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Shielding Processing Technique through the Calculations and Measurement of the Time Averaged Cross-Section of Multiphase Domain

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Karwi. Abbas Ali Mahhmmoed [α], Abdullah. Eman Mohammed [σ]

Abstract - The dual source computed tomography (DSCT) setup has been developing in the central and has potential for use as anon-invasive tool for determining the time averaged cross section of multiphase domain. The two sources used in (DSCT) setup are located inside source collimator device (SCD) to collimate the beam to give it a fan shape. The count rate of un-attenuated photons will be measured by two sets of detectors. Radiation shielding is based on the principle of attenuation, which is the ability to reduce a wave's or ray's effect by blocking or bouncing particles through a barrier material. Charged particles may be attenuated by losing energy to reactions with electrons in the barrier, while gamma radiation is attenuated through scattering, or pair production. . Calculated results showed a substantial convergence with the real measurement values of dose rates especially in the common points.

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I. Introduction

Radiation can be a serious concern in gamma-ray systems, containing radiation and preventing it from causing physical harm to employees or their surroundings is an important part of operating equipment that emits potentially hazardous rays. Preserving both human safety and structural material that may be compromised from radiation exposure are vital concerns, as well as shielding sensitive materials. The process of regulating the effects and degree of penetration of radioactive rays varies according to the type of radiation involved. Indirectly ionizing radiation, like gamma ray is categorized, which involves charged particles. Different materials are better suited for certain types of radiation than others, as determined by the interaction between specific particles and the elemental properties of the shielding material. The DSCT unit is a research machine designed to quantitatively determine the time averaged of multiphase flow systems.

It has been designed to use two sealed point gamma ray sources [1, 2, 3, and 4]. Currently, it is equipped with Co60 (~50 mCi) and Cs137 (~300 mCi). Each source is housed in a Source Collimator Device which is made of lead (for Cs137) and tungsten (for Co60). A fan beam arrangement of source-detectors is used for measuring the transmission of the gamma ray photons across the multiphase experimental setup [5, 6, 7, and 8]. The fan beam consists of a longitudinal section of a cone. Each point gamma ray source is placed at the vertex of a cone. Its detector array is placed along the bottom section of its cone and the multiphase experiential setup is placed in the middle. The sources are positioned at the geometrical center of their SCDs to provide maximum shielding. The setup is designed so that the multiphase experimental setup placed at the center is simultaneously exposed to gamma photons from both sources. A detector array is located at the side opposite to each source in the respective fan beams. These arrays are capable of counting the un attenuated photons or even the scattered photons of the gamma ray that pass through the multiphase experimental setup. Typically a window of energy is set and the counts that fall in this window are recorded. Before a DSCT experiment is be performed, it is first ensured that the multiphase experimental setup is operating at the desired conditions. The SCDs are opened, to turn on the source. The DSCT experiment called a scan is then started and typically runs for about 8 hours. At the end, the SCDs are closed to 'turn off' the sources. During the scan, for a given source position, the detectors array is made to move in an angular manner. For each motion, the computer and data acquisition system collect the gamma ray counts data. The detector plate is moved 21 times; hence, the 15 detectors are oriented at 21 angular positions each with respect to the source. This way, for a given position of the source, 315 angular positions are covered along the arc of the fan beam.

II. Materials And Methoeds

a) Gamma ray sources and the Collimator Devices (SCDs)

Figures (1-12) are for equipments used in Fulton Lab. The Source Collimator Devices (SCDs) were designed by Dr. Charles Alexander at Oak Ridge National Laboratory (ORNL) as a part of the DOE-anaerobic digester grant and manufactured by the

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Machine Shop facility at ORNL [9, 10, 11, 12, and 13]. Lead was used for the Cs^{137} SCD, and tungsten was used for the Co^{60} SCD [3]. The gamma ray beam emerges from the collimator window, which is always shut with a window wedge when the source is not in use. The wedge is secured by a wedge pin [14, 15, 16, and 17] as shown in Figure 1.

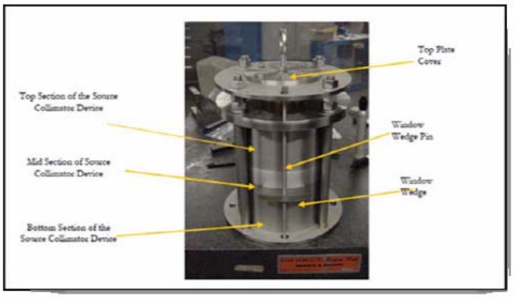


Fig. 1 : Front view of the Source Collimator Device provided by the manufacturer (Oak Ridge National Laboratory).

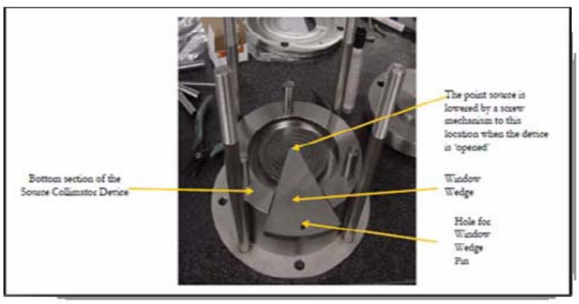


Fig. 2 : Front view of the bottom section of the Source Collimator Device when it is dismantled. The window wedge and location of the point source when the device is opened

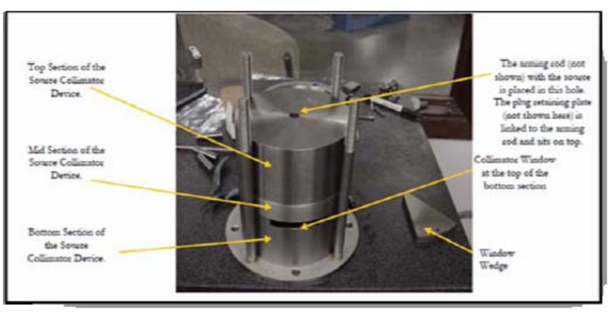


Fig. 3 : Front view of the Source Collimator Device with the top, mid, and bottom sections assembled

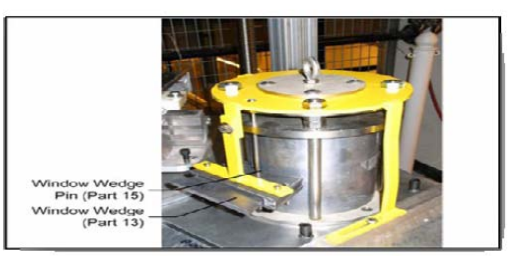


Fig. 4 : Side view of the Source Collimator Device

The point source is located inside the lower half of an arming rod. In use, the arming rod is at the axial center of the SCD. Figure 2 shows the disassembled SDC. The window wedge is placed so that its apex occupies the axial center of the device, the location the source will be lowered to when the source is to be 'turned on' or 'opened'. Figure 3 shows the SCD partially assembled and labels the window through which the gamma ray beam appears. This window is perfectly aligned with the detector lead collimators when the SCD is mounted on the DSCT setup. The source device has a wedge pin as a security device. To 'open' the source, the wedge pin is first removed. The window wedge is then removed with pliers. The top plate cover is removed by loosening the bolts attached to it. The removal of the top plate cover makes the plug retaining plate accessible. This plug retaining plate is attached to the arming rod that has the source in it. This externally threaded plate is lowered with a custom tool until the source is in the lower section of the SCD and centered in collimator window is in the lower section of the SCD and centered in collimator window.

b) Gamma ray sources and the Collimator Devices (SCDs)

The following shielding components are used in the DSCT setup. 1. Source Collimator Device (lead or tungsten) [18 and 19]. The Source Collimator Devices (SCDs) are 6 inches in diameter. The closest distance from the outer surface of the SCD to the source is source is 3 in. for Cs^{137} and 3.5 in. for Co^{60}. Hence, these are the minimum shielding thicknesses of the SCDs Tungsten collimator for the Co^{60} has an additional lead shield of ½ in. thickness. 2-External Beam Collimator (lead): External Beam Collimators have been attached to each of the SCDs with the aid of annex tension from the upper section of the collimator strap, so that they are in line with the collimator window, as shown in Figure 4. These collimators, 2 inches in length at their center, make the gamma ray beam shorter in height as it emerges from the collimator window. 3. Extended Window Wedge: The window wedges supplied by the manufacturer are not used on the SCDs when the external source collimators are attached to them, because they are short and are inaccessible through the extended collimator. Extended Window Wedges made of lead, are used for both the SCDs while they are installed on the DSCT apparatus. 4. Detector Array Lead Shield: The Detector Array Lead Shields are the major shielding component of the DSCT setup as shown in Figure 7. These are curved lead blocks 2.5 inch thick and 3 inch tall that are placed in front of the detectors. They have fifteen 1 inch diameter holes in them to accommodate the Detector Lead Collimators.. Only photons that are incident on the aperture of the collimator pass through unhindered to the detectors. 5. Detector Lead Collimators: The Detector Lead

Collimators have an aperture in the center. Two different sizes of apertures are used (small and large). The small aperture collimator is used by default. When a detector is not used in one of the slots in the detector array, a blind collimator (a collimator without an aperture) is inserted for that slot in the detector shield. 6. Extenders attached to Detector Array Lead Shield: Lead extenders shown in Figure 8, are placed at the edges of the detector array lead 7. Lead Beam Stops The Lead Beam Stop for each detector as indicated in Figures 9 and 10 is made of half inch thick lead and has area of 1cm x1 cm.

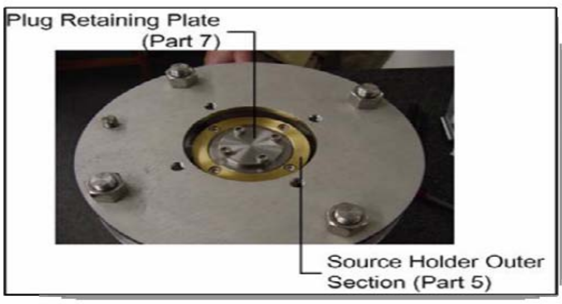


Fig. 5 : View of the SCD showing the Set screw and the Source holder outer section.

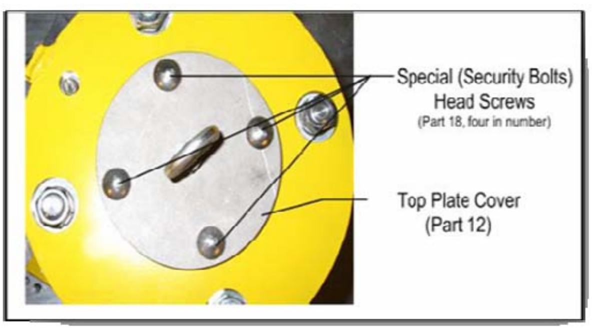


Fig. 6 : View of the SCD showing the security bolts and the top plate cover.

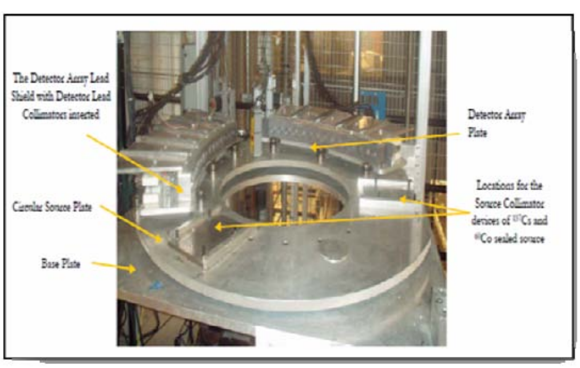


Fig. 7 : Photograph of the DSCT setup without the Source Collimator Devices.

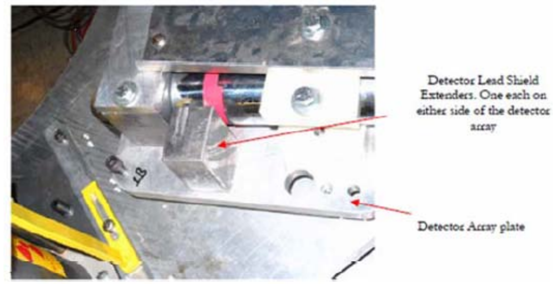


Fig. 8 : Detector Array Lead Shield extenders, made of lead, are secured by bolts to the detector array plate on either side of detector shields. They provide additional shielding at the sides.

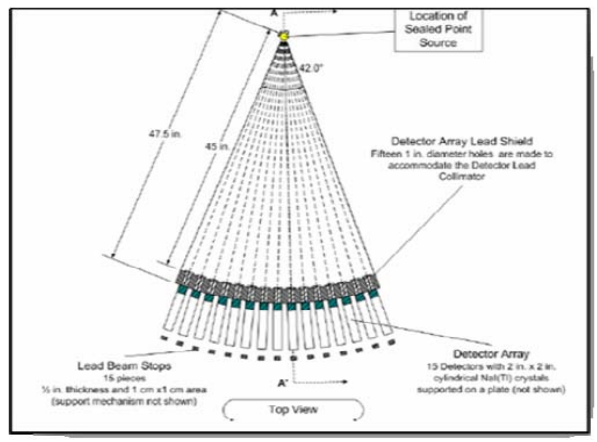


Fig. 9 : Schematic of the fan beam arrangement of the Detector Lead Collimators with the Detector Array Lead Shield.

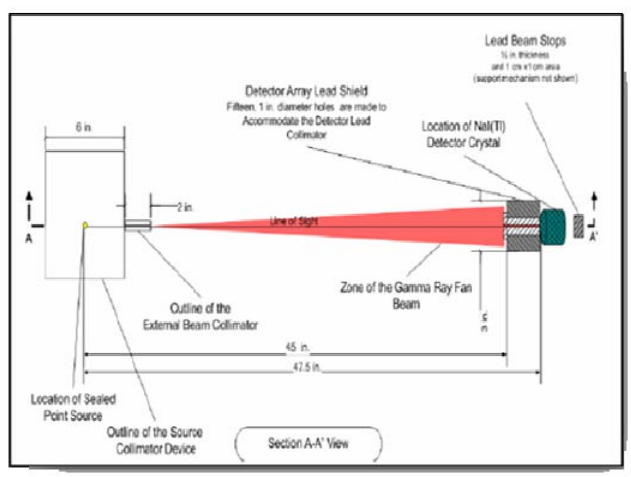


Fig. 10 : Source Collimator Device and detector arrangement. The shaded triangular region in the middle shows a section of the gamma ray fan.

c) Radiation dose rates through operation of (DSCT) setup

The local dose rates in and around the DSCT setup when both SCDs are 'turned on'. The highest possible dose received is at Location I, full body exposure with these dose rates at any location in the structure of the DSCT setup and around it. Since locations V and VI are beyond the aperture of the detector collimators as shown in Figure 11, the area of exposure for dose rates is same as the aperture of the collimator. Occupational dose rates when the SCDs are 'turned on'. The occupational dose has been calculated for a distance of 3 ft from the edges of the DSCT setup. Public dose rates. These doses have been calculated assuming the concrete walls and the doors are absent, and the fan beams are directly oriented towards the wall. The wall thickness and an additional distance of 30 cm (11.81 in.) have been considered to determine the distance for these calculations as shown in Figure 12. The shielding by the NaI crystal in the detector has been accounted. Since attenuation data for parts of the detector excluding the crystal was unavailable, attenuation by the crystal alone has been included. DSCT operation the public dose is calculated to be less than 2 mrem/hr. sight of the source when it is ''turned on''. These dose rates will be received, if one is .Since the dose rates calculated here doesn't account for the shielding from the block walls doors, and the multiphase experimental column in the center of the DSCT setup, the measured values will be less than 1mrem/hr in any one hour . Dosimeters will be placed on the walls on the North, the West and the South sides, and on the mesh on the East side such that they are in line with the DSCT set up. These will record the dose received at the periphery of the room due to the DSCT experiments. These dose records will be a good estimate (after accounting for attenuation by the walls) of the public dose rates. These dosimeters will be returned every quarter to Radiation Safety, and the new ones issued will be placed at the same location. Dose rates related to closed SCDs when the source is 'turned off'. These doses will be received in the region behind the SCD even when the source is 'turned off'

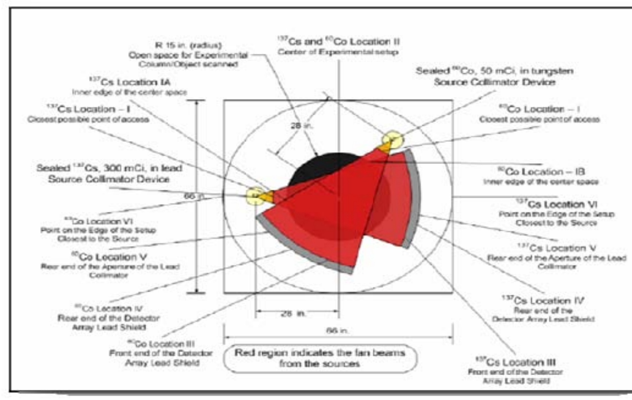
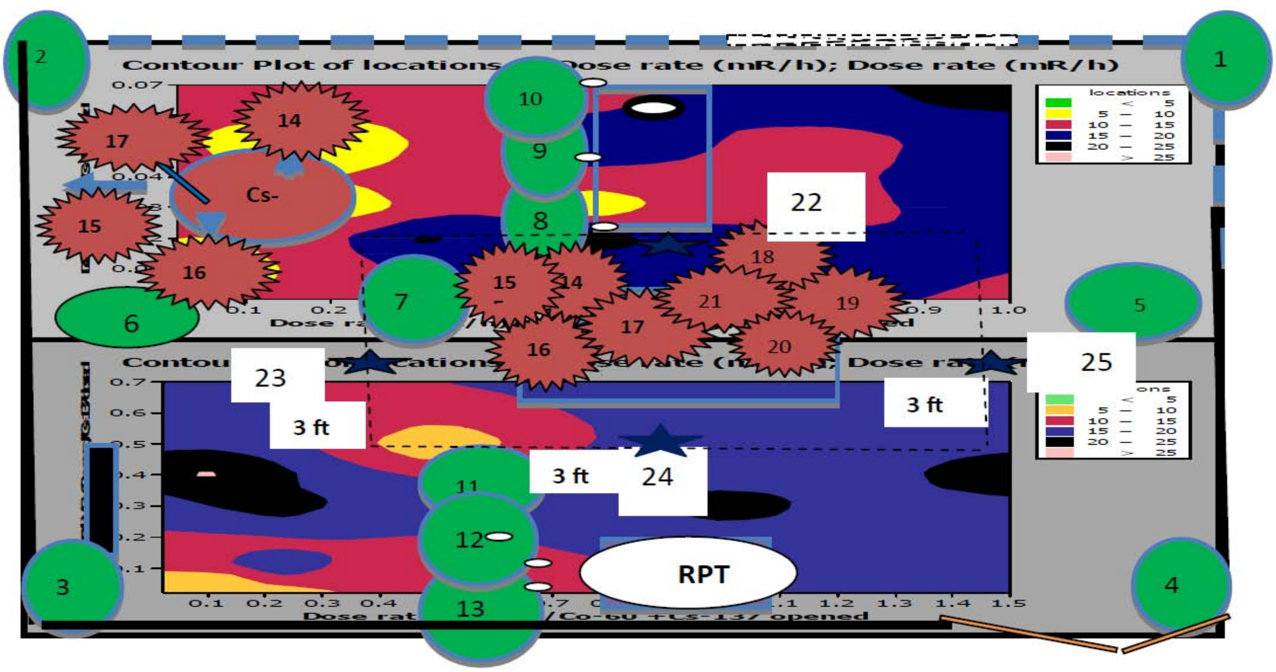


Fig. 11 : Schematic showing a top view of (DSCT) setup



[* Left side / (1ft) from Cs source –point (14) : * Behind / (1ft) from Cs source –point (15) : * Right side/ (1ft) from Cs source –point (16) *Above / (1ft) from Cs source –point (17) * Left side / (1ft) from Co source –point (20) : * Behind / (1ft) from Co source –point (19) : * Right side/ (1ft) from Co source –point (18) *Above / (1ft) from Co source –point (21)]

Fig.11 : Fulton Hall Lab

d) Operational Controls and surveying processes

1. Rope barrier around DSCT setup: The DSCT setup will have a rope barrier around it at a minimum distance of 3 ft from the DSCT, or the 2 mrem/hr perimeter, whichever is greater. This is to demarcate the minimum distance the DSCT User needs to maintain from the DSCT setup when a DSCT experiment is on. Further if the dose due to scatter is high near the DSCT setup.

2. Red Beacon: A red beacon is fitted on top of the DSCT's computer tower. This is connected to a sensor box, placed on the circular source table (Figure 1). When either of the SCDs is opened to 'turn the source on' the sensor detects the radiation and the beacon is turned on. This sensor is set at threshold of 2 mrem/hr.
3. Postings: The following signs will be posted on all doors (North, South and West). a- "Caution-Radioactive Material".b-"Authorized Personal Only".c-"Caution Radiation Area".d-"Warning: Do not enter if the RED BEACON is on.". e- " This gate is to be shut at all times"-(For the Riser gate) On all sides of the DSCT setup's frame. f-" Caution High Radiation Area" - on all sides of the DSCT structure. g-" Critical Shielding Component, not to be removed".
4. Tools for Opening Source Collimator Devices (SCDs): The SCDs require a special key to open the top cover plate and a special screw driver to rotate the source plate and lower it down to the collimator window.

DSCT radiation workers must conduct instrument surveys monthly and after any CT work, and must document these results properly. There must be no more than a 30 day gap between monthly surveys. If the lab contains no radioactive materials (RAM) or sealed sources, but the lab is still on active status as defined by radiation safety, it is still required to perform and document monthly lab surveys. The instrument surveys are used to detect radiation and to identify areas of contamination. Radiation workers must routinely survey the place of work and themselves individually, both during and after their work. The areas to be surveyed are: areas of radioactive material use and storage, components of the DSCT setup, experimental setup and its components, and the equipment used with the DSCT instrument. Radiation survey instruments are available in areas where sealed sources/devices are used. In these laboratories, there are two different types of portable Geiger-Muller (G-M) surveymeters: one is a Bicron Model 50 with cylindrical G-M probe, and the other is a Ludlum Model 3 with a pancake G-M probe. Instrument surveys are valuable in identifying areas where radioactive contamination may be present and surveying the radiation field around the sealed sources/devices. In a typical survey, dose rate measurements are made in the vicinity of the sources /devices and throughout the laboratory. In addition, these portable survey instruments are used for a variety of general tasks:

1. To conduct routine area surveys of the laboratory.
2. To confirm the successful opening and shutting of the collimator containing the sealed source.
3. To survey shipments of sealed sources received.
4. To monitor hands, shoes, clothing, and the work area for contamination before leaving the area.

G-M instruments are widely used for radiation survey work because of their reliability and low cost. The Bicron G-M probe is suitable for measuring exposure rates (mR/hr) in the vicinity of radioactive sources, but is relatively insensitive for detecting low levels of radioactivity associated with contamination. The Ludlum pancake G-M probe is much more sensitive to low levels of radioactive contamination, and the open side of the detector can be used for surface contamination measurements in counts per minute (cpm). The back side of the detector can be used like any G-M probe for exposure rate or dose rate measurements (mR/hr or mrem/hr). Figure 13 shows the Ludlum model3 survey meter with the pancake probe for general-purpose surveying.

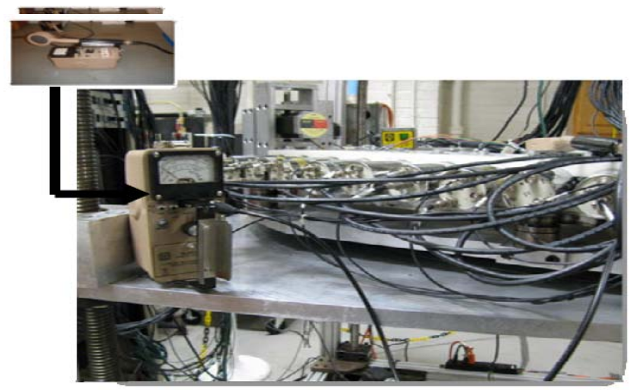


Fig. 13 : The Ludlum Model 3 Survey Meter with Model 44-9 G-M Pancake Probe

Electronic pocket dosimeter is suited for measuring the accumulated dose equivalent to X-ray of 20KeV , also used in medical service and other fields. The obtained data are stored in the battery for along time. There are three serial numbers for this device as shown in Table 1

Serial No	Dose equivalent	Error%	Calibrati on factor
E0740	41μSv	0.0	1
E0741	41μSv	0.0	1
E0742	41μSv	-2.4	1.03

Table 1 : Dosimeter models

Fig.14 : Electronic pocket dosimeter instrument (EPD^{TM})

III. Results And Discussion

Radiation protection can be divided into occupational radiation protection, medical radiation protection, and public radiation protection. There are three factors that control the amount of dose like; a- Time: Reducing the time of an exposure reduces the effective dose proportionally. Reducing radiation doses by reducing the time of exposures might be improving operator training to reduce the time they take to handle a source. b- Distance: Increasing distance reduces dose due to the inverse square law. Distance can be as simple as handling a source with forceps rather than fingers. c- Shielding: Biological shield refers to a mass of absorbing material placed around the radioactive source, to reduce the radiation to a level safe for humans. The effectiveness of a material as a biological shield is related to its cross-section for scattering and absorption, and to a first approximation is proportional to the total mass of material per unit area interposed along the line of sight between the radiation source and the region to be protected. Almost any material can act as a shield from gamma or x-rays if used in sufficient amounts. Experimental work as shown in Table 2 which presents the concentrations of the radiation of sources 235mCi Cs^{137} and 22mCi $C0^{60}$ for twenty five locations using gamma ray tomography. Doses for locations one-thirteen when the two sources closed are between 0.01-0.05 mR/h. The Doses for these points when the Cs^{137} source is opened are between 0.02-0.05 mR/h, but the doses when the Co^{60} source is opened are between 0.02-0.07mR/h. When the two sources are in work, the maximum concentration is at point 6 as shown in Figure 12. Table 3 presents the equivalent dose for locations 1ft far from the two sources at points fourteen-twenty one, the maximum dose rate is at point eigteen when the two sources are in work. Table 4 presents the doses rates for locations twenty two-twenty five for locations far 3ft from the view plate, so the maximum dose rate is at point twenty four and equal to 1.5 mR/h when the two sources are active in work. Figures 15, 16, 17, and 18 shows that the results obtained using the Ludlum Model 3 Survey Meter with Model 44-9 G-M Pancake Probe and electronic pocket dosimeter instrument(EPD™) Figures 19 and 20 shows that the equivalent dose rates in (mR/h) and (rad/h) in 3-D. The calculation dose rates induced by Cs^{137} and Co^{60} sources as shown.The maximum dose rates when 235mCi Cs^{137} source is active in work is 1 mR/h at a distance (1ft) far from view plate for points 14,15,16,17,18,19,20, and 21 as shown in Figure 12, the dose rates for these points are 0.8,0.5,0.5,1,0.4,0.4,0.3 and 0.4 resp. For points ate distance of (3ft) far from view plate, the minimum dose is 1 rad/h, while the maximum dose is 0.5 rad/h. Other locations 1-13 as shown in Figure 12 , the dose rates are between 0.02-0.03 rad/h, these doses are low and not affected on human health. Dose rates recorded by 22mCi Co^{60} source is lower than the rates of Cs^{137} source. When the two sources are in work, all doses are reached the maximum values near the view plate as shown in Figures 18, 19, and 20. So we can say that the doses are at the maximum limits when the two sources are in work around view plate. Gamma ray is the form of electromagnetic radiation that occurs with higher energy levels than those displayed by ultraviolet or visible light. There are several factors that influence the selection and use of radioactive shielding materials, such as attenuation effectiveness, strength, resistance to damage, thermal properties, and cost efficiency can affect radiation protection in numerous ways. So materials with high density are more effective than the low density for reducing the intensity of radiation. Low density materials can compensate for the disparity with increased thickness, which is as significant as density in shielding applications. Lead is particularly well suited for lessening the effect of gamma rays due to its high atomic number. This number refers to the amount of protons within an atom, so a lead atom has a relatively high number of protons along with a corresponding number of electrons. These electrons block many of the gamma ray particles that try to pass through a lead barrier, and the degree of protection can be compounded with thicker shielding barriers.

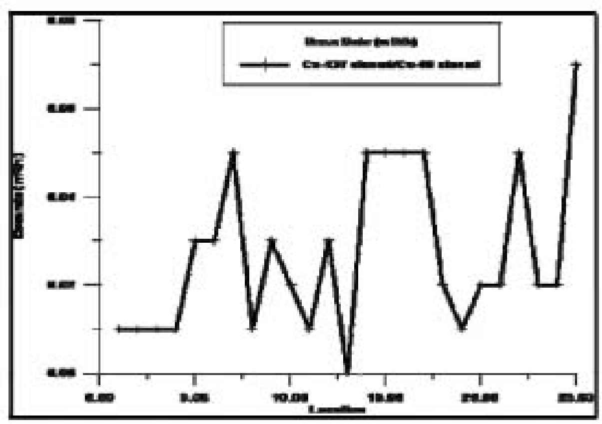


Fig.15 : Measured dose rate (mR/h) for G-2 Fulton Hall room when both sources are closed.

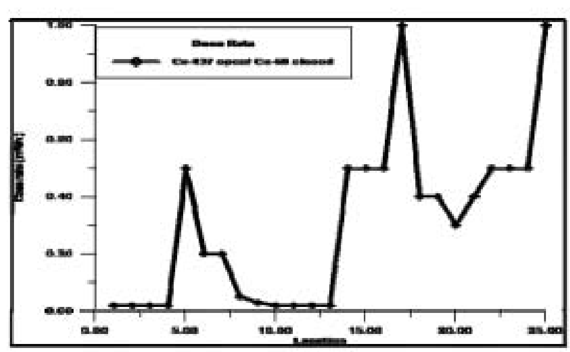


Fig. 15 : Measured dose rate (mR/h) for G-2 Fulton Hall room when both sources are closed

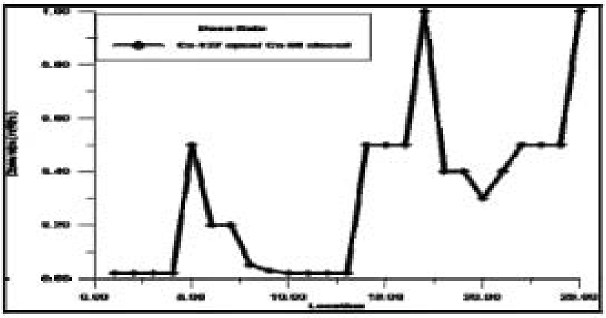


Fig. 16 : Measured dose rate (mR/h) for G-2 Fulton Hall room when Cs-137 open/Co-60 close

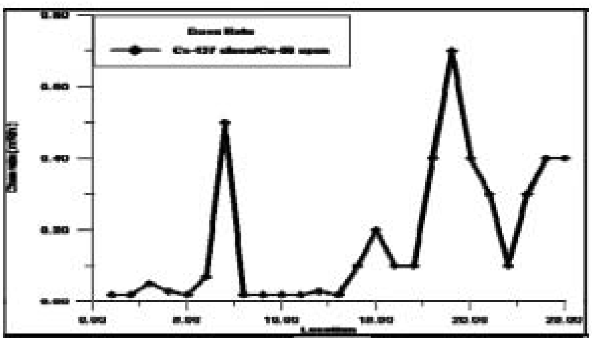


Fig. 17 : Measured dose rate (mR/h) for G-2 Fulton Hall room when Cs-137 close/Co-60 open

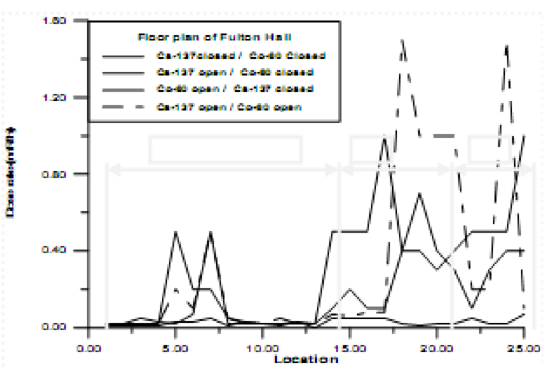


Fig. 18 : Measured dose rate (mR/h) for G-2 Fulton Hall room when Cs-137 close/Co-60 open

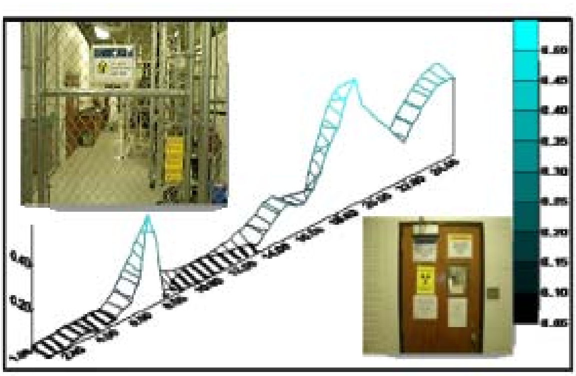


Fig. 19 : Dose rate(mR/h) of G-2 Fulton Hall room locations

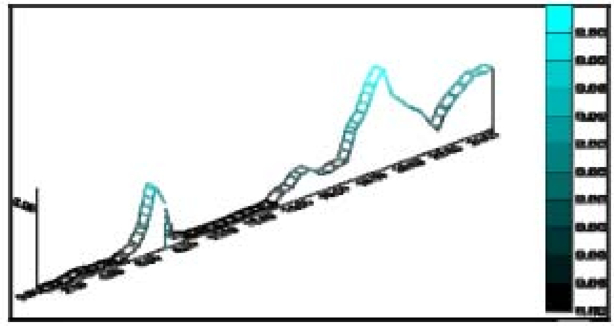


Fig. 20 : Dose rate (rad/h) of G-2 Fulton Hall room locations

Table 2 : Equivalent dose rate for locations (around, 1ft, and 3ft) from 200 mCi Cs-137 & 50 mCi Co-60 sources /Distance from source to floor =41in

Location	Dose rate (mR/h) /Cs-137 closed	Dose rate (mR/h)/ Cs-137 opened /Co-60 closed	Dose rate (mR/h) /Co-60 opened/ Cs-137 closed	Dose rate (mR/h)/ Co-60 + Cs-137 opened
1 (around)	0.01	0.02	0.02	0.02
2 (around)	0.01	0.02	0.02	0.02
3 (around)	0.01	0.02	0.05	0.02
4 (around)	0.01	0.02	0.03	0.02
5 (around)	0.03	0.5	0.02	0.2
6 (around)	0.03	0.2	0.07	0.1
7 (around)	0.05	0.2	0.5	0.5
8 (around)	0.01	0.05	0.02	0.05
9 (around)	0.03	0.03	0.02	0.02
10(around	0.02	0.02	0.02	0.02
11(around	0.01	0.02	0.02	0.05
12(around	0.03	0.02	0.03	0.02
13(around	0.00	0.02	0.02	0.02
14 (1ft)	0.05	0.8	0.1	0.07
15 (1ft)	0.05	0.5	0.2	0.06
16 (1ft)	0.05	0.5	0.1	0.08
17 (1ft)	0.05	1.0	0.1	0.08
18 (1ft)	0.02	0.4	0.4	1.5
19 (1ft)	0.01	0.4	0.7	1
20 (1ft)	0.02	0.3	0.4	1
21 (1ft)	0.02	0.4	0.3	1
22 (3ft)	0.05	0.5	0.1	0.2
23 (3ft)	0.02	0.5	0.3	0.2
24 (3ft)	0.02	0.5	0.4	1.5
25 (3ft)	0.07	1.0	0.4	0.1

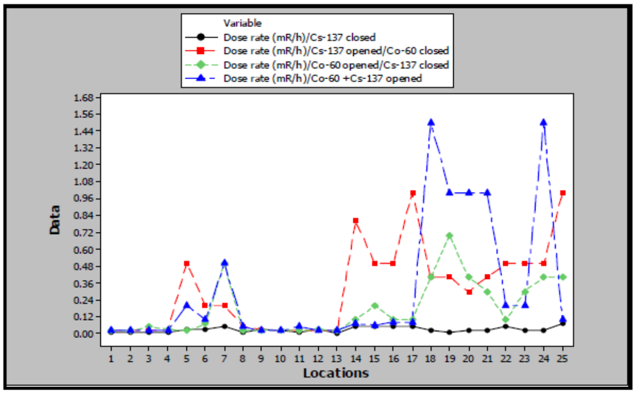


Fig. 21 : Dose rate (rad/h) of locations (1-25)

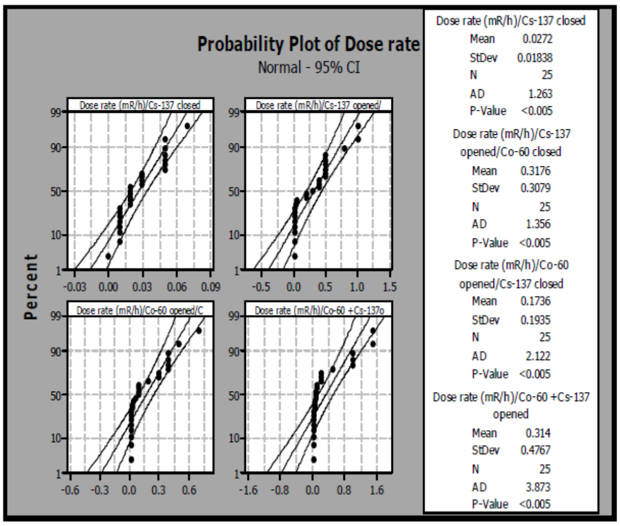


Fig. 22 : Probability plot of dose

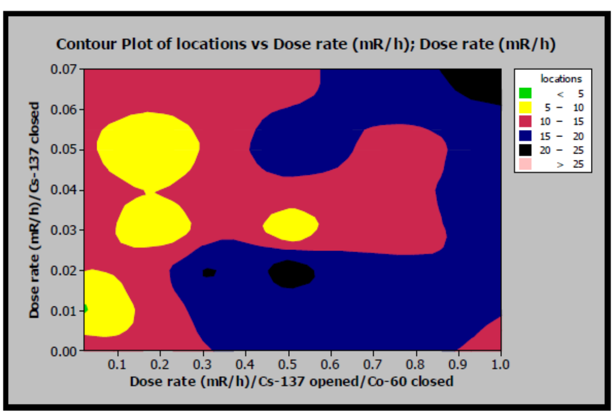


Fig. 23 : Contour plot locations vs dose rate

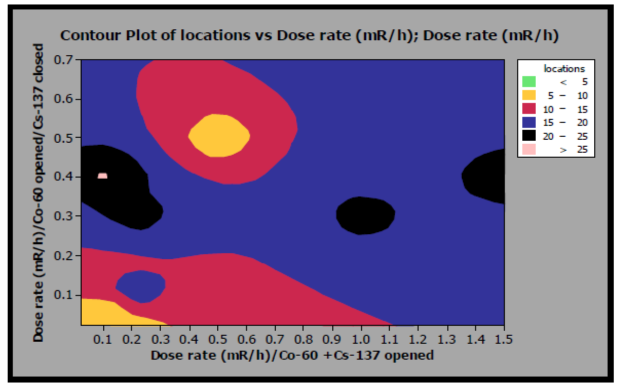


Fig. 24 : Contour plot locations vs dose rate

Table 3 : Input Data/Cs-137

No	Variable	Symbol	value	Unit
1	Cs-137 source activity	C1	235	mCi
2	Distance -1	d1	12.7cm=5in	Cm
3	Distance-2	d2	33.02cm=13in	Cm
4	Distance-3	d3	91.44cm=36in	Cm
5	Distance-4	d4	71.2cm=28in	Cm
6	Distance-5	d5	114.3cm=45in	Cm
7	Distance-6	d6	120.65cm=47.5in	Cm
8	Distance-7	d7	120.65cm=47.5in	Cm
9	Distance-8	d8	189.23cm=74.5in	Cm
10	Distance-9	d9	246.38cm=97in	Cm
11	Distance-10	d10	513cm	Cm
12	Distance-11	d11	520cm	Cm
13	Distance-12	d12	185	Cm
14	Distance-13	d13	303	Cm
15	Distance-14	d14	7.62cm=3in	Cm
16	Distance-15	d15	37.62cm=15.5in	Cm
17	Lead shielding distance-1	TL1	6.35cm=2.5in	Cm
18	Lead shielding distance-2	TL2	1.25cm=0.75in	Cm
19	Lead shielding distance-3	TL3	7.62cm=3in	Cm
20	NaI Shielding distance	TNaI	5.08cm=2in	cm

Table 4 : Output Data/Cs-137

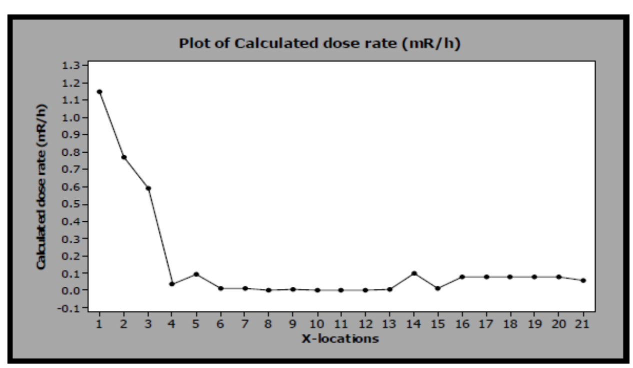


Fig. 25 : Plot of calculated dose rate

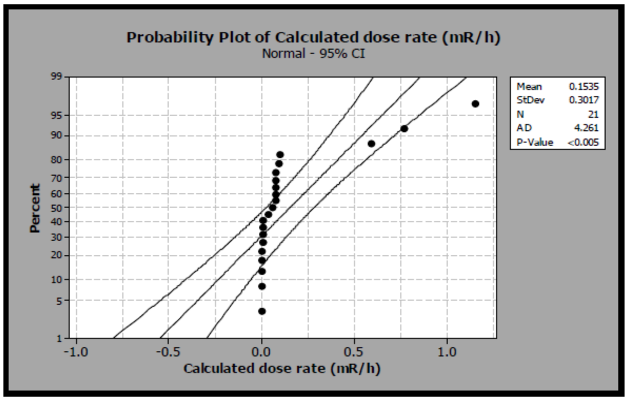


Fig. 26 : Probability plot of calculated dose rate

Radiation can be a serious concern in nuclear power facilities, industrial or medical x-ray systems, radioisotope projects, particle accelerator work, and a number of other circumstances. Containing radiation and preventing it from causing physical harm to employees or their surroundings is an important part of operating equipment that emits potentially hazardous rays. Preserving both human safety and structural material that may be compromised from radiation exposure are vital concerns, as well as shielding sensitive materials. The process of regulating the effects and degree of penetration of radioactive rays varies according to the type of radiation involved. Indirectly ionizing radiation, which includes neutrons, gamma rays, and x-rays, is categorized separately from directly ionizing radiation, which involves charged particles. Different materials are better suited for certain types of radiation than others, as determined by the interaction between specific particles and the elemental properties of the shielding material. Through Figure 22, we see that the standard deviation has the highest value in the case of open the two sources , so we see some points are out the domain of the probability lines, while we see that the standard deviation is less when we open the cesium source and the value becomes half when we open the cobalt source. From Figures 23 and 24 ,we see that the blue area is for the sites 15-20, these areas are widely exposure to gamma rays ,so we advise workers not to work for long periods within this region. The theoretical calculations as shown in Figures 25 and 26 ,we see there is a strong match between theoretical calculations and measurement processes up to 95% when the two sources are open, which confirms the correctness of theoretical calculations which we made.

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