

## Dose Calculations and Determination of Shielding Characteristics for Protecting Emergency Workers During the Response to Radiological Emergencies

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### Abstract

Effective and efficient response to radiation emergency including those with security related events is the main goal of the national strategy for emergency preparedness and response. Accidents due to radioactive sources have a wide range of possibilities and consequences. Mapping of the radiation doses related to the exposure of radioactive sources with different activities give a fast view and expectation of the consequences and the required protective actions and other response actions. The aim of this publication is to provide a practical guidance for emergency response in terms of absorbed dose rate and their related required shielding parameters for different categories of radioactive sources that, if implemented, will provide a fast assessment and response capability needed to protect the public and the workers in the event of different types of radiological emergencies including radioactive sources. MNCP Code is used for predicting the absorbed doses from the famous radioactive sources under different hazard categories (categories 2&3) in case of loss of their shielding at different distances and to calculate their appropriate shielding characteristics.

### 1. Introduction

Using of radioactive sources in different applications is growing daily. Despite all safety precautions taken in design and operations, accidents involving radiation sources do occur more frequently. The consequences and the impact of the accidentally and unmanaged exposure of such radioactive sources may be serious and fatal. The effective response with promptly and adequately actions to protect the public and the emergency workers is one of the most important aspects of managing a radiological emergency [1]. The categorization of radioactive sources is providing a fundamental and internationally harmonized basis for risk-informed decision making especially in emergency preparedness and response related activities [2]. The aim of this work is to provide a fast guideline for expecting dose rate and required shielding characteristics during the response to radiological emergencies involving radioactive sources. Monte Carlo calculations are carried out on several radioactive sources that mostly used in industrial applications and

are belonging to hazard categories 2 and 3. The provided fitted equations allow the planner to easily calculate the flux and the dose rates as well as the required shielding characteristics at a range of distances due to different types of radiation sources.

In this work, general Monte Carlo code MCNP5 is used taken into consideration the effect of real setup and situations including source geometry, self-attenuation due to material density and types of emitted radiations for dose rate calculations. Emitted radiations, type of isotopes, shielding geometry, shielding density and interaction of radiation with matter are the theoretical parameters used in determining the shielding characteristics. The general Monte Carlo code, MCNP5, has the feature of calculating the radiation flux gammas and neutrons at a specified point using the point detector “F5” tally. The energy distribution of the gamma rays emitted from the sources are identified using a distribution number “Dn” in the energy variable of the source definition card

“SDEF”. The distribution itself is defined in the source information “SI” and source probability distribution “SP” cards. The gamma energies with their emission probabilities are inserted in the source information and probability distribution cards. Finally, conversion of the calculated flux at the specified points into dose is accomplished using the “flux-to-dose conversion factors” listed in the DE/DF cards. The multiplier card “FMa” was used to modify the results such that they are directly given in units of  $\mu\text{Sv/hr}$ .

The Table of gamma flux-to-dose rate conversion factor given in the MCNP manual was used [3,4]. The selected isotopes with their corresponding activity in (TBq) and their modes of decay are presented as well as their industrial applications and hazard categories in Table 1 [2]. The results of calculations for both flux and dose rate as functions of distance are then fitted to a power function.

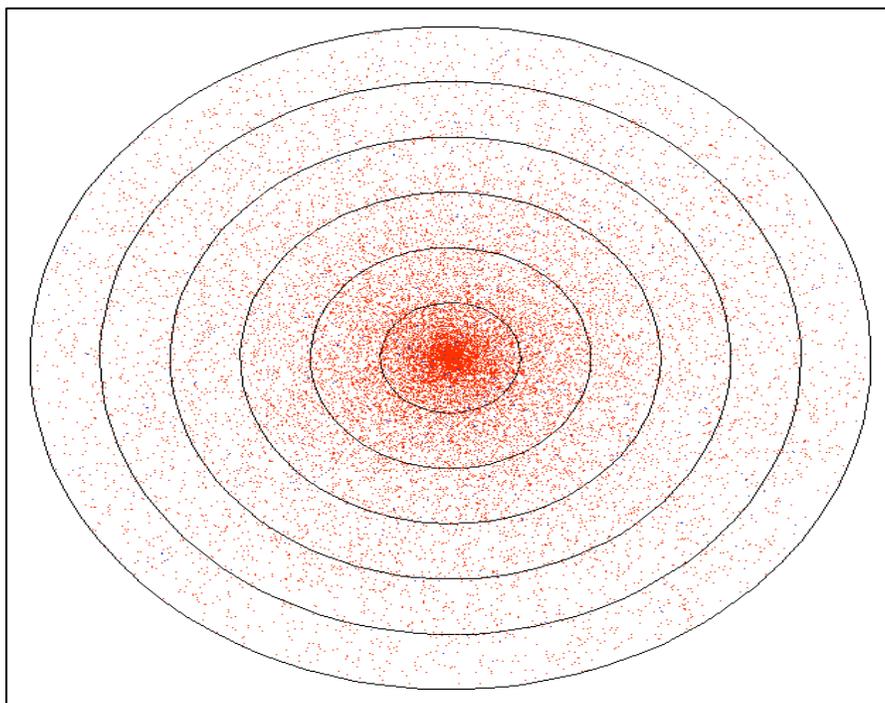
Category	Radioactive Source	Applications	Activity (TBq)			Mode of Decay
			Min.	Max.	Typ.	
Category II	$^{60}\text{Co}$	Industrial radiography	4.1E-01	7.4E+00	2.2E+00	Gamma
Category II	$^{192}\text{Ir}$		1.9E-01	7.4E+00	3.7E+00	Gamma
Category II	$^{137}\text{Cs}$	Calibration Source	5.6E-02	1.1E+02	2.2E+00	Gamma
Category III	$^{241}\text{Am}$		1.0E-01	7.4E-01	3.7E-01	Gamma
Category III	$^{137}\text{Cs}$	Level gauge	3.7E0-2	1.9E-01	1.9E0-1	Gamma
Category III	$^{241}\text{Am/Be}$	Well logging	1.0E-02	8.5E-01	7.4E-01	Neutron
Category III	$^{252}\text{Cf}$		1.0E-03	4.1E-03	1.1E-03	Neutron

**Table 1: The Used Radioactive Sources and Their Modes of Decay and Corresponding Energies**

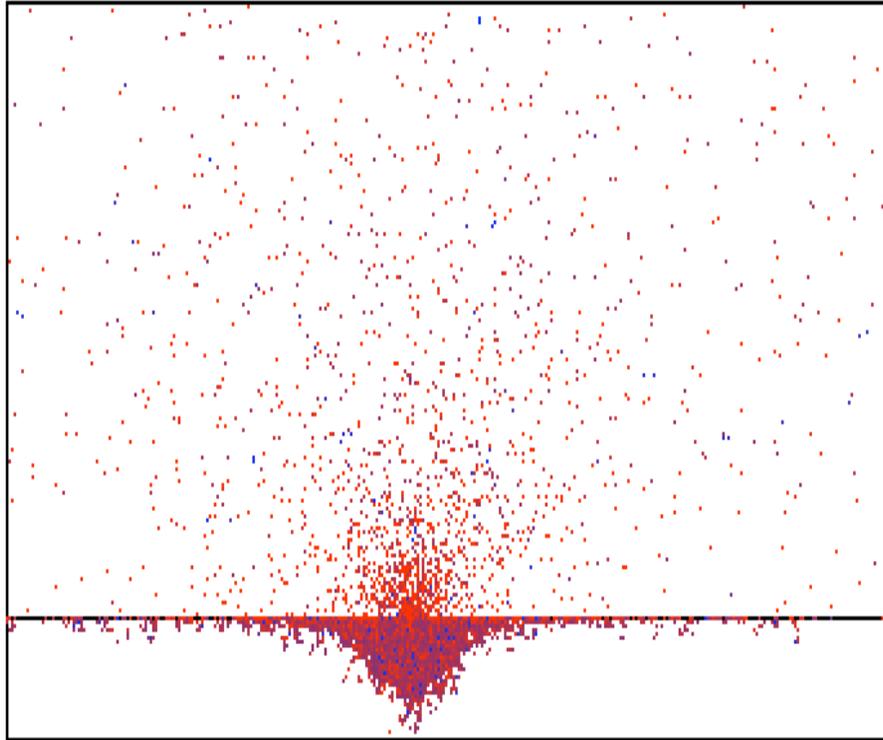
## 2. Results and Discussion

Two models for the calculation of dose rate due to the point sources are estimated, the first one; the point source is located on the air space as sphere model without any effect of the land and the dose rate calculated at different distances from the source as shown in Figure 1. The second one; the point source is located on

concrete land and in air space in rectangle shape to decrease the backscattering effect; where the dose rates are also calculated at different distances as shown in Figure 2. Figures 1&2 illustrate the particles display of the point source in each model. Another hypothetical model for dose calculation due to using Lead Pb, shield between the source and the worker is introduced.



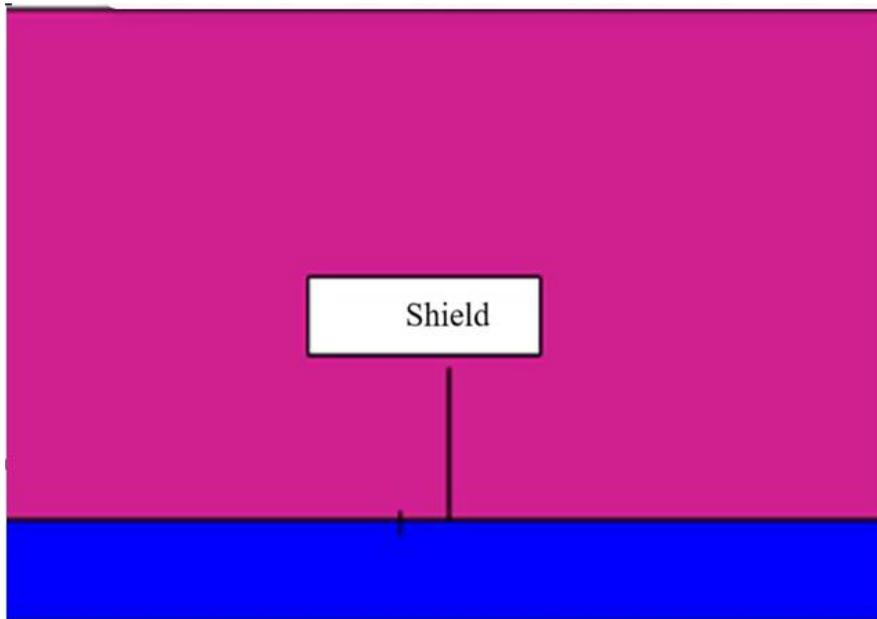
**Figure 1: The Particle Display of  $^{60}\text{Co}$  Point Source in Sphere Model Air Space without Concrete Land**



**Figure 2:** The Particle Display of  $^{60}\text{Co}$  Point Source in Rectangle Model Air Space with Concrete Land

The model estimated that the source and the shield are positioned at the concrete land and in air space. The geometry of the shield is described as rectangle shape with diameters 1.0 cm and 3.0 cm of Pb for gamma emitters. The location of the emergency worker

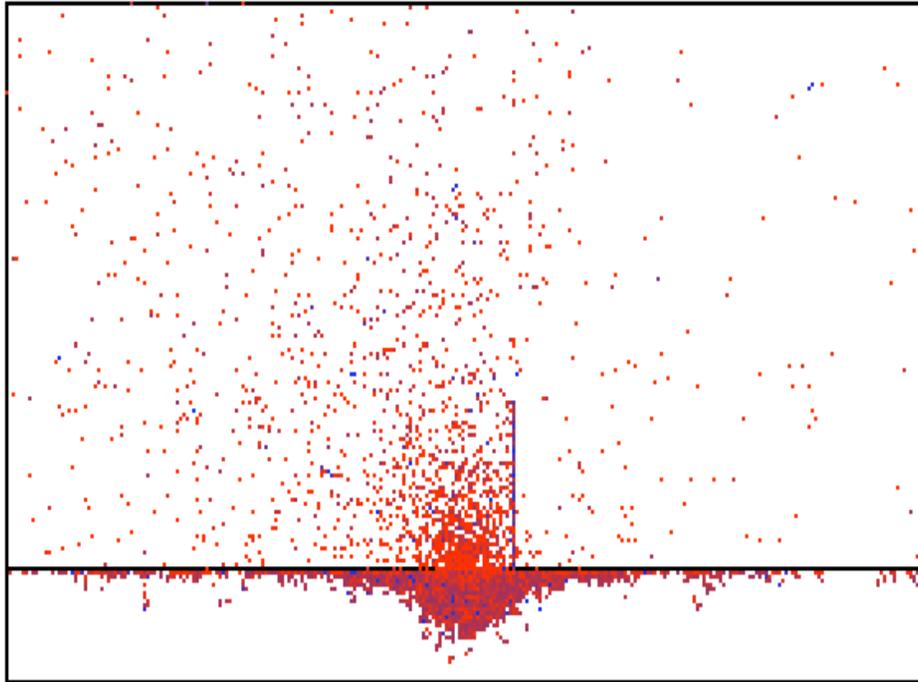
from the shield  $(x,y,z)$  are estimated as  $(x,0,100)$  where  $x$ , are the distance between the worker and the shield. Figure (3) illustrates the schematic diagram of the model.



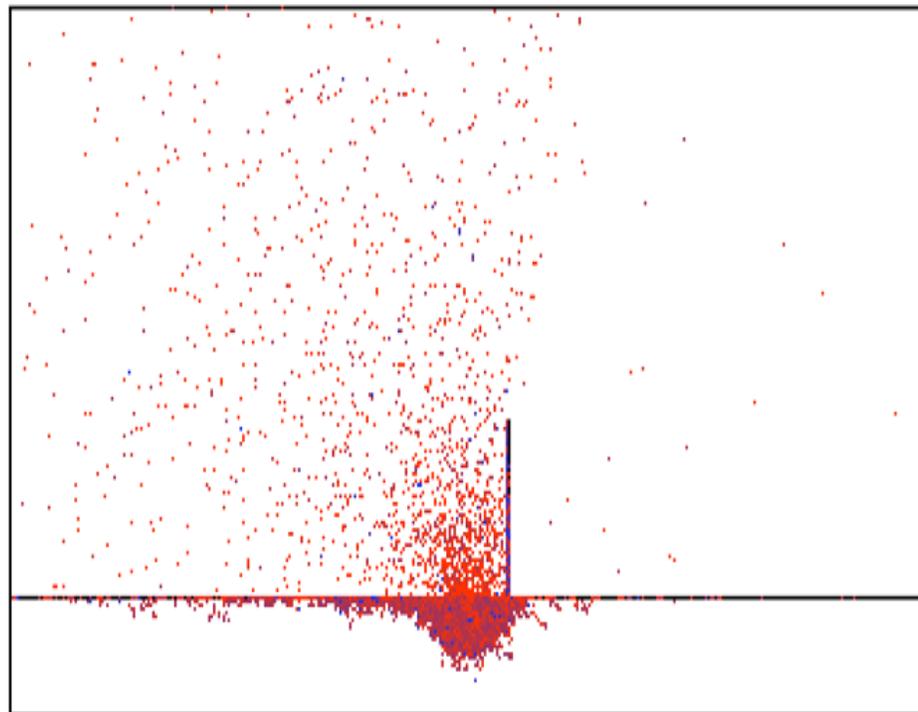
**Figure 3:** Schematic Diagram of the Estimated Shield Model

The absorbed dose rates at different distances from the point source and the shield (100, 150, 200, 250, 300, 350, 400, 450, 500 and 550 cm) were calculated. Figure 4 and Figure 5 illustrate the

particles display from 0.2 TBq  $^{137}\text{Cs}$  gamma line in the presence of 1.0 cm and 3.0 cm Pb shield respectively.



**Figure 4:** The Particle Display of the  $^{137}\text{Cs}$  (0.2 TBq) Photons in the Opposite Directions of 1.0 cm Pb Shield

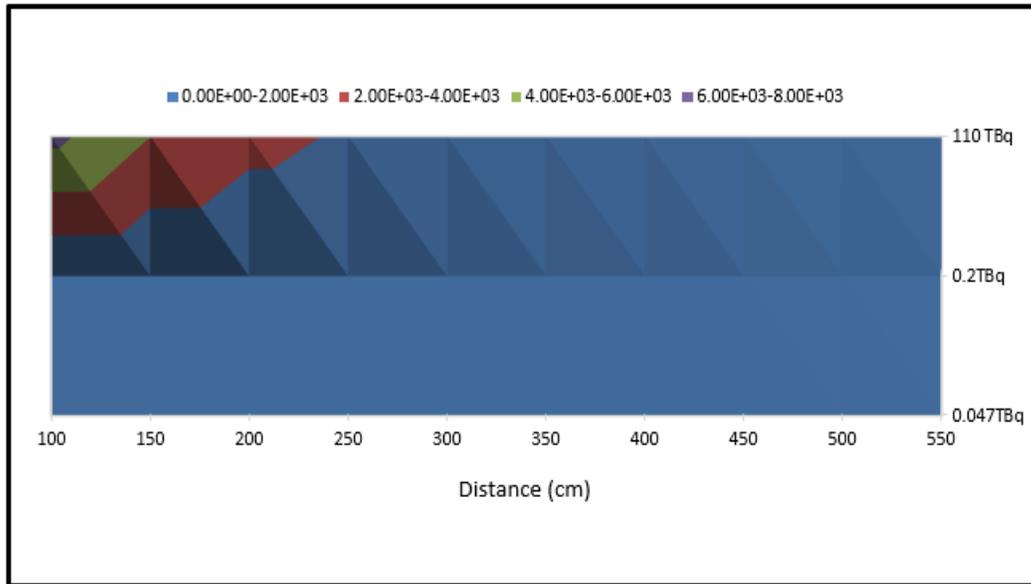


**Figure 5:** The Particle Display of the  $^{137}\text{Cs}$  (0.2 TBq) Photons in the Opposite Directions of 3.0 cm Pb Shield

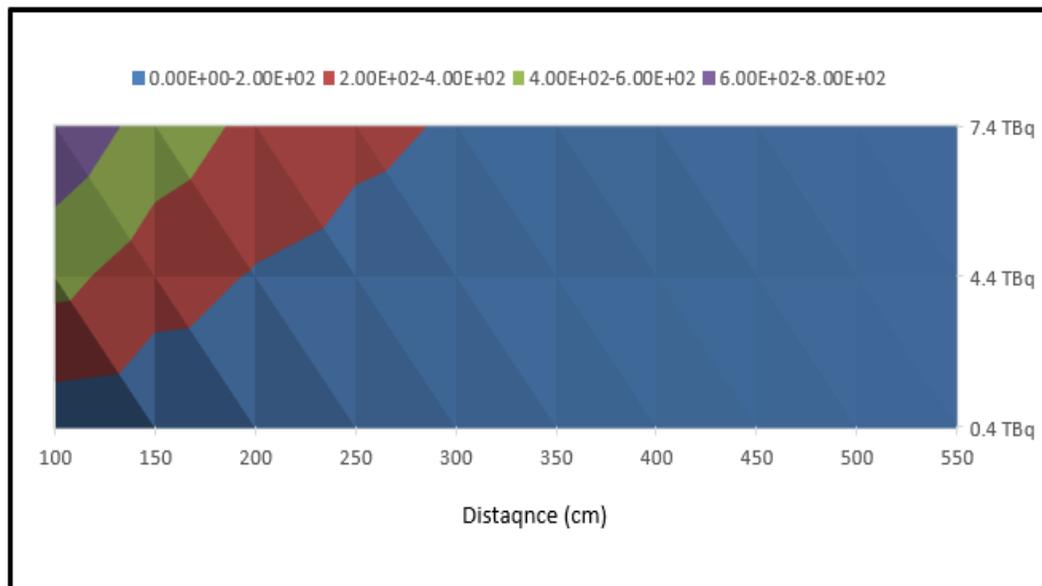
## 2.1 Dose Mapping of the Selected Isotopes

The dose rate due to three activities presented in Table 1 of each isotope were calculated using MCNP 5 code based on the estimated models. The dose map of the unshielded sources as

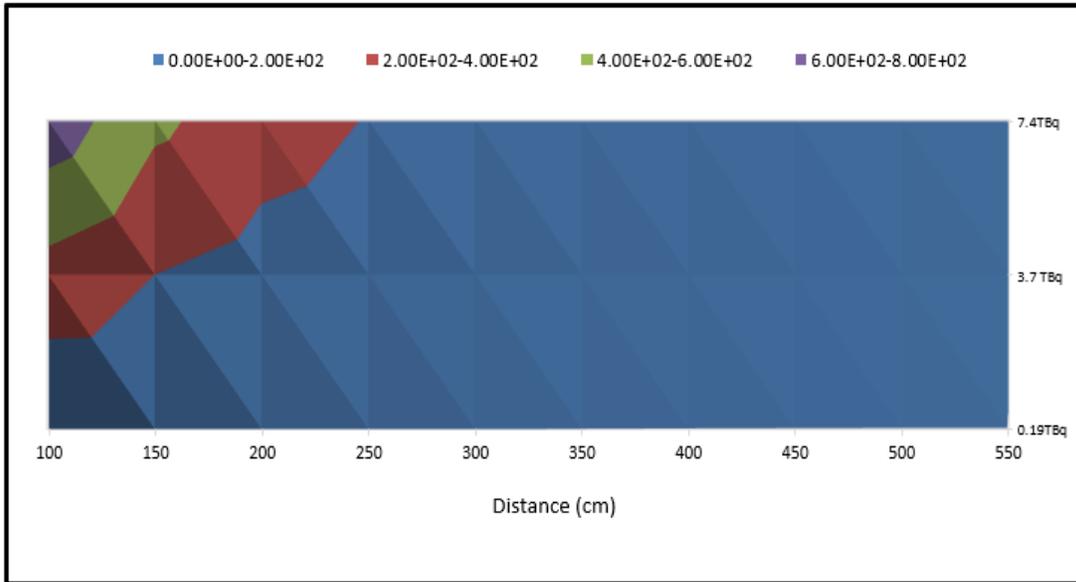
described in Figures 6,7,8 and 9 illustrate the dose rate (mSv/h) due to 0.2, 3.7 and 3.7 TBq of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$  and  $^{192}\text{Ir}$  respectively at three conditions (without shield, presence of 1.0 cm Pb shield and 3.0 cm Pb shield).



**Figure 6:** Dose Rate (mSv/h) due to  $^{137}\text{Cs}$  Point Source (0.047-110 TBq) at Different Distances

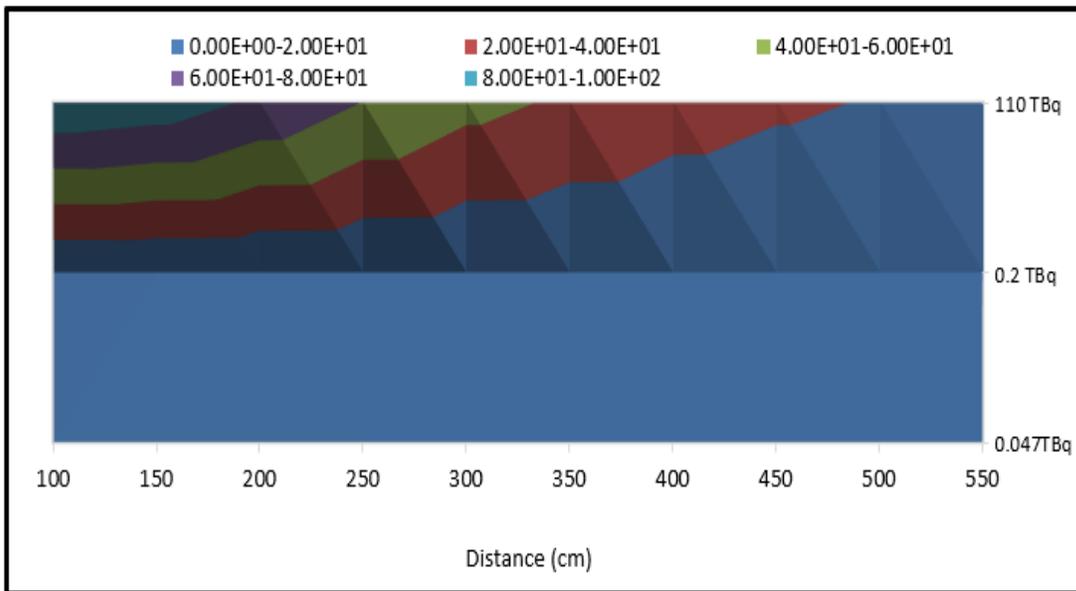


**Figure 7:** Dose Rate (mSv/h) due to  $^{60}\text{Co}$  Point Source (0.2 -7.4 TBq) at Different Distances

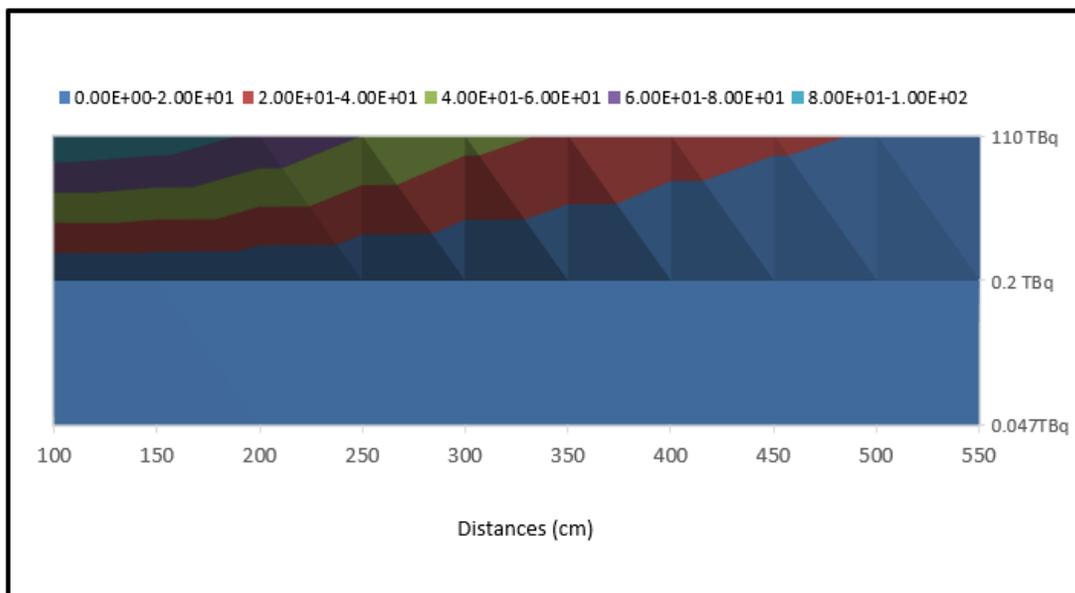


**Figure 8:** Dose Rate (mSv/h) due to  $^{192}\text{Ir}$  point source (0.2 -7.4 TBq) at Different Distances

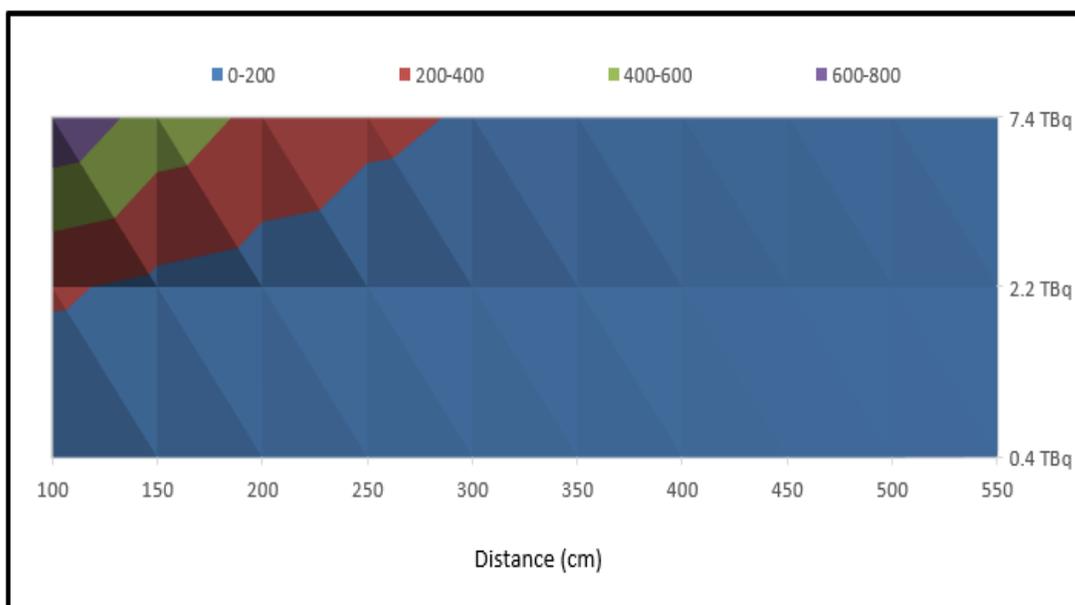
While figures 9, 10, 11 and 12 illustrate the dose mapping due to the presence of 1.0 cm and 3.0 cm Pb shield around  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$  and  $^{192}\text{Ir}$  respectively for the same selected activities.



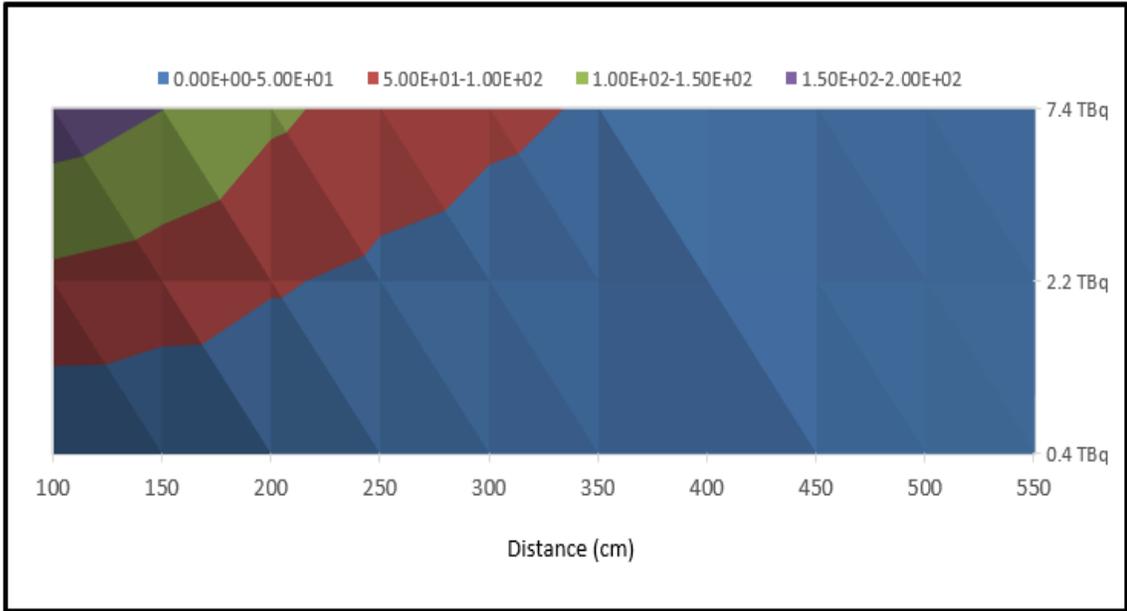
**Figure 9:** Dose Rate (mSv/h) for  $^{137}\text{Cs}$  Point Sources (0.047 -110 TBq) in the Presence of 1.0 cm Pb Shield at Different Distances



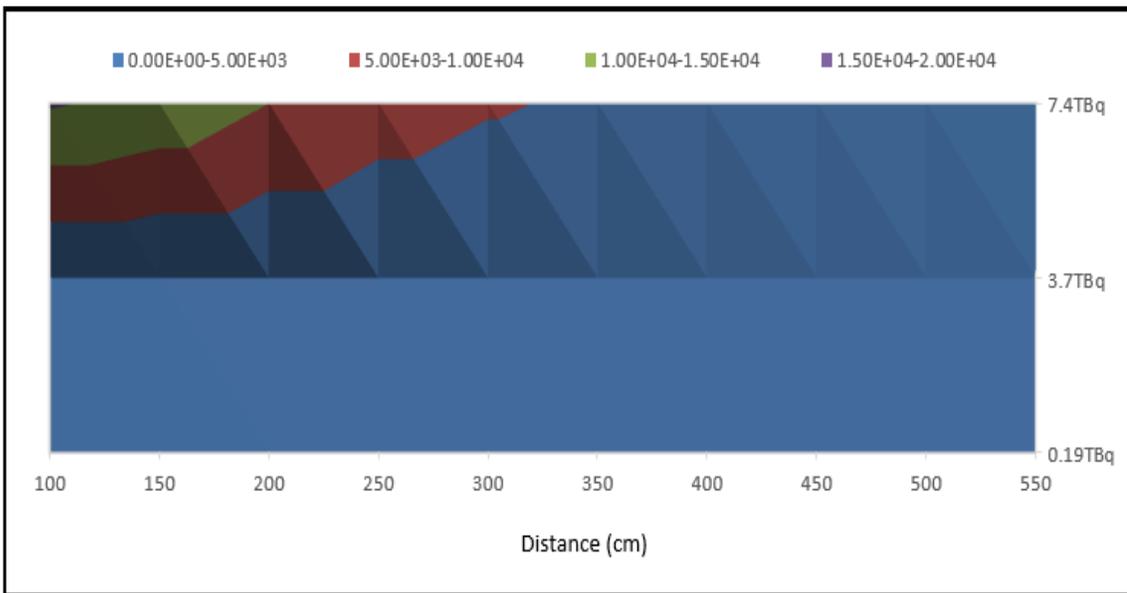
**Figure 10:** Dose rate (mSv/h) for  $^{137}\text{Cs}$  Point Sources (0.047 -110 TBq) in the Presence of 3.0 cm Pb Shield at Different Distances



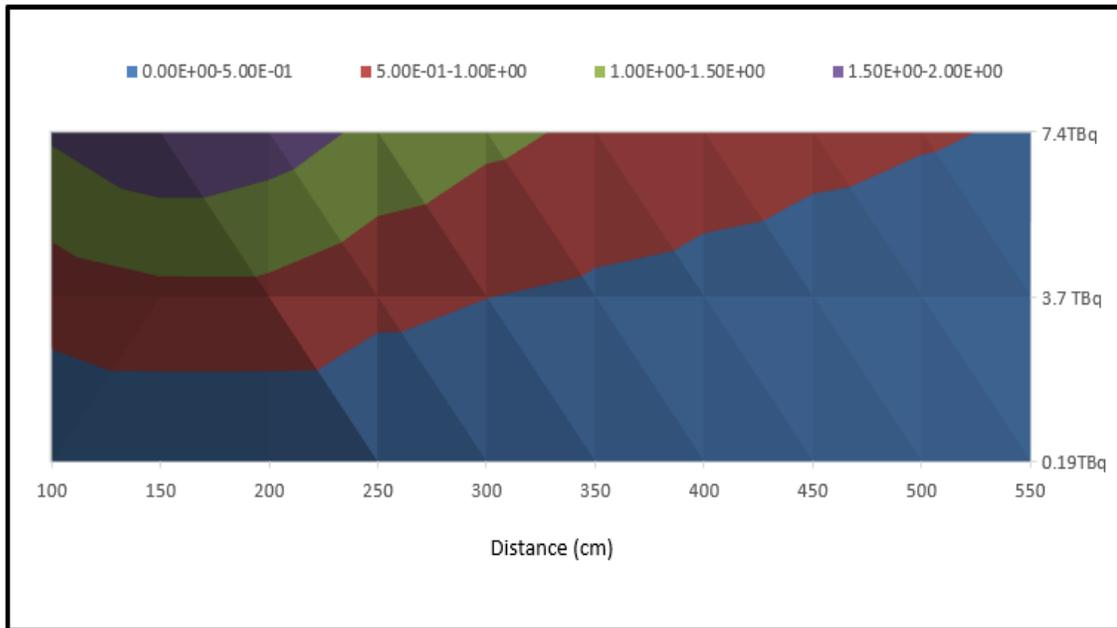
**Figure 11:** Dose Rate (mSv/h) due to  $^{60}\text{Co}$  Point Sources (0.4-3.7 TBq) in the Presence of 1.0 cm Pb Shield at Different Distances



**Figure 12:** Dose Rate (mSv/h) due to  $^{60}\text{Co}$  Point Sources (0.4-3.7 TBq) in the Presence of 3.0 cm Pb Shield at Different Distances



**Figure 13:** Dose Rate (mSv/h) due to  $^{192}\text{Ir}$  Point Source (0.2-7.4 TBq) in the Presence of 1.0cm Pb Shield at Different Distances

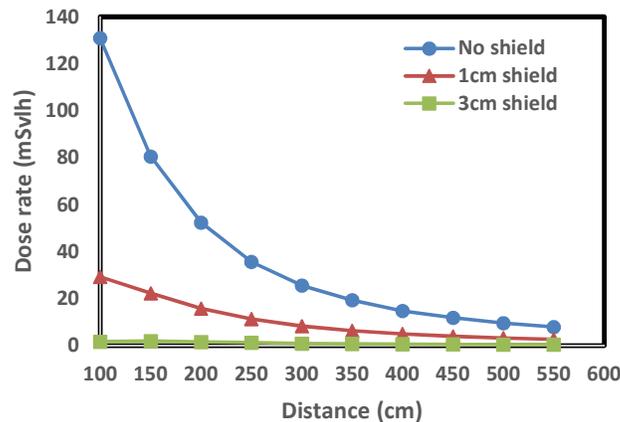


**Figure 14:** Dose Rate (mSv/h) due to  $^{192}\text{Ir}$  Point Source (0.2-7.4 TBq) in the Presence of 3.0 cm Pb Shield at Different Distances

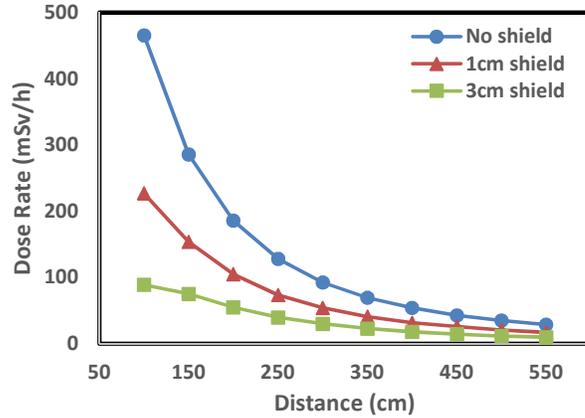
From the Figures, we can declare that the safety perimeter around  $^{137}\text{Cs}$  point source with maximum, activity 0.2 TBq (5.4 Ci) in the presence of rectangle shaped Pb shield with diameters 100 and 150 cm and thickness of 1.0 and 3.0 cm will be 500 and 250 cm respectively, showing that the worker's dose in these cases is still below the guidance values for emergency workers.

## 2.2 Calculations of Dose Rate due to Shielded and Unshielded Radioactive Point Sources

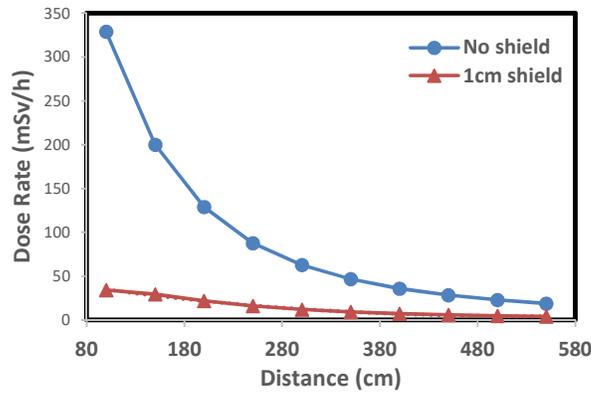
Figures 15, 16, 17 and 18 are presenting the fitting curves for typical activities of the three isotopes as selected in Table 1 in case of unshielded source and in the presence of 1.0 and 3.0 cm Pb shield.



**Figure 15:** Dose Rate (mSv/h) due to 0.2 TBq of  $^{137}\text{Cs}$  at Different Distances With and Without Shield



**Figure 16:** Dose Rate (mSv/h) due to 2.2 TBq of  $^{60}\text{Co}$  at Different Distances With and Without Shield



**Figure 17:** Dose Rate (mSv/h) due to 3.7 TBq of  $^{192}\text{Ir}$  at Different Distances With and Without 1.0 cm Pb Shield

### 2.3 Gamma Dose Rate Equation for Unshielded Radioactive Point Sources

The equation (1) can be used to calculate gamma dose rate (mSv/h) at any distance in the range of 100-550 cm due to an isotropic radioactive point source with activity A(TBq)

$$\text{Dose Rate } (A,x) = A^* [ ax^4 - bx^3 + cx^2 - dx + e ] \quad (1)$$

Where x is the distance from the shield; a, b, c, d and e are fitting parameters given in Table 2.

Isotope	Fitting Parameters				
	a	b	c	d	e
$^{137}\text{Cs}$	4.50E-08	5.00E-05	0.0465	13.3285	1590.65
$^{60}\text{CO}$	1.36E-08	2.27E-05	0.015864	5.201818	729.7273
$^{192}\text{Ir}$	5.41E-09	1.08E-05	0.006514	1.855108	218.727

**Table 2:** Fitting Parameters for Each Unshielded Isotopes

### 2.4 Gamma Dose Rate Equation for Shielded Radioactive Point Sources

The equation (2) can be used to calculate gamma dose rate (mSv/h) at any distance in the range of 100-550 cm due to a shielded

isotropic radioactive point source with activity A(TBq)

$$\text{Dose Rate } (A,x) = A^* [ ax^3 + bx^2 - cx + d ] \quad (2)$$

Where x is the distance from the shield, a, b, c and d are fitting parameters given in Table 3.

Isotope	Shielding thickness	Fitting parameters			
		a	b	c	d
<sup>137</sup> Cs	1.0 cm	-1.50E-06	0.0025	1.3155	255.585
	3.0 cm	2.00E-07	-2.00E-04	0.0305	7.1755
<sup>60</sup> Co	1.0 cm	-1.82E-06	0.002545	1.163545	194.95
	3.0 cm	-1.82E-07	0.000409	0.269045	64.65909
<sup>192</sup> Ir	1.0 cm	-1.9E-08	5.40541E-05	0.053703	14.18568
	3.0 cm	8.11E-09	-8.11E-06	0.00173	0.102027

**Table 3: Fitting Parameters for Shielded Isotopes (at 1.0 cm and 3.0 cm Pb Shield)**

### 3. Conclusion

Equations for flux and dose rate calculations for radioactive point sources that are most likely encountered in radiological emergencies including those of nuclear security events are presented. Shielding characteristics for gamma emitters at different thicknesses with different shapes were illustrated. Optimization of the shape and thickness of the shield are required to facilitate the dealing with the source and assure the protection of the emergency workers during the response of the recovery of unshielded sources. The results obtained can be used in preparation phase to provide the responder and radiological assessor with a full spectrum of the expected dose rates and suitable shielding characteristics needed while dealing with unshielded radioactive sources belonging to categories 2&3 [5-9].

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