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A Gamma Ray Scanning Approach to Quantify Spent Fuel Cask Radionuclide Contents

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Abstract

The International Atomic Energy Agency (IAEA) has outlined a need to develop methods of allowing re-verification of LWR spent fuel stored in dry storage casks without the need of a reference baseline measurement. Some scanning methods have been developed, but improvements can be made to readily provide required data for spent fuel cask verification. The scanning process should be conditioned to both confirm the contents and detect any changes due to container/contents degradation or unauthorized removal or tampering. Savannah River National Laboratory and The University of Tennessee are exploring a new method of engineering a high efficiency, cost effective detection system, capable of meeting the above defined requirements in a variety of environmental situations. An array of NaI(Tl) detectors, arranged to form a "line scan" along with a matching array of "honeycomb" collimators provide a precisely defined field of view with minimal degradation of intrinsic detection efficiency and with significant scatter rejection. Scanning methods are adapted to net optimum detection efficiency of the combined system. In this work, and with differing detectors, a series of experimental demonstrations are performed that map system spatial performance and counting capability before actual spent fuel cask scans are performed. The data are evaluated to demonstrate the prompt ability to identify missing fuel rods or other content abnormalities. To also record and assess cask tampering, the cask is externally examined utilizing FTIR hyper spectral and other imaging/sensing approaches. This provides dated records and indications of external abnormalities (surface deposits, smears, contaminants, corrosion) attributable to normal degradation or to tampering. This paper will describe the actual gathering of data in both an experimental climate and from an actual spent fuel dry storage cask, and how an evaluation may be performed by an IAEA facility inspector attempting to draw an independent safeguards conclusion concerning the status of the special nuclear material.

Introduction

The IAEA have identified a need for re-verifying the inventory of spent fuel contained in dry cask storage systems in order to maintain continuity of knowledge. The goal of a system designed to meet this need would be to provide assurance that the contents of a spent fuel cask have not been tampered with at any point during its life cycle. One potential method of carrying out this verification would be the use of a gamma counting system with sufficient collimation to allow a spatial resolution suitable for the detection of individual fuel assemblies inside the cask. There are significant issues that need to be addressed in the development of such a system; the two most significant of these being the large scattering background that is produced by the cask and its shielding and the attenuation of the radiation emitted by the fuel elements by the elements themselves and the cask itself. Previous experiments have shown that parallel plate type collimators demonstrate some ability to mitigate both of these issues. This experimental program begins an investigation into the suitability of these types of detector/collimator systems for this and other applications.

Creation of a well defined field of view for large gamma ray detectors is typically through the use of large and heavy collimation, often making portable applications impractical. This work overcomes this limitation with the use of a multi-plate collimator assembly that can provide "line" or other shaped fields of view with simple and easy manipulation. Of significance is that this collimation approach is highly effective up to 1.5 MeV for a system weight addition of less than 2.5 Kg. Such collimators readily provide 6 degrees (or better) field of view with minimal loss of detection efficiency when measured on the source-detector axis.

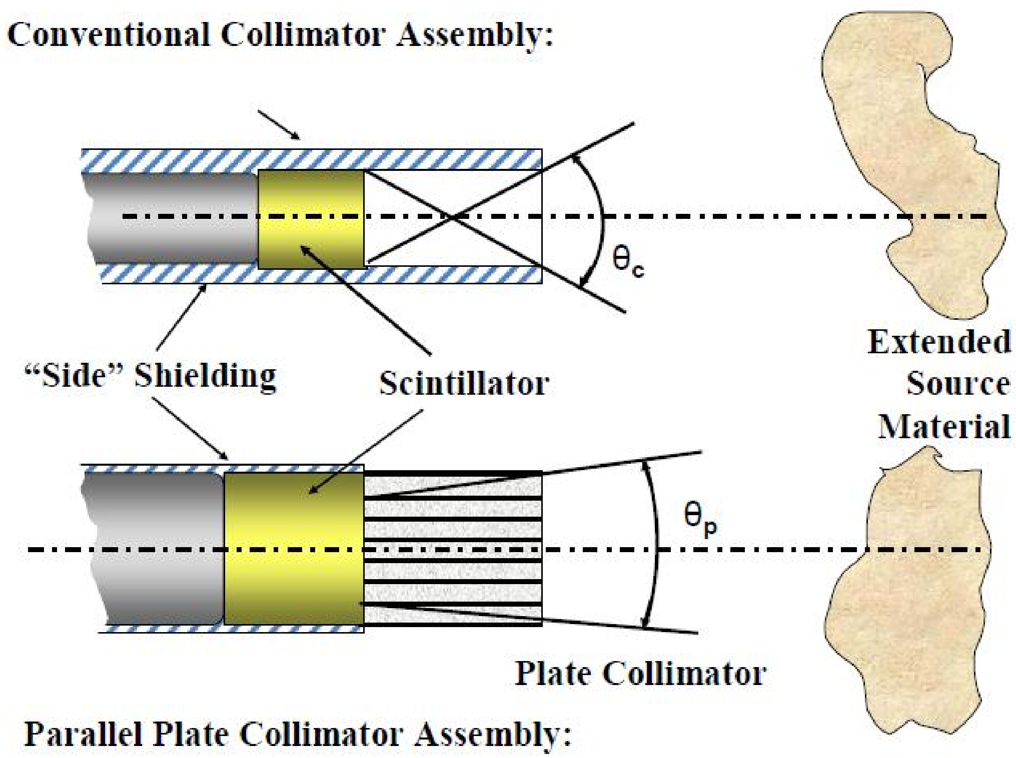

Figure 1 - Conventional Collimator and Parallel Plate Collimator assemblies

This type of lightweight collimator lends itself to the measurement of fuel assemblies inside a spent fuel cask where its tightly restricted field of view should allow determination of the contents of a spent fuel cask with high spatial resolution. Collimators of this type have been demonstrated to reduce detector "noise" produced by scattering from a large scattering body such as a fuel cask.

Methodology

The initial goal of this study was to take a measurement of the gamma spectrum from a spent fuel cask. This was done at Savannah River Site's L disassembly basin with a GE-2000 cask containing an aged HFIR core.

Figure 2 - GE 2000 cask on trailer

The cask was measured in a configuration similar to that in figure 2 with a Falcon 5000 high purity germanium detector at a range of distances from the cask. Spectra were obtained at each distance.

The collimator itself was tested separately during several different experiments to investigate its ability to reduce scatter and determine its spatial resolution. These experiments involved measurement of a source within a scattering body and the scanning of a source past the detector/collimator system to characterize the detectors response.

Results

The spectra obtained from measurement of the GE 2000 cask showed discernable peaks for several fission products, most notably Cs-137, as one might expect. While there was a significant scatter background from the cask, it was not sufficient to mask the peak for Cs-137. This result confirms that radiation from the fuel elements inside the cask should be detectable even through the cask shielding and the scatter background produced by the cask. These spectra appear in figure 3.

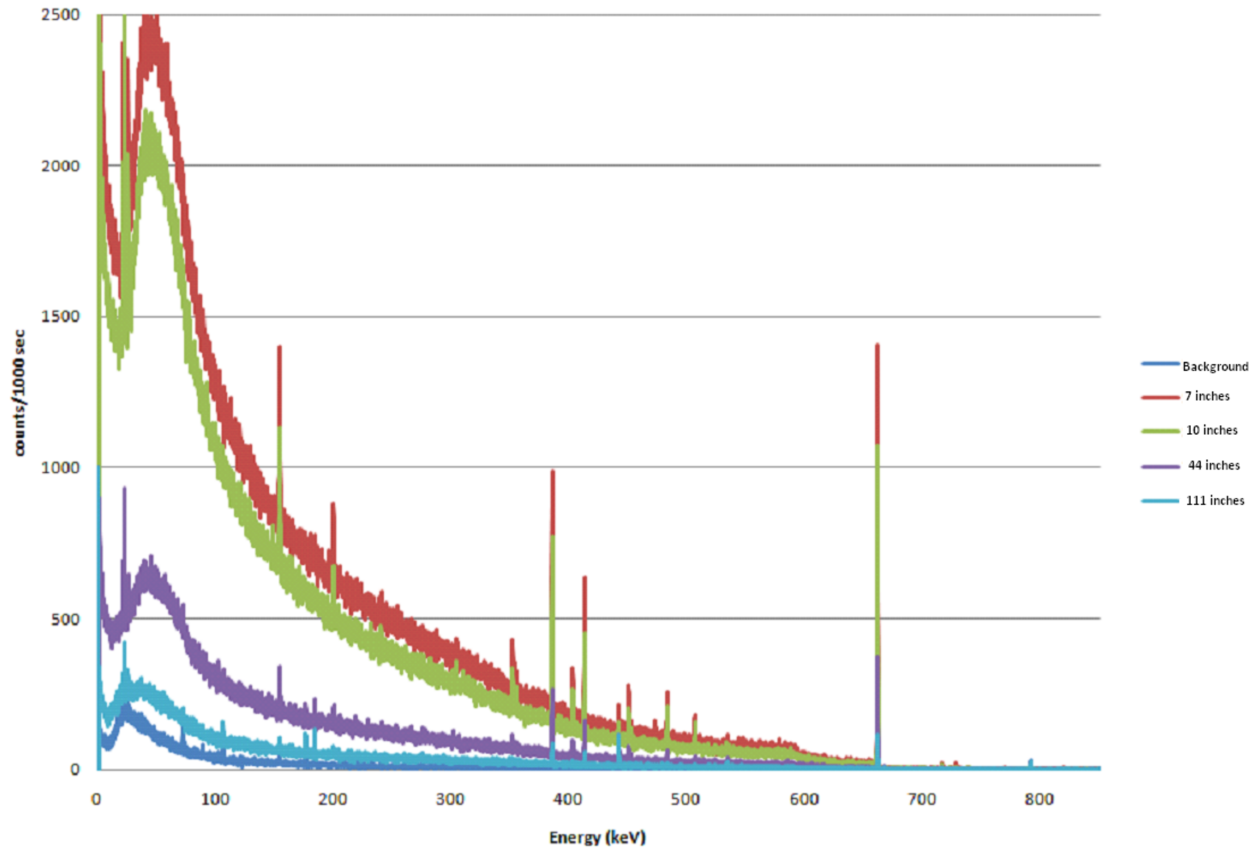

Figure 3 - Spectra from GE 2000 cask containing HFIR core at various distances from cask surface

Previous work has demonstrated the effects on detector spatial resolution of using a parallel plate collimator. Two different plate spacings were used and compared to the response from the same detector without collimation while a 20% enriched uranium source was scanned across the detector. Figure 4 shows the detector response in each of these three cases.

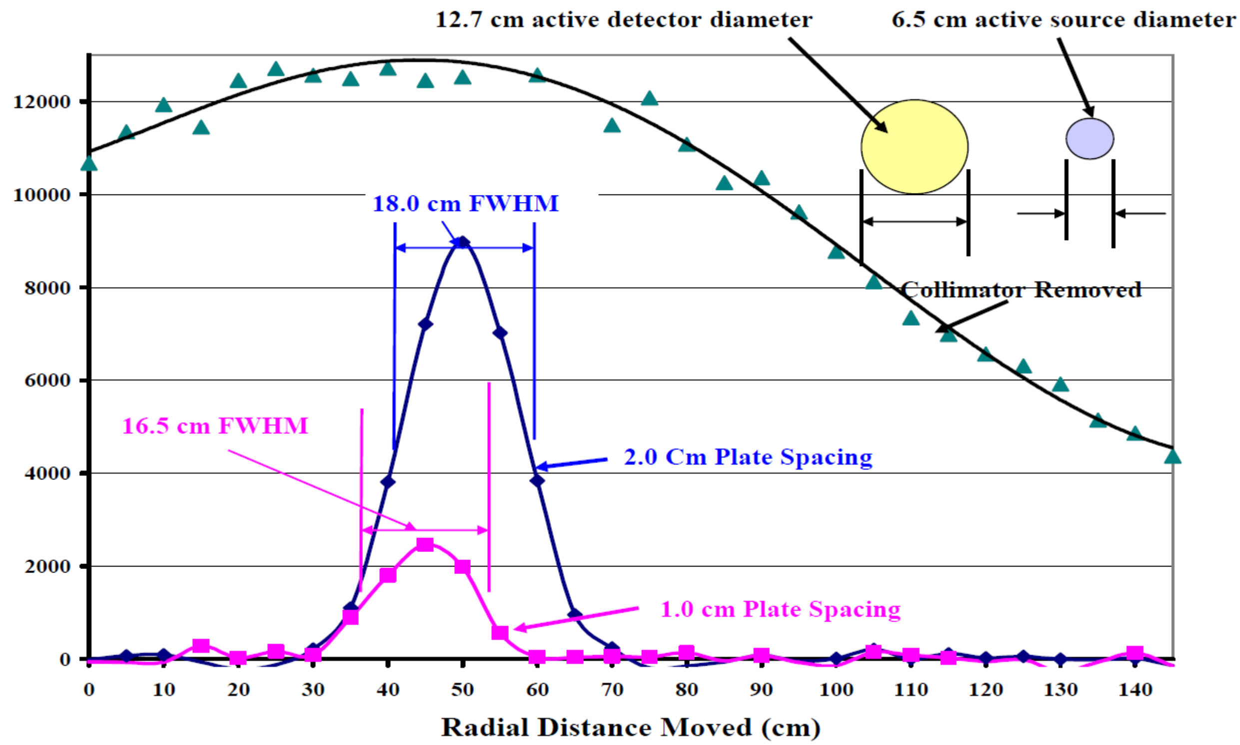

Figure 4 - Detector response with two different collimator plate spacings and without collimation

This test demonstrates that the collimator is able to provide good spatial resolution with smaller plate spacing producing better spatial resolution at the expense of count rate. Altered collimator geometries are being tested to further refine the spatial resolution possible with the collimator.

Scatter rejection by the collimator has also been tested experimentally. An Eu-152 source was used, shielded by a 10cm thick, 30cm by 30cm Lucite block. Measurements were made with a high purity germanium detector, with and without the collimator attached. Figure 5 shows the scatter reducing effect of the collimator.

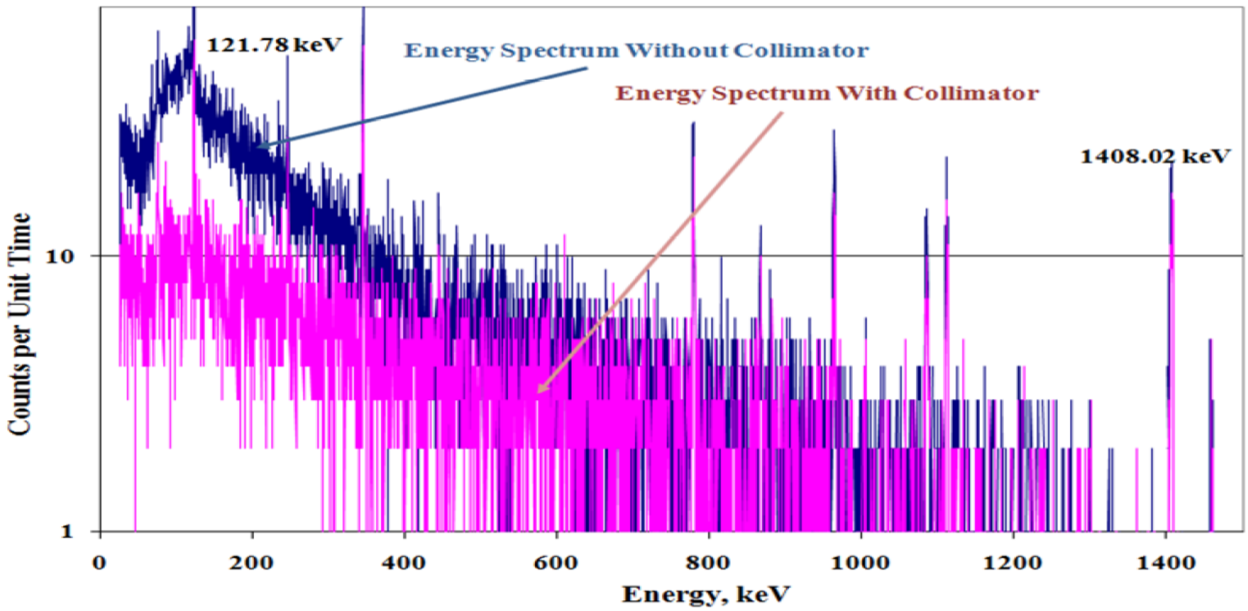

Figure 5 - Eu-152 source with scattering body between source and detector

The scatter reduction of the collimator is particularly evident in this test at lower energies.

Conclusions and further work

The measurement of the spent fuel cask showed that gammas from the elements inside the cask were still quite easily detectable amongst the scatter produced by the cask and its shielding. The separate testing of the collimator design shows that it is capable both of reducing background scatter and of restricting the field of view of a detector to a degree that may allow the identification of individual fuel elements inside a spent fuel cask. This is particularly the case where the elements are viewed "end on". A significant challenge will be demonstrating to what extent the collimator/detector system can "see" the central fuel elements within the cask. A modeling effort will be undertaken to explore this problem.

There are many other areas where the characteristics of this system make it ideal for radiation detection, including source location for law enforcement purposes and the measurement of hold up in bulk processing facilities.

References

High Performance, Directional gamma ray detector solutions for the detection and quantification of critical materials, G Walford, J S. Bogard, S E. Smith, A A. Solodov