



Viability for surgical uses of a portable NaI(Tl) scintillator detector.

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Abstract

The objective of this thesis is the determination of viability for surgical uses of a gamma detector, where it is able for surgical uses to detect shrapnel in case of a dirty-bomb, or nuclear accident, in a situation or extreme urgency of surgery. To help in the labour of the surgeons, to detect and locate with precision the radioactive shrapnels, and help to evaluate the case and viability of intervention. The gamma detector in study will be a portable scintillator of NaI(Tl), widely integrated in the emergency system in Sweden, for use at emergency wards.

This investigation will be based on some simulations with the help of some application informatics, in Matlab, developed for this project. There I will be able to simulate and see how the error of the detector (more than 15% uncertainty in the measurement) can affect in the measurements. Also, I will study which factors will affect the measurements, in the scenario of a attempted nuclear accident/terrorist attack, and if that is the case, how can it be avoided.

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1. Introduction

Since the 9/11 attacks in 2001, the fear of terrorist groups using dirty-bombs has increased significantly, which has been frequently reported in the media. One of the major risk, and cause of preoccupation of the authorities, is the possibility that of terrorists may be in possession of radioactive material to make up a dirty-bomb. In part the goal of this project is to be prepared incase of such misfortune, either in case of a terrorist attack or in battle field. In the case of an accident nuclear power plant it is unlikely the production of shrapnel, since such accident will most likely produce radioactive dust.

In principle and one of the great problems in this research will be the bare documentation of technical information or the scientific use, that comes with the equipment to investigate, the “Intensimeter 28/T”. This will restrict the possibility of simulation, and it will only be possible make some simulations in Matlab. On the other hand, It was not possible to make exhaustive measurement in the laboratory, because the necessary radionuclides with high enough activity was hard to find.

Nevertheless, the importance of this thesis is to see the possible problems we can find, for our aim, of the viability of this detector for surgical use, in case of a nuclear emergency. For logistical reasons, in a battlefield, It is possible that immediate intervention by a surgeon will be necessary in the same act.

For a possible surgical use of the gamma detector, it will be necessary optimize the portable detector, in order to locate as accurately as possible the traces of radioactive shrapnel that were able to accommodate within the body of an affected. Preferably, this would be done as soon as possible after the accident scenario / attack so that in this way the attendant surgeon of the intervention has the largest and most reliable information to assess the severity of the patient situation and have as much information as possible about where and how to perform the operation.

To achieve this aim, the key will be to get a reliable method for determining the vertical distance (OZ). To determine the depth, I am trying to optimize the detection capability of gamma particles from the detector, with the precision in the measurement and with a theoretical model (will be confirmed with the simulation), taking into account that every radionuclide have very specific mode of intensity decrease (moderation). This will permit, that with two measurement of intensity, at different height above the affected body, determine the rate of decrease, and with one simple interpolation determinate the depth of the shrapnel. In the other hand the horizontal distance (OX,OY) is easily detectable by the signal intensity of the gamma detector.

This thesis will consist in simulation in Matlab and the following theoretical model:

$$I_T = I_0(E, Ac) * \Omega(x, Rd, Rs) * e^{-\mu(E,m)d(x)} * B(E,x,m);$$

To translate this theoretical method in a real situation, it will be necessary to make corrections in the detected activity of the detector to estimate the precision in a real situation of emergency.

2. Theory

2.1. Introduction

In the theory of this project, and for the programme codes in Matlab for the simulation, I must consider all background of the theory about the moderation of photons in matter, and the study of this moderation of the photons from the radionuclide of interest

2.2. theoretical assumptions[1,2,3].

2.2.1. Interaction of photon with matter.

There is a long list of possible interactions of photons, but only three will be important for the effects in the measurements with the detector; they are the photoelectric effect Compton scattering, and pair production.

2.2.1. 1. The Photoelectric Effect

The photoelectric effect is an interaction between a photon and a bound atomic electron. As a result of the interaction, the photon disappears and one of the atomic electrons is ejected as a free electron, called the photoelectron. The probability of this interaction occurring is called the photoelectric cross section or photoelectric coefficient., and it is important to discuss the dependence of this coefficient on parameters such as photons energy(E_γ), atomic number (Z), and atomic weight (A). The equation giving the photoelectric coefficient may be written as:

$$\tau \text{ (m}^{-1}\text{)} = aN \frac{Z^n}{E_\gamma^m} [1 - O(Z)]$$

where τ = probability for photoelectric effect to occur per unit distance travelled by the photon.

a = constant, independent of Z and E_γ .

m, n = constants with a value of 3 to 5 (their value depends on E_γ).

The second term in brackets indicates correction terms of the first order in Z .

2.2.1. 2. Compton Scattering or Compton Effect

The Compton Effect is a collision between a photon and a free electron. Of course, under normal circumstances, all the electrons in a medium are not free but bound. If the energy of the photon of the radionuclide of interest is of the order of keV or more, while the binding energy of the electron is of the order of eV, the electron may be considered free.

The photon does not disappear after a Compton scattering. Only its direction of motion and energy change, the change of direction will affect in the measurement and must be taken into account.

The probability that Compton scattering will occur is called the Compton coefficient or the Compton cross section. It is a complicated function of the photon energy, but it may be written in the form

$$\sigma \text{ (m}^{-1}\text{)} = NZf(E_\gamma)$$

$$\sigma \sim \rho \frac{N_A}{A} Z f(E_\gamma) \sim \rho \left(\frac{N_A}{A} \right) \frac{A}{2} f(E_\gamma) \sim \rho \frac{N_A}{2} f(E_\gamma)$$

where σ = probability for Compton interaction to occur per unit distance $f(E_\gamma)$ = a function of E_γ .

2.2.1. 3. Pair Production

Pair production is an interaction between a photon and a nucleus. As a result of the interaction, the photon disappears and an electron-positron pair appears. This effect will only have to be considered for cobalt-60, since the other radionuclides, have gamma emission of less energy than 1.022 MeV.

The probability for pair production to occur, called the pair production coefficient or cross section is a complicated function of E_γ and Z .

$$\kappa \text{ (m}^{-1}\text{)} = NZ^2 f(E_\gamma, Z)$$

where κ is the probability for pair production to occur per unit distance travelled and $f(E_\gamma, Z)$ is a function that changes slightly with Z and increases with E_γ .

2.2.1. 4. Total Photon Attenuation Coefficient

When a photon travels through matter, it may interact through any of the three major ways discussed earlier. (For pair production, $E_\gamma > 1.022$ MeV.) There are other interactions, but they are not mentioned here because they are not important in the detection of gammas.

The total probability for interaction μ , called the total linear attenuation coefficient, is equal to the sum of the three probabilities:

$$\mu \text{ (m}^{-1}\text{)} = \tau + \sigma + \kappa$$

If a parallel beam of monoenergetic photons with intensity $I(0)$ strikes a target of thickness t , the number of photons, $I(t)$, emerging without having interacted in the target is given by:

$$I(t) = I(0)e^{-\mu t}$$

The probability that a photon will traverse thickness t without an interaction is

$$\frac{\text{number transmitted}}{\text{number incident}} = \frac{I(0)e^{-\mu t}}{I(0)} = e^{-\mu t}$$

The coefficient of attenuation in the Matlab simulation will be taken from; j. Hubbell NSRDS-NBS 29 C(1969). [Appendix A]

2.2.1. 5. Buildup Factors

If we consider a point isotropic monoenergetic gamma source at a distance r from a detector, with a shield of thickness t between source and detector, the total gamma beam hitting the detector consists of two components: the unscattered beam and (ϕ_u) and the scattered beam (ϕ_s)

Experience has shown that rather than calculating the total flux, there are advantages to writing the total flux in the form:

$$\Phi_t = B \Phi_u$$

where B is a buildup factor.

In general, the buildup factor depends on the energy of the photon, on the mean free paths traveled by the photon in the shield, on the geometry of the source (parallel beam or point isotropic) and on the geometry of the attenuating medium (finite, infinite, slab, etc.).

The formal definition of B upon which its calculation is based is

$$B(E, \mu r) = \frac{\text{quantity of interest due to total flux}}{\text{quantity of interest due to unscattered flux}}$$

The mathematical formulas for the buildup factors are (assuming a monoenergetic, $E\gamma$, point isotropic source) as follows:

$$B_N(E_0, \mu r) = \frac{\int_0^{E_0} \phi_{\text{tot}}(r, E) dE}{(S/4\pi r^2)e^{-\mu r}}$$

Extensive calculations of buildup factors have been performed, and the results have been tabulated for several gamma energies, media, and distances. In addition, attempts have been made to derive empirical analytic equations. In my simulation I will use the Berger Formula:

$$B(E, \mu r) = 1 + a(E)\mu r e^{b(E)\mu r}$$

The coefficient of the buildup factor from the Matlab simulation will be taken from A.B Chilton, C.M Eisenhauer, and G.L Simmons, Nuc Sci Eng 73:97(1980).

2.2.2. Geometry effects

The geometry may affect the measurement in two ways. First, the medium between the source and the detector may scatter and may also absorb some particles. Second, the size and shape of the source and the detector and the distance between them determine what fraction of particles will enter the detector and have a chance to be counted.

2.2.2. 1 The Solid Angle for a Disk Source Parallel to a Detector with a Circular Aperture

Consider a disk source (in my thesis I will take the approximation, that shrapnel is circular, parallel to a detector with a circular aperture [image 1] Starting with these assumptions one may

obtain an expression involving elliptic integral or the following equation in terms of Bessel functions.

$$\Omega = s \int_0^{\infty} dx e^{-xz} \frac{J_1(x)}{x} J_1(xs) ;$$

Where $s = R_d / R_s$, $z = d / R_s$, and $J_1(x)$ = Bessel function of the first kind. If R_d / d and R_s / d are less than 1, the following algebraic expression is obtained for the solid angle

$$\Omega = \frac{\omega^2}{4} \left\{ 1 - \frac{3}{4}(\psi^2 + \omega^2) + \frac{15}{8} \left(\frac{\psi^4 + \omega^4}{3} + \psi^2 \omega^2 \right) - \frac{35}{16} \left[\frac{\psi^6 + \omega^6}{4} + \frac{3}{2} \psi^2 \omega^2 (\psi^2 + \omega^2) \right] \right\}$$

Where $\psi = R_s / d$
 $\omega = R_d / d$

This equation will determine the limit of the mid-field simulation, if R_d / d and R_s / d are larger than 1, it is not possible to use this equation and must use an approximation, finite element methods, or simulation with a Monte Carlo model. In most cases this will depend on the diameter of the detector, in this case 4.51 cm, that under this distance, I will not be able to resolve the system in the Matlab simulation I developed.

Definition of the solid angle

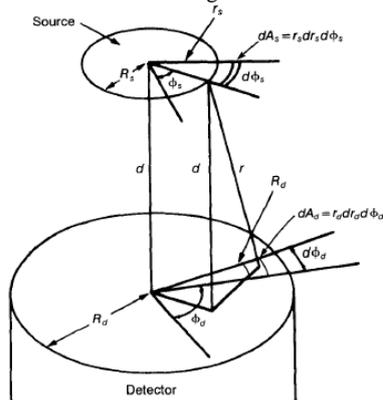


Image 1.1: Geometry involved in the detection of some radioactive source

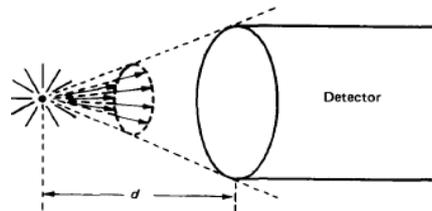


Image 1.2: The fraction of particles emitted by a point isotropic source and entering the detector is defined by the solid angle subtended by the detector at the location of the source.

2.2.1.4 Efficiency of NaI(Tl) Detectors

As we can see in the next graphic [image 2][1] the capacity of detection in the scintillator will depend on the energy and on the activity. In this way it will be necessary with exhaustive measurements in laboratory to determine the response of the detector with the largest possible accuracy, if we want to use this kind of detector for surgical use. On the other hand the efficiency decreases with energy up to about 5 MeV [image 2], and with the distance of the source. To determine the optimal position for the measurement of intensity, this factor must be taken into consideration.

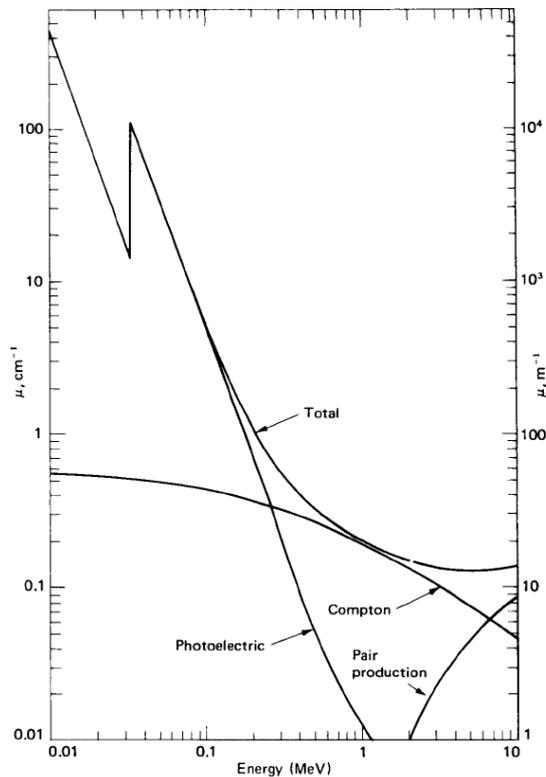


Image 2: The photon linear attenuation coefficients for NaI(Tl)

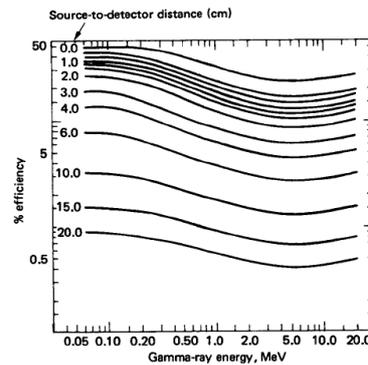


Image 3: Calculated absolute total efficiencies of a 3 in x 3 in (76.2 mm X 76.2 mm) NaI(Tl) scintillator as a function of energy for different source-detector distances.

2.3. Radionuclides of study[4]

According to the IAEA, the Nuclear Regulatory Commission (NRC)[5] and other studies American radioisotopes most likely to be used in dirty-bomb, are:

- ♣ cobalt-60,
- ♣ selenium-75,
- ♣ strontium-90,
- ♣ cesium-137,
- ♣ ytterbium-169,
- ♣ thulium-170,
- ♣ iridium-192,
- ♣ polonium-210,
- ♣ radium-226,
- ♣ plutonium-238,
- ♣ plutonium-239,
- ♣ americium-241,
- ♣ curium-244 and
- ♣ californium-252.

About nuclear accidents (civilian and military), they have been very varied over the history and with diverse materials, but in any case can be included within radionuclide of interest mentioned in dirty bombs.

2.4. The mathematical model

With all the previous theory in the field of the gamma emission, I will be able to build in Matlab, some model of how to simulate the gamma emission, and with this test the theoretical model to demonstrate the hypothesis that we can know the depths of radioactive shrapnel through two different distance measures . With the mathematics of the previous sections to arrive to:

$$I_T = I_0(E, Ac) * \Omega(x, Rd, Rs) * e^{-\mu(E,m)d(x)} * B(E,x,m);$$

Where:

- $I(E,Ac)$ =gamma Intensity(depend of the Energy[6] and Activity[7])
- $\Omega(x)$ =Solid Angle (depend of the distance from the radionuclide, the size of the source and the size of detector).
- $e^{-\mu(E,m)d(x)}$ = Total Photon Attenuation (depends of the energy, material and distance).
- $B(E,x,m)$ = Buildup factors. (Depend of the energy, material and distance).

This equation will be the objective of study and simulation in Matlab[Appendix C].

2.5 aim of the thesis

The problems a real situation in the case of the detonation of a dirty-bomb, for determining the depth of the radioactive shrapnel inside the body of some affected, with the gamma detector in study, are:

1. We don't know the size of the shrapnel (will depend on the shielding and strength of detonation).
2. In the body there can be several sources of radioactivity (shrapnels), giving rise to the interferences in the measurement(this will be easy avoid with some blind, to collimate the measurement).
3. We don't know the activity of the shrapnel (Ac_0).
4. We don't know the radionuclide (maybe some mix) with the make up the dirty-boom and with this the shrapnel, we don't know the Energy of the gamma particles (E).
5. The capacity of measurement and the response of the scintillator detector of NaI(Tl), depend in part of the activity and energy of the measurement(image 1,2).
6. When the measurement of the activity of shrapnel in the body there are affected for the interference of the bone (important chance in the moderation of the gamma particles).
7. Possible blind in the dirty-boom, cover the shrapnel and changing the activity, and the lecture of the detector.

In this thesis I will only address simulation in Matlab, to have an idea of how I can work out the decay intensity of the gamma particles, and if it will be possible, the shrapnel in the body with the NaI(Tl) Detectors, give some solution to the listed problem .

2.5. Matlab Simulation

In The Matlab simulation there are several problems to made one right simulation of activity, able to be detected for the scintillator.

1. When the distance from the shrapnel to the detector is less than the size of the diameter of the gamma detector, the Bessel equation does not have an analytical solution. In this case the normal procedure is to use finite element methods or Monte Carlo simulation. In this work it was not possible to perform a Monte Carlo simulation, because the company that manufactures the gamma detector didn't supply enough technical details to make the simulation.
2. When we try to simulate the moderation of the photons through two different media (body and air) the graphic will not be continuous, because the mathematical model change. In the moderation in air we must consider, one origin of activity in a source at the surface of the body and whit activity of the dimension of the diameter of the detector. In this case we have the same problem than before, and with 2π geometry for the geometrical factor, in the first measurement. This will oblige me to consider only valid the theoretical value they are at one distance or 8 cm from the body. With unless distance we cannot resolve the Bessel equations.
3. There are problems with the value was used for the buildup Factor (B) [Appendix B]. and the total mass attenuation coefficient (μ) [Appendix A]., because in the simulation in the case of the B, in body, the tabulated value for water was used (very close of the real valor of B in the body), in the case of (μ), the value for striated muscle was used.
4. The uncertainty in the simulation cannot be estimated, because the table for the interpolation of the value of the total linear attenuation coefficient(μ), and buildup factor, tare not detailed in the references, As I explained in point 3, without taking this in consideration, the uncertainty is about 1-2% in the calculation of these specific radionuclide (Cs-137 and Co-60). For other radioactive elements in the list provided in section 2.3 the uncertainty in the energy of gamma emission [5] can change this proportion of uncertainty.

3. Results

3.1 How the different size of the shrapnel affect the measurement.

To resolve, some of the first problem we can have: The uncertainty in the size of the shrapnel, and how this affects measurements.

After making the simulations for different sizes of shrapnel of Co-60 and Cs-137 , both with the same activity (3.2×10^{20} Bq/g)_[image 4,5], I get:

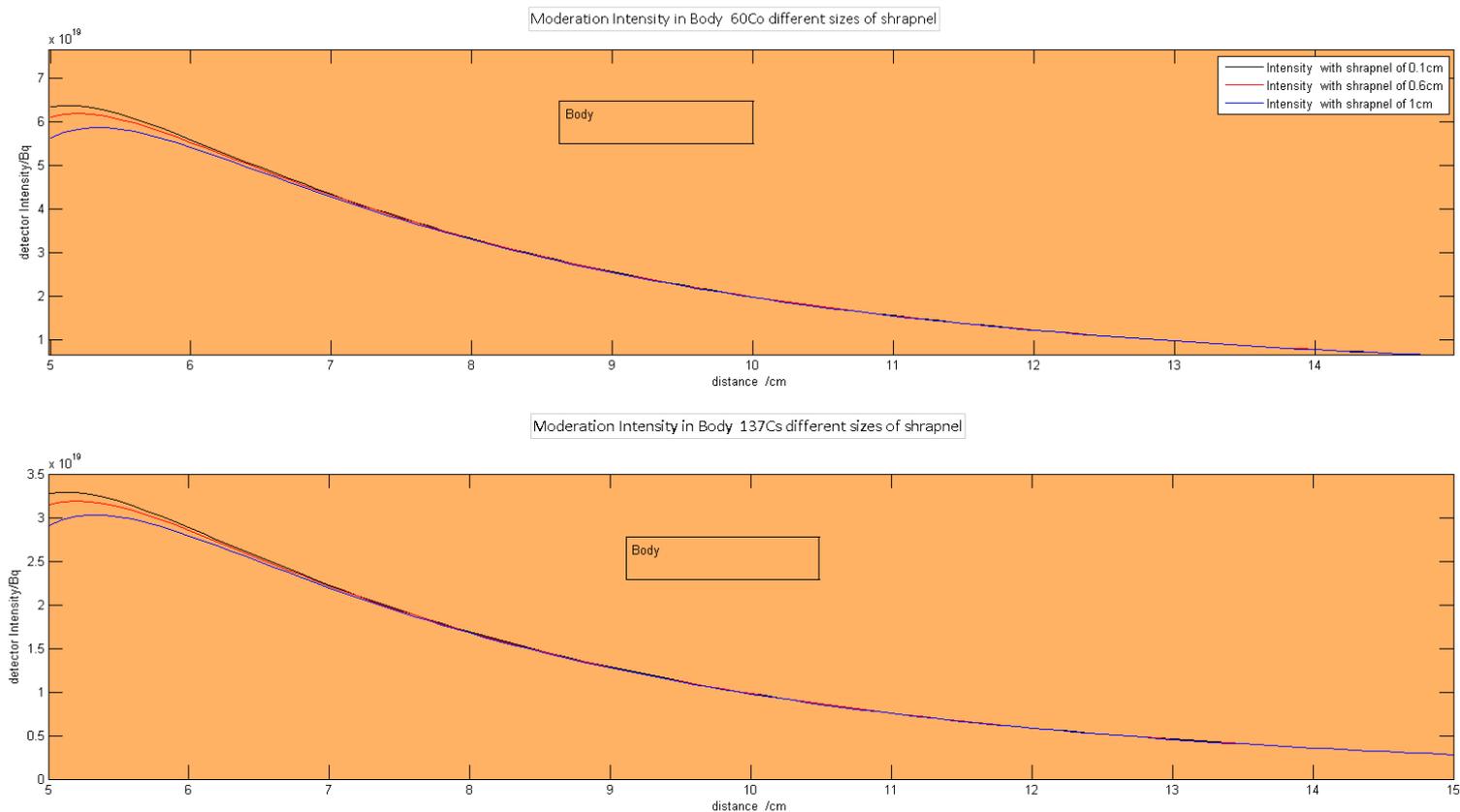


Image 4: moderation intensity in body with ^{137}Cs different sizes

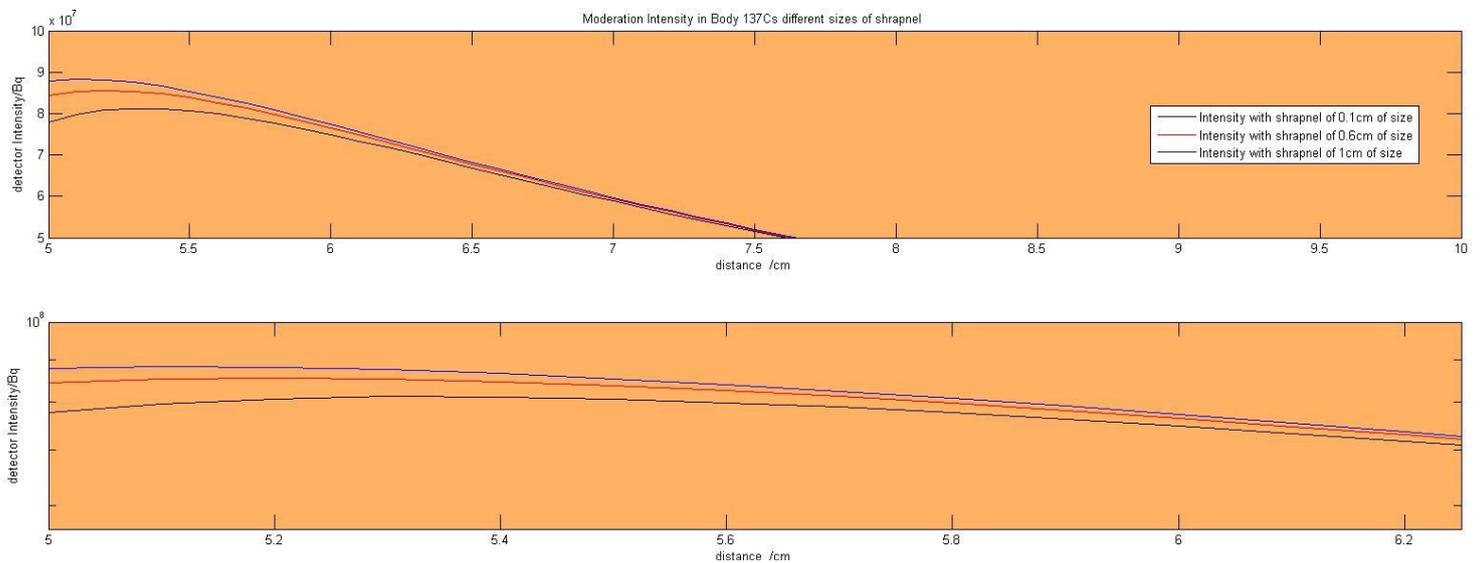


Image 5: detail image 4

How we see for the graphic_[image 5], of the simulation the effect of the size of the shrapnel, will be important in the near field, this mean that only when the distance of the measurement is close to the radionuclide, we will observe significant differences in the measurement for the same radionuclide and different size of source. But this will not be a serious problem in the case to try determining the depth of some shrapnel, the only thing one must make to avoid this problem is to take the first measurement at least at 5 cm from the body.

3.2 Moderation at different depth of shrapnel, determination of the distance.

One way to determine the depth of a source in the body, is to use information of the moderation of the gamma particles, for deeper radionuclide locations in body, there will be higher moderation.

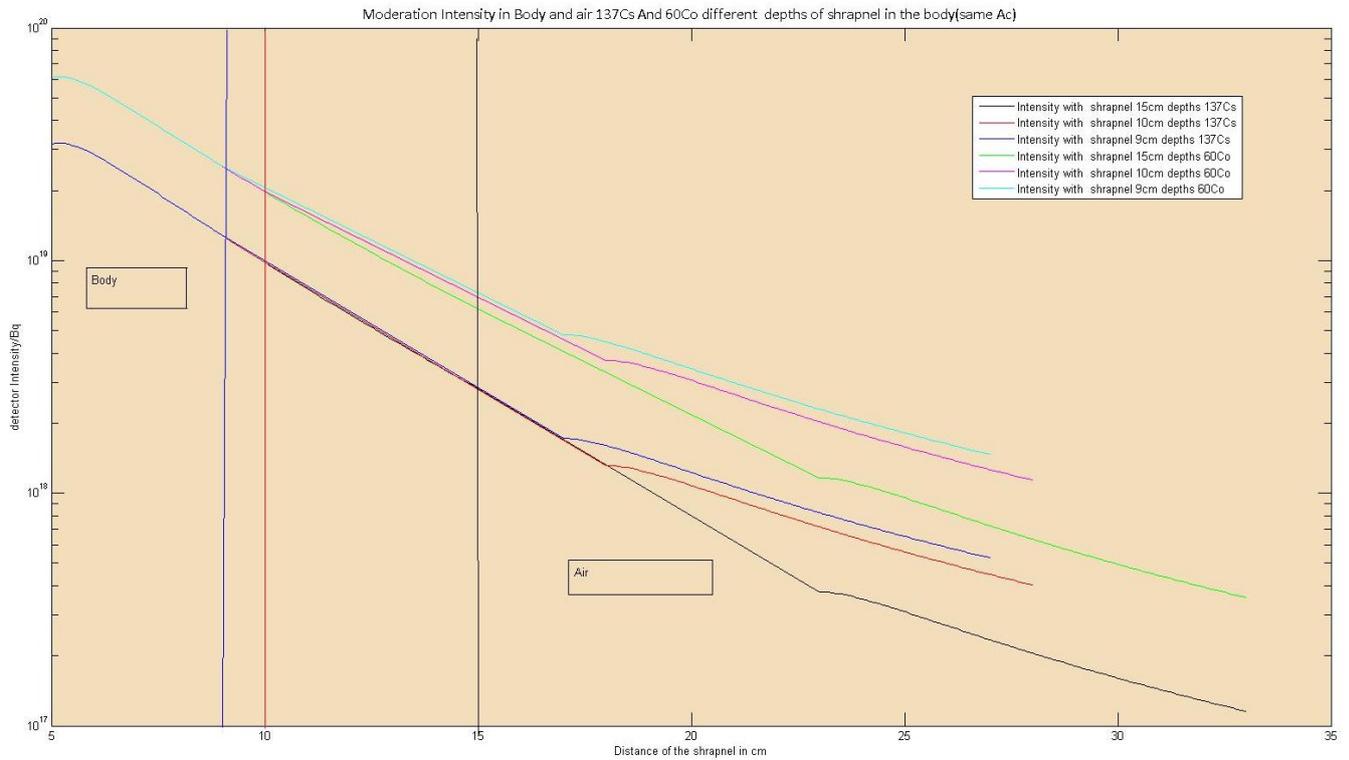


Image 6: Moderation intensity in Body and air Cs-137 and Co-60 with different depth in body of shrapnel.

In this graphic [image 6], we can see how for different depth of shrapnel, the moderation follow one very specific path, even in the case of small distance (1cm) and even would follow over shorter distances, where the limit in one real case will come from the uncertainty of measurement in the detector. In our case (scintillator detector of NaI(Tl)) has in principle an uncertainty of 15% in the measurement, but this can be improved, and optimized. We see too how the different radionuclides have different path of attenuation (from source with the same activity). At different depths, when we make two measurement; we will be in the situation of determining the depth, with one easy interpolation with values we obtain of the activity.

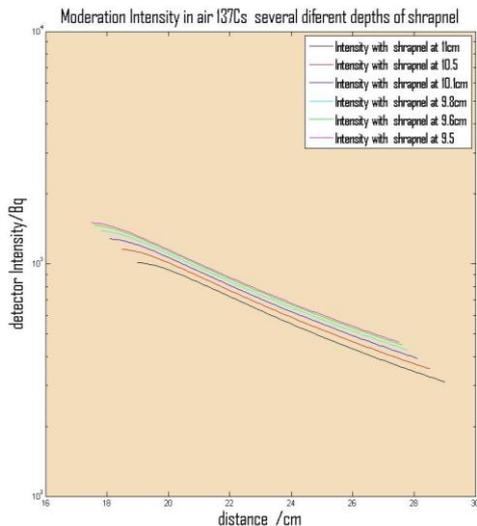


Image 7: Moderation intensity several different depths in Body 137Cs

Cs-137 with Shrapnel at depth from 11 to 9.5 cm in Body	
Differences in cm of depth	% intensity variation
1.5	44.09
1	32.12
0.6	21.26
0.5	17.3
0.4	14.17
0.3	10.87
0.2	7.39
0.1	5.77

Table 1: Proportion of different activity for different decay

In this table [table 1] we can see the different proportion of intensity between one path of decay to the other in Cs-137 (with one reference from 11 to 9.5 cm depth in the body) [image 7], when the difference of distance of the depth of the shrapnel are of the cm indicate. As we can see with our detector with 15 % uncertainty it will not be possible to have precision of the determination of the depth of the shrapnel of less than 0.5 cm. This value don't change with the activity of the radionuclide, and will be reduced when we considered some reference deeper in the body than from 11 cm to 9.5 cm.

For other radionuclide these proportions can oscillate [image 7], [Table 2].

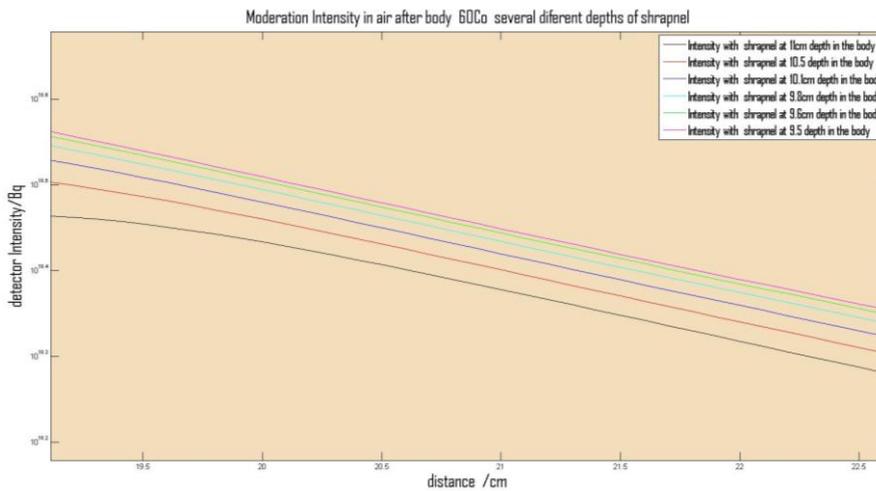


Image 7: Moderation intensity several different depths in Body 60Co

Co-60 with Shrapnel at depth from 11 to 9.5 cm in Body	
Differences in cm of depth	% intensity variation
1.5	42.87
1	31.17
0.6	20.57
0.5	16.67
0.4	13.67
0.3	10.49
0.2	7.15
0.1	5.64

Table 2: Proportion of different activity for different decay

3.3 How the different activity of the shrapnel affects the measurement.

One of the problems that can appear, is maybe that different activity, for one specific radionuclide, can make us think that the radiation comes from a different depth. In this case I made the simulation, where I amended the activity [image 8,9] in the shrapnel at 9.6 cm to look like it's at 9.5 cm depth.

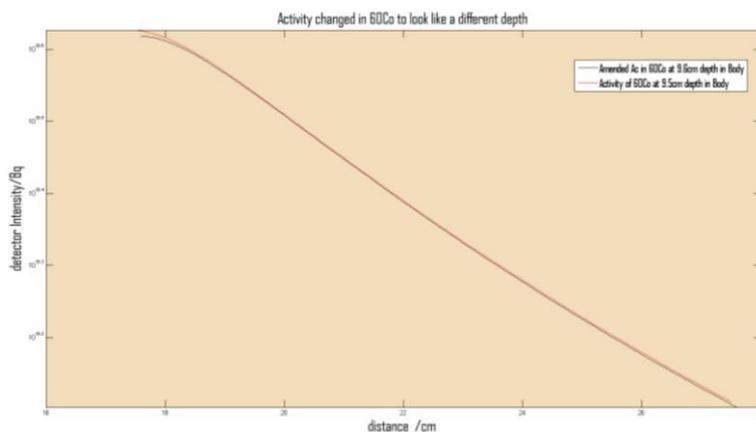


Image 8

As we can see [image 8,9] there will be a problem with the uncertainty in the activity in the shrapnel. In this case, to solve the depth, it must be necessary to take some sample of shrapnel in the affected area and make a first measurement to determinate the activity, because as we can realize the rate of decrease will in reality depend of the intensity of the gamma particles in the source of the body and not of the depth of the radionuclide in the body (for each specific radionuclide)

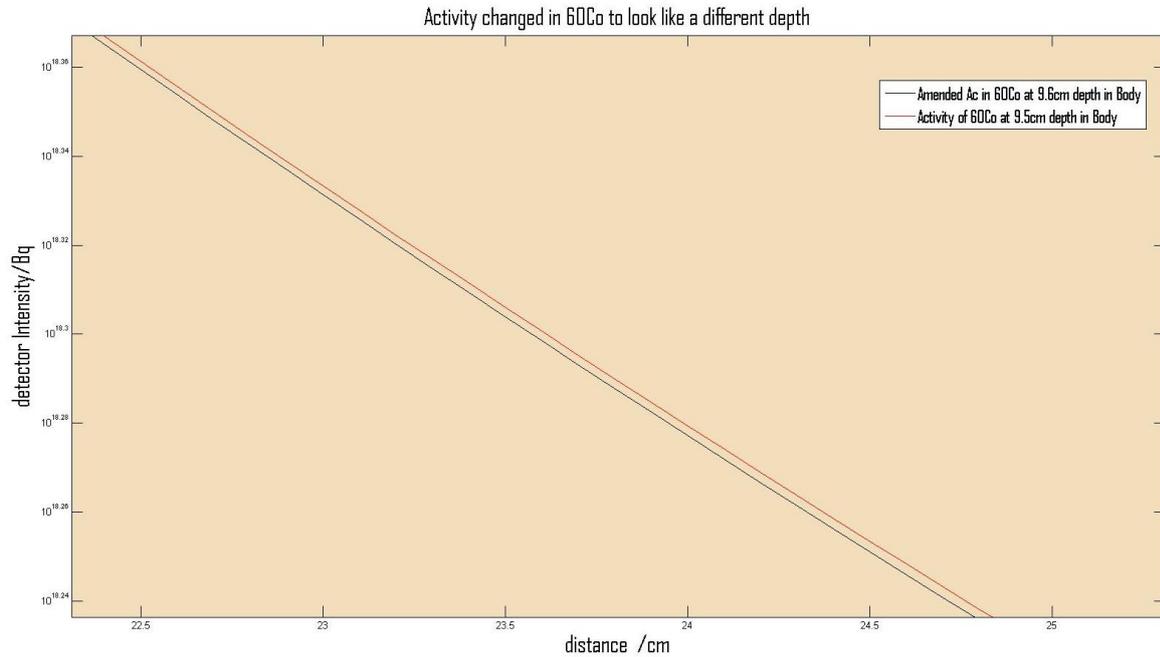


Image 9. Detail of image 8

3.4 Laboratory measurement with portable scintillator detector of NaI(Tl).

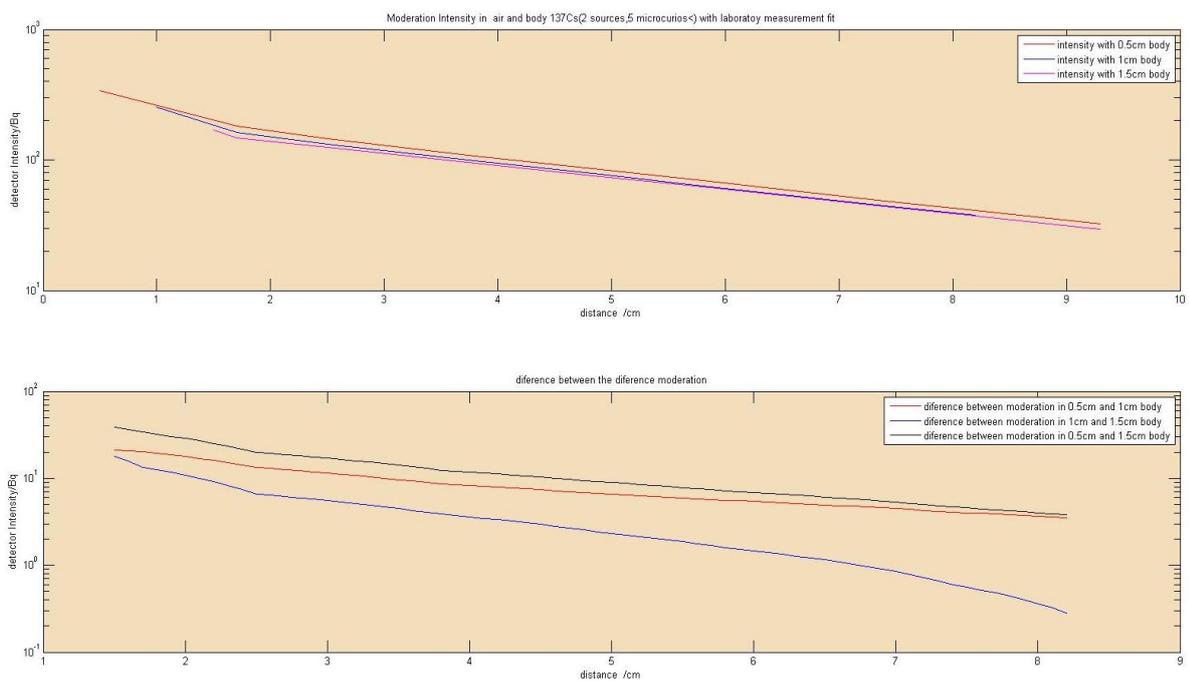


Image 10

In this last graphs[[image 10](#)] is shown measurements in the laboratory with the portable scintillator detector of NaI(Tl). We can observe that with different depths of shrapnel in the body, the moderation decrease of the intensity, will be very specific, for each surface of depth, even when the distance difference is only 0.5 cm. The second graphic shows the differences between the different moderations, where we can observe with more accuracy the differences, and how this difference starts to decrease, in the far field of the detection source. In this case it is because the activity was very low and at this distance (more than 7 cm), the activity detected for the gamma detector starts to be below the detection limit of the scintillator.

In the laboratory more measurements were made, but without the possibility to accurately making the measurement, and without some factor of correction (dead-time, background activity, real uncertainty of measurement, precision in distance measurements), it is impossible to compare the real value with the theoretical that we obtain with the simulation. However it's to be expected that, in the laboratory the measurement must have the same pattern of decrease of intensity, with 10-15% uncertainty of the detector. In this graphic the difference in intensity between the difference depths of shrapnel in the body from 0.5 cm to 1 cm, it's of 10% of proportion for the variation from one intensity path 1 cm to the other decay of 0.5 cm.

4. Discussion

After analyzing all the graphic I obtained, we can arrive to determine that for every radionuclide, they have very specific path of moderation, and will depend on the depth of the source in the body and of the activity. Without the shrapnel dimensions affecting the measures, since the measurements are taken at enough distance from the source (at least 5 cm for shrapnel with 6 cm of diameter). It will be a problem with the uncertainty in the activity, for different shrapnel activity, since we can think there is different depth in body. The only way to avoid this it is to take some samples of the radioactive shrapnel in the affected area.

It is shown that there is one relation between the activity and the localization of the radionuclide.

Something we must consider in a real situation in the case of one dirty-bomb, is that there can be several different factors, which was not taken into consideration in this thesis. For example, in this simulation I didn't take into consideration the shrapnel staying in the body with the interference of some bone in the acquisitions of the activity for the detector. This can affect seriously the moderation of the gamma particles, and in this case this entire theoretical model will not work. In other situation we have that the NaI(Tl) detectors, have an uncertainty of 15% and this means that we will not be able to determine the depth of the radionuclide with more accurately than 0.5 cm. In a real situation it can be bigger several times the uncertainty. Other problem we have, is that we don't know the radionuclide composing the shrapnel. For this we will need to use of a spectrometer, together the gamma detector.

However the laboratory measurement, were relatively very good, since we were in the situation of determining 0.5 cm with a difference in activity of 10%, and maybe with the necessary material, it will be possible to improve the capacity of detection of the scintillator detector of NaI(Tl).

5. Conclusion

In summary I can conclude that there is not viability for the surgical use of the portable scintillator detector of NaI(Tl). It is true that it will help a surgeon, to locate shrapnel, in the body, but will not be efficient for the determination of the depth.

To be efficient in locating a shrapnel (only 0X,0Y horizontal position), a collimator must be added to the detector, to collimate the gamma emission from one particular shrapnel, and avoid the interferences from others, close to the one we have interest to situate. For the axis 0Z, the vertical distance, we will need to determinate with precision, the intensity at two different point from the body, but with the uncertainty in measurement (in principle 15%), it will not be possible to determinate the depth with accuracy.

On the other hand, we need to know the composition of the shrapnel, and this will not be possible if we don't have a spectrometer. Also we will need to know the activity of the shrapnel, without moderation, for which will be necessary to have some sample of shrapnel from the affected area.

All these factors, make the uncertainty in the determination of the depth of the source in the body, very high for surgical use. However in case of extreme emergency this method, with this detector, can provide some help to a surgeon, if they can accept the uncertainty in the measurement, (at best case, from 1 to 1.5 cm). For the uncertainties we must consider the detector uncertainty, background (radioactive affected area), distance of measurement, Bone??, possibility of some blind of the dirty-bomb cover the radioactive shrapnel, proportion in the mix of radionuclide with what make up the dirty-bomb, etc...

Otherwise, to make possible the use of this theoretical method, it will be necessary to make the laboratory measurement with the radionuclide of interest and with several different activities, will also be necessary to make measurements for the significant mix or radionuclides, may appear in a dirty-bomb, to make the tables for the interpolation with the intensity detected, to determinate the depth with the method explained in this Thesis.

6. References and sources

- [1] Measurement and Detection of Radiation 2nd ed - N. Tsoulfanidis (Taylor and Francis, 1995).
- [2] Radioactivity Analysis 2nd ed-Michael F.L' Annunziata.(Dr. Werner Burkart, 2003).
- [3] Radiation Detection And Measurement, 2Nd, Part 1 202 (Dr.Knoll Frederick, 1998)
- [4] Wikipedia. http://en.wikipedia.org/wiki/Dirty_bomb. accessed 03/2010.
- [5] "Nuclear nonsense, black-market bombs, and fissile flim-flam", *Bulletin of the Atomic Scientists* **50** (2): 44–50 Belyaninov, K. (1994),
- [6] Energy from Nuclear Data center , http://www.nndc.bnl.gov/nudat2/indx_dec.jsp, accessed 04/2010.

7. Appendices

Appendix A

Coefficient of Photon Attenuation Coefficients

Photon energy (MeV)	H ₂ O	Compact bone	Muscle, striated	Concrete	Pyrex glass	Lucite (C ₅ H ₈ O ₂) _n
0.01	4.79	19.2	4.87	25.5	16.5	2.91
0.015	1.28	5.84	1.32	7.66	4.75	0.783
0.02	0.512	2.46	0.533	3.22	1.94	0.310
0.03	0.149	0.720	0.154	0.936	0.554	0.0899
0.04	0.0677	0.304	0.0701	0.393	0.232	0.0437
0.05	0.0418	0.161	0.0431	0.204	0.122	0.0301
0.06	0.0320	0.0998	0.0328	0.124	0.0768	0.0254
0.08	0.0262	0.0537	0.0264	0.0625	0.0428	0.0232
0.10	0.0256	0.0387	0.0256	0.0424	0.0325	0.0238
0.15	0.0277	0.0305	0.0275	0.0290	0.0274	0.0266
0.2	0.0297	0.0301	0.0294	0.0290	0.0276	0.0287
0.3	0.0319	0.0310	0.0317	0.0295	0.0289	0.0310
0.4	0.0328	0.0315	0.0325	0.0298	0.0295	0.0318
0.5	0.0330	0.0317	0.0328	0.0300	0.0297	0.0322
0.6	0.0329	0.0314	0.0325	0.0297	0.0294	0.0319
0.8	0.0321	0.0306	0.0318	0.0289	0.0287	0.0311
1.0	0.0309	0.0295	0.0306	0.0279	0.0277	0.0301
1.5	0.0282	0.0270	0.0280	0.0254	0.0252	0.0275
2	0.0260	0.0249	0.0257	0.0235	0.0233	0.0253
3	0.0227	0.0219	0.0225	0.0209	0.0207	0.0220
4	0.0206	0.0200	0.0204	0.0193	0.0190	0.0199
5	0.0191	0.0187	0.0189	0.0182	0.0179	0.0184
6	0.0180	0.0178	0.0178	0.0176	0.0171	0.0173
8	0.0166	0.0167	0.0164	0.0168	0.0163	0.0158
10	0.0157	0.0159	0.0155	0.0163	0.0157	0.0148

†Multiply by 10⁻¹ to obtain m²/kg.

‡From J. H. Hubbell, "Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV," NSRDS-NBS 29 C (1969).

From j. Hubbell NSRDS-NBS 29 C(1969)

Appendix B

TABLE OF BUILDUP FACTOR CONSTANTS

Coefficients of the Berger Equation for Dose Buildup Factors

$$B = 1 + a\mu r \exp(b\mu r)^{\dagger}$$

E (MeV)	Concrete [‡]		Air [§]		Water [§]	
	a	b	a	b	a	b
0.015	0.01	0.029	0.08	-0.034	0.09	-0.036
0.02	0.03	0.041	0.23	-0.032	0.26	-0.032
0.03	0.10	-0.036	0.93	-0.009	1.01	-0.006
0.04	0.26	0.035	2.40	0.018	2.58	0.024
0.05	0.52	-0.026	4.05	0.050	4.36	0.057
0.06	0.78	-0.008	5.27	0.075	5.59	0.082
0.08	1.42	0.007	6.11	0.102	6.47	0.108
0.1	1.83	0.028	5.93	0.113	6.11	0.120
0.15	2.19	0.054	4.70	0.121	4.88	0.125
0.2	2.20	0.065	3.94	0.113	4.13	0.118
0.3	2.03	0.067	3.10	0.094	3.18	0.096
0.4	1.87	0.061	2.61	0.079	2.67	0.080
0.5	1.73	0.055	2.29	0.067	2.32	0.068
0.6	1.60	0.049	2.05	0.058	2.07	0.059
0.8	1.41	0.040	1.71	0.045	1.74	0.045
1	1.27	0.032	1.50	0.035	1.50	0.036
1.5	1.02	0.021	1.16	0.021	1.16	0.021
2	0.89	0.014	0.97	0.013	0.97	0.013
3	0.71	0.007	0.75	0.005	0.74	0.005
4	0.59	0.004	0.61	0.001	0.62	0.000
5	0.49	0.004	0.53	-0.002	0.52	-0.002
6	0.45	0.002	0.47	-0.004	0.47	-0.005
8	0.36	0.001	0.37	-0.004	0.38	-0.006
10	0.30	0.003	0.31	-0.004	0.31	-0.005
15	0.21	0.004	0.23	-0.006	0.23	-0.008

[†]Good up to 40 mean free paths, for point isotropic source in infinite medium.

[‡]From A. B. Chilton, *Nuc. Sci. Eng.* 69:436 (1979).

[§]From A. B. Chilton, C. M. Eisenhauer, and G. L. Simmons, *Nuc. Sci. Eng.* 73:97 (1980).

A.B Chilton, C.M Eisenhauer, and G.L Simmons, *Nuc Sci Eng* 73:97(1980)

Appendix C

Programme code of simulation in Matlab .

```
clear all;
x=[0.001 0.015 0.02 0.03 0.04 0.05 0.06 0.08 0.10 0.15 0.2 0.3 0.4 0.5 0.6
0.8 1 1.5 2]; %valor of coefficient of total mass attenuation for muscle
striated Energy
x=10000*x;
y=[5.09 1.53 0.713 0.342 0.249 0.214 0.197 0.178 0.166 0.148 0.135 0.117
0.105 0.059 0.0887 0.0779 0.07 0.0570 0.0489]; %valor of coefficient of
total mass attenuation for muscle striated From J. H. Hubbell, "Photon
Cross Sections, Attenuation Coefficients, and Energy Absorption NSRDS-NBS
29 C (1969).
ya=[4.87 1.45 0.691 0.318 0.229 0.196 0.179 0.62 0.151 0.134 0.123 0.106
0.0953 0.0870 0.0805 0.0707 0.0636 0.0518 0.0445]; %valor of coefficient of
total mass attenuation for air From J. H. Hubbell, "Photon Cross Sections,
Attenuation Coefficients, and Energy Absorption NSRDS-NBS 29 C (1969).
y=0.933*y; %Body density
ya=0.00129*ya %air density
%buildup factor coefficient of the Berger Equation for water and air
x1=[15 20 30 40 50 60 80 100 150 200 300 400 500 600 800 1000 1500 2000
3000];
y1=[0.09 0.26 1.01 2.58 4.36 5.59 6.47 6.11 4.88 4.13 3.18 2.67 2.32 2.07
1.74 1.50 1.16 0.97 0.74]; %'a' for water
y2=[-0.036 -0.032 -0.006 0.024 0.057 0.082 0.108 0.120 0.125 0.118 0.096
0.080 0.068 0.059 0.045 0.036 0.021 0.013 0.005];%'b' for water
y3=[0.08 0.023 0.93 2.40 4.05 5.27 6.11 5.93 4.70 3.94 3.10 2.61 2.29 2.05
1.71 1.50 1.16 0.97 0.75]; %'a' for air
y4=[-0.034 -0.032 -0.009 0.018 0.050 0.075 0.102 0.113 0.121 0.113 0.094
0.079 0.067 0.058 0.045 0.035 0.021 0.013 0.005];%'b` for air
i=1;
%db=0 %distance to the detector in the body in cm
%dair=15 %%distance to the detector in the air in cm
%dt=4.51*2+db+dair;%%distance total to the detector in cm
sizesource=0.6 ; %size of radionucleid
sd=4.51; %diameter detector
s=sizesource;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
E1=661.657; %85.10-+20
E2=32.194; %3.64-+10
E3=31.817; %1.99-+5
E4=0;
%Ac=4773; %137Cs /06 low Ac;
Ac0=3.2*10^20; %True Ac/g
%Ac0=8.58*10^8; %Ac 137Cs /90 High
Ac=Ac0;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
ajuste=fittype('exp2'); %fitting curve between body and air
for d=5:0.1:11; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solidb(i)=solid;
MU1=interp1(x,y,E1);
MU2=interp1(x,y,E2);
```

```

MU3=interp1(x,y,E3);
T1=exp(-MU1*d);
T2=exp(-MU2*d);
T3=exp(-MU3*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
a3=interp1(x1,y1,E3);
b3=interp1(x1,y2,E3);
buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb1(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db21(i)=d;
i=i+1;

end

Ac=intensityb1(end)*2;%2pi geometry;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
for da=8:0.1:18;
psi=4.51/(da); %proportion beatween sourze and distance of the detector
omg=sd/(da); %proportion distance beatween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));solid=((omg^
2)/4)*((1-0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coeficient of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coeficient of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);
buildaup3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1

intensitya1(i)=(I1*buildaup1*T11+I2*buildaup2*T12+I3*buildaup3*T13)*solid;
daa1(i)=da+11;%vector distance air

i=i+1;

end
%
```

```

int1=[intensityb1,intensitya1];
da21=[db21,daa1] ;
[ea1,errores1]=fit(da21',int1',ajuste);
sajustado1=ea1.a*exp(ea1.b*da21)+ea1.c*exp(ea1.d*da21);

% %to fit the graphics
% daa2=23:0.1:33;
% db2=5:0.1:15;
% intensityaa=intensitya1(102:202);
% intensitybb=intensityb1(1:101);
% int21=[sajustado1(1:101),intensitya1(102:202)];%second fitting
% [ea21,errores21]=fit(da21',int21',ajuste);
% sajustado21=ea21.a*exp(ea21.b*da21)+ea21.c*exp(ea21.d*da21);
% %%%second comparative%%
% Ac=Ac0/10^6; %Ac 137Cs /90 High
Ac=Ac0;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
%s=0.6 %source sice of the shapnel
for d=5:0.1:10.5; %in cm
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solidb(i)=solid;
MU1=interp1(x,y,E1);
MU2=interp1(x,y,E2);
MU3=interp1(x,y,E3);
T1=exp(-MU1*d);
T2=exp(-MU2*d);
T3=exp(-MU3*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
a3=interp1(x1,y1,E3);
b3=interp1(x1,y2,E3);
buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb2(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db22(i)=d;
i=i+1 ;

end

%
Ac=intensityb2(end)*2;%2pi geometry;;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
daa=0;
for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the detector

```

```

omg=sd/(da); %proportion distance beatween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));solid=((omg^
2)/4)*((1-0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coeficient of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coeficient of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaupa1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaupa2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);
buildaupa3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1
intensity2(i)=(I1*buildaupa1*T11+I2*buildaupa2*T12+I3*buildaupa3*T13)*solid;
daa2(i)=da+10.5;%vector distance air

i=i+1 ;

end
%
int2=[intensityb2,intensity2];
da22=[db22,daa2] ;
[ea2,errores2]=fit(da22',int2',ajuste);
sajustado2=ea2.a*exp(ea2.b*da22)+ea2.c*exp(ea2.d*da22);

%% to fit the graphics
%% daa2=23:0.1:33;
%% db2=5:0.1:15;
%% intensityaa=intensity2(102:202);
%% intensitybb=intensityb2(1:101);
%% sajustado12=sajustado2(1:101);
%% int22=[sajustado2(1:101),intensity2(102:202)]%second fitting
%% [ea22,errores22]=fit(da22',int22',ajuste);
%% sajustado2=ea22.a*exp(ea22.b*da22)+ea22.c*exp(ea22.d*da22);
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Ac=Ac0/10^12; %Ac 137Cs /90 High
Ac=Ac0;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
%s=1 %source sice of the shapnel
for d=5:0.1:10.1; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beatween sourze and distance of the detector

```

```

omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % % %only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solidb(i)=solid;
MU1=interp1(x,y,E1);
MU2=interp1(x,y,E2);
MU3=interp1(x,y,E3);
T1=exp(-MU1*d);
T2=exp(-MU2*d);
T3=exp(-MU3*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
a3=interp1(x1,y1,E3);
b3=interp1(x1,y2,E3);
buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb3(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db23(i)=d;%vector distance body
i=i+1 ;

end

Ac=intensityb3(end)*2;%2pi geometry;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1 ;
daa=0;
for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
% % % % %only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coeficient of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coeficient of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);

```

```

    buildaupa3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1

intensitya3(i)=(I1*buildaup1*T11+I2*buildaup2*T12+I3*buildaup3*T13)*solid;
    daa3(i)=da+10.1;%vector distance air
    i=i+1 ;
end

int3=[intensityb3,intensitya3];
da23=[db23,daa3] ;
[ea3,errores3]=fit(da23',int3',ajuste);
sajustado3=ea3.a*exp(ea3.b*da23)+ea3.c*exp(ea3.d*da23);
Ac=Ac0; %Ac 137Cs /90 High
    I1=Ac*0.85;
    I2=Ac*0.364;
    I3=Ac*0.199;
    i=1;

for d=5:0.1:9.8; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solidb(i)=solid;
MU1=interp1(x,y,E1);
    MU2=interp1(x,y,E2);
    MU3=interp1(x,y,E3);
    T1=exp(-MU1*d);
    T2=exp(-MU2*d);
    T3=exp(-MU3*d);
    a1=interp1(x1,y1,E1);
    b1=interp1(x1,y2,E1);
    buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
    a2=interp1(x1,y1,E2);
    b2=interp1(x1,y2,E2);
    buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
    a3=interp1(x1,y1,E3);
    b3=interp1(x1,y2,E3);
    buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb4(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db24(i)=d;
    i=i+1 ;

end

Ac=intensityb4(end)*2;%2pi geometry;
    I1=Ac*0.85;
    I2=Ac*0.364;
    I3=Ac*0.199;
    i=1;
for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)

```

```

solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));solid=((omg^
2)/4)*((1-0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coeficent of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);
buildaup3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1

intensity4(i)=(I1*buildaup1*T11+I2*buildaup2*T12+I3*buildaup3*T13)*solid;
daa4(i)=da+9.8;%vector distance air

i=i+1 ;

end
%
int4=[intensityb4,intensitya4];
da24=[db24,daa4] ;
[ea4,errores4]=fit(da24',int4',ajuste);
sajustado4=ea4.a*exp(ea4.b*da24)+ea4.c*exp(ea4.d*da24);

% %to fit the graphics
% daa2=23:0.1:33;
% db2=5:0.1:15;
% intensityaa=intensitya1(102:202);
% intensitybb=intensityb1(1:101);
% int21=[sajustado1(1:101),intensitya1(102:202)];%second fitting
% [ea21,errores21]=fit(da2',int21',ajuste);
% sajustado21=ea21.a*exp(ea21.b*da2)+ea21.c*exp(ea21.d*da2);
% %%%second comparative%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Ac=Ac0; %Ac 137Cs /90 High
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
%s=0.6 %source size of the shapnel
for d=5:0.1:9.6; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion between sourze and distance of the detector
omg=sd/d; %proportion distance between detector and distance of the
sourze
%only weend (psi and omg)<1; (if not the calculation is too complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solidb(i)=solid;

```

```

MU1=interp1(x,y,E1);
MU2=interp1(x,y,E2);
MU3=interp1(x,y,E3);
T1=exp(-MU1*d);
T2=exp(-MU2*d);
T3=exp(-MU3*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
a3=interp1(x1,y1,E3);
b3=interp1(x1,y2,E3);
buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb5(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db25(i)=d;
i=i+1 ;

end

%
Ac=intensityb5(end)*2;%2pi geometry;;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
daa=0;
for da=8:0.1:18;
psi=4.51/(da); %proportion between source and distance of the detector
omg=sd/(da); %proportion distance between detector and distance of the
source
%only weend (psi and omg)<1; (if not the calculation is too complicated)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));solid=((omg^
2)/4)*((1-0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coefficient of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coefficient of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);
buildaup3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1

intensitya5(i)=(I1*buildaup1*T11+I2*buildaup2*T12+I3*buildaup3*T13)*solid;
daa5(i)=da+9.6;%vector distance air
i=i+1 ;

```

```

end
%
int5=[intensityb5,intensitya5];
da25=[db25,daa5] ;
[ea5,errores5]=fit(da25',int5',ajuste);
sajustado5=ea5.a*exp(ea5.b*da25)+ea5.c*exp(ea5.d*da25);

% % to fit the graphics
% % daa2=23:0.1:33;
% % db2=5:0.1:15;
% % intensityaa=intensitya2(102:202);
% % intensitybb=intensityb2(1:101);
% % sajustado12=sajustado2(1:101);
% % int22=[sajustado2(1:101),intensitya2(102:202)]%second fitting
% % [ea22,errores22]=fit(da2',int2',ajuste);
% % sajustado2=ea22.a*exp(ea22.b*da2)+ea22.c*exp(ea22.d*da2);
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%3 comparative%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Ac=Ac0; %Ac 137Cs /90 High
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1;
    %s=1 %source size of the shapnel
    for d=5:0.1:9.5; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % % %only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solidb(i)=solid;
MU1=interp1(x,y,E1);
    MU2=interp1(x,y,E2);
    MU3=interp1(x,y,E3);
    T1=exp(-MU1*d);
    T2=exp(-MU2*d);
    T3=exp(-MU3*d);
    a1=interp1(x1,y1,E1);
    b1=interp1(x1,y2,E1);
    buildaup1=1+a1*MU1*d*exp(b1*MU1*d);
    a2=interp1(x1,y1,E2);
    b2=interp1(x1,y2,E2);
    buildaup2=1+a2*MU2*d*exp(b2*MU2*d);
    a3=interp1(x1,y1,E3);
    b3=interp1(x1,y2,E3);
    buildaup3=1+a3*MU3*d*exp(b3*MU3*d);
intensityb6(i)=(I1*buildaup1*T1+I2*buildaup2*T2+I3*buildaup3*T3)*solid;
db26(i)=d;%vector distance body
i=i+1 ;

end

Ac=intensityb6(end)*2;%2pi geometry;
I1=Ac*0.85;
I2=Ac*0.364;
I3=Ac*0.199;
i=1 ;
daa=0;
for da=8:0.1:18;

```

```

psi=4.51/(da); %proportion beatween sourze and distance of the detector
omg=sd/(da); %proportion distance beatween detector and distance of the
sourze
% % % % %only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*(1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2));
solida(i)=solid;
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
MU13=interp1(x,ya,E3);%coeficent of moderation in the air
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
T13=exp(-MU13*da); %moderation in air
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaupa1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaupa2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
a3=interp1(x1,y3,E3);
b3=interp1(x1,y4,E3);
buildaupa3=1+a3*MU13*da*exp(b3*MU13*da); %buildup factor for Energy in
air 1
intensitya6(i)=(I1*buildaupa1*T11+I2*buildaupa2*T12+I3*buildaupa3*T13)*solida;
daa6(i)=da+9.5;%vector distance air
i=i+1 ;
end

int6=[intensityb6,intensitya6];
da26=[db26,daa6] ;
[ea6,errores6]=fit(da26',int6',ajuste);
sajustado6=ea6.a*exp(ea6.b*da26)+ea6.c*exp(ea6.d*da26);

% % to fit the graphics
% % daa2=23:0.1:33;
% % db2=5:0.1:15;
% % intensityaa=intensitya3(102:202);
% % intensitybb=intensityb3(1:101);
% % sajustado3=sajustado3(1:101);
% % int3=[sajustado3(1:101),intensitya3(102:202)];%second fitting
% % [ea23,errores23]=fit(da2',int3',ajuste);
% % sajustado23=ea23.a*exp(ea23.b*da2)+ea23.c*exp(ea23.d*da2);
%
% % %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% % %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% % %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%% Energy from Nuclear Data center
http://www.nndc.bnl.gov/nudat2/indx_dec.jsp
E1=1173.228; %99.85-+3
E2=1332.492; %99.98-+6
E3=0;
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;

i=1;
%s=0.1;

```

```

for d=5:0.1:11; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solid1(i)=solid; %vector with the valor of the geometrical factor
MU1=interp1(x,y,E1);%coeficent of moderation in the body
MU2=interp1(x,y,E2);
T1=exp(-MU1*d); %moderation in body
T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb1(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb1(end)*2;%2pi geometry;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1 ;

for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the
detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
% % % % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
Cointensitya1(i)=(I1*buildaup1*T11+I2*buildaup2*T12)*solid;
i=i+1 ;
end
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1;
%s=0.6;
for d=5:0.1:10.5; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze

```

```

% % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solidl(i)=solid; %vector with the valor of the geometrical factor
MU1=interp1(x,y,E1);%coeficent of moderation in the body
MU2=interp1(x,y,E2);
T1=exp(-MU1*d); %moderation in body
T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb2(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb2(end)*2%2pi geometry;
i=1 ;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;

for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the
detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
% % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
Cointensitya2(i)=(I1*buildaup1*T11+I2*buildaup2*T12)*solid;
i=i+1 ;
end
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1;
%s=1;
for d=5:0.1:10.1; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)

```

```

solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solid1(i)=solid; %vector with the valor of the geometrical factor
MU1=interp1(x,y,E1);%coeficent of moderation in the body
MU2=interp1(x,y,E2);
T1=exp(-MU1*d); %moderation in body
T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb3(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb3(end)*2%2pi geometry;
i=1 ;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac
for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the
detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
% % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
Cointensitya3(i)=(I1*buildaup1*T11+I2*buildaup2*T12)*solid;
da(i)=d+9
i=i+1 ;
end
E1=1173.228; %99.85--+3
E2=1332.492; %99.98--+6
E3=0;
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1;
%s=0.1;
for d=5:0.1:9.8; %in cm%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % % % % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)

```

```

solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solid1(i)=solid; %vector with the valor of the geometrical factor
MU1=interp1(x,y,E1);%coeficent of moderation in the body
MU2=interp1(x,y,E2);
T1=exp(-MU1*d); %moderation in body
T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb4(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb4(end)*2;%2pi geometry;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac
i=1 ;

for da=8:0.1:18;
psi=4.51/(da); %proportion beetween sourze and distance of the
detector
omg=sd/(da); %proportion distance beetween detector and distance of the
sourze
% % % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
Cointensitya4(i)=(I1*buildaup1*T11+I2*buildaup2*T12)*solid;
i=i+1 ;
end
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1;
%s=0.6;
for d=5:0.1:9.6; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beetween sourze and distance of the detector
omg=sd/d; %proportion distance beetween detector and distance of the
sourze
% % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*(((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*(((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)))));
solid1(i)=solid; %vector with the valor of the geometrical factor

```

```

MU1=interp1(x,y,E1);%coeficent of moderation in the body
MU2=interp1(x,y,E2);
T1=exp(-MU1*d); %moderation in body
T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb5(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb5(end)*2%2pi geometry;
i=1 ;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;

for da=8:0.1:18;
    psi=4.51/(da); %proportion beatween sourze and distance of the
detector
omg=sd/(da); %proportion distance beatween detector and distance of the
sourze
% % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
    MU11=interp1(x,ya,E1);%coeficent of moderation in the air
    MU12=interp1(x,ya,E2);
    T11=exp(-MU11*da); %moderation in air
    T12=exp(-MU12*da);
    a1=interp1(x1,y3,E1);
    b1=interp1(x1,y4,E1);
    buildaupal=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
    a2=interp1(x1,y3,E2);
    b2=interp1(x1,y4,E2);
    buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
    Cointensitya5(i)=(I1*buildaupal*T11+I2*buildaup2*T12)*solid;
    i=i+1 ;
end
Ac=Ac0;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac;
i=1;
%s=1;
for d=5:0.1:9.5; %in cm%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
psi=s/d; %proportion beatween sourze and distance of the detector
omg=sd/d; %proportion distance beatween detector and distance of the
sourze
% % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
solid1(i)=solid; %vector with the valor of the geometrical factor
    MU1=interp1(x,y,E1);%coeficent of moderation in the body
    MU2=interp1(x,y,E2);
    T1=exp(-MU1*d); %moderation in body

```

```

T2=exp(-MU2*d);
a1=interp1(x1,y1,E1);
b1=interp1(x1,y2,E1);
buildaup1=1+a1*MU1*d*exp(b1*MU1*d); %buildup factor for Energy 1
a2=interp1(x1,y1,E2);
b2=interp1(x1,y2,E2);
buildaup2=1+a2*MU2*d*exp(b2*MU2*d);%buildup factor for Energy 2
Cointensityb6(i)=(I1*buildaup1*T1+I2*buildaup2*T2)*solid;
i=i+1 ;
end

Ac=Cointensityb6(end)*2%2pi geometry;
i=1 ;
I1=Ac; %intensity E1 from certificate of calibration
I2=Ac
for da=8:0.1:18;
psi=4.51/(da); %proportion beatween sourze and distance of the
detector
omg=sd/(da); %proportion distance beatween detector and distance of the
sourze
% % % % % only weend (psi and omg)<1; (if not the calculation is too
complicatited)
solid=((omg^2)/4)*((1-
0.75*((psi^2)+(omg^2))+1.875*((psi^4+omg^4)/3)+(psi^2)*(omg^2))-
2.1875*((psi^6+omg^6)/4)+1.5*(psi^2)*(omg^2)*(psi^2+omg^2)));
MU11=interp1(x,ya,E1);%coeficent of moderation in the air
MU12=interp1(x,ya,E2);
T11=exp(-MU11*da); %moderation in air
T12=exp(-MU12*da);
a1=interp1(x1,y3,E1);
b1=interp1(x1,y4,E1);
buildaup1=1+a1*MU11*da*exp(b1*MU11*da); %buildup factor for Energy in
air 1
a2=interp1(x1,y3,E2);
b2=interp1(x1,y4,E2);
buildaup2=1+a2*MU12*da*exp(b2*MU12*da);%buildup factor in air Energy
2
Cointensitya6(i)=(I1*buildaup1*T11+I2*buildaup2*T12)*solid;
da(i)=d+9
i=i+1 ;
end

% % % % %diferences% % % % %
% % Coresta1=[Cointensityb1,Cointensitya1];
% % Coresta2=[Cointensityb2,Cointensitya2];
% % coresta=[Cointensityb3,Cointensitya3];
% % Cores1=Coresta1-Coresta2;
% % Cores2=Coresta1-Coresta2;
% % Csresta1=[intensityb1,intensitya1];
% % Csresta2=[intensityb2,intensitya2];
% % Csresta3=[intensityb3,intensitya3];
% % % % %resta different Distance% % % % %
% Csresta1=intensitya3(51:101);
% Csrest=intensityb2-Csresta1
% daares=daa2(1:51)
% semilogy(daares,Csrest)
% Csresta2=[intensityb2,intensitya2];
% Csresta3=[intensityb3,intensitya3];
% Csres1=Csresta1-Csresta2;
% Csres2=Csresta1-Csresta3;
% Csres3=Csres2-Csres1;
% % % subplot(3,1,3)

```

```

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Vesctor%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Cs1=[intensityb1,intensitya1];
% distance1=[db21,daa1];
% Cs2=[intensityb2,intensitya2];
% distance2=[db22,daa2];
% Cs3=[intensityb3,intensitya3];
% distance3=[db23,daa3];
% Col1=[Cointensityb1,Cointensitya1];
% Co2=[Cointensityb2,Cointensitya2];
% Co3=[Cointensityb3,Cointensitya3];
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Porcentages%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%137Cs%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
resta1=mean(intensitya2(1:96))-mean(intensitya1(6:end));
medial=mean(intensitya2(1:96));
por1=resta1*100/medial;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 05cm
resta2=mean(intensitya3(1:97))-mean(intensitya2(5:end));
media2=mean(intensitya3(1:97));
por2=resta2*100/media2;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 04cm
resta3=mean(intensitya4(1:98))-mean(intensitya3(4:end));
media3=mean(intensitya4(1:98));
por3=resta3*100/media3;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 03cm
resta4=mean(intensitya5(1:99))-mean(intensitya4(3:end));
media4=mean(intensitya5(1:99));
por4=resta4*100/media4;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 02cm
resta5=mean(intensitya6(1:96))-mean(intensitya5(2:end));
media5=mean(intensitya5(1:96));
por5=resta5*100/media5;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 01cm
resta6=mean(intensitya6(1:95))-mean(intensitya3(7:end));
media6=mean(intensitya5(1:95));
por6=resta6*100/media6;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 06cm
resta7=mean(intensitya6(1:91))-mean(intensitya2(11:end));
media7=mean(intensitya6(1:91));
por7=resta7*100/media7;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 1cm
resta8=mean(intensitya6(1:86))-mean(intensitya1(16:end));
media8=mean(intensitya6(1:86));
por8=resta8*100/media8;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 1.5cm
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%60Co%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
resta1=mean(Cointensitya2(1:96))-mean(Cointensitya1(6:end));
medial=mean(Cointensitya2(1:96));
Copor1=resta1*100/medial;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 05cm
resta2=mean(Cointensitya3(1:97))-mean(Cointensitya2(5:end));
media2=mean(Cointensitya3(1:97));
Copor2=resta2*100/media2;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 04cm
resta3=mean(Cointensitya4(1:98))-mean(Cointensitya3(4:end));
media3=mean(Cointensitya4(1:98));
Copor3=resta3*100/media3;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 03cm
resta4=mean(Cointensitya5(1:99))-mean(Cointensitya4(3:end));
media4=mean(Cointensitya5(1:99));
Copor4=resta4*100/media4;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 02cm
resta5=mean(Cointensitya6(1:96))-mean(Cointensitya5(2:end));
media5=mean(Cointensitya5(1:96));
Copor5=resta5*100/media5;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 01cm
resta6=mean(Cointensitya6(1:95))-mean(Cointensitya3(7:end));
media6=mean(Cointensitya5(1:95));
Copor6=resta6*100/media6;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 06cm
resta7=mean(Cointensitya6(1:91))-mean(Cointensitya2(11:end));
media7=mean(Cointensitya6(1:91));
Copor7=resta7*100/media7;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 1cm
resta8=mean(Cointensitya6(1:86))-mean(Cointensitya1(16:end));
media8=mean(Cointensitya6(1:86));
Copor8=resta8*100/media8;%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%distace 1.5cm
% resta2=Cointensitya3(1:91)-Cointensitya2(11:end)
% propor=resta1*100/(intensitya4(1:98))
% semilogy(da2,Csres1,'r',da2,Cores1,'m')

```

```

%% title('differences between graphic with different Ac')
%% Legend('between Ac and Ac/10^6 137Cs', 'between Ac and Ac/10^6 137Cs')
%% xlabel('distance /cm')
%% ylabel('detector Intensity/Bq')
%% plot(da2,Csres3)
%%
%%
%% subplot(3,1,1)
%%
semilogy(db2,Cointensityb1,'K',daa,Cointensitya1,'k',db2,Cointensityb2,'r',
daa,Cointensitya2,'r',db2,Cointensityb3,'b',daa,Cointensitya3,'b')
%% title('Moderation Intensity in Body and air 60Co different Ac')
%% xlabel('distance /cm')
%% ylabel('detector Intensity/Bq')
Legend('Intensity with shrapnel 15cm depths ', 'Intensity with shrapnel
10cm depths', 'Intensity with shrapnel 9cm depths')
%% subplot(3,1,2)
semilogy(daa1,Cointensitya1,'k',daa2,Cointensitya2,'r',daa3,Cointensitya3,'
b',daa4,Cointensitya4,'c',daa5,Cointensitya5,'g',daa6,Cointensitya6,'m')
%semilogy(distance1,Cs1,'k',distance2,Cs2,'r',distance3,Cs3,'b',distance1,C
o1,'g',distance2,Co2,'m',distance3,Co3,'c')
ylabel('detector Intensity/Bq')
xlabel('distance /cm')
title('Moderation Intensity in air 60Co several diferent depths of
shrapnel')
Legend('Intensity with shrapnel at 11cm', 'Intensity with shrapnel at
10.5', 'Intensity with shrapnel at 10.1cm', 'Intensity with shrapnel at
9.8cm', 'Intensity with shrapnel at 9.6cm', 'Intensity with shrapnel at
9.5')
%% %% %%

```