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SELECTIVE, HIGH-ENERGY BETA SCINTILLATION
SENSOR FOR REAL-TIME, IN SITU CHARACTERIZATION
OF URANIUM-238 AND STRONTIUM-90

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SELECTIVE, HIGH-ENERGY BETA SCINTILLATION SENSOR FOR REAL-TIME,
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Abstract

A novel scintillating-fiber sensor for detecting high-energy beta particles has been designed and built at the Pacific Northwest Laboratory to characterize ^{238}U and ^{90}Sr in surface soils. High-energy betas generate unique signals as they pass through multiple layers of scintillating fibers that make up the active region of the detector. Lower-energy beta particles, gamma rays, and cosmic-ray-generated particles comprise the majority of the background interferences. The resulting signals produced by these latter phenomena are effectively discriminated against due to the combination of the sensor's multi-layer configuration and its interlayer coincidence/anti-coincidence circuitry.

Introduction

A recent study (Riley and Zachara, 1992) identified 59 individual waste sites at 14 U.S. Department of Energy facilities across the nation that exhibit radionuclide contamination in excess of established limits, and in many cases the radionuclides of concern included ^{238}U and ^{90}Sr . The need to rapidly and efficiently characterize these sites and the potentially

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sensor are canceled through the use of an overlying anti-coincidence ribbon. Hence, by establishing an electronic requisite for coincident signals from multiple layers, one may target high-energy beta events from strontium and uranium decay, exclusively.

Many examples exist in the field of radiation detection that rely on scintillating materials and penetration depths to observe and quantify the effects of the passage of charged species, but the combination of a stacked arrangement of thin ribbons (composed of plastic scintillating fibers) and extremely fast supporting electronics for these purposes is a truly revolutionary concept. This paper will provide some details on the status of the current version of the sensor as well as its precursor, and discuss the results from specific investigations performed during their development.

Sensor Evolution

A schematic of the "proof-of-principle" detector is shown in Figure 1. For this sensor, a number of square, 1-mm-thick scintillating fibers were fashioned into three flat ribbons (150 mm wide by approximately 125 cm long), each end of which was bundled, milled flat, and placed in optical contact with a 19-mm low-noise, high-gain photomultiplier tube (PMT). The PMT signal outputs were amplified and passed via a 3-m cable to an electronic package containing secondary amplifiers, signal discriminators, and custom logic circuitry. The resulting data (e.g., total counts in individual layers and interlayer coincidences) were displayed on counters and relayed to a personal computer for storage (see Figure 2).

Despite the simplicity of the sensor design and its pre-optimized configuration, it performed remarkably well in laboratory trials with spiked soil standards (Figure 3). Furthermore, it was successfully demonstrated in a

field setting at a defunct uranium processing facility for the purpose of mapping contamination levels in surface soils and assisting in the establishment of remedial protocols (see Schilk et al., 1993; Schilk et al., 1994). The minimum detectable activity for ^{238}U , around 10-15 pCi/g, was limited by the high baseline signal (i.e., approximately 17 counts per second in the triple-coincidence mode were due primarily to background influences).

The current sensor design (Figure 4), with an active region measuring 30 cm by 60 cm, incorporates improvements that mitigate the inherent background signal observed in the proof-of-principle detector and thereby enhance the overall signal-to-noise ratio. Cosmic influences are minimized through the incorporation of an overlying anti-coincidence ribbon that acknowledges energetic charged particles originating above the sensor and rejects their contribution. A 6-mm-thick acrylic absorber separates this ribbon from the lower layers and prevents any upward-moving charged particles from triggering the anti-coincidence circuitry. Gamma-ray-induced triple-coincidences are reduced by placing a thinner scintillating-fiber layer on the bottom to decrease the probability of generating a Compton electron in this layer. In addition, significant improvements to the electronic components and circuitry (Figure 5) allowed the establishment of a much narrower coincidence window (i.e., on the order of 10-20 ns), thereby further decreasing the background by minimizing the total number of "false positives" generated by coincident thermionic emissions from multiple PMTs. This combination has led to a much lower background count rate (approximately 7 counts per second) despite the fact that the existing sensor has a larger sensitive region (2700 cm^3 vs 1500 cm^3) than the earlier version. A laboratory calibration with ^{238}U -spiked sands indicates the linearity of the sensor response at activity levels approaching background (Figure 6).

As an exercise, the detector was mounted above a conveyor belt for the purpose of monitoring contaminated soils (from the aforementioned uranium processing plant) that had been subjected to a series of mechanical-attrition and chemical-leaching steps to remove the ^{238}U . A typical example of the "washed" soils (Figure 7) still exhibits appreciable uranium activity, which is observable even at belt speeds of nearly 5 m/min (8 cm/sec). The actual activity level associated with this test soil is yet uncertain and still under evaluation, as the samples were damp from the stripping process and sensor response as a function of sample moisture content is currently undetermined. In any case, the remnant activity is most certainly in excess of the currently established cleanup limit (35 pCi/g of total uranium) and, hence, these results would suggest that the decontamination process is not entirely successful at this stage.

Conclusion

Construction and testing of a novel high-energy beta detector has demonstrated the capability to measure uranium and strontium in surface soils. The sensor's multi-layer configuration and custom electronic circuitry combine to provide the necessary speed and sensitivity required for the rapid, in situ measurement of these radionuclides in the field for supporting environmental cleanup operations, facility decontamination and decommissioning, and routine mapping.

Acknowledgments

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Figure 1. Simplified diagram of the proof-of-principle sensor showing the potential interactions between the scintillant material and incident beta particles and gamma rays. Double lines denote particle tracks that lead directly to excitations/ionizations and consequent scintillations.

Figure 2. Circuitry diagram for the early version of the detector identifying the actual sensor box, the supporting electronic package, and the connecting signal cable. Note the intralayer and interlayer coincidence capabilities for mitigating PMT noise and determining particle penetration depth, respectively.

Figure 3. Calibration plot for the proof-of-principle sensor based on a series of $^{90}\text{SrCl}_2$ -spiked medium-grained sands (100-second counts). Detector response is seen to be quite linear over a significant range of activities. The non-zero count rate associated with 0 pCi/g is due to the naturally occurring uranium radioactivity in the sand samples.

Figure 4. Schematic representation of the current sensor design highlighting potential interactions (refer to Figure 1 for details). Any triple-coincidence events that occur contemporaneously with scintillations in the overlying layer are assumed to be due to cosmic events and therefore rejected. Triple-coincidences caused by energetic Compton electrons are quite rare (due to the low-Z material of the sensor), but their likelihood is further reduced by decreasing the mass in the first (lowermost) layer.

Figure 5. Improved electronic circuitry associated with the current sensor. The individual components are faster and further miniaturized with respect to the earlier version and fully enclosed within a lightweight, ruggedized sensor package.

Figure 6. Calibration plot for the current sensor based on three $^{238}\text{UO}_2(\text{NO}_3)_2$ -spiked medium-grained sands (100-second counts; refer to Figure 3).

Background-Corrected Triple-Coincidences (cps)

Background-Corrected Triple-Coincidences (cps)

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