



# Derived CDG for bioassay – a tool for screening people in a radiological emergency

Reis A. A.

*Instituto de Radioproteção e Dosimetria, CEP 22783-127, Rio de Janeiro, Brasil.*

*arlene@ird.gov.br*

---

## ABSTRACT

The decision on initiating clinical treatment for a person who has been internally contaminated by radionuclides is not trivial. NCRP Publication 161 presented an operational quantity named Clinical Decision Guide - CDG to help in this decision. The bases for establishing the CDG values are dose values related to the risks of stochastic and deterministic effects to body tissues. This work shows a computational system - Derived CDG - which calculates CDG and derived CDG applied to in vivo and in vitro radiobioassay for several age groups and for several times after intake by inhalation and ingestion. It is a tool to be used to screen people with internal contamination who need medical follow-up. The system enables the users to change parameters used in calculation for different simulated scenarios.

*Keywords: Radiological emergency, internal contamination, medical follow-up.*

---



## 1. INTRODUCTION

Internal contamination of people may occur in a radiological emergency. In such situation, internally contaminated people receive a committed effective dose which is directly related to the time that incorporated radioactive material remains in the body. One possibility is to reduce the committed effective dose by carrying out decorporation therapies whose objective is to accelerate the excretion of incorporated radioactive material. Another possibility is the medical follow-up of the person who has been contaminated in order to observe the appearance of an effect so that the treatment can start immediately.

An issue that has been discussed for a long time is regarding dose threshold or intake level to start a clinical follow-up. The question is about the criteria to make a decision on clinical follow-up of internally contaminated people.

The National Council on Radiation Protection and Measurements (NCRP) presented recommendations on clinical follow-up of internally contaminated people [1, 2]. The International Atomic Energy Agency (IAEA) presented recommendations on the intake threshold for treatment on internally contaminated people [3].

The NCRP 161 [1] presented a new operational quantity called Clinical Decision Guide (CDG) that represents the activity incorporated (intake) by an adult individual that corresponds to threshold dose to which a clinical follow-up is recommended. It was also highlighted that the threshold dose could be modified according to the emergency conditions as number of people affected, treatment capability, etc.

Decorporation therapies enhance the excretion of radioactive material deposited into the body and can be recommended for people with a certain level of internal contamination. Thus, according to NCRP [1], decorporation therapies are recommended for incorporations of 1 to 2 CDGs; certainly carried out for incorporations greater than 2 CDGs; and, unusual for incorporations of  $\sim 0.2$  CDGs [1].

The decorporation efficacy is greatest if treatment is immediately initiated after intake. So, tools for making decisions on decorporation therapies to be used in emergency situations should be developed in the response preparation phases [4].

Also, to be operational, the CDG calculated could be derived for different bioanalysis techniques applied for monitoring internally contaminated people, which is useful in emergency situations. The derived CDG is the activity concentration in excrete or organs of the body that corresponds to the dose threshold adopted to initiate clinical follow-up.

The objective of this work was to develop a computational application to calculate CDG and derived CDG for bioanalysis for individuals in different age groups: adults, 15 years of age, 10 years of age, 5 years of age, 1 year of age and 3 months of age.

This application allows the user to change parameters used in the calculation to simulate different scenarios.

## 2. MATERIALS AND METHODS

The theoretical base used in this work is the publication NCRP 161[1] which presented the operational quantity CDG – Clinical Decision Guide – to assist in the decision on clinical treatment of a person who has incorporated radioactive material.

CDG is the amount of incorporated activity (intake) by an individual who receives a dose in the defined level for which clinical follow-up is recommended. CDG considers the effective dose and absorbed dose weighted by relative biological effectiveness (RBE) in the lungs and red marrow. For computing the CDG intake values for different radionuclides, excluding isotopes of iodine, in adults, the following values of dose are considered:

- 0.25 Sv is the value of effective dose in 50 years for consideration of stochastic effects;
- 0.25 Gy-Eq is the value of RBE-weighted absorbed dose in 30 days for consideration of deterministic effects in bone marrow; and
- 1.0 Gy-Eq is the value of RBE-weighted absorbed dose in 30 days for consideration of deterministic effects in the lungs.

According to Equation 1, the CDG for adults is the minimum intake satisfying these dose constraints for both stochastic and deterministic effects,

$$CDG (Bq) = MIN \left[ \frac{0.25 Sv}{e (Sv Bq^{-1})}, \frac{0.25 Gy-Eq}{d_{Red Marrow} (Gy-Eq Bq^{-1})}, \frac{1.0 Gy-Eq}{d_{Lung} (Gy-Eq Bq^{-1})} \right] \quad (1)$$

where:

$e$ : effective dose coefficient for the radionuclide

$d_{Red\ Marrow}$ : RBE weighted absorbed dose coefficient for red marrow

$d_{Lung}$ : RBE weighted absorbed dose coefficient for lungs

$MIN$ : minimum value of the three arguments

The NCRP 161 [1] recommends that for other age groups, as well as, for pregnant women, one fifth of the CDG for adults should be used. However, the adoption of this fraction (1/5) has been discussed in other studies and the authors made suggestions for improvements in the calculation of CDG for children and pregnant women [5, 6].

A study to evaluate radionuclide concentration in excrete corresponding to CDG pointed out that the adoption of one fifth of adult value for other age groups, rises the dose values up to 3.5 for children in relation to the value defined for adults, mainly if ingestion is the incorporation pathway. Therefore, it was suggested that CDG can be calculated for each age group specifically [5].

The adoption of one fifth of the adult CDG value for other age groups was also discussed in a study in which the objective was to calculate the concentration of activities in excreta for different possible scenarios involving radiological emergencies. As it was also verified that the dose for children would be much higher than for adults, the authors did not adopt for children one fifth of the CDG value of adults. However, they considered as reference the one fifth of the adult dose as a limit for calculating the CDG for other age groups [6].

According to the studies cited before, the system presented here considered for no adult individuals, the values of dose to calculate CDG as follows:

- 0.05 Sv is the value of effective dose in 50 years for consideration of stochastic effects;
- 0.05 Gy-Eq is the value of RBE weighted absorbed dose in 30 days for consideration of deterministic effects in bone marrow; and
- 0.2 Gy-Eq is the value of RBE weighted absorbed dose in 30 days for consideration of deterministic effects in the lungs.

Thus, the Equation 2 was used in this work to calculate CDG for other age groups than adults.

$$CDG (Bq) = MIN \left[ \frac{0.05 Sv}{e (Sv Bq^{-1})}, \frac{0.05 Gy-Eq}{d_{Red\ Marrow} (Gy-Eq Bq^{-1})}, \frac{0.20 Gy-Eq}{d_{Lung} (Gy-Eq Bq^{-1})} \right] \quad (2)$$

## 2.1 Application development

For each radionuclide of interest, the CDG value was calculated for age groups defined by ICRP Publication 72 [7]. The dose coefficients used to calculate the CDGs are those presented by the ICRP CD-1 [8]. The RBE values for alpha, beta and gamma emitting radionuclides are shown in GSR Part 7 [9]. The system solves Equations 1 and 2, selects the lowest value among the three arguments and adopts it as CDG.

Then, the system calculates the derived CDG for the different monitoring bioanalysis techniques according to the biokinetic model. For this, it was necessary to obtain the fraction of excretion and retention of activity in excreta and organs as a function of time after incorporation. These fractions were calculated using DCAL software [10].

A file is generated with the worksheets: Report, 15 years, 10 years, 5 years, 1 year, 3 months and Adults. In the Report worksheet, the parameters used in the calculations are presented, as well as, the CDG values calculated for each age group. The worksheets of the age groups show the concentration of activity in the excreta and in the organs that correspond to 1 CDG. The concentrations of activity in the organs and excreta are presented in units of Bq; the concentration of activity in urinary excretion can be presented in units of Bq/L, according to the user's choice. The daily urinary excretion volumes for age groups used in the calculation are those presented by ICRP publication 89 [11].

In some situations, to change the value of the parameters used in the calculation of the CDG could be necessary. A specific form for changing parameter values allows the user to simulate different scenarios.

## 2.2 Results verification

To verify the results generated by this system, the CDG values presented in other publications [1, 5] was calculated using the same parameters for each simulated scenario described.

The NCRP 161 presented CDG values for adult individuals for certain radionuclides, considering AMAD of 5  $\mu\text{m}$ . Dose coefficients different from those recommended by the ICRP for Cs-137 were used; the same values were used to reproduce the calculations according to the table 11.1 of NCRP 161 [1].

One study showed CDG values for the age groups considering AMAD of 5  $\mu\text{m}$  for radionuclides of interest [5]. Dose coefficients from the ICRP were used for public individuals in different age groups: 3 months of age, 1 year of age, 5 years of age, 10 years of age and 15 years of age.

## 3. RESULTS AND DISCUSSION

Figure 1 presents the initial screen of the application, which contains four tables with sets of parameters necessary for calculating the CDG and derived CDGs for bioanalysis. Tables with values of Derived CDGs for bioanalysis were calculated and can be accessed by clicking the **Derived CDG for Bioanalysis** button.

A dialog box will be displayed for choosing the spreadsheet of the radionuclide of interest: Ag-110m, Am-241, Am-243, Ba-140, Ce-141, Ce-144, Cf-252, Cm-242, Cm-244, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Fe-59, Ga-67, Ir-192, Lu-177, Mn-54, Np-237, P-32, Pa-231, Pb-210, Po-210, Pu-238, Pu-239, Pu-240, Pu-241, Ra-226, Ra-228, Rb-86, Ru-103, Ru-106, Sb-124, Sm-153, Sr-85, Sr-89, Sr-90, Tc-99m, Th-228, Th-229, Th-230, Th-232, Tl-201, U-224, U-235, U-238, Y-90, Zn-65 ou Zr-95. It is possible to insert other radionuclides into the system.

**Figure 1:** The first screen of the Derived CDG for Bioassay.

The spreadsheets were generated according to the scenario defined in the initial screen: Radionuclide, Incorporation: inhalation or ingestion, Solubility: F (fast), M (moderate) or S (slow) and AMAD = 1  $\mu\text{m}$ . The initial screen also shows the parameter values for CDG calculation presented in the following tables: RBE, dose level for CDG and daily urinary excretion (mL). The values shown in these tables can be changed by clicking the **Change parameter values** button, and a specific screen will be displayed for the user to make the desired changes and save them by clicking the **Save Data** button.

After this step, click the **Calculate CDG** button to perform calculations. If the user has changed the value of the parameters, the system will require a name to save a file with the results.

To view the results, click the **Result** button and a screen with the results will be displayed, as shown in Figure 2. The CDG values are presented by age groups with the limiter, which is the smallest argument in the Equation 1 and 2.

Figure 2 illustrates the calculation of CDG for an incorporation of Y-90 by inhalation, type M and AMAD of 1  $\mu\text{m}$ , which is the scenario: Y-90 / Inhalation / Type M / AMAD 1  $\mu\text{m}$ . It can be

seen that the limiting factor for adults, 15 years of age and 10 years of age, is the RBE weighted absorbed dose in the lung; for other age groups, the committed effective dose is the limiting factor.

Age group	Limitier	CDG (Bq)
Adult	ADlung	1.28E+08
3 months	Effective Dose	3.85E+06
1 year	Effective Dose	5.68E+06
5 years	Effective Dose	1.19E+07
10 years	ADlung	1.82E+07
15 years	ADlung	2.17E+07

Derived CDG for Bioassay

**Figure 2:** CDG calculated for age groups and the corresponding limiter.

By clicking the **Derived CDG for bioassay** button, it is possible to access the file with the calculations performed by the system.

Age	Limitier	CDG (Bq)	Urine (L/d)	CDG effective	CDG red marrow	CDG lung
Adult	ADlung	1.28E+08	1.6	1.67E+08	2.08E+11	1.28E+08
3 months	Effective Dose	3.85E+06	0.3	3.85E+06	1.32E+09	6.06E+06
1 year	Effective Dose	5.68E+06	0.4	5.68E+06	3.85E+09	7.69E+06
5 years	Effective Dose	1.19E+07	0.5	1.19E+07	9.09E+09	1.33E+07
10 years	ADlung	1.82E+07	0.7	1.85E+07	1.72E+10	1.82E+07
15 years	ADlung	2.17E+07	1.2	2.78E+07	2.94E+10	2.17E+07

Report / 15 years / 10 years / 5 years / 1 year / 3 months / Adult

**Figure 3:** Report created by the system with parameters used in the CDG calculation.

The Report presented in Figure 3 contains information on the parameters used by the system in the calculation of CDG and derived CDGs for bioanalysis.

In the age groups tables, the values of derived CDGs for bioanalysis are presented as a function of the time elapsed after the incorporation until 70 years of age. Figure 4 shows the Adult table, in



which the activity concentration values are presented in excreta, whole body, liver, skeleton, lungs and extrathoracic region. To view the derived CDG values for the other age groups, click on the table of interest.

Time	Faeces (Bq)	Urine (Bq/L)	Whole Body (Bq)	Liver (Bq)	Skeleton (Bq)	Lung (Bq)	Extrathoracic (Bq)
1 d	5.95E+06	2.23E+03	3.32E+07	3.74E+03	1.25E+04	1.30E+07	5.42E+06
2 d	7.09E+06	2.48E+02	1.68E+07	3.23E+03	1.08E+04	9.79E+06	1.54E+06
3 d	2.92E+06	7.62E+01	9.71E+06	2.62E+03	8.72E+03	7.47E+06	4.41E+05
4 d	9.84E+05	5.23E+01	6.43E+06	2.10E+03	7.01E+03	5.71E+06	1.28E+05
5 d	3.23E+05	3.97E+01	4.62E+06	1.69E+03	5.63E+03	4.36E+06	3.87E+04
6 d	1.17E+05	3.03E+01	3.45E+06	1.35E+03	4.51E+03	3.33E+06	1.28E+04
7 d	4.97E+04	2.31E+01	2.61E+06	1.08E+03	3.61E+03	2.55E+06	5.00E+03
8 d	2.65E+04	1.77E+01	1.99E+06	8.64E+02	2.88E+03	1.95E+06	2.48E+03
9 d	1.68E+04	1.35E+01	1.52E+06	6.89E+02	2.30E+03	1.49E+06	1.52E+03
10 d	1.18E+04	1.03E+01	1.16E+06	5.49E+02	1.83E+03	1.14E+06	1.06E+03
15 d	2.75E+03	2.71E+00	3.04E+05	1.73E+02	5.76E+02	2.98E+05	2.68E+02
20 d	6.69E+02	7.07E-01	7.97E+04	5.31E+01	1.77E+02	7.83E+04	7.24E+01
25 d	1.64E+02	1.87E-01	2.09E+04	1.60E+01	5.34E+01	2.05E+04	1.95E+01
30 d	3.99E+01	4.88E-02	5.53E+03	4.80E+00	1.60E+01	5.44E+03	5.30E+00
35 d	9.81E+00	1.29E-02	1.46E+03	1.42E+00	4.73E+00	1.44E+03	1.43E+00
40 d	2.41E+00	3.42E-03	3.88E+02	4.16E-01	1.39E+00	3.82E+02	3.89E-01
45 d	5.94E-01	9.09E-04	1.03E+02	1.21E-01	4.04E-01	1.01E+02	1.05E-01
50 d	1.43E-01	2.37E-04	2.74E+01	3.51E-02	1.17E-01	2.70E+01	2.86E-02

**Figure 4:** Derived CDGs for an adult in the excreta and organs related to time after intake.

The reliability of the calculations was assessed using the system presented here to reproduce CDG values found in other publications. Simulations were carried out to calculate the CDG values presented in two publications [1, 5]. The comparison between the values generated by the system and those presented by the publications did not show significant variation, as can be seen in annexes I and II of this article.

## CONCLUSION

The operational quantity CDG is an important contribution to the screening of people internally contaminated with radioactive material that need clinical monitoring. The dose levels established by NCRP 161 as a basis for calculating the CDG are the threshold from which the risk must be reduced

through clinical treatment. However, it was recognized that depending on the characteristics of the emergency, for example, the number of people involved, these dose values may change.

The system for calculating derived CDG for bioanalysis described in this article presents the concentration of activity in each compartment of the biokinetic model or in the excreta that can be monitored through bioassay. The activity concentrations are presented in electronic spreadsheets, by age group according to the time elapsed after the incorporation. The purpose of generating these worksheets is that they are simple to consult in an emergency situation, since the time interval before the start of treatment influences the effectiveness of decorporation therapies.

In this way, the application to derived CDG calculation is a tool to be used for screening internally contaminated people in situations of radiological emergency, which allows the user to change the values of the parameters to simulate scenarios of interest.

## ACKNOWLEDGMENT

The author is grateful to Dr. Luiz Bertelli for the discussions and suggestions that contributed for the development of the computational application presented in this article.

## REFERENCES

- [1] National Council on Radiation Protection and Measurements. **Management of persons contaminated with radionuclides: handbook**. Recommendations of the National Council on Radiation Protection and Measurements, NCRP 161 I, 2008.
- [2] National Council on Radiation Protection and Measurements. **Management of persons contaminated with radionuclides: scientific and technical bases**. Recommendations of the National Council on Radiation Protection and Measurements, NCRP 161 II, 2008.
- [3] IAEA- International Atomic Energy Agency. **Medical Management of Persons Internally Contaminated with Radionuclides in a Nuclear or Radiological Emergency**, EPR - Internal Contamination 2018, Viena, 2018.

- [4] IAEA- International Atomic Energy Agency. **Preparedness and Response for a Nuclear or Radiological Emergency**, IAEA Safety Standards Series No. GSR Part 7, International Atomic Energy Agency, Viena, 2015.
- [5] A. A. dos Reis, L. Bertelli, W. O. Sousa – Evaluation of reference urinary excretion concentration of selected radionuclides corresponding to clinical decision guides for application in radiological and in nuclear emergency. **Radiation Protection Dosimetry**, Vol. 175, No. 1, pp. 134–148, doi:10.1093/rpd/ncw279, 2017.
- [6] Monitoring and Dose Assessment for Children Following a Radiation Emergency – Part I: Reference Values for In Vitro Bioassay. **Health Physics**, Vol.112 (3), pp. 282-293, 2017.
- [7] ICRP. International Commission on Radiological Protection Publication 72: **Age-Dependent Doses to Members of the Public from Intake of Radionuclides (Part 5)**. Compilation of Ingestion and Inhalation Coefficients, in *Annals of the ICRP* 26(1), 1996.
- [8] ICRP. International Commission on Radiological Protection, **ICRP-CD1: Database of Dose Coefficients: Workers and Members of the Public**, Version 3.0, in *Annals of the ICRP* 26(1), 1996.
- [9] IAEA- International Atomic Energy Agency. **Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards Generic Safety**, GSR Part 3, AEA, 2015.
- [10] Eckerman KF, Leggett RW, Cristy M, Nelson CB, Ryman JC, Sjoreen AL, Ward RC. DCAL system dose and risk calculation system, version 8.4. Oak Ridge, TN: Oak Ridge National Laboratory; **ORNL/TM2001/190**; 2006.
- [11] ICRP. International Commission on Radiological Protection Publication 89: **Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values**, in *Annals of the ICRP* 32(3–4), 2002.

## ANNEX I

**Table 1:** CDG (Bq) values published by NCRP [1] and CDG values calculated by the system presented in this paper for an adult worker.

Radionuclide	Intake pathway	Solubility	CDG (Bq)	
			NCRP [1]	calculated
Co-60	Inhalation	Type M	$3,5 \times 10^7$	$3,5 \times 10^7$
Co-60	Inhalation	Type S	$1,5 \times 10^7$	$1,5 \times 10^7$
Sr-90	Inhalation	Type F	$8,3 \times 10^6$	$8,3 \times 10^6$
Sr-90	Ingestion	Soluble	$8,9 \times 10^6$	$8,9 \times 10^6$
Cs-137	Inhalation	Type F	$5,8 \times 10^7$	$5,8 \times 10^7$
Cs-137	Ingestion	Soluble	$2,8 \times 10^7$	$2,8 \times 10^7$
Ir-192	Inhalation	Type M	$5,9 \times 10^7$	$5,9 \times 10^7$
Ir-192	Inhalation	Type S	$5,0 \times 10^7$	$5,0 \times 10^7$
Pu-238	Inhalation	Type M	$8,1 \times 10^3$	$8,1 \times 10^3$
Pu-238	Inhalation	Type S	$2,3 \times 10^4$	$2,3 \times 10^4$
Pu-239	Inhalation	Type M	$7,6 \times 10^3$	$7,6 \times 10^3$
Pu-239	Inhalation	Type S	$3,0 \times 10^4$	$3,0 \times 10^4$
Am-241	Inhalation	Type M	$9,3 \times 10^3$	$9,3 \times 10^3$

## ANNEX II

**Table 2:** CDG (Bq) values for age groups published in a work [5] and CDG values calculated by the system presented in this paper.

Scenario	Reference	3 months	1 year	5 years	10 years	15 years
Am-241/Inhalation/M	[5]	$1,28 \times 10^3$	$1,35 \times 10^3$	$1,52 \times 10^3$	$1,85 \times 10^3$	$1,56 \times 10^3$
	System	$1,28 \times 10^3$	$1,35 \times 10^3$	$1,52 \times 10^3$	$1,85 \times 10^3$	$1,56 \times 10^3$
Am-241/Ingestion	[5]	$1,35 \times 10^4$	$1,35 \times 10^5$	$1,85 \times 10^5$	$2,27 \times 10^5$	$2,50 \times 10^5$
	System	$1,35 \times 10^4$	$1,35 \times 10^5$	$1,85 \times 10^5$	$2,27 \times 10^5$	$2,50 \times 10^5$
Cs-137/Inhalation/F	[5]	$4,55 \times 10^6$	$7,35 \times 10^6$	$9,80 \times 10^6$	$9,80 \times 10^6$	$7,35 \times 10^6$
	System	$4,55 \times 10^6$	$7,35 \times 10^6$	$9,80 \times 10^6$	$9,80 \times 10^6$	$7,35 \times 10^6$
Cs-137/Ingestion	[5]	$2,38 \times 10^6$	$4,17 \times 10^6$	$5,21 \times 10^6$	$5,00 \times 10^6$	$3,85 \times 10^6$
	System	$2,38 \times 10^6$	$4,17 \times 10^6$	$5,21 \times 10^6$	$5,00 \times 10^6$	$3,85 \times 10^6$
Co-60/Inalation/M	[5]	$1,67 \times 10^6$	$2,17 \times 10^6$	$2,94 \times 10^6$	$4,17 \times 10^6$	$5,00 \times 10^6$
	System	$1,67 \times 10^6$	$2,17 \times 10^6$	$2,94 \times 10^6$	$4,17 \times 10^6$	$5,00 \times 10^6$
Co-60/Inhalation/S	[5]	$1,09 \times 10^6$	$1,19 \times 10^6$	$1,39 \times 10^6$	$2,27 \times 10^6$	$2,17 \times 10^6$
	System	$1,09 \times 10^6$	$1,19 \times 10^6$	$1,39 \times 10^6$	$2,27 \times 10^6$	$2,17 \times 10^6$
Co-60/Ingestion	[5]	$9,26 \times 10^5$	$1,85 \times 10^6$	$2,94 \times 10^6$	$4,55 \times 10^6$	$6,33 \times 10^6$
	System	$9,26 \times 10^5$	$1,85 \times 10^6$	$2,94 \times 10^6$	$4,55 \times 10^6$	$6,33 \times 10^6$
Sr-90/Inhalation/F	[5]	$3,57 \times 10^5$	$8,62 \times 10^5$	$1,32 \times 10^6$	$9,80 \times 10^5$	$6,76 \times 10^5$
	System	$3,57 \times 10^5$	$8,62 \times 10^5$	$1,32 \times 10^6$	$9,80 \times 10^5$	$6,76 \times 10^5$
Sr-90/Inhalation/S	[5]	$3,13 \times 10^5$	$3,33 \times 10^5$	$3,85 \times 10^5$	$5,26 \times 10^5$	$5,00 \times 10^5$
	System	$3,13 \times 10^5$	$3,33 \times 10^5$	$3,85 \times 10^5$	$5,26 \times 10^5$	$5,00 \times 10^5$
Sr-90/Ingestion	[5]	$2,17 \times 10^5$	$6,85 \times 10^5$	$1,06 \times 10^6$	$8,33 \times 10^5$	$6,25 \times 10^5$
	System	$2,17 \times 10^5$	$6,85 \times 10^5$	$1,06 \times 10^6$	$8,33 \times 10^5$	$6,25 \times 10^5$
Ir-192/Inhalation/F	[5]	$2,94 \times 10^6$	$4,17 \times 10^6$	$7,25 \times 10^6$	$1,25 \times 10^7$	$1,79 \times 10^7$
	System	$2,94 \times 10^6$	$4,17 \times 10^6$	$7,25 \times 10^6$	$1,25 \times 10^7$	$1,79 \times 10^7$
Ir-192/Inhalation/M	[5]	$2,94 \times 10^6$	$3,85 \times 10^6$	$6,25 \times 10^6$	$8,48 \times 10^6$	$7,14 \times 10^6$
	System	$2,94 \times 10^6$	$3,85 \times 10^6$	$6,25 \times 10^6$	$8,48 \times 10^6$	$7,14 \times 10^6$
Ir-192/Inhalation/S	[5]	$2,78 \times 10^6$	$3,33 \times 10^6$	$5,32 \times 10^6$	$7,14 \times 10^6$	$6,06 \times 10^6$
	System	$2,78 \times 10^6$	$3,33 \times 10^6$	$5,32 \times 10^6$	$7,14 \times 10^6$	$6,06 \times 10^6$
Ir-192 /Ingestion	[5]	$3,85 \times 10^6$	$5,75 \times 10^6$	$1,09 \times 10^7$	$1,79 \times 10^7$	$2,94 \times 10^7$
	System	$3,85 \times 10^6$	$5,75 \times 10^6$	$1,09 \times 10^7$	$1,79 \times 10^7$	$2,94 \times 10^7$
Pu-238/Inhalation/M	[5]	$1,19 \times 10^3$	$1,25 \times 10^3$	$1,35 \times 10^3$	$1,67 \times 10^3$	$1,47 \times 10^3$
	System	$1,19 \times 10^3$	$1,25 \times 10^3$	$1,35 \times 10^3$	$1,67 \times 10^3$	$1,47 \times 10^3$
Pu-238/Inhalation/S	[5]	$2,00 \times 10^3$	$2,17 \times 10^3$	$2,78 \times 10^3$	$3,85 \times 10^3$	$4,17 \times 10^3$
	System	$2,00 \times 10^3$	$2,17 \times 10^3$	$2,78 \times 10^3$	$3,85 \times 10^3$	$4,17 \times 10^3$
Pu-238/Ingestion	[5]	$1,25 \times 10^4$	$1,25 \times 10^5$	$1,61 \times 10^5$	$2,08 \times 10^5$	$2,27 \times 10^5$
	System	$1,25 \times 10^4$	$1,25 \times 10^5$	$1,61 \times 10^5$	$2,08 \times 10^5$	$2,27 \times 10^5$