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Cs-137, Co-60 ve Na-24 için Monte Carlo Simülasyonu Kullanılarak Farklı Vücut Organlarının Doz Değerlendirilmesi

Umit Kara
Suleyman Demirel University, Vocational School of Health Services, Medical Imaging Department, Isparta, Turkey
e-mail: umitkara@sdu.edu.tr

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Anahtar Kelimler
Etkin doz; Organ; Monte Carlo; Fantom; ICRP

Özet

Yapılan araştırmada, Cs-137, Co-60 ve Na-24 radyoaktif kaynaklarının harici kullanımında bireysel organ dozunun ve insan vücuduna etkin dozun tahmini için Monte Carlo VMC kod simülasyonu kullanılmıştır. Organ dozunun kaynak gücü ve maruz kalınan süre ile değiştiği gözlemlenirken, insan vücudunun etkin doza maruz kalma süresi ile lineer bağımlılığı bulunmuştur.

Assessment of Different Body Organs Using Monte Carlo Simulation for Cs-137, Co-60 and Na-24

Keywords
Effective dose;Organ; Monte Carlo; Phantom; ICRP

Abstract

In the present investigation, Monte Carlo VMC code simulation was used for the estimation of individual organ dose and effective dose to human body using Cs-137, Co-60 and Na-24 radioactive external sources. It was observed that the organ dose varies with source strength and the duration of exposure whereas the effective dose to human body is linearly dependent upon the exposure time.

1. Introduction

Utilization of radioactive sources and radiation inmedical, industrial, agricultural and nuclear fieldsas well as scientific research has been increasing inmodern era. The application of radiation in medicalsciences has been boosted up many folds formedical imaging, cancer treatment, brachytherapy,etc. Partial body parts or full body are subjected toradiation exposure during various applications.Exposure assessment and reduction has alwaysbeen a key measurement point in radiationprotection and shielding. The required shielding isdetermined according to the amount of radiationexposure to different vital organs. Various types ofradiation accounts for exposure through external,internal or contamination. Most importantly,exposure mode is external exposure, which can becontrolled by simple philosophy of time, distanceand shielding. Various types of high energyradiation sources are available, among which Cs-137 and Co-60 are globally available. Additionally,Na-24 is being used as a radioactive source in nonmedicalapplications for leakage in pipeline.The amount of exposure that reaches to differentparts of the body depends on the type of thesource and also to exposure geometry and distanceto the source. The point source of radiation followsinverse square law of exposure whereas this doesnot apply for the beam source. Measurement ofeffective dose to human body can be estimatedthrough (i) using strength of source, distance to thesource and duration of exposure (ii) placingdosimeters on different parts of the actual bodyand (iii) simulation of both exposure and humanbody. The estimation of exposure using sourcestrength, distance and duration of exposure is achallenging method whereas application ofdosimeters can succefully mimic the actualexposure to human body. Both of these methodsare proven to be useful in non-medical practices.However, in medical and radiological application of radiation, dose distribution to vital body organs is calculated accurately before actual situation.The Monte Carlo method was employed toevaluate the external dose to different bodyorgans. The Monte Carlo (MC) programmecomputation simulates mathematically theirradiation of the body by different radiationmaterial, including mark, ground, cloud or internalmaterial. The Equivalent dose is calculated forsuitable tissues and the effective dose is alsocalculated. It is especially beneficial to quicklyestimate the doses from radioactive material in thecase of emergencies or accidents (Kis *et al*. 2003,Jacob *et al*. 1987, Meckbach *et al*. 1988). The codedoes not take into account biokinetic designs usedfor radionuclides used in nuclear medicineprocessing, since it was originally written foroccupational exposed workers. Therefore, it wasassumed that the residence time in the primarysource organs is the same interested (Velasques *etal*. 2005). It has been broadly validated bycomparing the data from the program with thedoses measured in physical phantoms, and also bydirect comparison with data created using otherMonte Carlo software such as EGSnrc and MCNP.

2. Materials and Methods

2.1. Simulation geometry setup and validation

Radioactive sources Cs-137 (662.2 keV), Co-60 (1173 and 1332 keV) and Na-24 (1.37 and 2.75 keV)have been considered as external point sources ofradiation to irradiate the human body organs.Elemental compositions of human body organs aregiven in Table-1 (ICRP-103). Used phantoms areshown in Figure 1 and 2. Tissue weighting factorsused in the present investigations are taken fromICRP-103 and given in Table-2. The tissue weightingfactor, is the risk of stochastic effects that mayarise from irradiation of that typical tissue. Thetissue weighting factor, calculate for theradiosensitivities of organs and tissues in thehuman body to ionising radiation.The experimental set-up for simulation ispresented in Figure-2.The radioactive sources Cs-137, Co-60 and Na-24 were point sources ofidentical activity of 300 mCi in the presentexperiment. Distance between sources to humanbody was fixed at 100 cm and x-, y- and zcoordinatesare presented in set-up. Exposure timevaried from 1 hour to 10 hours to simulate theexperimental condition and assessment of dose tothe organs. Monte Carlo simulation was carried outfor 1000000 nuclear transformations.

3. Results

The effective dose for human body using selected gamma emitting radionuclides for differentexposure times is given in Table-3. The organ dosecorresponding to individual organ for differentexposure time is shown in Figure 3-5.

3.1. Effective dose

From Table-3, it is observed that the effective doseto human body is lowest for Cs-137 and highest forNa-24. However, the effective dose for humanbody for Co-60 is less than Na-24 and higher thanCs-137. The variation in effective dose to humanbody is due to variation in energy of photo emitted from the selected radioactive sources. It isto be noted that photon energy from Cs-137 is thelowest whereas it is the largest for Na-24.It is also to be noted that the effective dose ofhuman body increases with exposure time linearly.The time dependency of effective dose is shownFigure-6, wherein tangent of line is dependentupon photon energy. The time dependent equationfor effective dose using linear fitting is shown inFigure-6. The effective dose to human body ispossible to estimate using linear equations for anyexposure time without simulations, also.

3.2. Organ dose

The individual organ dose of human body fordifferent exposure times is presented in figure

3-5.It can be observed that the organ dose varies withexposure time and increases with increase inexposure time for most of the organs.

Absorbed dose, D (J kg-1, special unit Gy), is the mean energy given by ionizing radiation to a unit mass of matter. It is, in principle, a quantity that is physically measurable. According to the mean weights of patients are similar to those of ICRP simulators, it was used ICRP dose conversion factors for calculate the absorbed dose. The absorbed dose DT in the target organ T due to the cumulative radionuclide in a single source organ S is (equation 1)

$$DT = AS .S(T \leftarrow S) \qquad (1)$$

A is the time cumulated activity, that is, the total count of disintegrations in the organ and S(T S) is the dose conversion factor which depends on the kind of radiation, emitted energy per disintegration, the mass of the target organ and geometry of the simulators.

Effective dose, E (J kg-1, special unit Sv), is the totally of equivalent doses in tissues or organs each multiplied by the eligible organ weighting factors specified in the ICRP Publications cited. E is the sum of all absorbed doses weighted by radiation weighting factors and by the suitable organ weighting factors of the whole body (equation 2).

$$\text{Effective dose organ doses } W = \sum \times (T) \qquad (2)$$

The calculated organ dose for Cs-137 results shown in Figure 3, for the whole body; bone marrow, colon, lung, stomach, breast, remainder, gonads, bladder , oesophagus, liver ,thyroid, bone surface, brain, salivary glands, skin, adrenals, extrathor airways, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, eye lens.The calculated effective dose for Cs-137 results given in Table 3 and shown in Figure 6, the effective dose increase from 1 to 10 hours, are consistent with the relationship between time and dose. For Cs-137, major organs the interaction possibility is higher, the organ and effective doses are increased as expected with the time. For the first radioactivity source, an effective dose for status using a Cs-137 radioactive source with 300 mCi activity, a ditance of 300 cm and an exposure time of 1 to 10 hours. The Monte Carlo Simulation calculation results for 1 to 10 hours; 0.58 1.07,1.38, 1.98, 2.39, 2.88, 3.52, 4.43, 4.48, 5.32 mSv were found.

The calculated organ dose for Co-60 results shown in Figure 4, for the whole body; bone marrow, colon, lung, stomach, breast, remainder, gonads, bladder, oesophagus, liver,thyroid, bone surface, brain, salivary glands, skin, adrenals, extrathor airways, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, eye lens.The calculated effective dose for Co-60 results given in Table 3 and shown in Figure 6, the effective dose increase from 1 to 10 hours, are consistent with the relationship between time and dose. For Co-60, major organs the interaction possibility is higher, the organ and effective doses are increased as expected with the time. For the second radioactivity source, an effective dose for status using a Co-60 radioactive source with 300 mCi activity, a ditance of 300 cm and an exposure time of 1 to 10 hours. The Monte Carlo Simulation calculation results for 1 to 10 hours; 2.10, 4.11, 6.32, 8.11, 9.31, 12.85, 15.14, 16.07,17.61,19.28 mSv were found.

The calculated organ dose for Na-24 results shown in Figure 5, for the whole body; bone marrow, colon, lung, stomach, breast, remainder, gonads, bladder, oesophagus, liver,thyroid, bone surface, brain, salivary glands, skin, adrenals, extrathor airways, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, eye lens.The calculated effective dose for Na-24 results given in Table 3 and shown in Figure 6, the effective dose increase from 1 to 10 hours, are consistent with the relationship between time and dose. For Na-24, major organs the interaction possibility is higher, the organ and effective doses are increased as expected with the time. For the third radioactivity source, an effective dose for status using a Na-24 radioactive source with 300 mCi activity, a ditance of 300 cm and an exposure time of 1 to 10 hours. The Monte Carlo Simulation calculation results for 1 to 10 hours; 2.73, 5.52, 9.78, 11.05, 14.13, 17.04, 21.64, 22.84, 25.95, 27.95 mSv were found.

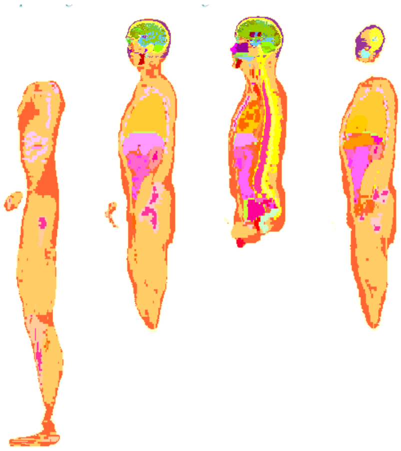


Figure 1. Side View of Male and Female Phantom

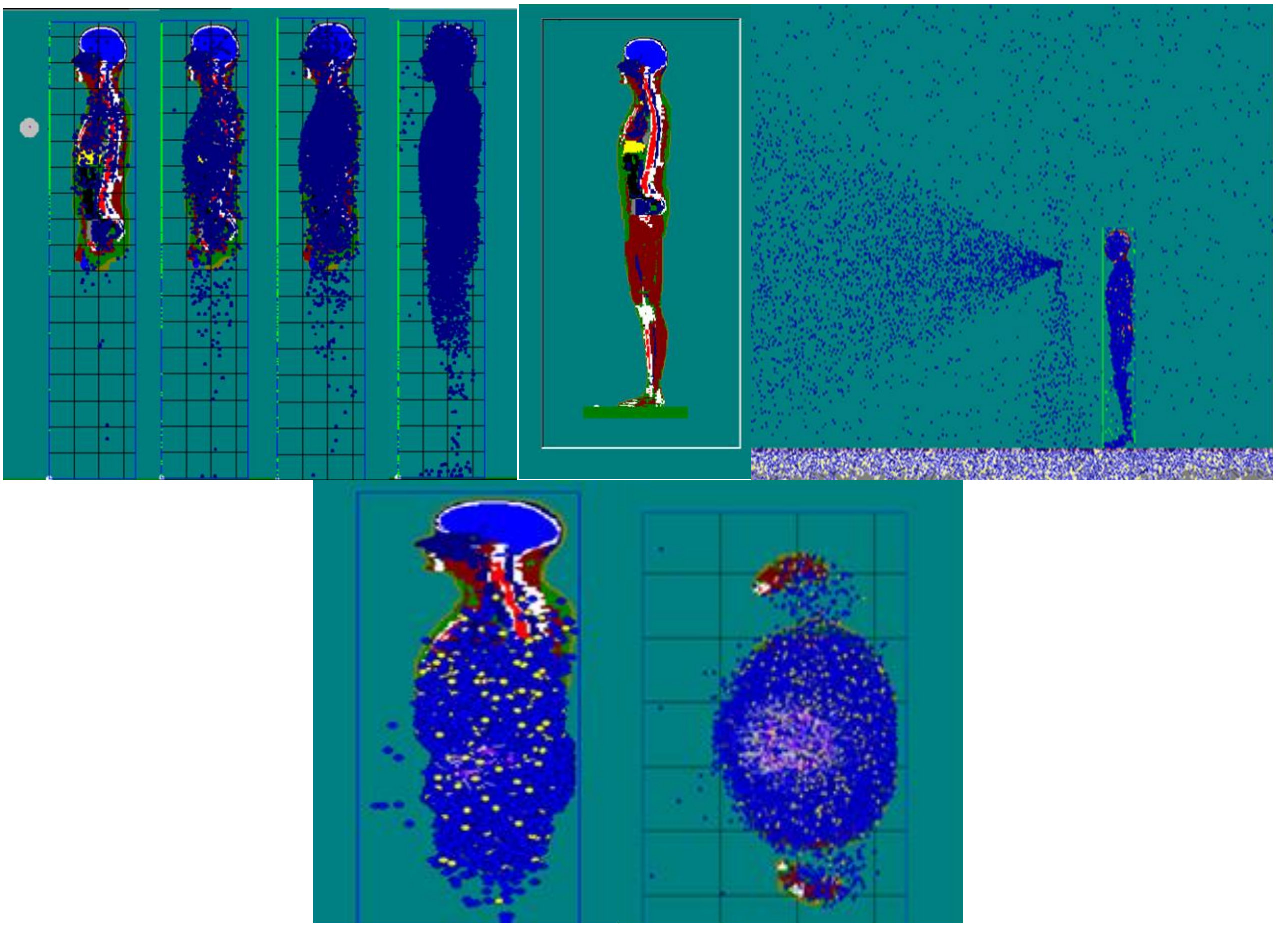
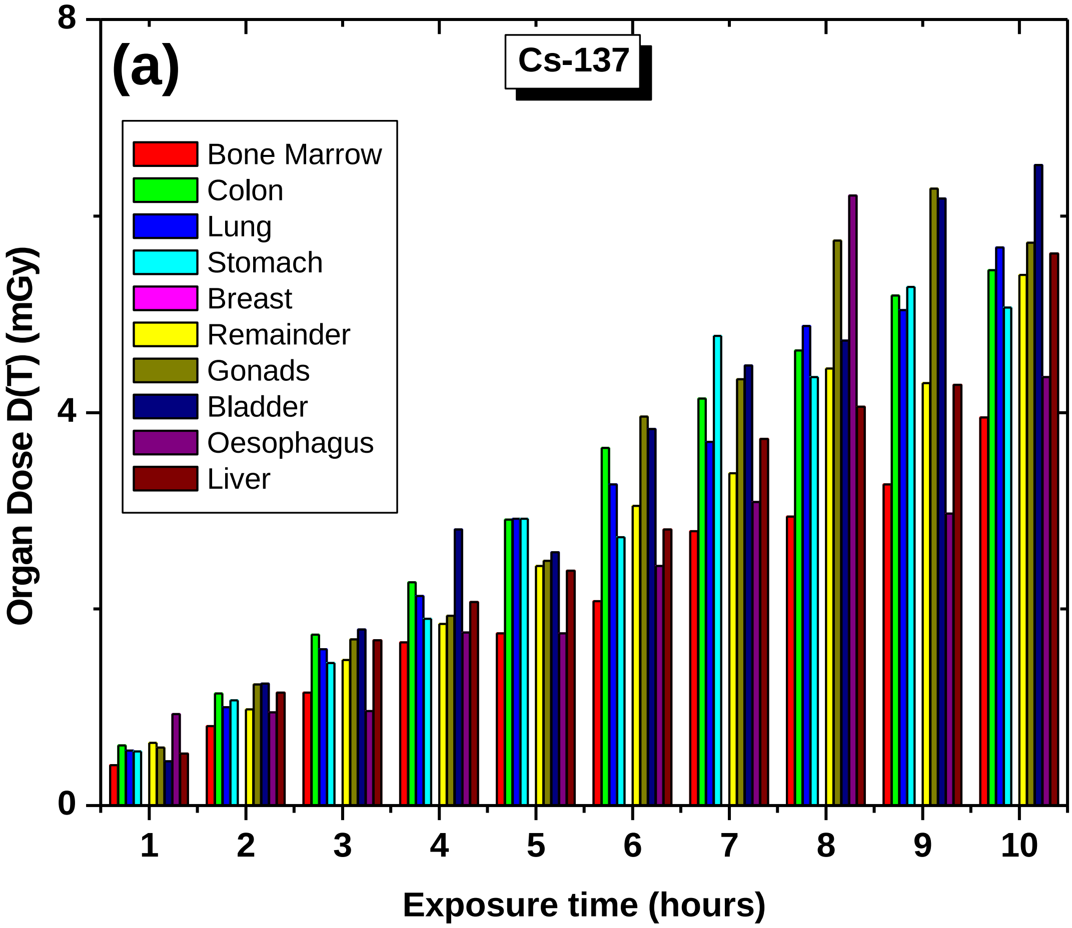
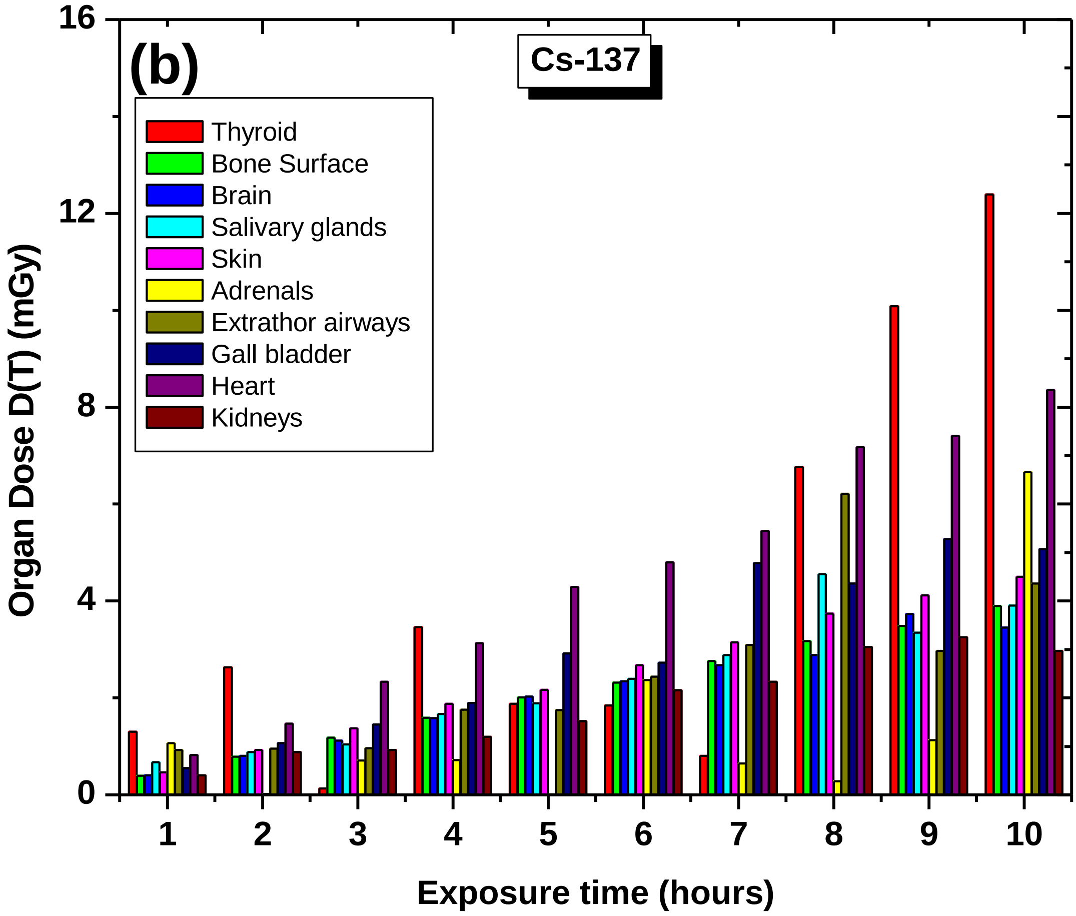


Figure 2. View of used Phantom (x, y and z coordinates)


(a)
Cs-137
Bone Marrow
Colon
Lung
Stomach
Breast
Remainder
Gonads
Bladder
Oesophagus
Liver
Organ Dose D(T) (mGy)
0
4
8
1
2
3
4
5
6
7
8
9
10
Exposure time (hours)


(b)
Cs-137
Thyroid
Bone Surface
Brain
Salivary glands
Skin
Adrenals
Extrathor airways
Gall bladder
Heart
Kidneys
Organ Dose D(T) (mGy)
0
4
8
12
16
1
2
3
4
5
6
7
8
9
10
Exposure time (hours)

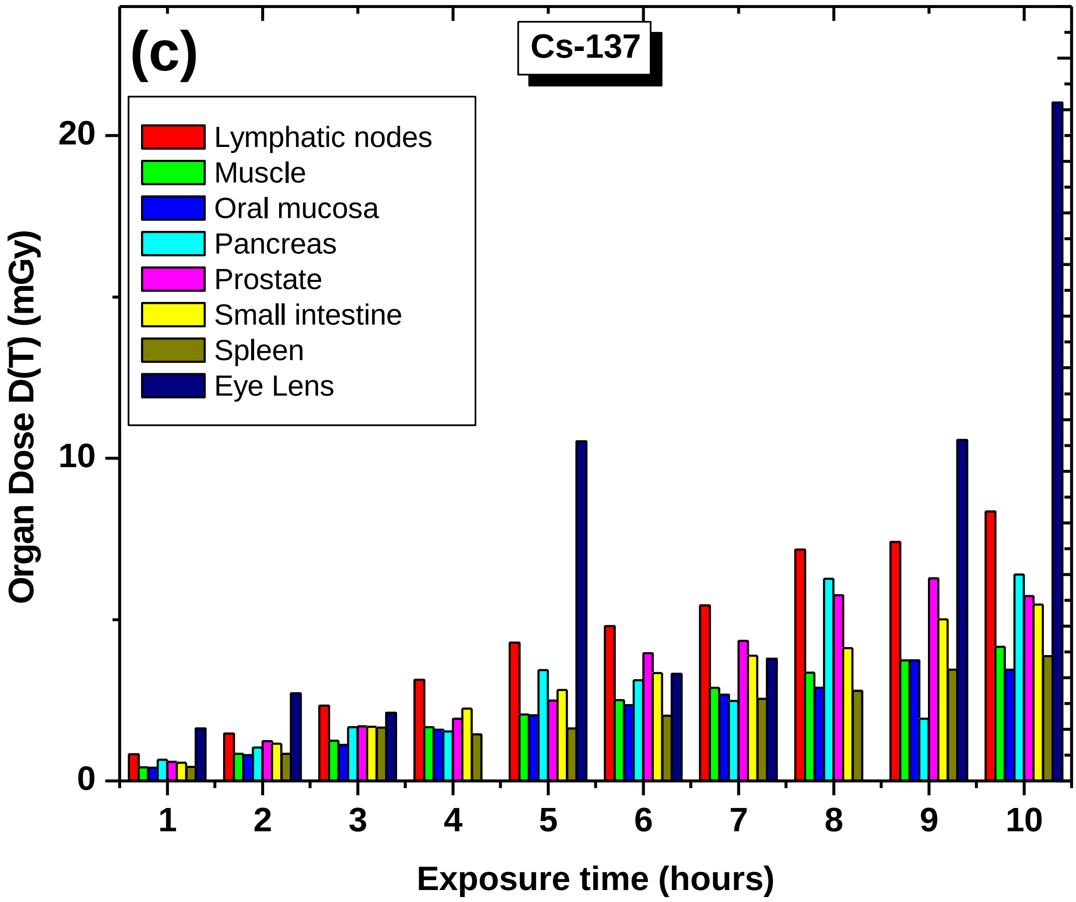
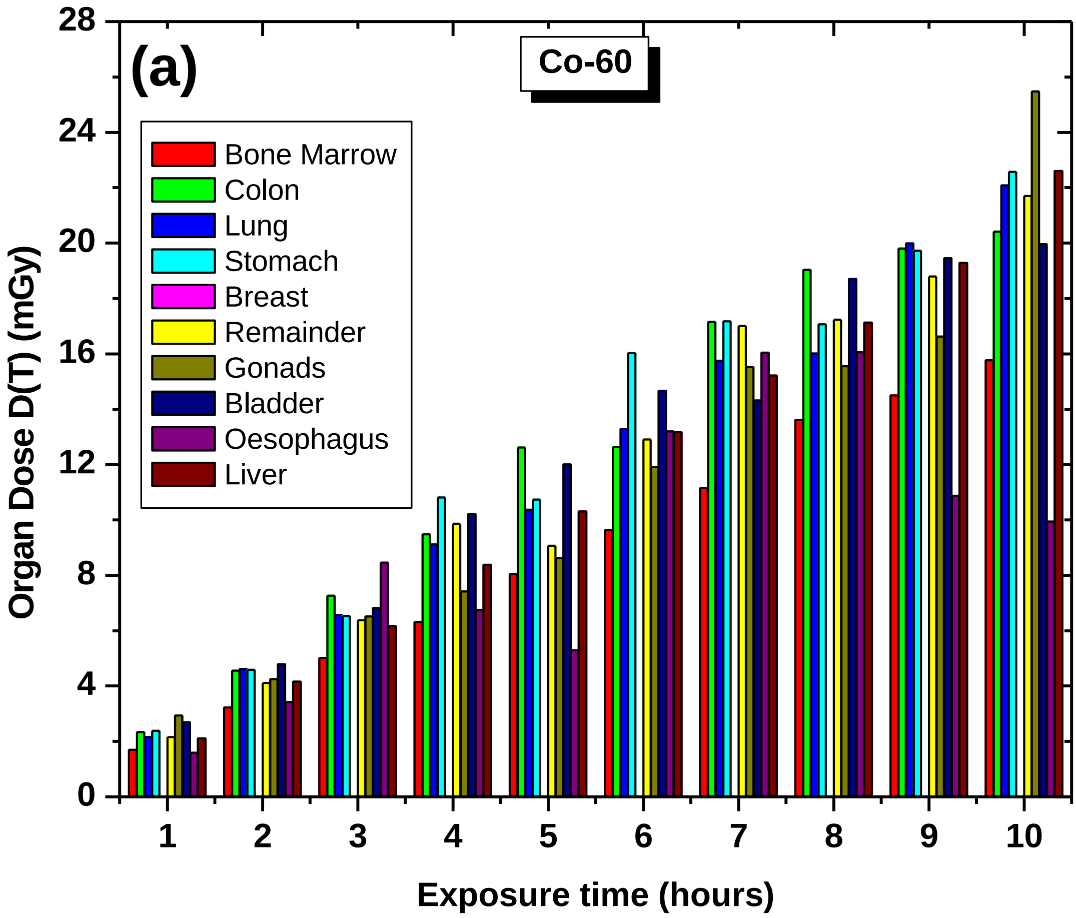
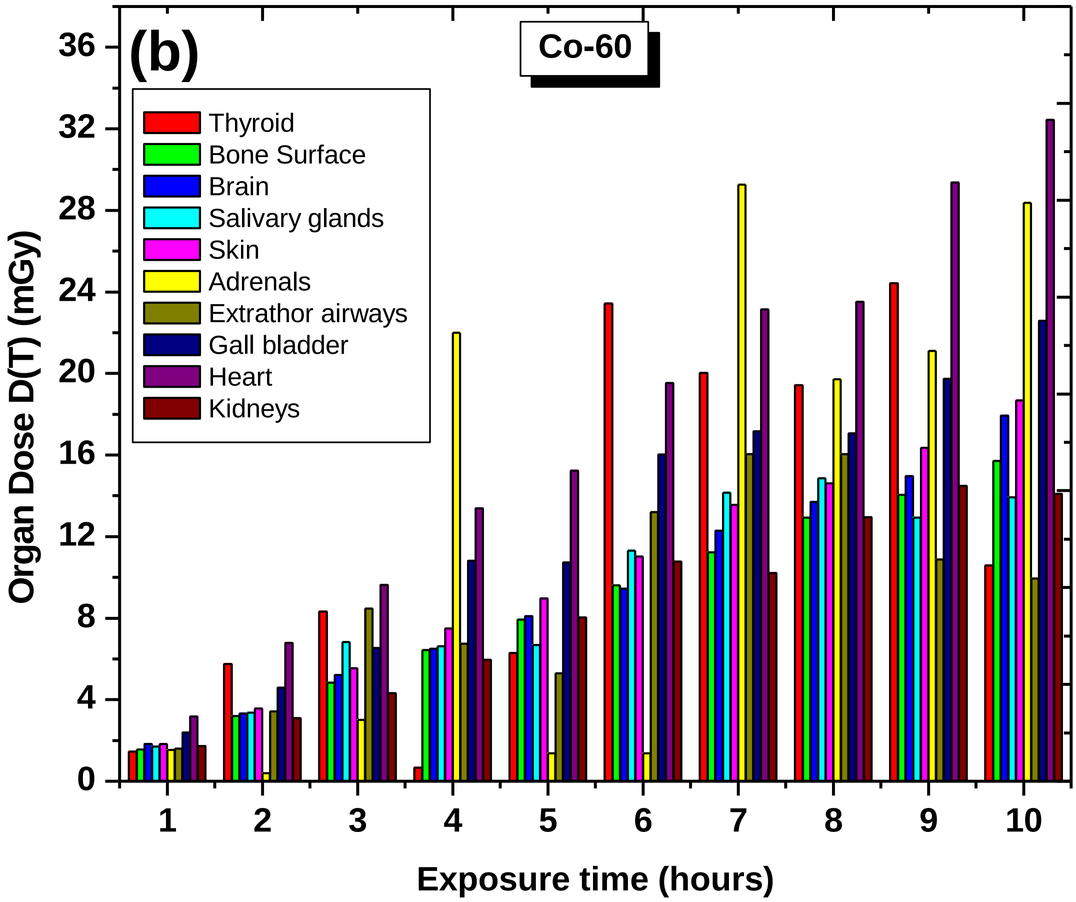


Figure 3. Organ dose for Cs-137


(a)
Co-60
Bone Marrow
Colon
Lung
Stomach
Breast
Remainder
Gonads
Bladder
Oesophagus
Liver
Organ Dose D(T) (mGy)
Exposure time (hours)
0
4
8
12
16
20
24
28
1
2
3
4
5
6
7
8
9
10


(b)
Co-60
Thyroid
Bone Surface
Brain
Salivary glands
Skin
Adrenals
Extrathor airways
Gall bladder
Heart
Kidneys
Organ Dose D(T) (mGy)
0
4
8
12
16
20
24
28
32
36
1
2
3
4
5
6
7
8
9
10
Exposure time (hours)

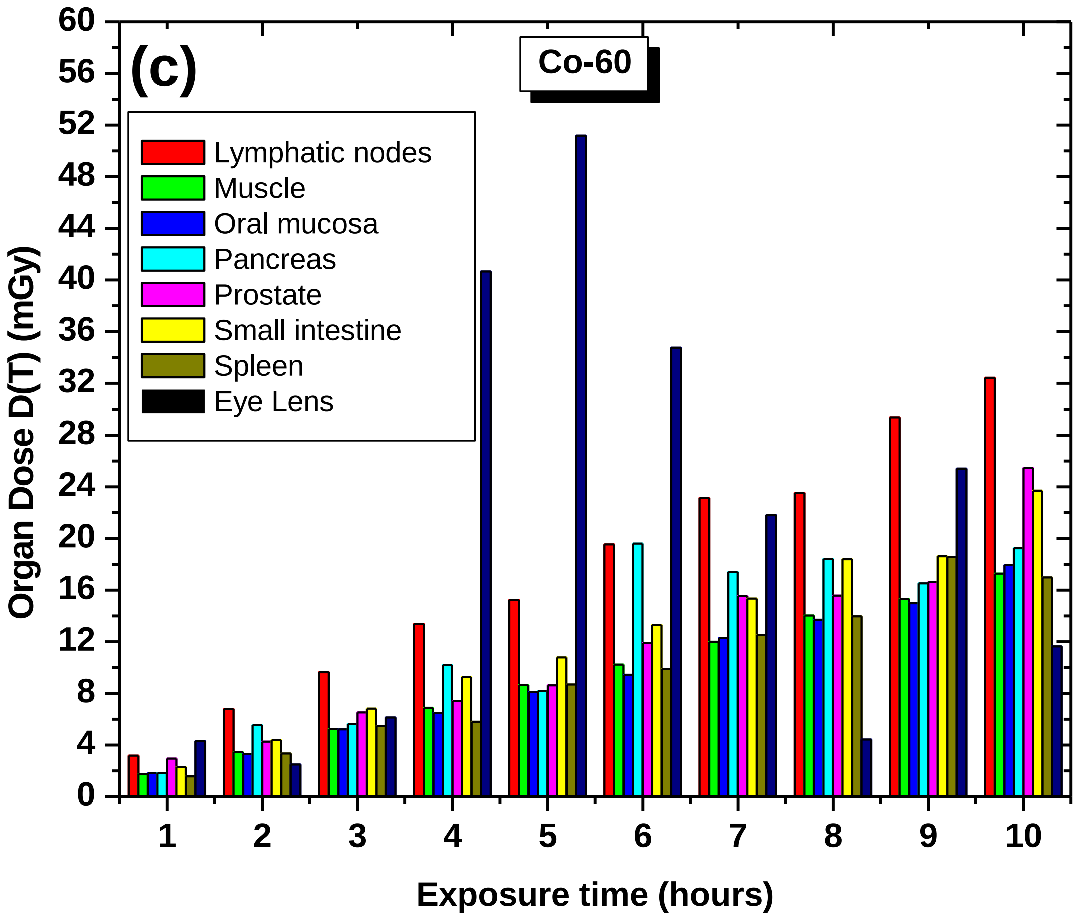
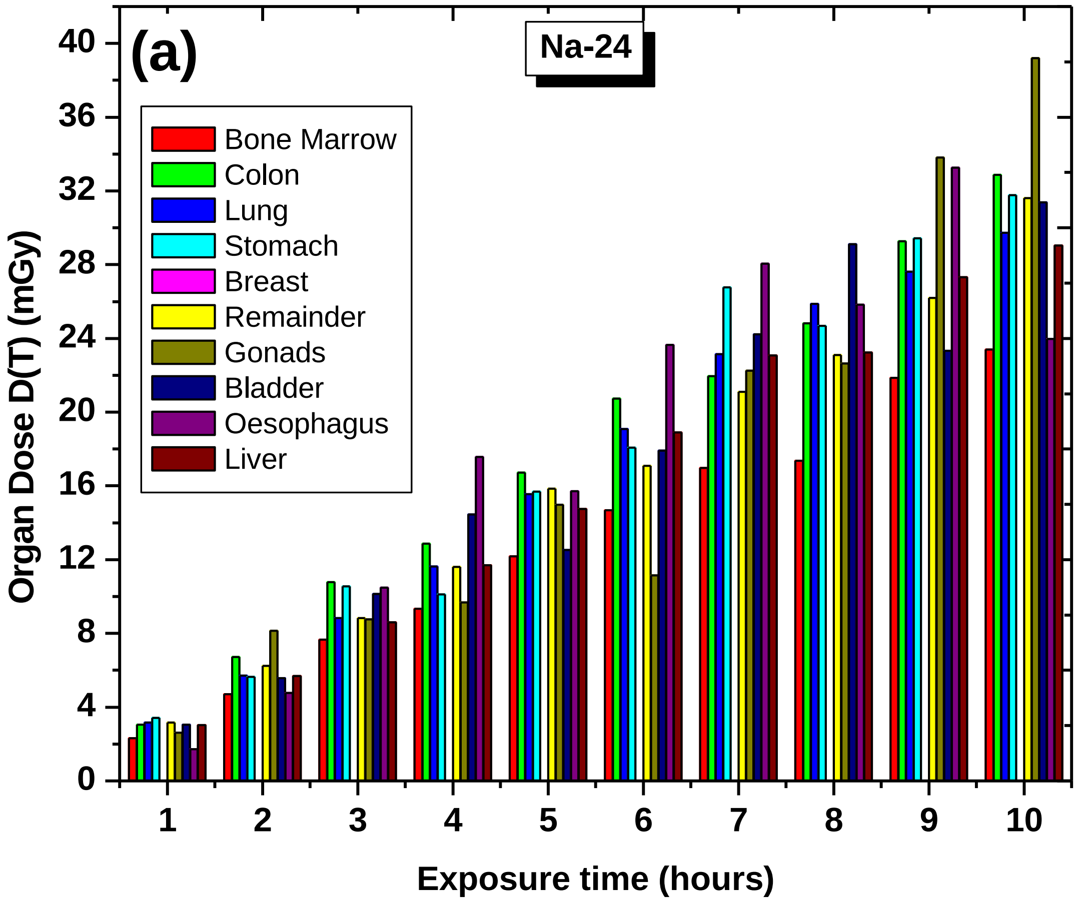
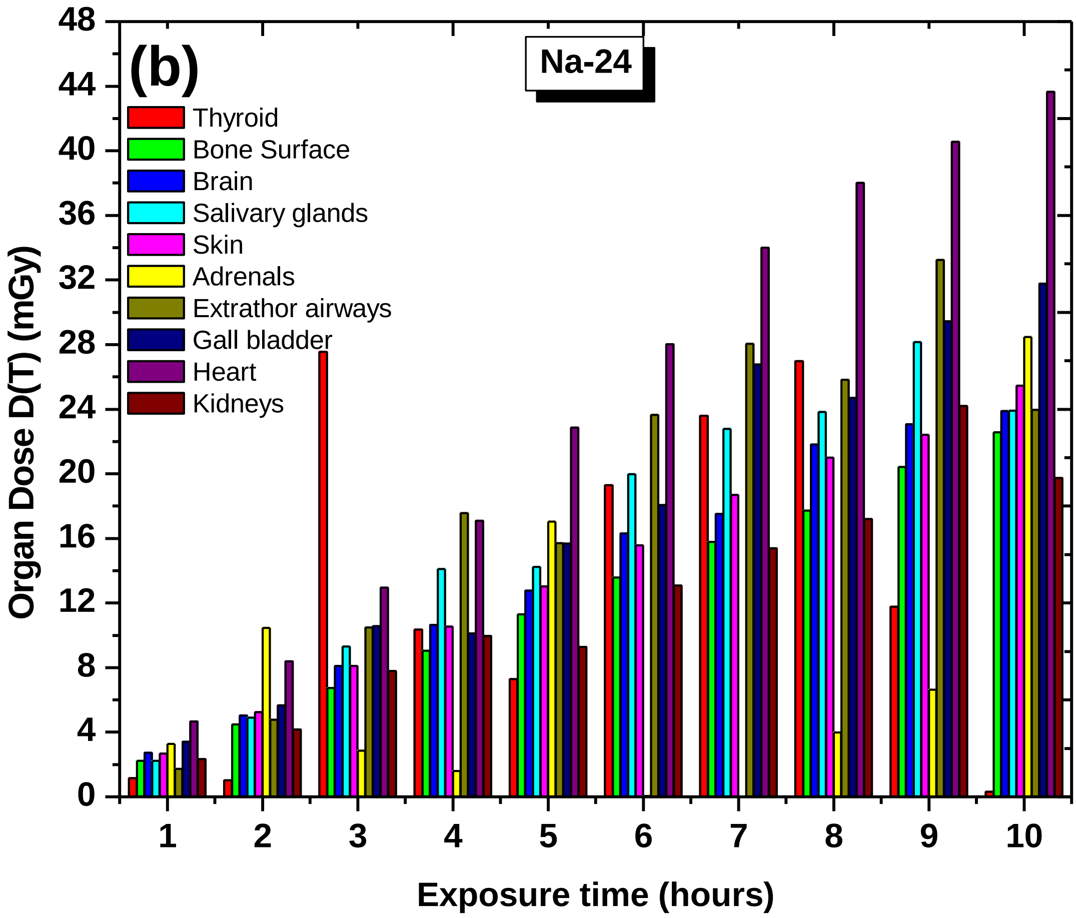


Figure 4. Organ dose for Co-60


(a)
Na-24
Bone Marrow
Colon
Lung
Stomach
Breast
Remainder
Gonads
Bladder
Oesophagus
Liver
Organ Dose D(T) (mGy)
0
4
8
12
16
20
24
28
32
36
40
1
2
3
4
5
6
7
8
9
10
Exposure time (hours)


(b)
Na-24
Thyroid
Bone Surface
Brain
Salivary glands
Skin
Adrenals
Extrathor airways
Gall bladder
Heart
Kidneys
Organ Dose D(T) (mGy)
0
4
8
12
16
20
24
28
32
36
40
44
48
1
2
3
4
5
6
7
8
9
10
Exposure time (hours)

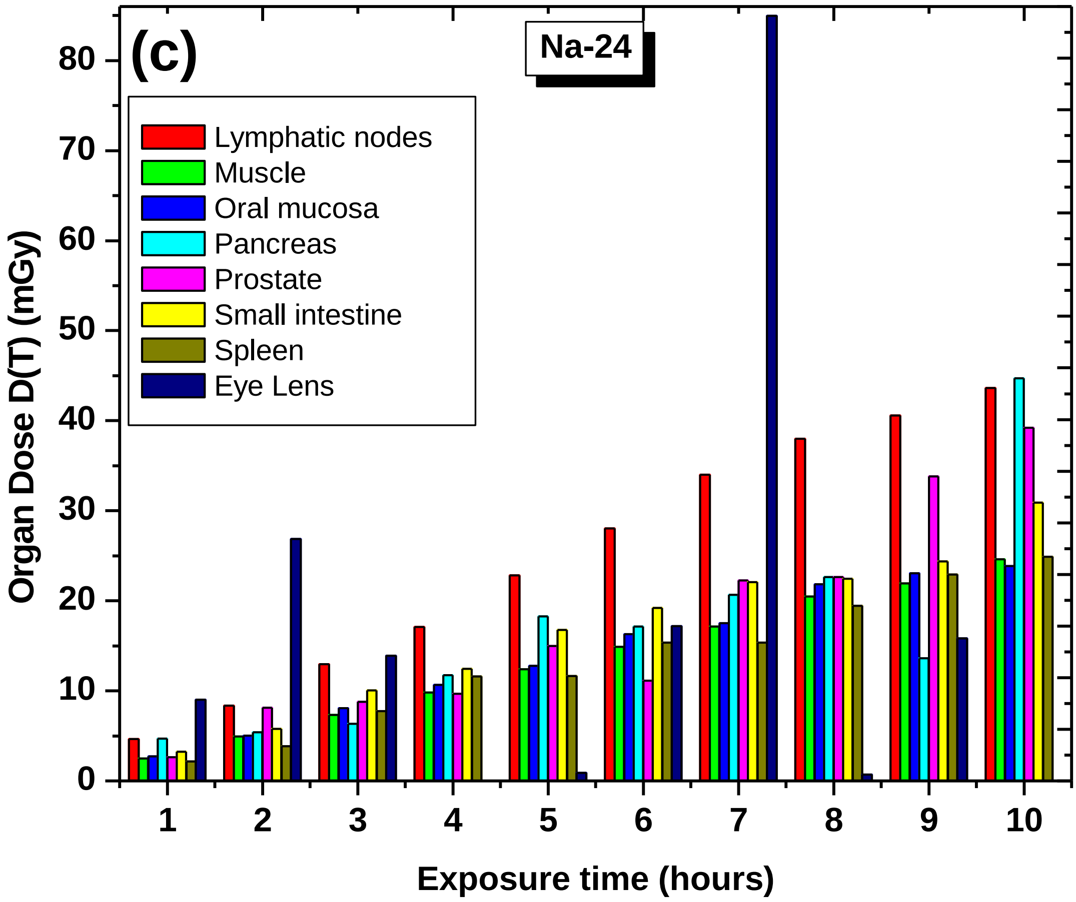


Figure 5. Organ dose for Na-24

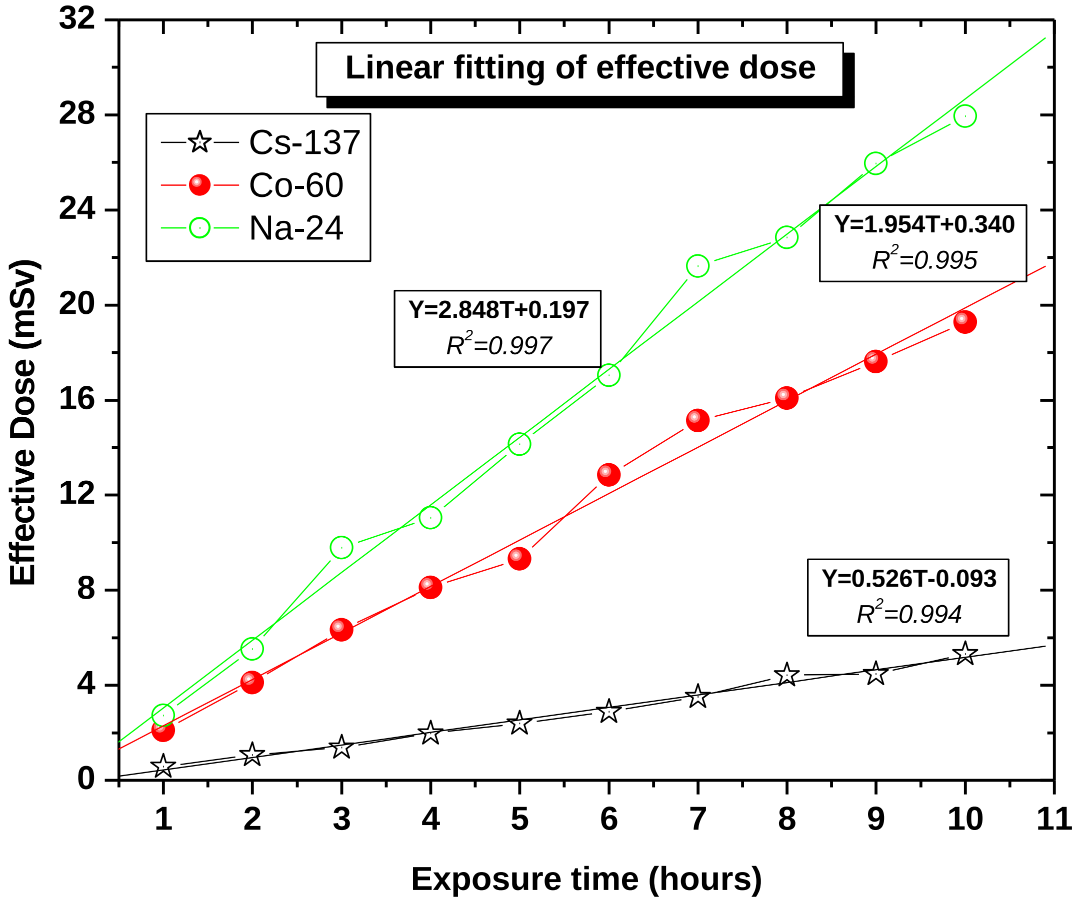


Figure 6. Linearfitting of effectivedoseexposure time

Table 1.Elemental compostions of human body organs

Elemental Concentration (%)	Bone d=1.85 g/cm^3	Brain d=1.039 g/cm^3	Eye Lens d=1.1 g/cm^3	Lung d=1.05 g/cm^3	Muscle d=1.04 g/cm^3	Skin d=1.1 g/cm^3	Tissue d=1.00 g/cm^3
H	0.06398	0.11066	0.09926	0.10127	0.10063	0.10058	0.10447
C	0.278	0.12542	0.19371	0.10231	0.10783	0.22825	0.23219
N	0.027	0.01328	0.05327	0.02865	0.02768	0.04642	0.02488
O	0.41001	0.73772	0.65375	0.75707	0.75477	0.619	0.63023
Nn	-	0.00184	-	0.00184	0.00075	0.00007	0.00113
Mg	0.002	0.00015	-	0.00073	0.00019	0.00006	0.00013
Si	-	-	-	-	-	-	-
P	0.07	0.00354	-	0.0008	0.0018	0.00033	0.00133
S	0.002	0.00177	-	0.00225	0.00241	0.00159	0.00199
Cl	-	0.00236	-	0.00266	-	0.00267	0.00134
K	-	0.0031	-	0.00194	-	0.00085	0.00199
Ca	0.147	0.00009	-	0.00009	-	0.00015	0.00023
Fe	-	0.00005	-	0.00037	-	0.00001	0.00005
Zn	-	0.00001	-	0.00001	-	0.00001	0.00003

Table 2.Tissue weighting factor (ICRP-103)

Tissue	Tissue weighting factor wT	ΣwT
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues(adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
	Total	1.00

Table 3.The measured effective dose and exposure time (Cs-137, Co-60 and Na-24)

Exposure time (hours)	Effectivedose (mSv)	Exposure time (hours)	Effectivedose (mSv)
	Cs-137	Co-60	Na-24
1	0.58	2.10	2.73
2	1.07	4.11	5.52
3	1.38	6.32	9.78
4	1.98	8.11	11.05
5	2.39	9.31	14.13
6	2.88	12.85	17.04
7	3.52	15.14	21.64
8	4.43	16.07	22.84
9	4.48	17.61	25.95
10	5.32	19.28	27.95

4. Conclusions

In the present investigation, individual organ dose and effective dose to human body were estimatedusing Monte Carlo simulation using Cs-137, Co-60and Na-24 radioactive sources for arbitrary activity.It was observed that the organ dose varies withsource strength and time of exposure whereas theeffective dose to human body is linearly dependentupon the exposure time. Overall, having moreexposure time from radioactive sources increasedthe organ dose. In our calculations, thyroid showedhigher amount of organ dose. It can be concludedthat to use the radiation protection materials forthyroid is quite important. On the other hand, Itcan be also concluded that Monte Carlo is aneffective tool for organ dose investigations whereexperimental studies are quite difficult or notpossible In this study, the data from VMC MonteCarlo Simulation for absorbed dose in organs as thetime photon energy was presented. This workproved that Monte Carlo method is a convenientand effective technique for the estimation ofabsorbed doses in different energy fields and maybe useful for future works. It can be also concludedthat estimated absorbed organ dose properties ofdifferent organs can be useful as a standard outputfor estimation of absorbed dose values in nuclearmedicine and medical, industrial, environment radiation studies.

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