Passive gamma-ray analysis of UO_2 fuel rods using $SrI_2(Eu)$ scintillators in multi-detector arrangements

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***Abstract*— The use of passive gamma analysis (PGA) to interrogate nuclear fuel rods for quality assurance and non-proliferation purposes has been demonstrated to be as efficient and safer than the more common neutron activation analysis (NAA) for fresh fuel assessment. In this work we will build on existing experimental measurements using a single probe $SrI_2(Eu)$, to simulate the response of a multi-probe $SrI_2(Eu)$ detector array in the analysis of nuclear fuel rods, containing sintered UO_2. The work compares the results to literature studies using bismuth germinate and annulus CsI(Tl) multi-probes to evaluate light water reactor fuel rods. The enhanced scintillation performance of $SrI_2(Eu)$ over CsI(Tl) and BGO make it ideally suited for nuclear fuel inspection.**

***Index Terms*— Uranium enrichment, infinite thickness technique, passive gamma analysis.**

I. INTRODUCTION

THE measurement of uranium enrichment is critical for non-proliferation and quality assurance purposes. It occurs at several points throughout the nuclear fuel manufacture process to ensure that all materials are accounted for, and the correct enrichment is being used. One of the key points for this measurement is the assessment of fuel pellets when loaded into fuel pins. This can be achieved by neutron activation analysis (NAA) and passive gamma analysis (PGA).

NAA utilizes an external neutron source (e.g. ^{252}Cf) to induce fission of ^{235}U within the fuel pellets, releasing a large amount of delayed γ-rays. From the induced γ-rays, the content and enrichment of the pellets can be determined [1]. PGA can be used by measuring the characteristic 186 keV emission from ^{235}U decay. The magnitude of the emissions is directly related to the enrichment of the uranium under inspection [2].

NAA is a fast, reliable, and accurate method to analyze fresh fuel rods, however, the use of external neutron sources increases technical complexity and operating costs, and it requires heightened radiation protection measures. PGA is less efficient than NAA due to the fewer γ-rays, and as such requires longer analysis times. However, it is

In recent years there have been advances in the development of PGA techniques, focused principally on using multiple annulus scintillation detectors [3]. In this work we study the use of europium-doped strontium iodide ($SrI_2[Eu]$), a new high performance, low resolution scintillator [4], for the use in multi-detector passive gamma-ray analysis of fresh fuel pellets.

II. MATERIALS AND METHOD

This work utilized Monte Carlo simulations, using GEANT4 nuclear particle code to simulate pressurized water reactor (PWR) UO_2 pellets. The simulated data was verified using γ-ray measurements from advanced gas cooled reactor (AGR) UO_2 pellets. The simulated pellets had the dimensions 9.4 mm Ø and up to 25 mm, with a UO_2 density of 10.9 g cm^3. The enrichment of the UO_2 was calculated using the infinite thickness technique [5].

Both simulated and experimental measurements utilized $SrI_2(Eu)$ scintillators (Scionix, Netherlands). For the experiments, the scintillators were connected via a 14-pin to a digiBASE photomultiplier tube base (Ametek Ortec, USA) and controlled using MAESTRO Multichannel Analyser Emulator software (Ametek Ortec, USA). Calibrated AGR UO_2 fuel pellets were acquired from the UK National Nuclear Laboratory. A 3-d rendering of four $SrI_2(Eu)$ arranged around the central LWR pellet stack is shown in Figure 1.

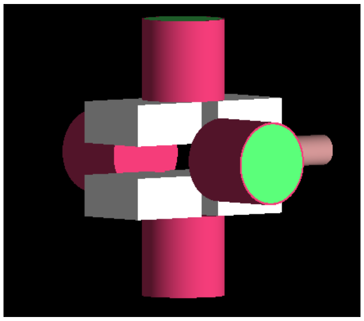

Figure 1. GEANT4 3D rendering of four $SrI_2(Eu)$ scintillators (red/green) arranged around lead collimator blocks (white), the PWR pellet stack (pink) will pass through the center.

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III. RESULTS AND DISCUSSION

The first simulations modelled two fuel pellets aligned along their longitudinal axis. The gross count measurement from the 186 keV photopeak was taken at 5 mm increments as the pellets pass under a collimated SrI_2(Eu) detector.

A comparison of the simulated gross counts is shown in Figure 2. It can be seen in both Fig 2A and 2B, that as the pellets pass under the collimated field of view the gross count-rate increases to a plateau that is proportional to the pellet enrichment. In Figure 2A, both pellets have a simulated enrichment of 4.460%. The count-rate for the plateau is ~118 cps. In Figure 2B, pellet 1 has a simulated enrichment of 1.312%, which manifests as a count-rate of ~62 cps. It can also be seen from Fig 2B that the count rate changes between these two values over 20 mm, as the detector passes along the fuel pellets.

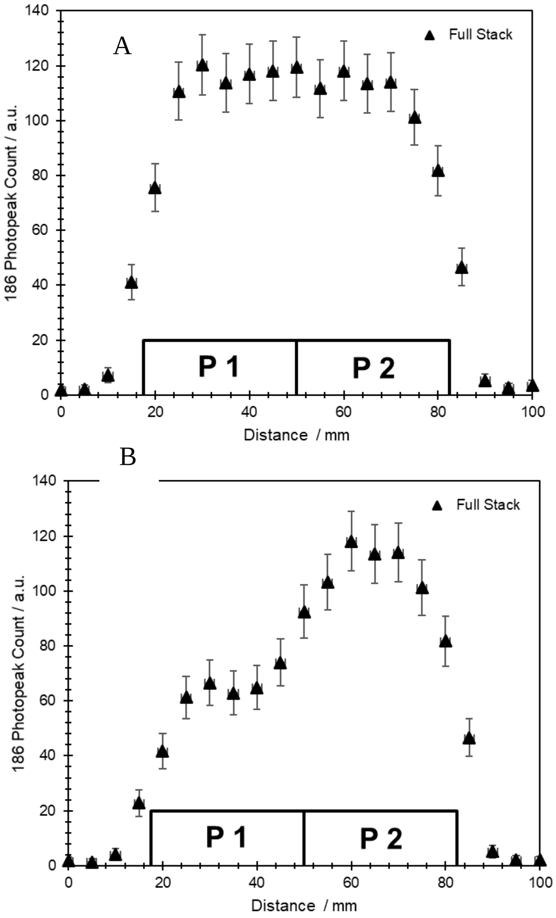

Figure 2. Gross count arising from the 186 keV ^{235}U photopeak from two simulated UO_2 pellets stacked along their longitudinal axis as they pass under the SrI_2(Eu) detector field of view. (Top) P1=P2=4.460% enrichment, (Bottom) P1=1.312%, P2=4.460% enrichment.

Figure 3 shows the collated count-rate from a 1000 mm fuel rod containing four different enrichment pellets, collected with a multi-detector arrangement consisting of eight SrI_2(Eu) probes connected in parallel. The additional detectors and change in geometry increase the detected count-rate significantly to ~3000 cps for a 4.460% enriched fuel pellet. Like the previous data, a clear transition can be seen as pellets of differing enrichment pass under the detection field of view.

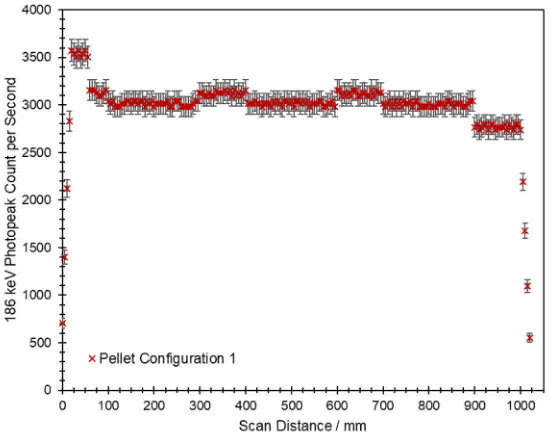

Figure 3. The relationship between ^{235}U enrichment of a UO_2 fuel pellet and the associated count arising from the 185.6 keV photopeak.

The principal limitation of this work is that the results have not been validated with experimental measurements. Additionally, similar works using multi-detector setups in PGA use annulus detectors. At the time of publication, there have been no reports of the use of annulus SrI_2(Eu) scintillators manufactured, and the largest reported crystal size produced is 103 cm^3 [6]. As shown in other fuel rod measurement studies, large-crystal, annulus scintillators provide the most effective means of PGA of fuel pins at scanning rates > 6 m min^{-1}. Accordingly, the use of SrI_2(Eu) may not yet be technically feasible.

IV. CONCLUSION

This work applied infinite thickness technique and multi-detector setup to simulate the enrichment measurement of nuclear fuel rods. The preliminary results show.

The main finding of this work is that the determination of enrichment for individual LWR UO_2 pellets within nuclear fuel rods is feasible. Along with the data presented here, a more comprehensive set of data is in preparation necessary to understand the counting statistics associated with counting time and the fuel rod scanning rates.

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