Childress, N. and W. H. Miller, "MCNP Analysis of a Phoswich Detector," Trans. Am. Nucl. Soc., 86, 229 (June 10-13, 2002).

A series of triple crystal phosphor sandwich detectors have been developed and constructed for testing at the University of Missouri-Columbia [1-7]. These detectors can simultaneously measure alpha, beta, and gamma radiation and utilize digital pulse shape discrimination to identify and separate radiation events coming from each of the separate phosphors. The research reported here uses Monte Carlo [8] software analysis to determine operating parameters for this detector system and optimizes its design for measuring trace amounts of alpha, beta and gamma-ray activity in effluent streams from nuclear waste cleanup processes.

The previously designed, fabricated and tested phoswich detector [5] consisted of three scintillators placed on top of each other with a common diameter of 5.08 cm and viewed with a single photomultiplier tube. The scintillators (ZnS – 0.00376 cm, CaF_2 – 0.254 cm and NaI – 2.54 cm) interact preferentially with alpha, beta and gamma-ray radiation, respectively. This design allows preferential, but not exclusive, interaction of various radiations with specific layers. Taking into account and correcting for events that can occur in the "wrong" phosphor, this system was experimentally shown to have a 99% accuracy for properly identifying radiation coming from a mixed alpha/beta/gamma-ray source.

In an attempt to better understand this system and provide design guidance for a detector system to be used in monitoring effluents from nuclear waste treatment facilities, this detector was modeled using MCNP [8]. This analysis [9] indicated that the thin ZnS layer adequately stops alpha particle energy, but greatly reduces beta detection efficiency to essentially zero at beta E_{max} energies below 300 keV. The CaF_2 layer, designed to keep any beta particle energy from entering the NaI detector results in an incorrect gamma-ray response that is approximately 23% of the NaI's response and is variable with energy. High energy beta events in the CaF_2 can lead to Bremsstrahlung radiation being detected in the NaI. These errors must be corrected by system software.

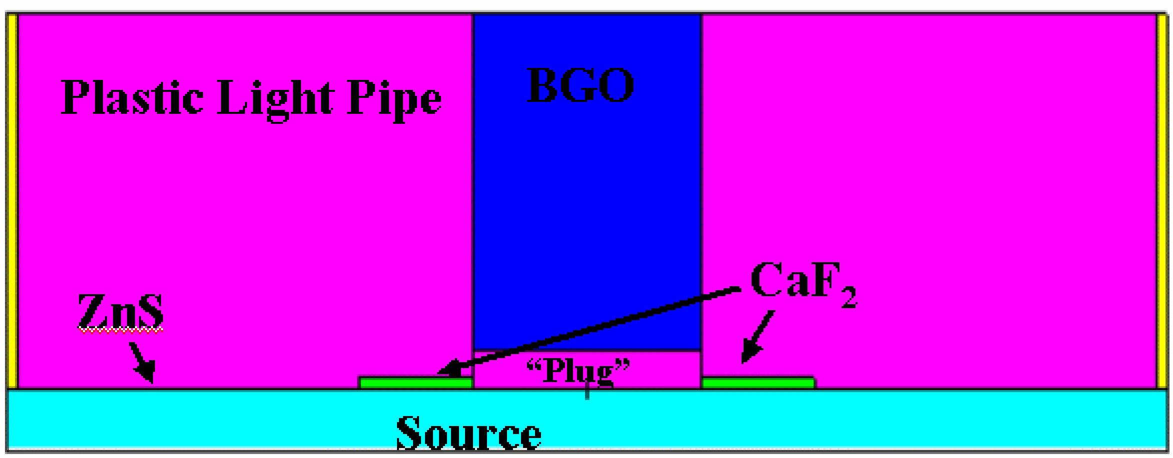
A new co-axial geometry is proposed as shown in Figure 1. This geometry is designed to optimize the detector for typical effluents in nuclear waste processing streams (nominally expected to be approximately 10 nCi/ml for alpha, beta and gamma-ray radiation [10]) and to eliminate some of the shortcomings identified above. This geometry separates the three phosphors into concentric regions, minimizing "cross-talk" events and provides other optimizations. In this design the ZnS detector is 0.00244 cm thick with an inner radius of 2.0 cm and an outer radius of 5.0 cm. The CaF_2 is 0.1 cm thick with an inner radius of 1.0 cm and an outer radius of 2.0 cm. A BGO detector (replacing the NaI) has a radius of 1.0 cm, a height of 3.0 cm and is protected from beta particles by a 0.3 cm plastic "plug." All scintillators are backed by a common light pipe to effectively collect light output.

MCNP analysis of this design reveals that the ZnS detector's thickness no longer stops low energy beta particles from reaching the CaF_2, thus eliminating the 300 keV E_{max} threshold for beta particles seen in the previous detector. Also, since the relative number of alpha events reaching the detector will typically be small (due to their short range in aqueous effluent streams) the cross sectional area of the ZnS can be increased, increasing the alpha particle count rate. The CaF_2 can be made thin to reduce gamma-ray interactions, but with a larger cross sectional area to provide comparable count rates between the number of beta events in the CaF_2 and gamma-ray events in the BGO. The thickness of 0.1 cm is sufficiently thick that on average, only 13% of a high energy, 2.0 MeV electron incident on the CaF2 escapes into the plastic light pipe. This thinner beta phosphor reduces its gamma-ray response from 23% in the previous design to 9.5% +/- 0.5% from 0.3 to 2.0 MeV, which can be more easily corrected by the software. The BGO detector was used to replace the NaI detector due to its higher density. A BGO scintillator also has lower light output which more closely matches the light output of the CaF_2, improving the dynamic range of the system.

In conclusion, a new phoswich detector design has been proposed and modeled using MCNP. This detector exhibits properties that improves on many of the limitations noted in the previous design and is optimized for measurements of effluents from nuclear waste stream processing facilities.

This project was funded by a NEER grant from the Department of Energy (DE FG07 01ID14118 A000 Miller).

Figure 1: Co-Axial Detector Design



References:

1) Miller, W. H., Al-Haddad, M. N., Wu, X., Lin, C., and Shen, X., "A DSP-based, analog-to-digital converter for nuclear radiation spectroscopy," Trans. Am. Nucl. Soc., 66, p. 417-418 (1992).

2) Al-Haddad, M. N., Lin, C., Miller, W. H., and Berliner, R. R., "Development and testing of a flash analog-to-digital converter based system for pulse shape discrimination of nuclear radiation pulses," IEEE Transactions on Nuclear Science, 41(5), p 1765-1779 (October 1994).

3) Miller, W. H., Jackson, P., and Lin, C., "Utilization of a GaGe CompuScope 1012 computer-based oscilloscope for pulse shape discrimination and radiation spectroscopy," Nuclear Instruments & Methods in Physics Research, Section A, 353, n 1-3 (December 30, 1994).

4) Miller, W. H., "An Alpha / Beta / Gamma Swipe Counter Based Upon Digital Pulse Shape Discrimination", Health Physics, Supplement to Vol. 72, 6 (June 1997).

5) White, T. and W. H. Miller, "Evaluation of a Three Phosphor, Phoswich Detector for Alpha / Beta / Gamma Detection Using Digital Signal Processing," IEEE Transactions on Nuclear Science (accepted for publication).

6) Pillai, S., J. Feng and W. H. Miller, "Phoswich Detectors with DSP analysis for low energy, low activity photon measurements," Trans. Am. Nucl. Soc., 80, 64-65 (1999).1) Al-

7) Duncan, L., "Applying the phoswich detector to measuring uranium in workers," A Master's Degree Project, Nuclear Engineering Program, Missouri University (May, 1999).

8) Hendricks, J. S., "MCNP4C - Monte Carlo N-Particle Transport Code System," Distributed by Oak Ridge National Laboratory, RSICC Computer Code Collection, CCC-770 (July, 2000).

9) Childress, N. L. and W. H. Miller, "MCNP Analysis and Optimization of a Triple Crystal Phoswich Detector," Nuclear Instruments and Methods (accepted for publication).

10) "Procurement Specifications: Salt Waste Processing Facility In-Line/On-Line Radionuclide Detection Monitor," J-SSP-H-00222, Revision A (June 2000).