCNP input parameters.

Conclusions:

Design simulations showed that the “Slab with Titanium foil” detector geometry traded about 23% of detector sensitivity loss for better manufacturability and lower memory effect. A detector prototype is being fabricated and will be tested in the coming weeks along with the Power and Stabilization Module hardware, firmware and control software.

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References:

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Figure 1: simulated geometries (clock wise iron top): hemisphere, 2” sphere, 2” cylinder and 2” slab.

Figure 2: Energy resolution of the four considered geometries as a function of photon energy.

Figure 3: Transmission of 23Xe(x) ann 40Xe(y) photons.

Figure 4: Power and Stabilization Module.

Figure 5: Detector geometry and Control Software architecture.

Table 1: MCNP input parameters.

Detector Material and window

Consistent results between MCNP simulations and experiments [6]. In turn, memory effect mitigated using a 12.5 mm thick Ti windows will translate into a marginal X-ray sensitivity loss (fig. 3) and a beta sensitivity loss of about 23% for Xe-133 (fig. 4).

Power and Stabilization Module (PSM) Development.

On deployment, it is desirable to use the instrument right away, and, as a field instrument, that will certainly include operation in environments where the temperature changes during data taking, often dramatically. Therefore automatic gain stabilization is essential to allow for rapid instrument setup and operation, since large temperature gradients can be expected during instrument setup. Also, detector gain changes due to scintillator and PMT temperature coefficients will have to be tracked over long measurement time periods (many hours). We are currently developing an electronic module (fig. 5) that will plug into the detector and which will provide temperature stable information for gain drift calculation and compensation.

Hardware Integration and control software.

The detector, shield, electronics and controller have then to be integrated to fit together as a compact, rugged and modular analysis system. The minimum size system will consist of two cases, namely a detector case (fig. 6) and a standard controller case hosting the data acquisition electronics (fig. 6) [2]. The physical properties are such that the two cases can be carried and assembled by a single person.