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Investigation of a dynamic measurement methodology for fast detection of gross defects in regularly distributed nuclear material samples

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A B S T R A C T

Non-Destructive Assay (NDA) techniques are widely used to verify Nuclear Materials (NM). Most of these techniques are static ones for which, the measuring device and the assayed samples are located at fixed positions during measurements. While assaying regularly distributed NM, attenuation and screening effects may contribute negatively to the accuracy of the results, especially for relatively high density materials. Another factor that may affect the accuracy is the allowable time of measurement. Detection of gross defects in such materials could be achieved more accurately and much faster by employing dynamic measurements. In this work, an investigation for a proposed Non-Destructive Dynamic (NDD) measuring system is presented. The system is assumed to detect gross defects in nuclear fuel assemblies of EK-10 type more accurately and faster than other traditional systems based on static measurements. Different scenarios were considered and studied using the MCNP5 Code. The results showed that the investigated method could be easily applied to detect gross defects in regularly-distributed NM samples.

1. Introduction

In some cases, the use of non-destructive static measurements (in which the measuring device and the measured sample are located in fixed positions during measurements) may not provide sufficient information about a measured item. This may occur due to attenuation and/or screening effects. Consequently, it might be necessary for the material to be moved with respect to the used detector or rotated in order to obtain more informative results. Meanwhile, the measuring device should record and respond to the acquired data. While using scanning gamma-ray measurement techniques, the response of a measuring system to radiation emitted from a regularly-distributed rotating NM results in a spectrum with a specific pattern. This pattern could represent a signature for a NM sample measured with specific setup configuration and dynamic parameters (like speed of rotation). Any deviation from this signature may indicate some defect in the measured material. In this work, a Non-Destructive Dynamic (NDD) method is investigated to detect gross defects in a regularly-distributed NM. Different scenarios were considered and studied using the MCNP5 Code. The results showed that the investigated method could be easily applied to detect gross defects in regularly-distributed NM samples.

Dynamic measurements are considered whenever fast measurements are needed. In some cases, like verification of NM in nuclear facilities under operation, fast measurements have to be considered due to time limitations. This is because of two main reasons. First, NM inventory at the facility has to be verified while shutdown. The second reason arises due to the fact that not all NM samples could be usually verified; accordingly, a representative sample from the NM population has to be selected. With dynamic measurements the measuring time per sample could be effectively reduced. This allows the increase of the number of items in the representative sample and consequently increasing the detection probability of inconsistency [1].

Although Tomographic Gamma Scanning (TGS) systems could be used to verify such types of NM, however, these systems are more sophisticated than the proposed method. The TGS techniques are usually used with algorithms - and in some cases – external radiation sources to construct 3D images for the assayed items [2]. The investigated method depends only on the spontaneous radiation emitted from the NM to check its pattern. Moreover, whenever any deviation from the expected pattern is detected the system may stop and triggers an alarm. Consequently, the measuring time is always less than or at most equal to the assigned life time.

In this paper the proposed method is investigated while assuming some NM defects including the existence of dummy items and the removal of some NM.

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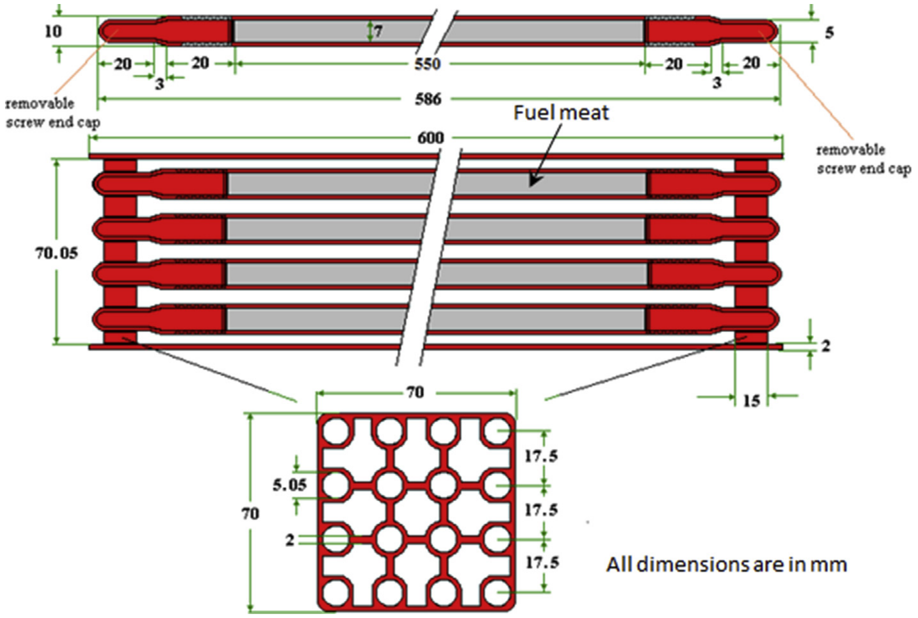
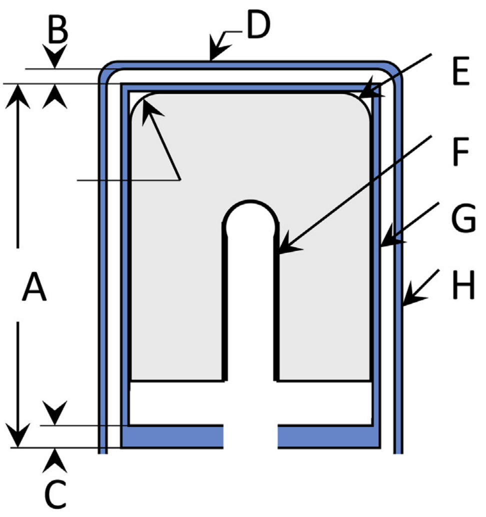


Fig. 1. Schematic diagram for the EK-10 Fuel Assembly.

Material and method

2.1. Regular NM samples under investigation

Nuclear fuel rods of 50cm length and 0.7cm diameters are regularly distributed in a 4×4 matrix to construct the EK-10 assembly fuel type. The NM is cladded with Al tubes of 0.15cm thickness. The fuel is made up of a 10% enriched uranium dioxide-magnesium alloy (with 8.045g ^{235}U content per fuel rod) [3]. Fig. 1 is a schematic diagram for the fuel illustrating a longitudinal section of the fuel and the dimensions of the



DETECTOR DIAMETER	50 mm
DETECTOR LENGTH	30 mm, MINIMUM
DETECTOR END RADIUS (I)	8 mm, NOMINAL
HOLE DIAMETER	9 ± 1 mm
HOLE DEPTH	15 mm, MINIMUM
HOLE BOTTOM RADIUS	4 mm, NOMINAL

IDENTIFIER	DIMENSION		DESCRIPTION	MATERIAL(S)
A	45	mm	MOUNT CUP, LENGTH	Al
B	8	mm	END CAP TO CRYSTAL GAP	N.A.
C	3.2	mm	MOUNT CUP BASE	Al
D	1	mm	END CAP WINDOW	Al
E	700	micron	OUTSIDE CONTACT LAYER	Ge (w/ Li IONS)
F	0.3	micron	HOLE CONTACT LAYER	Ge (w/ B IONS)
G	0.79	mm	MOUNT CUP WALL	Al
H	1.5	mm	END CAP WALL	Al

Fig. 2. Characteristics of HPGe detector as provided by the manufacturer.

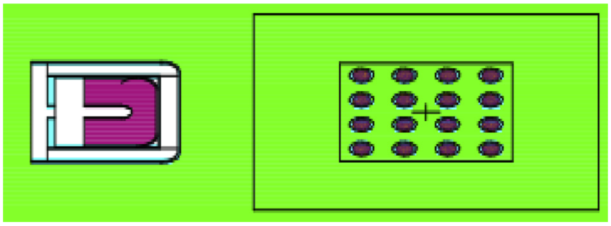


Fig. 3. Model of detector as and fuel assembly drawn by MCNP visual editor.

fuel meat, clad and case.

2.2. *Monte Carlo calculations*

The MCNP5 Code [4] was used to investigate the proposed method of dynamic measurement. The pulse height tally "F8" was considered to estimate the detected fraction of gamma rays of 185.7 keV due to 235U isotope. The modelled detector is based on manufacturer data provided for a Micro-spec-trans ORTEC HPGe detector. The detailed specifications of the detector are presented in Fig. 2 [5]. Samples containing regularly distributed NM were modelled. The considered samples are the square shaped nuclear reactor fuel assemblies of EK-10 type (Fig. 1). All calculations were performed with detector surface-to-fuel assembly centre distance of 10.9 cm without using any collimators. The MCNP source distribution and rotation cards were used to define NM source in the assembly and rotate the fuel assembly about its longitudinal axis of symmetry, respectively Fig. 3 shows The MCNP detector and fuel assembly model, as drawn by the MCNP visual editor, including surfaces and cells. The extended axis of symmetry of the detector was selected to be perpendicular to the longitudinal axis of symmetry of the assembly and passes through its middle. The calculations were performed at seventy-two angles of rotation per assemble that covers one complete rotation. Cone source biasing variance reduction technique was used to improve statistics and reduce time of calculations.

Since the dimensions of the fuel are relatively larger than those for the detector a number of histories of 2E8 events were selected to perform the calculations. The running time was about one hour on an I5 processor. In a real scanning experiment, the fuel assembly will be rotated continuously. According to the ^{235}U mass content in the fuel assembly and the pulse height "F8" tally results obtained using the MCNP Code, the count rates are expected to range between 1970.54 and 2321.25 count/sec for the minimum 3.3637×10^{-4} and maximum 3.9869×10^{-4} calculated F8 values which corresponds to angle rotations of 0° and $25^{\circ}$of the fuel assembly, respectively. Hence to obtain experimental results of better than 3%, a total time of 8 minutes is needed for a full complete rotation of the fuel. And also the dynamic feature of the system could be used in which, the acquired data are directly compared to the control spectrum (pattern), and that the system respond immediately whenever any deviation is detected.

3. Results

The response of the detector depends on three main parameters. They include the solid angle of the fuel assembly subtended by the detector, the self-attenuation for the emitted gammas inside each fuel rod, and the screening of gamma rays due to other fuel rods. As the fuel assembly is rotated about its longitudinal axis of symmetry in front of the detector all these parameters are varied and, therefore, the numbers of gamma rays detected are also varied for each angle of rotation. This variation results in a specific pattern for the response of the detector. This variation is expected to be repeated symmetrically whenever symmetric NM distribution exists.

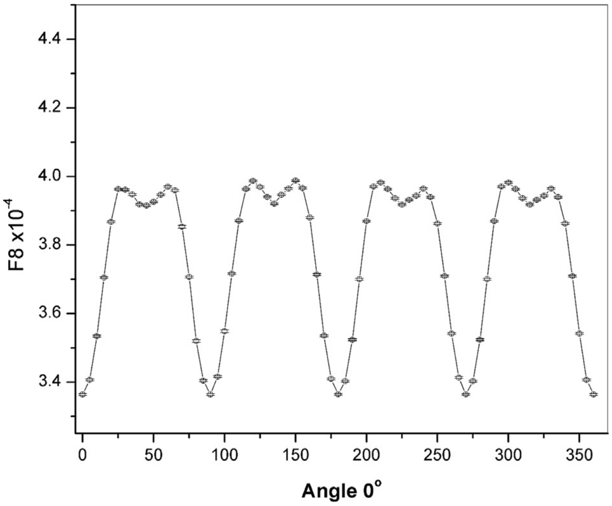


Fig. 4. Results of calculation for a complete fuel assembly.

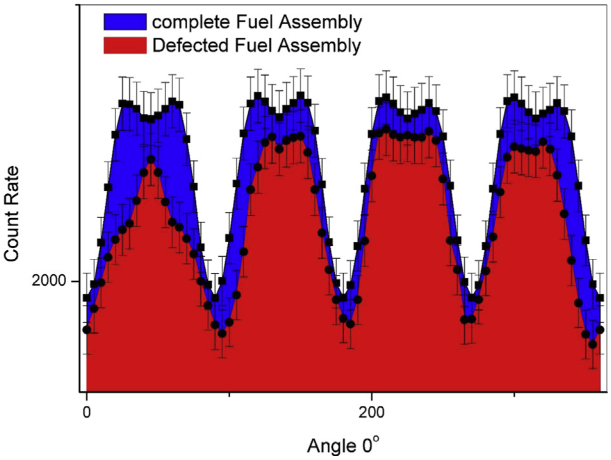


Fig. 5. Count rate due to the complete fuel assembly and the defected one.

3.1. *Symmetric detector response pattern for complete fuel assembly*

The results of calculation for a complete fuel assembly are presented in Fig. 4. The symmetry of the calculated pulse heights (represented on the ordinate of Fig. 4 as F8) for each repeated 90 angle degree is clear in the Figure. Any deviation from this pattern indicated a defect in the fuel assembly.

Fig. 5 shows the count rate due to the complete fuel assembly and the defected one. The figure shows that the difference in the estimated standard deviation between the complete and defected fuel assembly is not within the estimated errors.

3.2. *Detector response pattern for fuel assembly with removed sources*

To investigate the possibility of detection of gross defect (loss of any of the fuel rods) sources were removed from the fuel. Four scenarios were investigated in which one, two, three and four sources were assumed to be missed.

The results of calculations are presented in Fig. 6. The generated patterns do not only indicate the existence of gross defect; they could identify the location of defected rods as well.

It is clear that the resulted spectra are unique for each scenario.

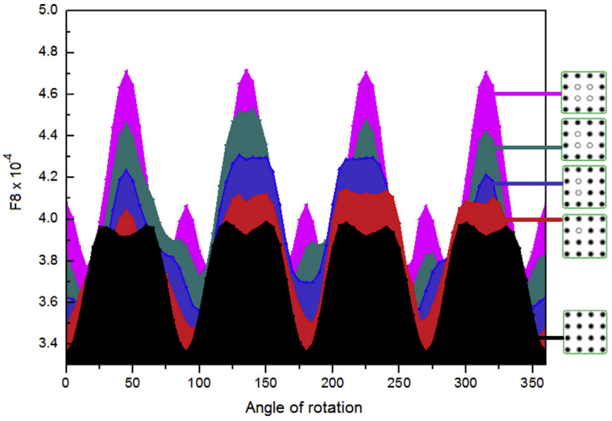


Fig. 6. Generated spectra patterns for one (red circle), two (blue circle) three (green circle) and four (pink circle) missed sources in comparison with non-defected Source (black circle).

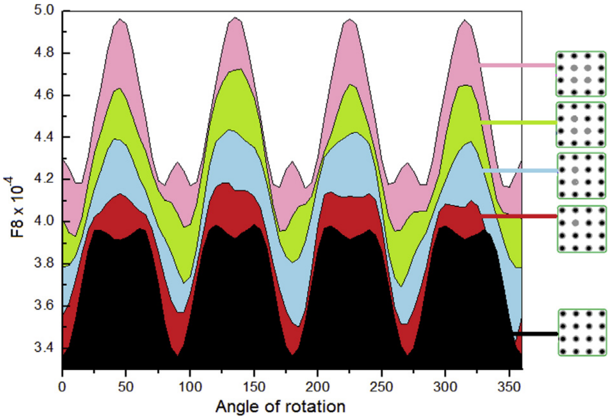


Fig. 7. Generated spectra patterns for one (red circle), two (blue circle) three (green circle) and four (pink circle) dummy items in comparison with non-defected Source (black circle).

Consequently, whenever any spectrum deviation from that of the complete assembly is recognized the measuring system may immediately respond. The response may rise on form of an alarm indicating the deviation.

3.3. Detector response pattern for fuel assembly with dummy rods

Again four scenarios were considered in which one, two, three and four fuel rods were assumed to be replaced by dummy ones. In this case both sources and fuel meat were removed. Fig. 7 shows the generated patterns. The deviation from the full assembly pattern is still clear.

4. Conclusion

In this work the use of a Non-Destructive Dynamic (NDD) method is investigated to detect gross defects in regularly distributed NM (fuel assembly of EK-10 type). Different scenarios were considered and studied using Monte Carlo calculation method employing the MCNP5 Code. The results showed that the investigated method could be easily applied to detect gross defects in such nuclear materials.

Declarations

Author contribution statement

Wael El-Gammal, Moustafa Darweesh: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sahara Shawky: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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