Critical Dose of Internal Organs Internal Exposure - 14332

G.Grigoryan*, N.Grigoryan, A.Amirjanyan*****
***** State Engineering University of Armenia
****** Yerevan State Medical University
******* Nuclear and Radiation Safety Centre

105 Teryan, 375010 Yerevan, Armenia
4Tigran Mets,375010 Yerevan, Armenia
Email:g.grigoryan@anra.am

ABSTRACT

The health threat posed by radionuclides has stimulated increased efforts to developed characterization on the biological behavior of radionuclides in humans in all ages. In an effort motivated largely by the Chernobyl nuclear accident, the International Commission on Radiological Protection (ICRP) is assembling a set of age specific biokinetic models for environmentally important radioelements. Radioactive substances in the air, mainly through the respiratory system and digestive tract, is inside the body. Radioactive substances are unevenly distributed in various organs and tissues. Therefore, the degree of damage will depend not only on the dose of radiation have but also on the critical organ, which is the most accumulation of radioactive substances, which leads to the defeat of the entire human body. The main objective of radiation protection, to avoid exceeding the maximum permissible doses of external and internal exposure of a person to prevent the physical and genetic damage people. The maximum tolerated dose (MTD) of radiation is called a dose of radiation a person in uniform getting her for 50 years does not cause changes in the health of the exposed individual and his progeny. The following classification of critical organs, depending on the category of exposure on their degree of sensitivity to radiation: First group: the whole body, gonads and red bone marrow; Second group: muscle, fat, liver, kidney, spleen, gastrointestinal tract, lungs and lens of the eye; The third group: bone, thyroid and skin; Fourth group: the hands, forearms, feet. MTD exposure whole body, gonads and bone marrow represent the maximum exposures (5 rem per year) experienced by people in their normal activities. The purpose of this article is intended dose received from various internal organs of the radionuclides that may enter the body by inhalation, and gastrointestinal tract. The biokinetic model describes the time dependent distribution and excretion of different radionuclides that have intake into the organism or absorbed into blood. Transport of different radionuclides between compartments is assumed to follow first order kinetics provided the concentration in red blood cells (RBCs) stays below a nonlinear threshold concentration. When the concentration in RBCs exceeds that threshold, the transfer rate from diffusible plasma to RBCs is assumed to decrease as the concentration in RBCs increases. For the calculations used capabilities AMBER by using the traces of radionuclides in the body. Model for the transfer of radionuclides in the body has been built on the basis of existing models at AMBER for lead.

INTRODUCTION

The biological effect of radioactive substances introduced into the body, is determined by the absorbed dose, which creates the radiation emitted by this radionuclide in the decay process during his stay in the body. Some radionuclides are extremely slow elimination from the body, so once in a given body, they will be subjected to continuous exposure for a long time.

We know that the role of various organs in the maintenance of normal functioning of the body is different. Therefore, when radioactive substances into the organism level of radiation damage will depend not only on the dose produced, but also on the organ in which mainly occurred radionuclide accumulation, i.e., what organ is critical. It should be noted that for the same radionuclide critical organs may be different depending on the solubility of the compound and the way it enters the body.

With internal radiation exposure is difficult to dose. Experimental methods for determining the dose does not exist and, in general, has to do the mathematical evaluation of the expected dose. Much more accurate results are obtained when calculating internal doses when applied certain computer code to calculate. This method of calculating the internal dose, allows to take into account the distribution of activity in the body, which changes over time, with the release of the active substances is taken into account by individual organs or enrich their due place in the physiological processes of the body. Information about them is very important for the entire problem of dosing.

Maximum allowable dose of radioactive isotopes is closely related to the maximum allowable concentration of these isotopes in the different organs.

The purpose of this paper are to use the conceptual model of the radionuclide transfer between compartment as developed for the ICRP and study their exposure on the different human organs.

Maximum Permissible Dose of Human Body

Ionizing radiation can cause physical and genetic damage in human exposure and its progeny. Somatic lesions may manifest as leukemia, cancer, reduced life expectancy, fertility.
The main objective of protection against ionizing radiation is not exceeded the maximum permissible doses of external and internal exposure of a person to prevent the somatic and genetic damage people.
Maximum Permissible Dose (MPD) of ionizing radiation is called a human dose, which is in uniform getting her for 50 years does not cause changes in the health status of the irradiated and his offspring / 1 /.

Internal radiation is the radiation exposure of radionuclides that lie inside the human body with water, food or inhaled or by violations of personal hygiene when working with sources of radiation (eg, smoking, eating with unwashed hands. Internal exposure is caused by α-, β-, and γ-radiation. Since radiation exposure occurs, with different quality factors, hereafter will focus on the dose equivalent, Sv, or dose, Sv/year. Neutrons transfer their energy to the biological tissue, not directly as a result of the formation of secondary radiation (mainly protons and γ-rays), so the power of the neutron dose can be calculated by considering all the reaction of secondary radiation on the elements that make up the biological tissue, to find the energy of secondary radiation and identify them created in the tissue dose. For this we need to take into account all the processes neutron interactions with carbon, hydrogen, oxygen and nitrogen, as well as the quality of the resulting secondary radiation. useful to remember that the flux of neutrons with energies greater than ~ 2 MeV, 25 neutrons / (cm^2 s), the dose rate is 0.01mkSv / s, respectively, at a density neutron flux is the same energy of 20 neutrons / (cm^2 s) dose of neutrons is 0.008mkSv / s.

Internal radiation is the radiation exposure of radionuclides that lie inside the body γcheloveka with water, food or inhaled or by violations of personal hygiene when working with sources of radiation (e.g., smoking, eating with unwashed hands. Internal exposure is caused by α-, β-, and γ-radiation. Since radiation exposure occurs, with different quality factors, hereafter will focus on the dose equivalent, Sv, or dose, Sv/s. Neutrons transfer their energy to the biological tissue, not directly as a result of the formation of secondary radiation (mainly protons and γ-rays), so the power of the neutron dose can be calculated by considering all the reaction of secondary radiation on the elements that make up the biological tissue, to find the energy of secondary radiation and identify them created in the tissue dose. For this we need to take into account all the processes neutron interactions with carbon, hydrogen, oxygen and nitrogen, as well as the quality of the resulting secondary radiation. useful to remember that the flux of neutrons with energies greater than ~ 2 MeV, 25 neutrons / (cm^2 s), the dose rate is 0.01mkSv / s, respectively, at a density neutron flux is the same energy of 20 neutrons / (cm^2 s) dose of neutrons is 0.008mkSv/s.

Radioactive substances are unevenly distributed in various organs and tissues. Therefore, the degree of damage will depend not only on the dose of radiation have but also on the critical organ, which is the largest accumulation of radioactive substances, which leads to the defeat of the entire body. In general, the following classification of critical organs in the degree of their sensitivity to radiation [1-3]:

1. First group: the whole body, gonads and red bone marrow;
2. Second group: muscle, fat, liver, kidney, spleen, gastrointestinal tract, lungs, eye lens;
3. The third group, bone, thyroid and skin;
4. The fourth group, hands, forearms, feet level.

MPD exposure whole body, gonads, or bone marrow represent the maximum exposures (3 mSv/year), which overthroweth therewith people in normal conditions during operation.
The total dose of irradiation of the whole organism, gonads or bone marrow should not exceed

$$D \leq 5(N - 18) \text{ Sv} \quad (1)$$

where N is the person's age in years, 18 years, a person's age to the beginning of occupational exposure.
total dose accumulated by the age of 30, in all cases, must not exceed 0.6 Sv.

For all organs or tissues (except for the whole body, gonads and bone marrow) MPD external and internal exposure should not exceed the values given in Table 1:

Table. 1.

Organ or tissue	MPD (for the quarter) Sv	MPD (for the year) Sv
The whole body, gonads, red bone marrow	0.05	0.05
Any individual (excluding the gonads, bone marrow, bone, thyroid, and skin)	0.08	0.15

Bone, thyroid gland, the skin of the body (except the skin of the hands, forearms feet)	0.15	0.3
Hands, forearms and feet	0.4	0.75

The content and delivery of radioactive substances in the human body must be limited so that the dose does not exceed the traffic shown in Table 1.

Under certain conditions, may be allowed a special irradiation dose (or intake of radioactive substances into the body) twice, and if absolutely necessary five times the annual MPD. This provided for a particular exposure is not permitted if the addition to the previously accumulated dose exceeds the value set by the formula (1).

For dose assessment are decisive information about the content of radioactive substances in the body, not the data on the concentrations in the environment. Increases in annual maximum concentration of radioactive substances in the air if they do not produce radiation doses in excess of the values given in Table 1 should not be observed as dangerous.

Amber Modeling

To determine the internal dose used the capabilities of AMBER. The proposed model describes the time dependent distribution and excretion of different radionuclides. This systemic model may be used in conjunction with any model describing the translocation of radionuclides from the respiratory or gastrointestinal tract into blood. The respiratory and gastrointestinal model used in the present paper to evaluate different human organs exposure data with observations of the fate of inhaled or ingested radionuclides.

The AMBER model of the compartments used in the systemic model and directions of movement of radionuclides among these compartments is given in Figure 1.

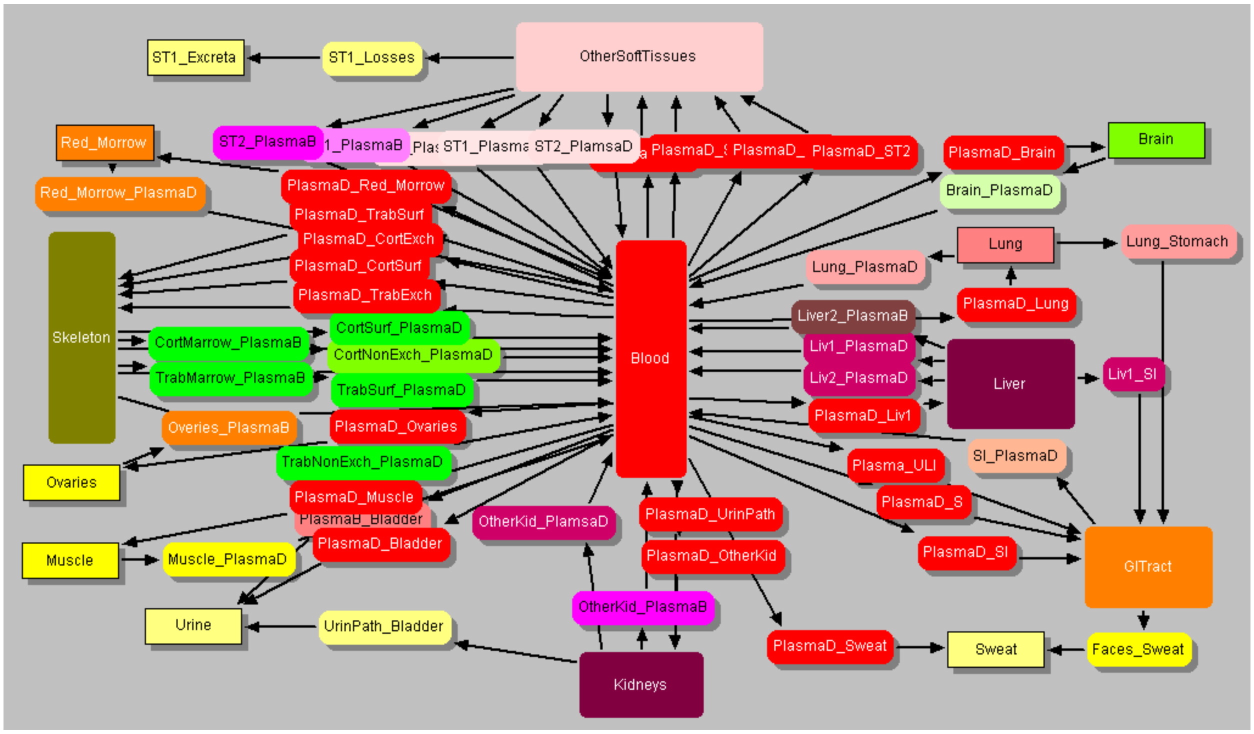


Fig. 1. Amber Model

All human body is mainly represented by the six submodels: 1. Blood 2. Kidney, 3. Liver, 5. Gastrointestinal tract, 5. Skeleton, 6. Soft tissue.

This model addresses six radionuclides of concern because of their availability, relatively high dose per unit intake and mobility in human body: Co-60, Sr-90, Cs-137, Ir-192, Pu-239, Am-241.

The data base necessary for calculations have been compiled using different ICRP and other publications [4-13].

Transfer coefficients between the compartments as dose conversion factors for radionuclides are constant numbers. All the data on the dose coefficient taken from [13] Table. 2.

Table. 2. Dose coefficients taken from [13].

	Dose Coefficient (Sv Bq^{-1})	
	Ingestion	Inhalation
Co-60	$3.4 \cdot 10^{-9}$	$1.0 \cdot 10^{-8}$
Cs-137	$1.3 \cdot 10^{-8}$	$4.6 \cdot 10^{-9}$
Pu-239	$2.5 \cdot 10^{-7}$	$5.0 \cdot 10^{-5}$
Am-241	$2.0 \cdot 10^{-7}$	$4.2 \cdot 10^{-5}$
Sr-90	$2.8 \cdot 10^{-8}$	$3.6 \cdot 10^{-8}$
Ir-192	$1.3 \cdot 10^{-8}$	$4.6 \cdot 10^{-9}$

Because of the lack of data on the dose coefficients for the Iridium data was taken as the cesium assuming that the energy spectra of the radiation of the atomic nuclei of these substances are close to each other   [15] (conservative approach).

The dose received by each body is directly proportional to the number of radionuclides that are contained in this body for a certain period of time:

$$Dose = DC \cdot Amount \quad (2)$$

where DC is the radionuclide dose coefficients in this body (Sv/Bq), and

$Amount$ is the amount of radionuclides in the same organ given in Becquerel.

For the calculations necessary to set the starting amount of radionuclides entering the body in a certain period of time. This initial value can be different for different possible ways of entry of radionuclides into the body, i.e. at ingestion and inhalation.

Starting value determined according to the expression :

$$C_f(t) I_f \, H_{ing} \quad (3)$$

where $C_f(t)$ is radionuclide concentration in the edible part of foodstuff f at time t, allowing for delay between production and consumption (Bq kg^{-1}),

I_f is ingestion rate of foodstuff f (kg y^{-1}),

H_{ing} is organ dose equivalent of effective dose per unit intake by ingestion (Sv Bq^{-1}).

The intake rates for inhalation and for water have been taken the following values $I_{inhalation}$= 8100 m^3 y^{-1}[10,11] and $I_{water\ ingestion}$= 0.6 m^3 y^{-1}[12]. Water ingestion value exclude intakes of water by food, including milk, by oxidation of food, by inhalation or by absorption through the skin.

For $C_f(t)$ have been taken the values recommended by International Codex (Codex 1989) [16]:

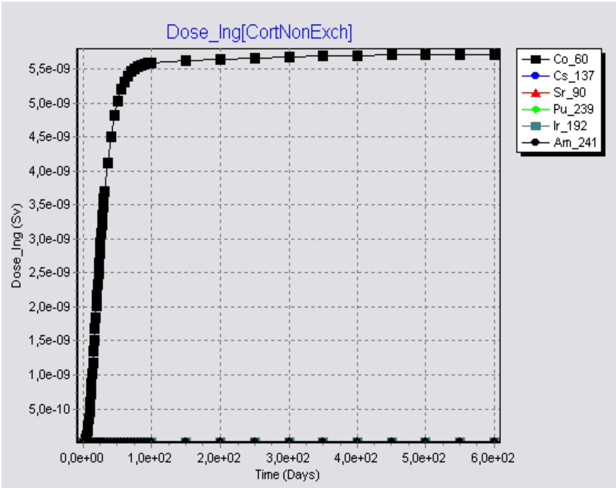
Table. 3. Derived Intervention Levels (DIL) Values Recommended by Codex(Codex 1989)

Representative Radionuclide	$C_f(t)$ (Bq kg^{-1}) (DIL)
Am-241, Pu-239	10
Sr-90, Co-60	100
Cs-137, Ir-192	1000

The daily intake values in grams per day provided in [17]. The total annual intakes are rounded to nearest 1 kg y^{-1}. ($I_f = 1 \text{ kg } y^{-1}$).

Calculations Results

In Figures 1-6 shows the dependence of the radiation dose of various radionuclides in certain organs at ingestion case.



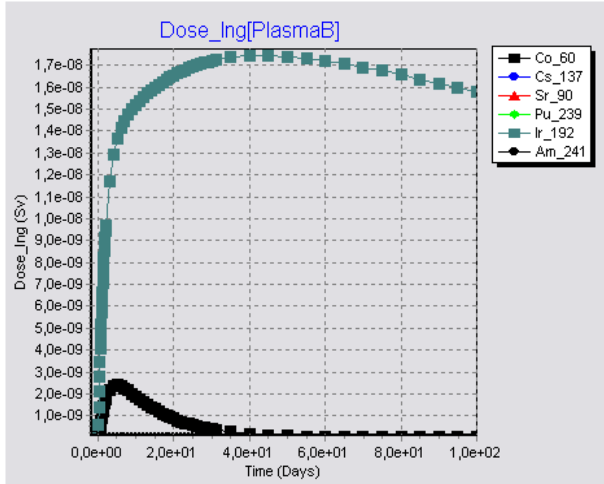
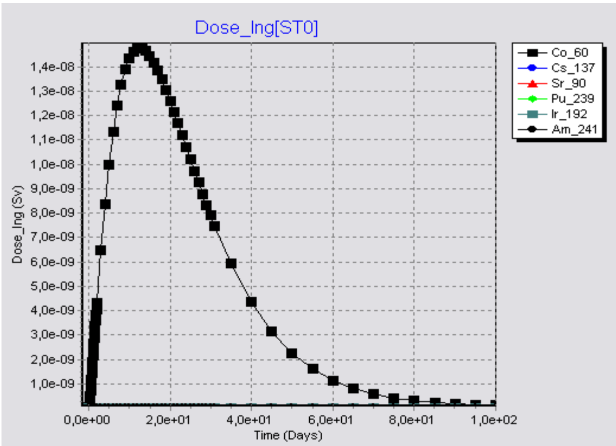


Fig.1. Dose effects on the Skeletal System by ingestion Fig.2. Dose effects on the Blood by ingestion



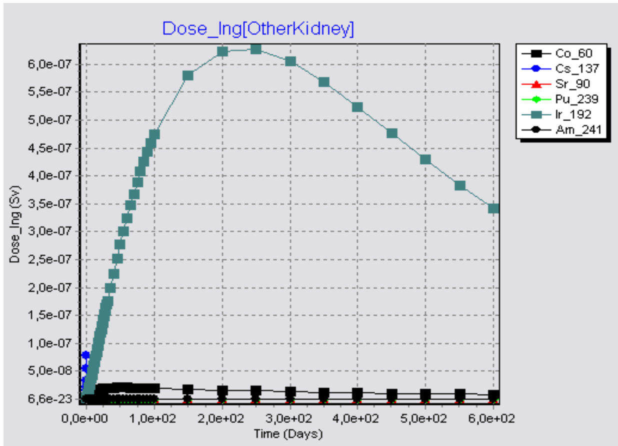


Fig.3.Dose effects on the Soft Tissue system by ingestion Fig.4. Dose effects on the Kidney by ingestion

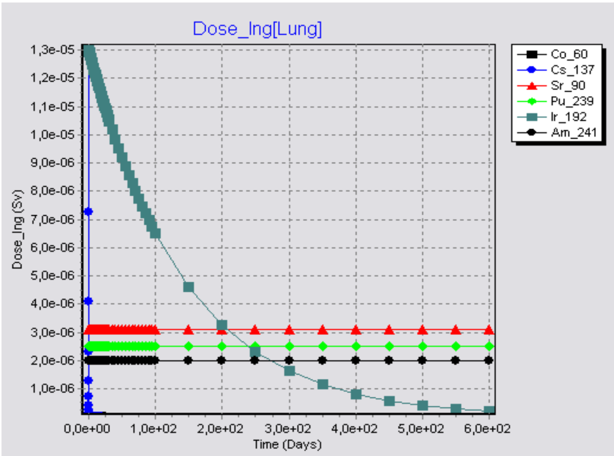


Fig.5. Dose effects on the Lung by ingestion

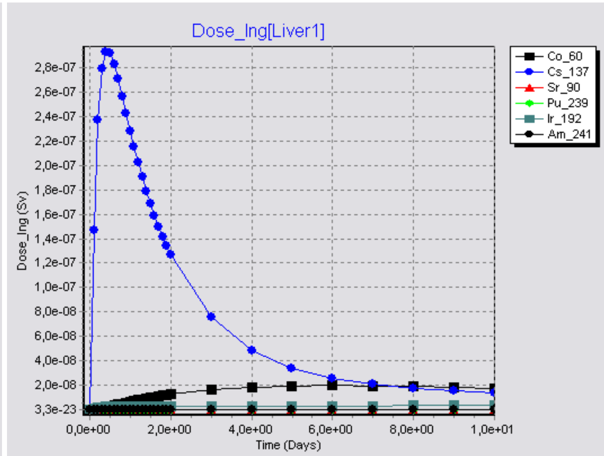


Fig.6. Dose effects on the Liver by ingestion

In Figures 7-12 shows the dependence of the radiation dose of various radionuclides in certain organs at inhalation case.

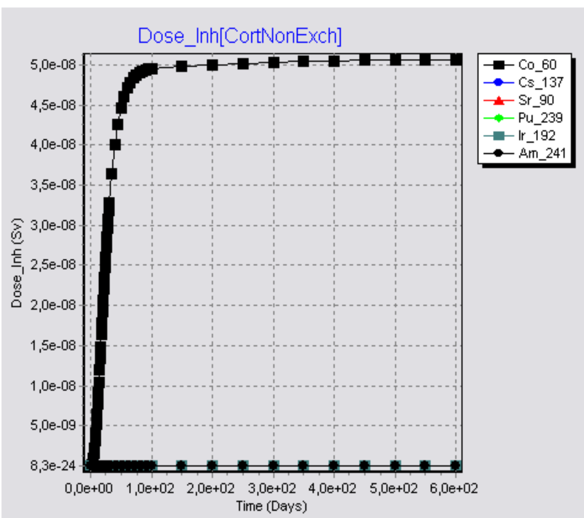


Fig.7. Dose effects on the Skeletal system by inhalation

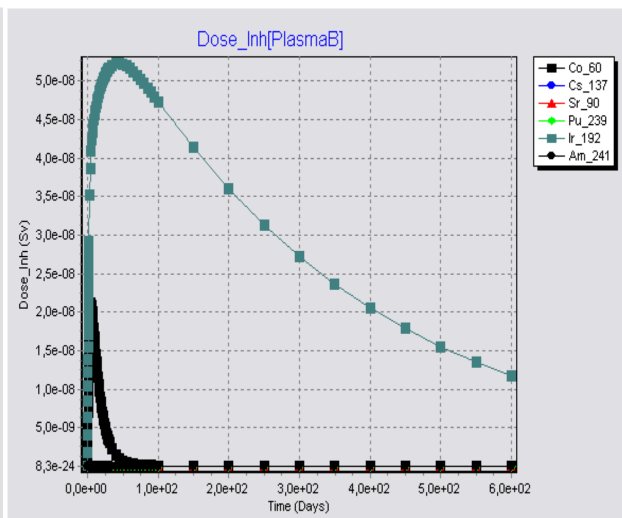
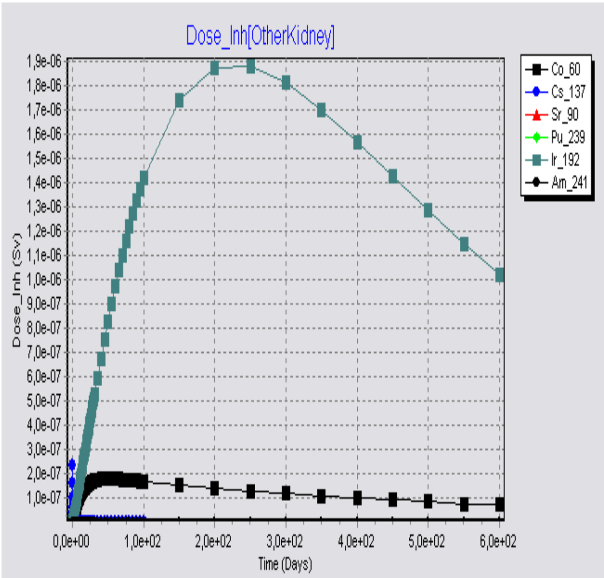


Fig.8. Dose effects on the Blood system by inhalation



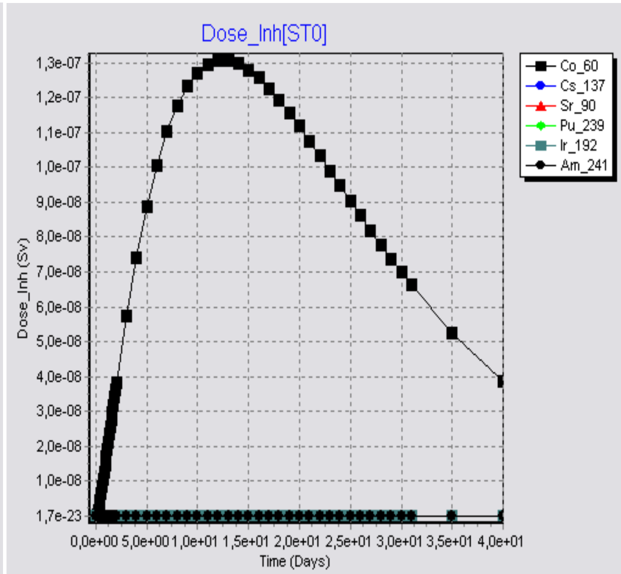
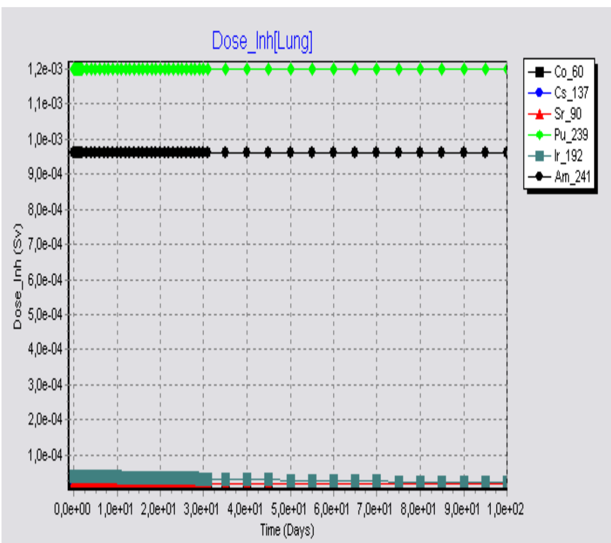


Fig.9. Dose effects on the Kidney system by inhalation.

Fig.10.Dose effects on the Soft Tissue system by inhalation.



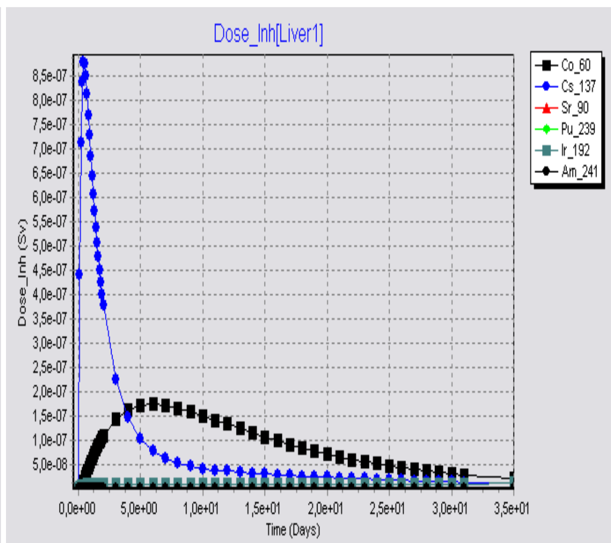
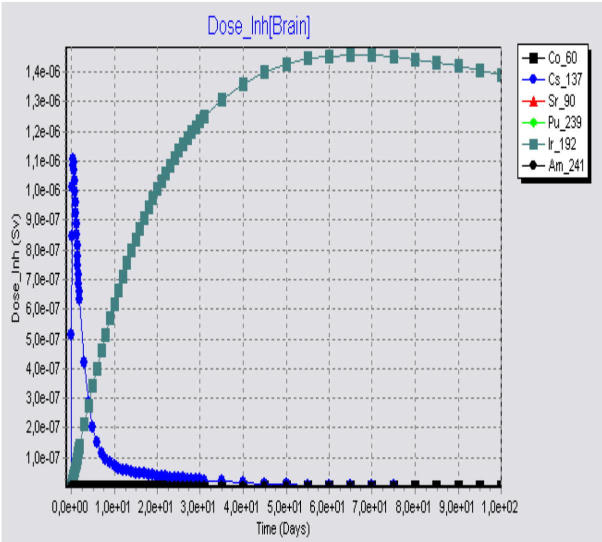


Fig.11. Dose effects on the Lung by inhalation

Fig.12. Dose effects on the Liver by inhalation



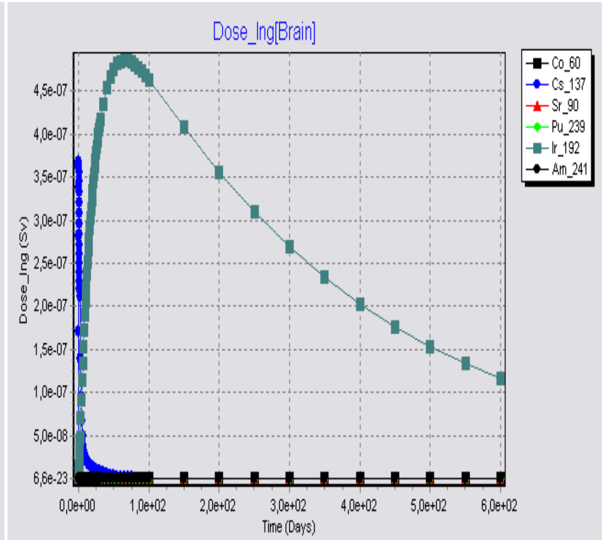


Fig.13. Dose effects on the Brain by inhalation

Fig.14. Dose effects on the Brain by ingestion

Table. 4. The most dangerous radionuclides and their peak dose to different organs

Organ	Hazardous Radionuclide	Peak Dose (Sv)	
		Ingestion	Inhalation
Skeleton	Co-60	$5.7 \cdot 10^{-9}$	$5.0 \cdot 10^{-8}$
Blood	Ir-192	$1.8 \cdot 10^{-8}$	$6.0 \cdot 10^{-8}$
Soft Tissue	Co-60	$1.5 \cdot 10^{-8}$	$1.3 \cdot 10^{-7}$
Kidney	Ir-192	$7.0 \cdot 10^{-7}$	$1.9 \cdot 10^{-6}$
Lung	Ir-192,Cs-137, Pu-239,Am-241	$1.3 \cdot 10^{-5}$	$1.2 \cdot 10^{-3}$, Pu-239 $1.0 \cdot 10^{-3}$, Am-241
Liver	Cs-137,Co-60	$1.3 \cdot 10^{-8}$	$8.5 \cdot 10^{-7}$
Brain	Ir-192,Cs-137	$1.5 \cdot 10^{-6}$	$5.0 \cdot 10^{-7}$

Conclusions

Radiological impact of radionuclides on the body depends on the activity of this isotope, as the biological processes in the body that affect the biological mobility of these isotopes because of the mobility they travel to different parts of the body.

For the skeleton of the most dangerous are the Co-60 as a radionuclide accumulates on bone parts of the body. For the Liver - Cs-137, Co-60; Lung - Ir-192,Cs-137, Pu-239,Am-241; Kidney - Ir-192; Soft Tissue - Ir-192 and Blood - Ir-192 are the most dangerous radionuclides. However, if the above starting values input of radionuclides by their effect on the various organs do not exceed the limit value i.e. the norm (1 mSv y^{-1}) then are not dangerous to human health.

ACKNOWLEDGEMENTS

Authors wish to acknowledge and thank the ANRA workers and YSMU lecturers management for its support in activities of work modeling and studying.

REFERENCES

1. About extremely permissible levels of ionizing radiation, Moscow, Medicine,1961.(in Russian).

2. Sanitary rules for dealing with radioactive substances and sources of ionizing radiation, Moscow, 1960. (in Russian).

3. Radiation safety standards, Atom Publishing, 1970. (in Russian).

4. ICRP Publication 103 and beyond (Internet).

5. ICRP publication 106, Radiation Dose to Patients from Radiopharmaceuticals, Addendum 3 to ICRP Publication 53, Approved by the Commission in October 2007.

6. A. Luciani, Plutonium Biokinetics in Human Body, Wissenschaftliche Berlicht FZKA 6748, October 2002.

7. R.W.Leggett, K.F.Eckerman, Dosimetric Significance of the ICRP's Updated Guidance and Models, 1989-2003, and Implications for U.S. Federal Guidance, Prepared by OAK RIDGE NATIONAL LABORATORY P.O. BOX 2008, August 2003.

8. R.W.Leggett, K.F.Eckerman, Assessment of Dose to the Nursing Infant from Radionulides in Breast Milk, OAK RIDGE NATIONAL LABORATORY Managed by UT-BATTELLE for the DEPARTMENT of ENERGY, OAK RIDGE, Tennessee 37831, ORNL/TM-2008/,August 2008.

9. Dose limits, Schedule 2 (Internet).

10 ICRP (1975). Report of the task group on reference man. ICRP Publication 23, Pergamon Press.

11 ICRP (1994). Human Respiratory Tract Model for Radiological protection, ICRP Publication 66. Ann. ICRP, 24(1-3).

12. Smith K.R. and Jones A.L. (2003). Generalized habit data for radiological assessments. Chilton, NRPBW41.

13. ICRP (1996). Age dependent doses to members of the public for intakes of radionuclides: Part 5 compilation of ingestion and inhalation dose coefficients. ICRP publication 72. Ann ICRP, 26(1).

14. ACCIDENTAL RADIOACTIVE CONTAMINATION OF HUMAN FOOD AND ANIMAL FEEDS: RECOMMENDATIONS FOR SATE AND LOCAL AGENCIES; Radiation Pergamon

Branch, Division of Mammography Quality and Radiation Programs Office of Health and Industry Programs. U.S. Department of Health and Human Services Food and Drug Administration Centre for Devices and Radiological Health Rockville, MD 20850, Document issued on: August 13. 1998.

15. Radiation protection, ICRP Publication 38, Radionuclide Transformations, Energy and Intensity of Emissions, Report of a Task Group of Committee 2 of the ICRP on data used in ICRP Publication 30; 1987 (in Russian).

16. (CODEX 1989) Codex Alimentarius Commission. Contaminants: Guideline Levels for Radionuclides in Food following Accidental Nuclear Contamination for Use in International Trade. Suppleiuentl to Codex Aliinentarius Volume XVII, 1st ed. Rome: Joint FAO/WHO Food Standards Programme; 1989.

17. (EPA 1984b) Environmental Protection Agency. An Estimation of the Daily Average Food Intake by Age and Sex for Use in Assessing the Radionuclide Intake of Individuals in the General Population. Office of Radiation Programs. Washington, D.C.:EPA 520/1-84-021; 1984.