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A study on Detection of Internal Defects in Lead Bricks using Gamma Radiometric Method

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Abstract: In nuclear industry augmentation of proper shielding plays a key role in controlling the radiation levels while handling, storing and transporting the radioactive materials. Various types of materials are used to fabricate shielding components and structures. Among these, lead is widely used for fabrication of such components due to high density, structural stability and viability to fabricate in various shapes. During the process of fabrication defects such as voids and blow holes are likely to be present. In order to ensure the compliance of set tolerance within the specified level evaluation by non-destructive method is essential. Radiometric technique by using gamma radiation is conventionally applied for this purpose. A study was carried out using radiometric testing with a set of lead bricks having different types of known defects. The results from the testing are used to obtain minimum tolerance level that could be detected.

Keywords: Radiometric, lead bricks, gamma radiation.

1 Introduction

Controlling radiation exposure to operational employees within legal limits is critical in nuclear facilities; it is required to keep radiation levels in occupancy areas as low as reasonably possible. The majority of radionuclides found in nuclear power plants are gamma emitters [1]. The use of suitable gamma shielding materials prevents radiation exposure from these radionuclides. The most efficient material for gamma shielding is lead, which has a high density (ρ=11.35 g/cc). The lead brick manufacturing process involves melting lead and antimony raw materials, mixing them in the proper quantities, putting the molten liquid into a mould for casting, and finishing cast bricks to bring them within the specified dimensional tolerance. Lead bricks with fewer faults are difficult to manufacture. Because lead bricks are widely employed as gamma shielding materials in nuclear facilities, a loss in thickness caused by a defective manufacturing process will expose operational people to undesired radiation.

Prior to installation in nuclear facilities, the lead bricks must be inspected for their integrity, shielding effectiveness, and the presence of faults such as voids and blow holes. In terms of thickness and coarse-grained structure, traditional Non-Destructive Evaluation (NDE) procedures such as radiography and ultrasonic testing have limits. In comparable applications, gamma radiometry based on the idea of differential attenuation of radiation has been effectively implemented [2,3]. In gamma radiometry, the source and its strength, as well as the use of a high-sensitivity gamma detector and an experimental setup that minimizes scattering radiation, are all important factors that influence thickness estimation and hence the quality of the results. No studies have been reported to verify the defect in lead bricks using radiometry in literature in detail. There were no studies on correlation between internal defect size and transmitted dose rate. In the present study, lead bricks with internal defects are fabricated and tested with gamma radiometric method. The extent of defect in lead bricks which could be detected by a gamma-based radiometric technique was studied at.

2 Materials and methods

2.1 Lead bricks

Solid brick of lead having dimensions of 5 x 5 x 5 cm^3 was fabricated with defects of odd and cylindrical shaped cavity of various size and solidification cracks. Five types of lead bricks were fabricated for the present study and details are listed below:

Specimen A : Lead brick with no defect

Specimen C1 : solidification crack defect in the plane of thickness with small crack

Specimen C2 : Solidification crack defect in the plane of thickness with increased crack size

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Specimen B1 : Blow hole defect of spherical cavity

Specimen B2 : Blow hole defect odd shaped cavity

In each category, eight numbers of lead bricks were fabricated. Eight blocks in each category, hence a total of 40 lead bricks were prepared for the study. The bricks were arranged in a stacking position in a frame and the eight defective lead bricks are fixed in between as shown in Fig. 1.

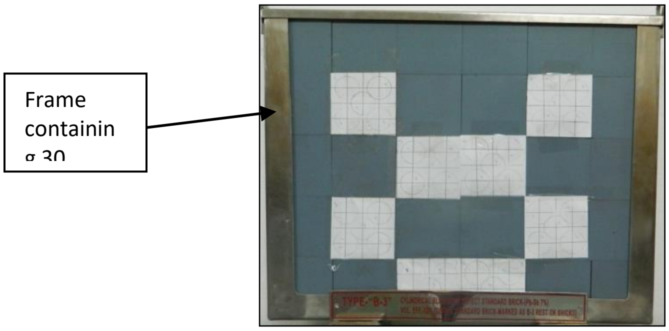

Fig.1: Arrangement of lead bricks.

2.2 Gamma source

The choice and source strength of gamma source used in radiometry has the most impact on results of radiometric technique. As a general guideline, the source's activity should be chosen so that the dosage rate intensity is three times that of the background level. The usual background level is 0.1± 0.03 µR/h, according to measurements. As a result, the dosage rate should be 0.3± 0.09 Sv/h for a minimum detectable intensity more than three times the background level. The current investigation used a Cobalt - 60 source with source strength of 1.554 MBq. ^{60}Co is chosen due to its emission of two high energy gammas 1.1732 MeV and 1.3325 MeV and widely used in radiometric testing [4].

2.3 Gamma detector

The choice of gamma detector for dose rate measurements should have high accuracy and precision. A well calibrated portable radiation survey meter (target make 'Identifier') which employs NaI(Tl)-detector of dimensions 1.4" dia x 2" thick based was used. The instrument was calibrated with a standard source prior to the testing and an acceptance criterion was fixed as ± 30% as per the ANSI standard [5].

2.4 Radiometry testing

A basic schematic layout describing the basic principle of radiometry testing is shown in Figure 1. The differential absorption of X-ray or gamma radiation as it passes through a material is the basis for radiometry. It is identical to conventional radiography except that the radiation detector is a NaI(Tl)-based radiation detector that detects the intensity of the transmitted radiation rather than standard film. The transmitted radiation (I) through any material is governed by the following exponential relationship;

$$I = B(\mu t, E) I_0 e^{-\mu t} \qquad (1)$$

where: I = Intensity of radiation transmitted through the shielding material at a given distance,

I_0 - Initial radiation intensity measured at the same distance without shielding material, µ - Linear attenuation coefficient, t - shielding material thickness, E - gamma energy in MeV &

B - Build up factor of the medium.

2.5 Gamma dose rate estimation

The dimensions of the Co-60 gamma source are 1cm dia and 2 cm height and it can be assumed as a 'Point Source' in the dose calculation. Gamma dose rate (D) at a distance 'r' from a source having activity 'A' Ci is estimated using the relation, [6]

$$D = \frac{BK\Gamma \exp(-\mu t)}{r^2} \text{ ---} \qquad (1)$$

where k - dose conversion factor (R/h for 1 Ci at 1 m)

B – Gamma exposure build up factor,

t- Thickness of lead brick in cm,

µ - linear attenuation coefficient (cm^{-1}) and E – Gamma energy in MeV

3 Experimental techniques

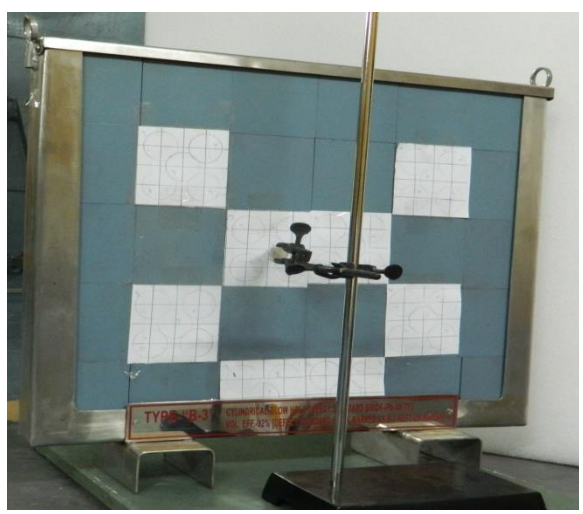

Fig.2: shows the experimental arrangement used in the present study. Gamma source was placed on one side of the lead brick. The detector used to measure the transmitted gamma radiation was positioned in line with gamma source

on the other side of the lead. Grids were marked on the surface of the lead brick facing the detector for ease measurements and cover the entire surface.

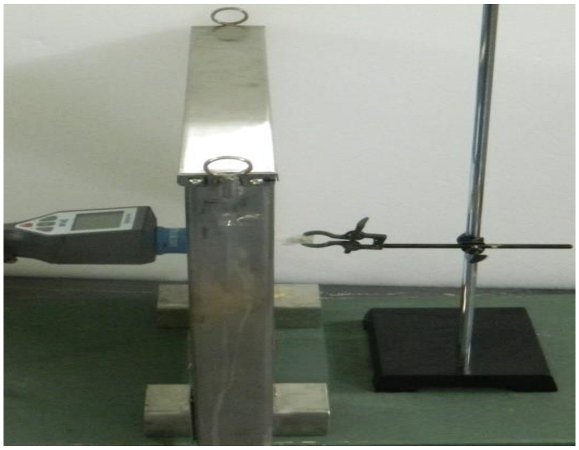

Fig.2: Experimental setup showing source & detector positioning.

A ^{60}Co source optimized strength of 0.042 ± 0.001 mCi was employed for testing. The source was positioned at the center of the shielding plug through a guide. The dose rates were measured at center of grid locations. Each brick is divided into five girds as the diameter of the detector is 3.5 cm, as shown in Fig.3.

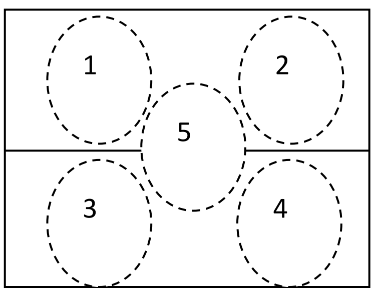

Fig. 3: Grid marking on each lead brick.

4 Results and discussion

Gamma transmission through 5 cm lead is calculated using the relation (1) and it is shown in Fig.4.

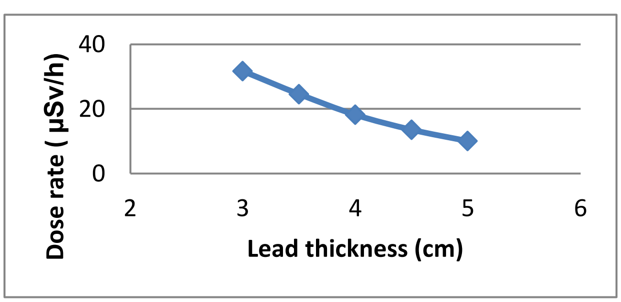

Fig. 4: Gamma transmission curve through defect fee lead.

It is found that the exit dose rate is 10.2 ± 0.1 (3σ level) µSv/h for defect free 5 cm lead thickness. Regression analysis is carried out in order to find the relation between loss of thickness and resultant gamma dose rate [Fig.5]. The equation obtained with R^2 =0.997 is given below.

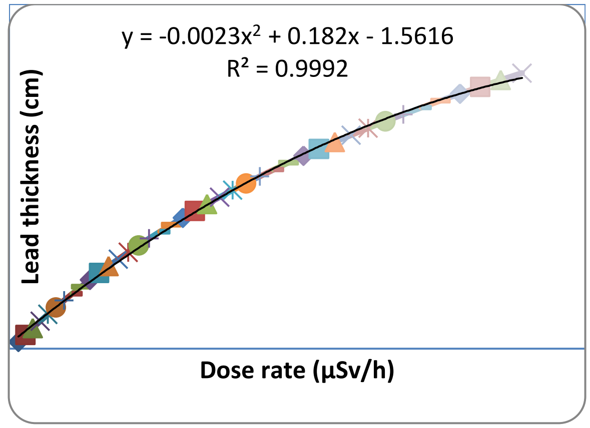

Fig. 5: Thickness loss vs Gamma dose rate.

$$\text{Loss of thickness} = -0.002D^2 + 0.182D - 1.561 \quad \text{--- (2)}$$

Using the relation (2), from the measured gamma radiation dose rate for each specimen of lead block, the loss of thickness is calculated and tabulated (Table 1). The gamma radiation rate in Specimen A is quite close to what is expected. Lead specimen blocks C1, C2, B1, and B2 have a thickness loss of 1.1 cm, 1.56 cm, 2.24 cm, and 2.4 cm, respectively.

Table 1: Estimation of loss of thickness.

Specimen	Observed dose rate (µSv/h)	Loss of thickness Δt (cm)
A1	9.76	0.06
C1	19.2	-1.106
C2	25	-1.561
B2	35	-2.141
B1	40.8	-2.405

By plotting a contour map for each case, the spatial distribution of dose rate on the surface of the lead block is examined, and the results are shown in Figs. 6-10. For plotting a counter map, the length of the lead block is used as the x-axis, the breath as the y-axis, and the dose rate as the z-axis. It clearly depicts the faulty zones present inside each lead specimen.

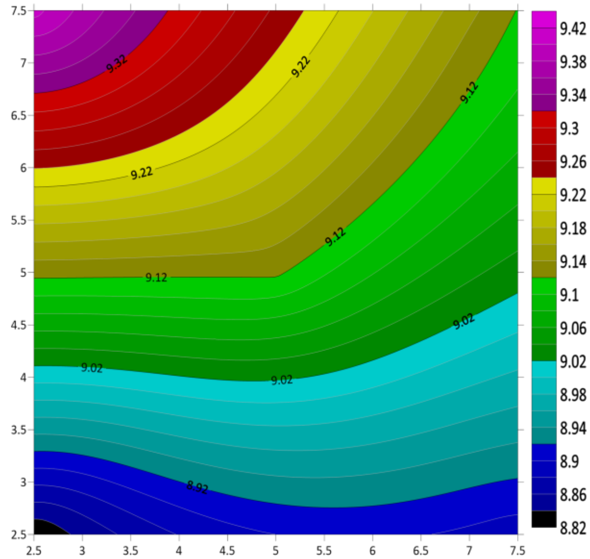

Fig. 6: Surface plot of gamma dose for specimen A.

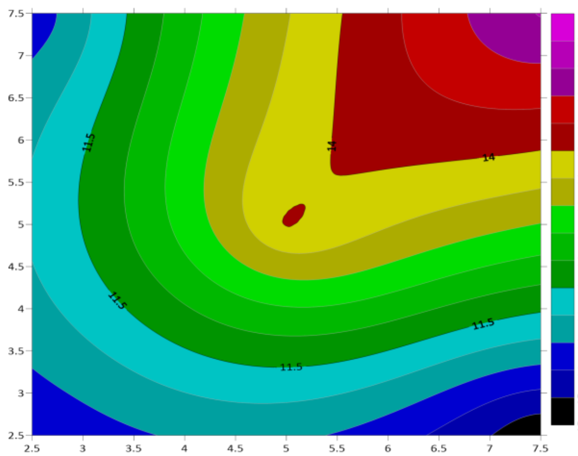

Fig. 7: Surface plot of gamma dose for specimen C1.

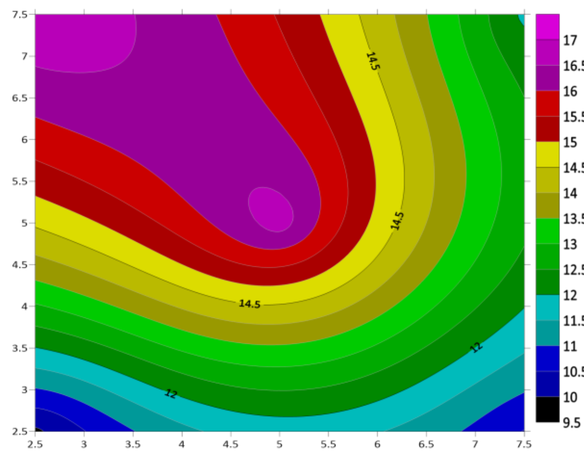

Fig.8: Surface plot of gamma dose for specimen C2.

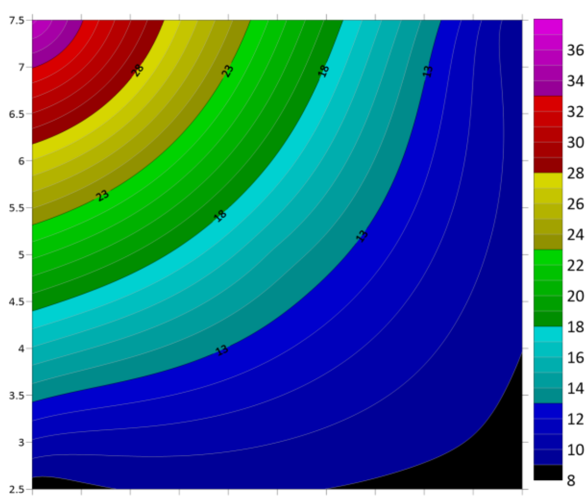

Fig. 9: Surface plot of gamma dose for specimen B1.

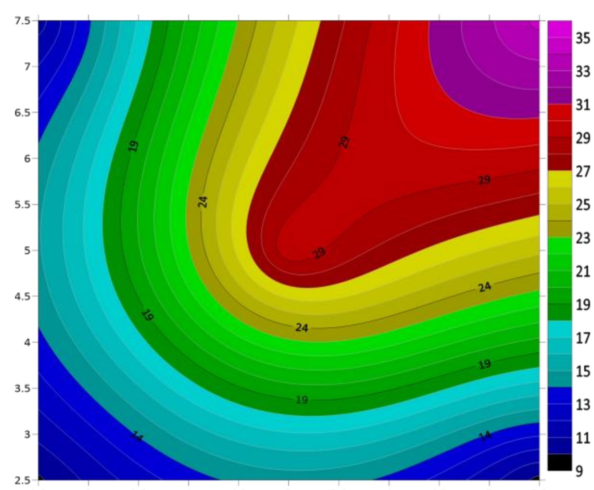

Fig. 10: Surface plot of gamma dose for specimen B2.

5 Conclusions

With the right choice of gamma source strength and high sensitive detector, defects in defective lead blocks can be easily detected out in this method with thickness losses ranging from 0.06 to 2.4 cm. The correlation between internal defect size and transmitted gamma dose rate is well established by a polynomial relation.

The faulty zones are also can be detected with contour map. While performing radiometry testing, the approach provided here could be useful in determining the tolerance level in identification of defects in lead blocks prior to installation in nuclear facilities.

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