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CALCULATION OF SPECIFIC ABSORBED FRACTIONS IN BODY USING MONTE-CARLO SIMULATIONS

INTRODUCTION

- Specific absorbed fraction (SAF) is a fraction of radiation R of energy $E_{R,i}$ emitted within the source region r_S that is absorbed per mass in the target region r_T.
- SAF are used to estimate doses from internal exposure caused by radionuclides distributed in human body.
- Monte-Carlo simulations are used for calculation of radiation doses in organs of human.

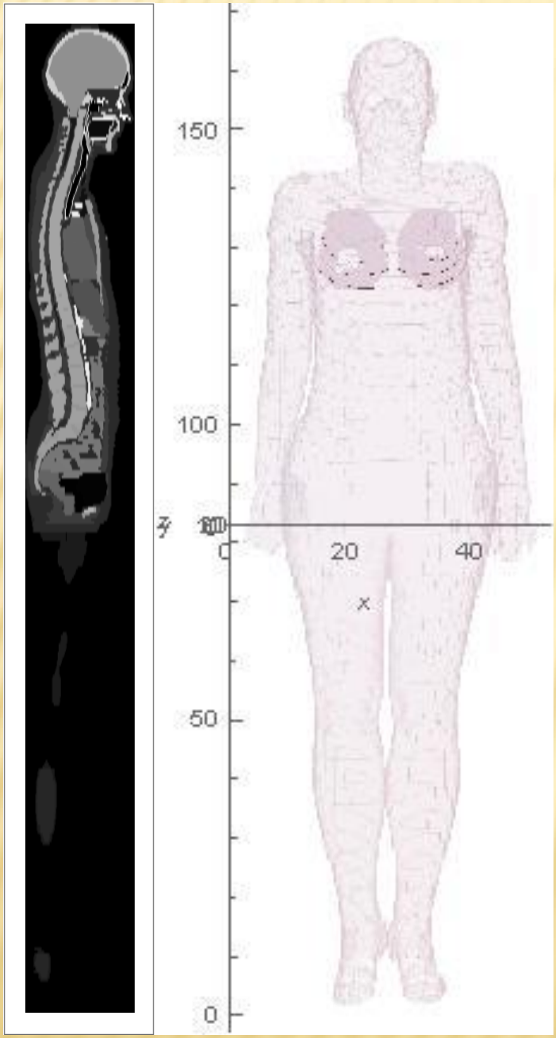
OBJECTIVE

- To calculate specific absorbed fractions in the breast tissue of adult female from ^{131}I distributed in breast and ^{137}Cs+^{137m}Ba, ^{134}Cs as whole body sources.

REFERENCE INDIVIDUAL

- Reference individual is an idealised human with characteristics defined by the International Commission on Radiological Protection (ICRP) for radiation protection purposes [IAEA safety glossary].
- Average height and weight, masses of organs and tissues, etc. of a reference Caucasian man are given in ICRP Publication 89 : Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values (2002).

REFERENCE ADULT FEMALE PHANTOM



- ICRP recommends using voxel phantoms of reference adult male and female described in ICRP Publication 110 (2007).
- Reference adult female phantom is a voxel phantom, which was created based on tomograms of a real person.
- Reference adult female phantom phantom consists of 3 886 020 voxels.
- Each parallelepiped has dimensions $1.775 \times 1.775 \times 4.84$ mm^3.
- Huge computational resources are required for radiation transport calculations.

DATA FROM ICRP PUBLICATION 110

1. Array of numbers that describe each point of the phantom
2. Table of 136 organ IDs, names, tissue numbers and densities
3. Table of elemental composition of 53 media
4. List of 53 media with blood ratio (contents of blood in each medium)

PROGRAM "FANTOM110"

A program "Fantom 110" was developed.

1. reading of the array of numbers, which describe the phantom;
2. reading of tables of organs and media;
3. plotting images of the phantom;
4. writing the Monte-Carlo input file.

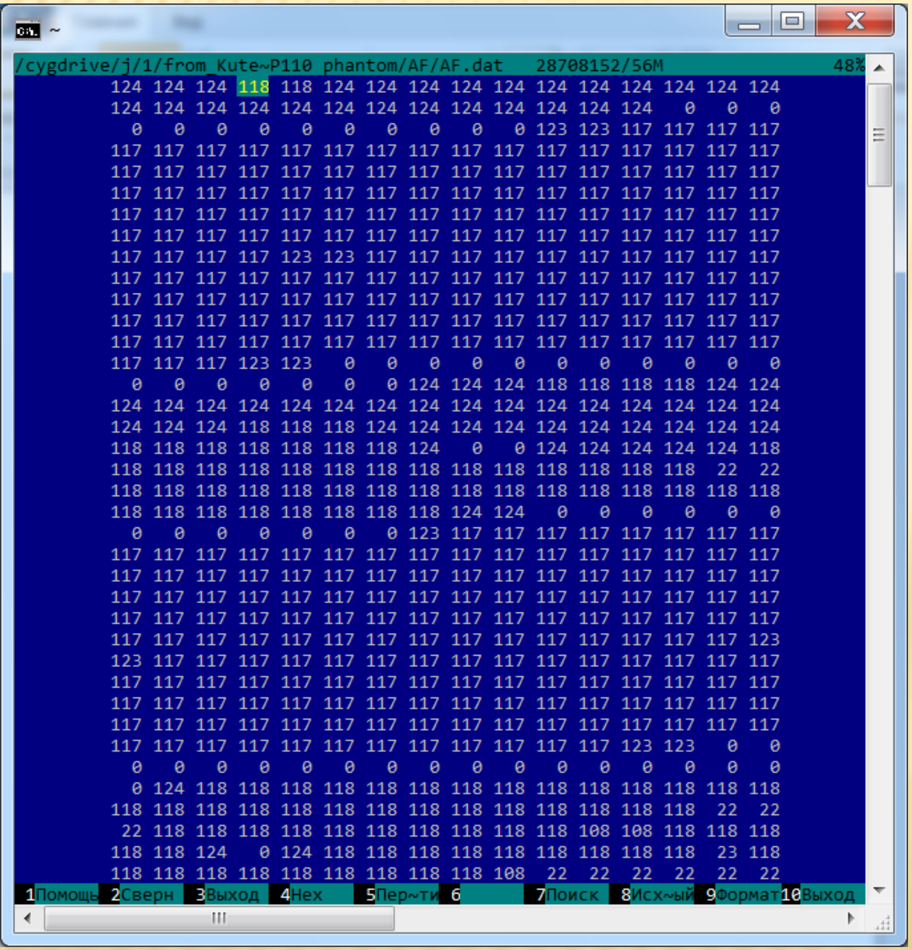
- Program "Fantom110" was written in Wolfram Mathematica 12.1 computer algebra system.
- The main array of numbers is read using ReadList function.

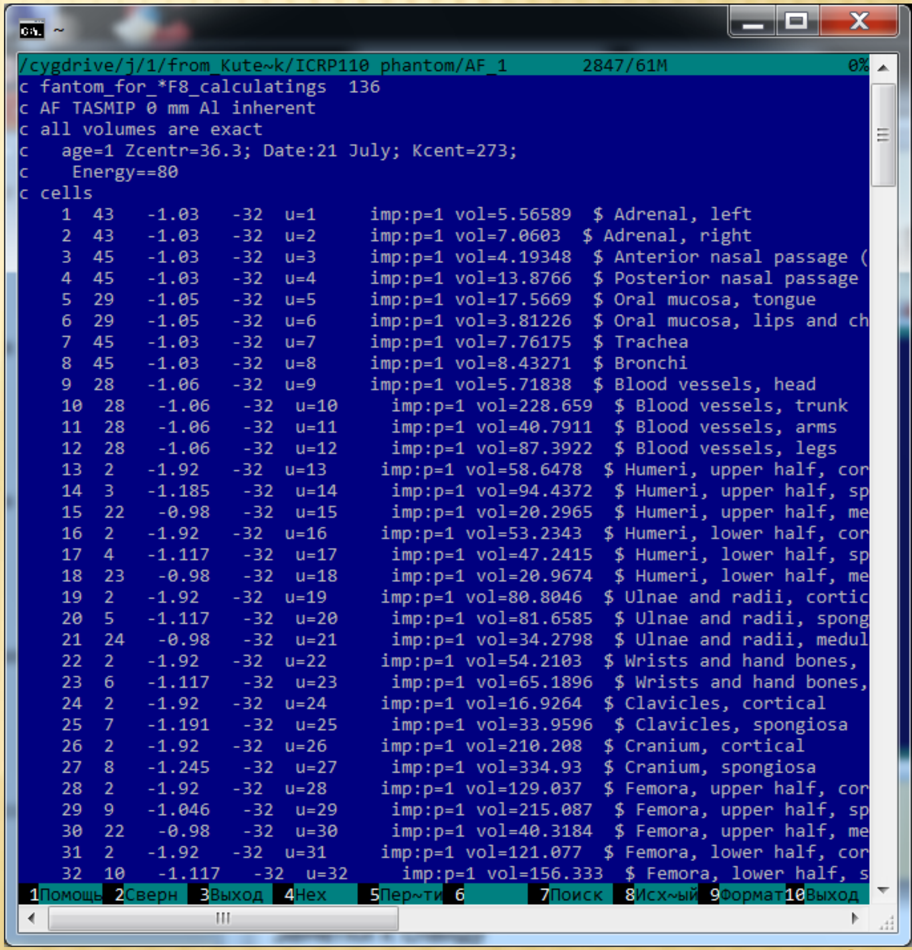
[Viarenich et al. Proceedings of NPCS 2021]

PROGRAM “FANTOM110” OUTPUT

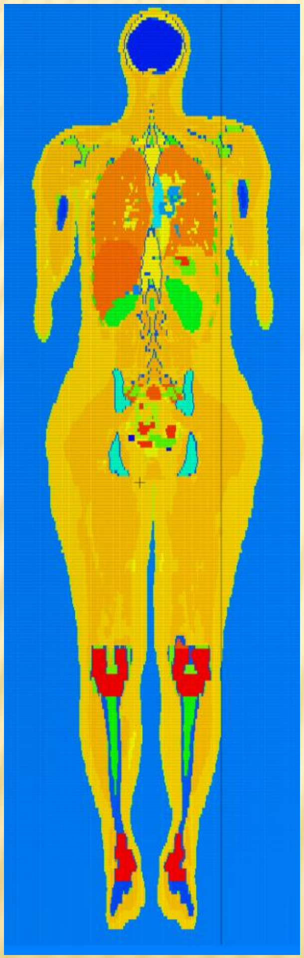
Array of numbers

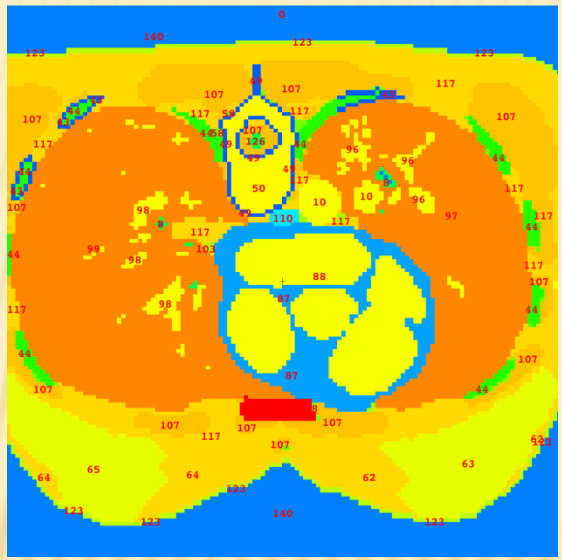
Input file





PLOTS IN MONTE-CARLO CODE





- lung tissue
- brain
- blood in heart
- air
- breast glandular tissue
- breast adipose tissue

section in frontal plane (y=+4 cm)

section in horizontal plane

CALCULATION OF SAF USING MONTE-CARLO METHOD

SAF from mono-energetic radiation is calculated using the following equation:

$$\Phi = \frac{1}{m}\frac{E_{absorbed}}{E_{emitted}},$$

where *m* is the mass of target region, kg,

$E_{emitted}$ is the energy of source particles.

$E_{absorbed}$ is energy absorbed in target region per source particle,

SOURCE SHAPE SPECIFICATION

- Volume source is distributed homogeneously over the region.
- In Monte-Carlo code the following is defined:

1) Coordinates of position of central voxel
2) Three dimensions of central voxel
3) The array of indexes which describe the organ.

VERIFICATION OF THE METHOD

Comparison of Specific Absorbed Fractions calculated using phantom generated using “FANTOM110” program with SAFs from ICRP Publication 133.

[ICRP, 2016. The ICRP computational framework for internal dose assessment for reference adults: specific absorbed fractions. ICRP Publication 133. Ann. ICRP 45(2), 1–74]

SAF FROM MONO-ENERGETIC RADIATION

SAFs from mono-energetic radiation were compared with values from ICRP Publication №133

Radiation	Φ (breast ← breast), kg^{-1}		Discrepancy (our study-ICRP)/ICRP, %
	Our study	ICRP №133	
200 keV electrons	1.9162±0.0003	1.915	0.06
200 keV photons	0.13734±0.0005	0.1384	-0.8

Notes:

1) SAF was adjusted for mass of breast with blood (500 g breast+15.4 g blood=515.4 g).
2) Glandular and adipose tissue are treated as a single organ.

CALCULATION OF SAF FOR A NUCLIDE

SAF from radiation R of a radionuclide is calculated using following equation

$$\Phi_R = \frac{\sum_{i=1}^{n} \eta_i \Phi_{e,\gamma}(E_i)}{Y_R},$$

where η_i is the yield of particles with energy E_i, particles/nt,

$\Phi_{e,\gamma}(E_i)$ is SAF from electrons (e) or photons (γ) of energy E_i, kg^{-1},

Y_R is yield of radiation of type R, particles/nt,

n is number of lines in spectrum of radiation.

SAF from a certain radionuclide is calculated using equation:

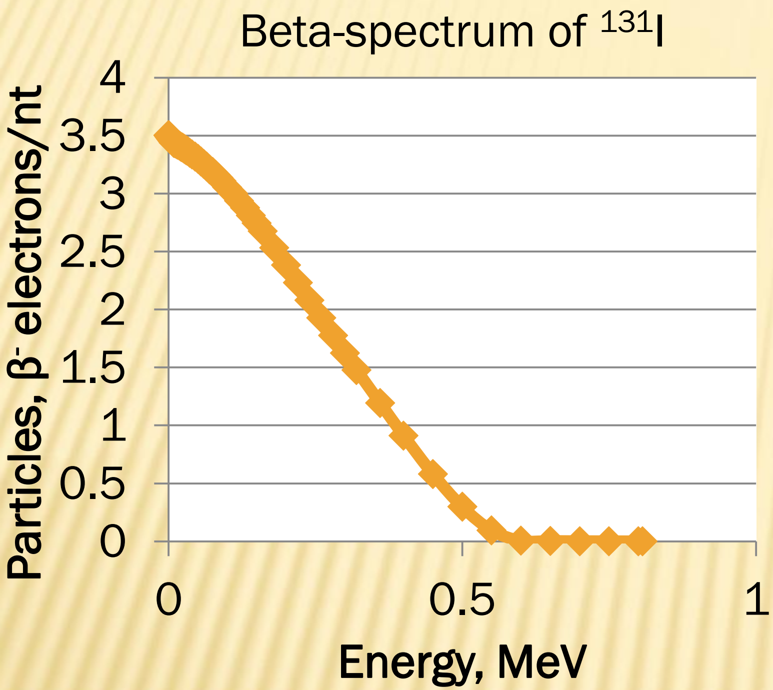
$$\Phi = \frac{\sum_R \Phi_R E_R}{\sum_R E_R},$$

where Φ_R is specific absorbed fraction calculated separately for radiation of type R (β, γ, internal conversion electrons etc.), kg^{-1}

E_R is the energy of radiation of type R per nuclear transformation, MeV

RADIATIONS FROM RADIONUCLIDES

^{131}I



Radiation type	Yield Y_R, particles/nt	Energy E_R, keV/nt
γ-rays	1.008	381.2
X rays	0.8175	1.522
β^-	1	181.9
Internal conversion electrons	0.06458	9.567
Auger electrons	0.6975	0.4129

*nt – nuclear transformation

Note: ^{131}I decays into ^{131m}Xe, which has a half-life of 11 days.
Xenon is a chemically inactive element, therefore we suppose that it is removed from the tissue before it decays

[ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations, 2007]

SPECIFIC ABSORBED FRACTIONS FOR ^{131}I

Verification:

1)comparing of mean energy of each emitted radiation from Monte-Carlo with mean energy from ICRP Publication 107;

2)comparing specific absorbed doses.

Nuclide	Φ (breast ← breast), kg^{-1}		Discrepancy (our study-ICRP)/ICRP, %
	Our study	ICRP №133	
^{131}I	0.7036±0.0007	0.7113	-1.1

Note:

Beta-electrons, Auger-electrons and X-rays and of ^{131}I have energies below 1 keV, which is a cut-off energy in Monte-Carlo code. Test calculation was made for energies above the cut-off energy which showed, that in this situation everything is accounted for correctly.

S-VALUES

- S-value is absorbed dose in target tissues per unit of nuclear transition in source region [Lamart et al. Radiation Protection Dosimetry 2016].
- S-values can be calculated using the following equation:

$$S(r_T \leftarrow r_S) = 1.602 \cdot 10^{-13} \sum_{i=1}^{n} E_i \Upsilon_i \Phi(r_T \leftarrow r_S, E_i)$$

where S is the S-value, $Gy{\cdot}(Bq{\cdot}s)^{-1}$,
$1{,}602{\cdot}10^{-13}$ is the conversion factor from MeV/kg to Gy
n is the number of energies in source spectrum of a nuclide

Notes:

1) breast is divided into glandular and adipose tissues (both as source and target regions);
2) S-values from [Lamart et al. 2016] were calculated using MCNPX;
3) Blood is not included into calculation of S-values [Lamart et al. 2016].

WHOLE BODY SOURCE

- When SAF is calculated from total body, SAF from electrons emitted from bones is assumed to be 0 [Lamart et al. Radiat. Prot. Dosim. 2016]

$$\Phi(\text{outside bones} \leftarrow \text{bone, electrons})=0$$

- When the source is the whole body, the density of organ or tissue where a source point is located is assigned to the statistical weight of starting particle history.
- Water content of body mass in adults 73% [ICRP Publication 89] $\rho=1$ g/cm^3. Most soft tissues have $\rho=1.02..1.05$ g/cm^3.

SAF FROM WHOLE-BODY SOURCE

SAFs from whole body source to breast

$^{137}Cs + ^{137m}Ba$

$\Phi(\text{breast} \leftarrow \text{body}, ^{137}Cs + ^{137m}Ba) = 8.55 \cdot 10^{-3}\ kg^{-1}$; $\varepsilon = 0.8\%$

^{134}Cs

$\Phi(\text{breast} \leftarrow \text{body}, ^{134}Cs) = 5.61 \cdot 10^{-3}\ kg^{-1}$; $\varepsilon = 1.1\%$

SUMMARY

- Specific absorbed fractions were calculated for

1) self-absorption of ^{131}I in breast;
2) ^{134}Cs and ^{137}Cs+^{137m}Ba whole-body sources to breast;

- Verification of computational method was performed.
- The work is performed with financial support of National Institute of Health and State Scientific Program Research “Energy and nuclear processes and technologies”.

THANK YOU