
Results, comments and questions should be addressed to:

David Broggio

IRSN/DRPH/SDI/LEDI

BP-17 F-92262 Fontenay-aux-Roses Cedex, France

Phone: +33 (0)1.58.35.82.51

Fax: +33 (0)1.58.35.93.65

david.broggio@irsn.fr

Intercomparison on Monte Carlo modelling of in vivo measurements of lung contamination with a Livermore phantom

1. INTRODUCTION

Voxel phantoms and Monte Carlo techniques have been widely used in computing radiation dosimetry for the last years. In particular, the application to in vivo assessment of internal radionuclide body burdens is becoming an increasingly interesting alternative for calibration purposes. In that sense, the aim of this intercomparison is to analyse the different approaches considered by the participants for modelling a real case of in vivo measurement of enriched uranium in lungs with Low Energy Germanium (LE Ge) detectors using a thoracic phantom, namely the Livermore phantom.

The proposed tasks are hereafter given and the relevant technical details given in the appendix (detector model, material compositions, voxel phantom specifications).

Participants are free to answer all or a part of the proposed tasks.

2. COMPANION MATERIAL

Accompanying this document you should have received a file named EuradosLungCounting.zip. After uncompressing this file, check that you have the following files and folders:

- P0.dat
- P4.dat
- Template.xls
- P0Ascii: this folder contains 255 files named P0_XXX.txt, where XXX takes values from 001 to 255
- P4Ascii: this folder contains 255 files named P4_XXX.txt

3. PROPOSED TASK

3.1 Task 1: simulation of a single pulse height spectrum for a ^{241}Am calibration source.

Let us assume the bottom centre of the ^{241}Am calibration source described in Appendix 2 located at the origin of a reference frame. The active bead of the source can be considered as a point source. Let us consider the centres of the entrance windows of Germanium detectors, described in Appendix 1, located at:

P1 (-10.5; -4.125; 15.7)

P2 (-10.5; 4.125; 15.7)

P3 (10.5; -4.125; 15.2)

P4 (10.5; 4.125; 15.2),

the coordinates are in *cm*, in the reference frame depicted in **Fig. 1**. The thickness of the PMMA plate is about 0.5 cm, composition is given in Appendix 2.

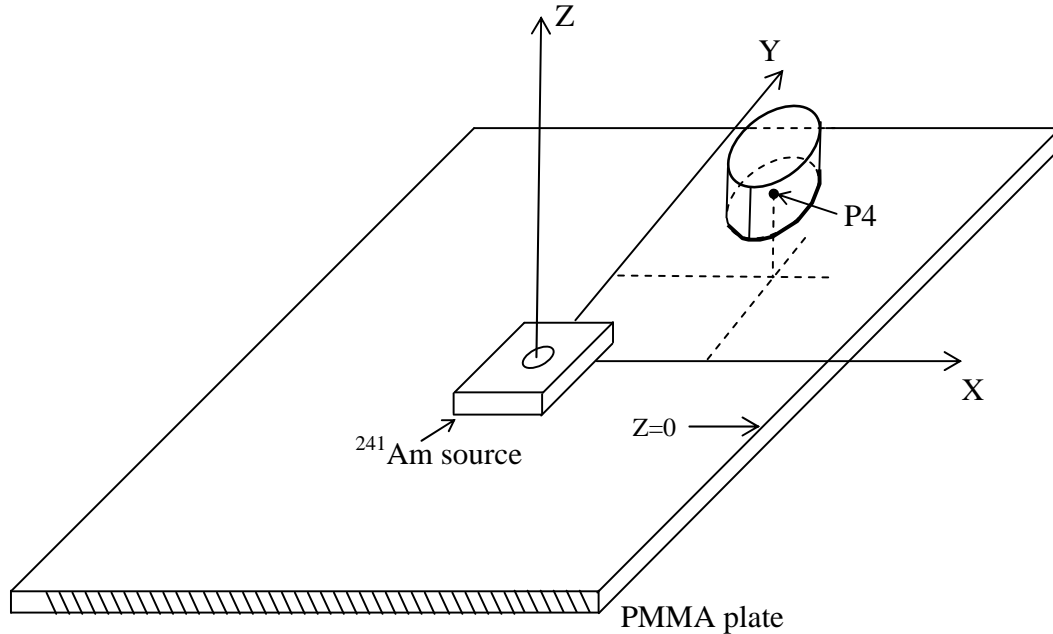


Figure 1: Schematic view of the simulation geometry for a calibration source measurement (not at scale).

The gaussian energy broadening of the sum spectrum is given by the experimentally fitted relation relating the Full Width at Half Max as a function of the energy (everything in keV):

$$\text{FWHM}(E) = 0.5548 + 0.023\sqrt{E}$$

a) It is asked to calculate the pulse height spectrum corresponding to the sum of the four germanium detector, between 7.011 keV (channel #1) and 64.0098 keV (channel #214). This energy range corresponds to the energy calibration which gives 0.2676 keV/channel. The result must be given in units of counts/second.

b) The counting efficiency at 59.5 keV for a region of interest between channel 192 and 203, the results will be given in [(counts/second)/Bq]¹.

3.2 Task 2: lung counting simulation with a four germanium detector system.

¹ For a given gamma ray the counting efficiency (ϵ), in counts/second/Bq, relates the experimental count rate (τ) in the photopeak of interest and the source activity (A) according to $\tau = \epsilon A$. Experimentally it is calculated as the net area in the photopeak divided by the counting time divided by the source activity. The net area is the integral under the photopeak minus the background counts and the Compton contribution.

The goal of this task is to simulate two relatively realistic lung counting measurements with a four Germanium detector system. The first case reproduces a measurement with the Livermore phantom without extra-thoracic plate, the second one with plate #4 (case P0 and P4). The following activities, as given by the source supplier, will be considered:

	Left Lung Activity (Bq)	Right Lung Activity (Bq)
U-234	17 750.0	24 500.0
U-235	677.6	935.4
U-238	3 401.0	4 696.0

Recommended gamma ray energies and yields for these radionuclides and daughters are given in Appendix 1. Participants are free to use more detailed data or use other values than those recommended.

For the two cases, the coordinate of the centres of the carbon entrance windows of the detectors are:

P1 (12.8; 28; 12.75)

P2 (12.8; 28; 21)

P3 (33.5; 28.5; 12.75)

P4 (33.5; 28.5; 21),

given in *cm* in the frame of reference of the voxel phantom, as described in Appendix 3.

The counting geometry to simulate is illustrated in **Fig. 2**.

The four detectors are the same and described in Appendix 1. As in real case measurements the spectrum of interest is the sum of the four spectra given by each Germanium crystal. The gaussian energy broadening of photopeaks as been assessed during the reference experiments, as a result the Full Width at Half Max (in keV) is given as a function of energy (in keV):

- $FWHM(E) = 0.2785 + 0.05467\sqrt{E}$ (for the P0 case)

- $FWHM(E) = -0.3621 + 0.1421\sqrt{E}$ (for the P1 case).

It is asked to calculate:

- a) For the P0 case the pulse height spectrum, corresponding to the sum of the four spectra given by each detector, between 31.0000 keV (channel #1) and 210.4925 keV (channel #672), using 0.2675 keV per channel. The result must be given in units of [counts/second]. All the information in this document should be used in order to reproduce the experimental spectrum at best.
- b) Idem for the P4 case.
- c) For the P0 case the counting efficiencies [counts/second/Bq] at the following energies
 - (i) 185.7 keV with a region of interest between 184.1 and 187.6 keV
 - (ii) 143.8 keV with a region of interest between 142.3 and 145.3 keV
 - (iii) 63.3 keV with a region of interest between 62 and 64.5 keV.

The first two photopeaks are used to assess the ^{235}U activity while the third one is used to assess the ^{238}U activity through the ^{234}Th photopeak.

- d) Idem for the P4 case. The regions of interest are:
 - (i) between 183.8 and 188.6 keV,
 - (ii) between 142.1 and 146.1 keV,
 - (iii) between 62 and 64.5 keV.

The method to compute these efficiencies should be shortly described (do you use the preceding calculated spectra or do you use a different method).

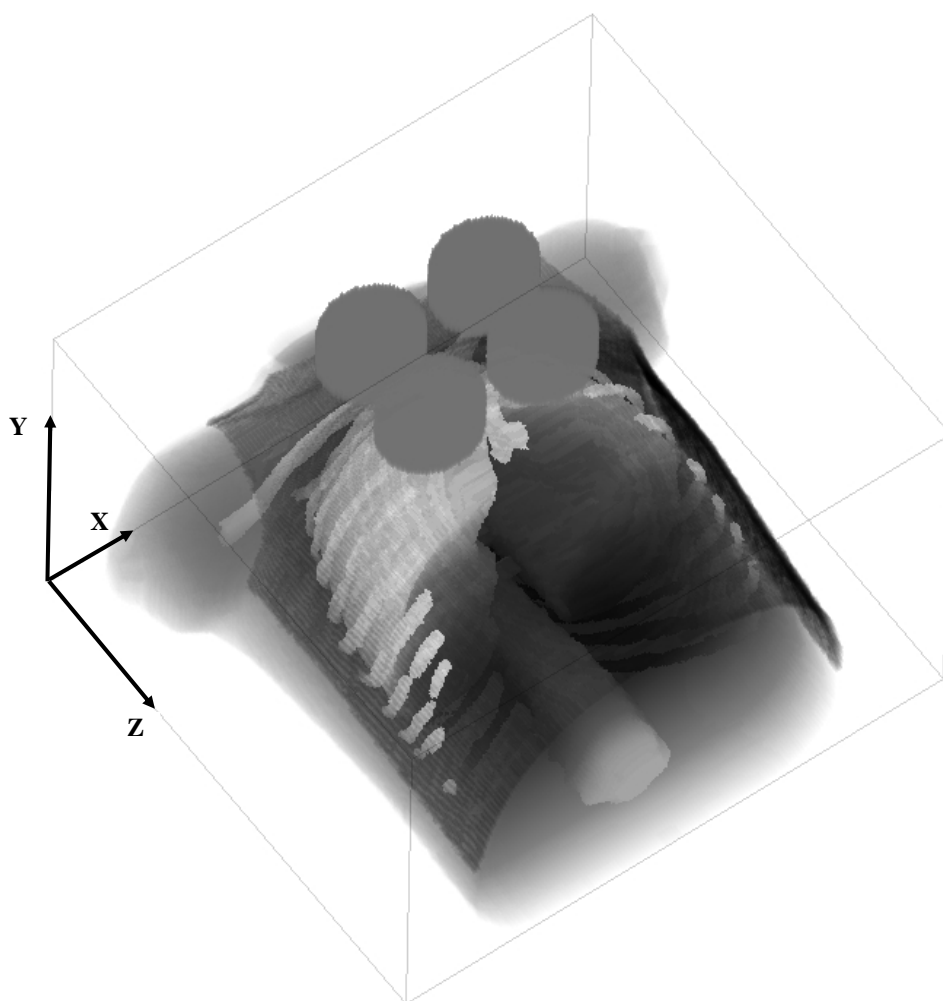


Figure 2. Illustration of the counting geometry; the positions of the detector are defined in the "phantom box" according to the position of the axis drawn here.

3.3 Task 3: simulation of your own measurements: Optimizing counting efficiency

A final meeting is proposed for the participants who are interested in the performance of measurements at the in-vivo monitoring facility of CIEMAT, in order to proceed with their own counting geometries and simulate them. The goal of this task is to offer participants the possibility to set-up detectors on their own, trying to maximise the counting efficiency, and to develop a method to reproduce accurately the position of detectors in their simulation.

Participants will send their measured spectra and deduced efficiencies as well as the calculated data.

This part of the exercise is open from 15th June 2010 to 31st December 2010. Interested participants are invited to contact Maria-Antonia Lopez Ponte (ma.lopez@ciemat.es) 2-3 months before the starting date in order to schedule the experiments.

4. INSTRUCTION TO RETURN THE RESULT

The deadline to return the results (Task 1 and 2) is April 1st 2010.

The deadline to return the results of Task 3 will be arranged according to the number of participants.

Use the provided Excel template to write down your solutions. Feel free to return additional information.

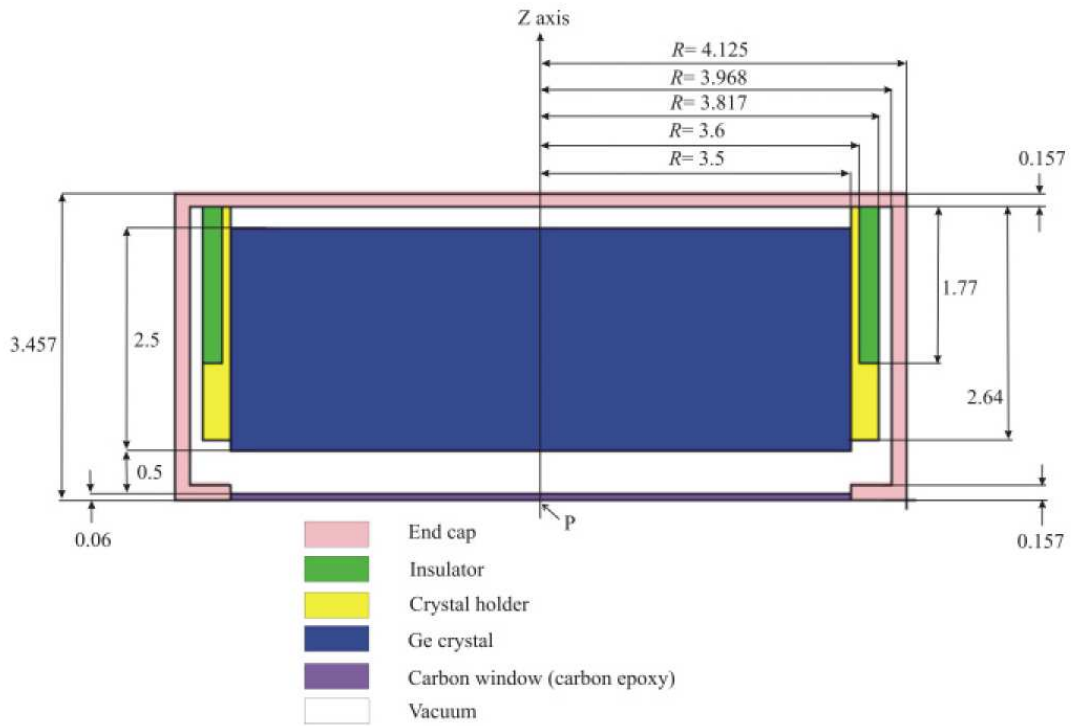
5. ACKNOWLEDGMENT

This work is the result of a joint collaboration of EURADOS WG7 « Internal Dosimetry » coordinated by M.A. Lopez (CIEMAT) and EURADOS WG6 « Computational Dosimetry » coordinated by G. Gualdrini (ENEA).

The organizers of this new Monte Carlo exercise appreciate the support and contributions of Jose Maria Gomez Ros and Montse Moraleda (CIEMAT) who were involved in the organization of the former CONRAD Monte Carlo Intercomparison for the in-vivo measurement of Americium in a knee voxel phantom.

With reference to the In-vivo monitoring results, the organizers appreciate the close collaboration between IRSN and CIEMAT, that facilitate the correct design and elaboration of the exercise.

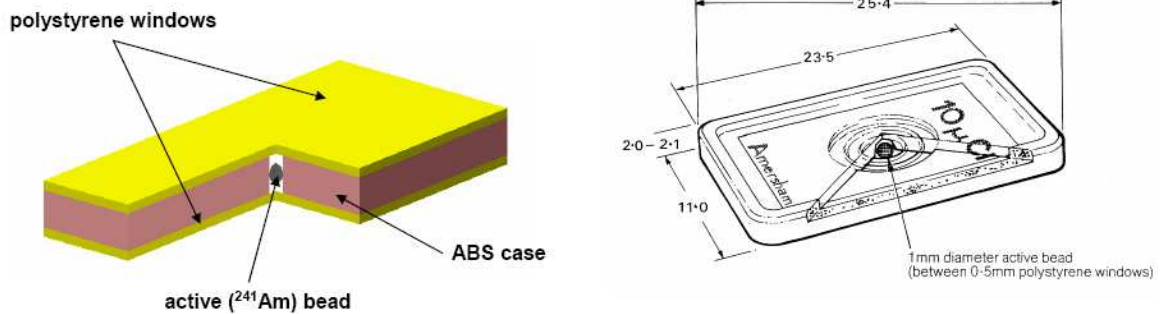
Appendix 1: detector technical specifications



Element	Elemental composition (weight fractions)	Density	Dimensions
Carbon window (carbon epoxy)	C (71.5%), H (12.6%), O (15.9%)	2.3 g/cm ³	Radius: 3.5 cm Height: 0.06 cm
Ge crystal (High purity Ge)	Ge	5.32 g/cm ³	Radius: 3.5 cm Height: 2.5 cm
Crystal holder (Copper)	Cu	8.96 g/cm ³	Internal Radius: 3.5 cm External Radius: 3.817 cm Height: 2.64 cm
Insulator (PVC)	H (9%), C (38%), Cl (53%)	1 g/cm ³	Internal Radius: 3.6 cm External Radius: 3.817 cm Height: 1.77 cm
End cap (Stainless steel)	Fe (72.85%), C (0.15 %), Mn (2 %), Si (1%), Cr (17%), Ni (7%)	7.9 g/cm ³	Internal Radius: 3.968 cm External Radius: 4.125 cm Height: 3.457 cm Thickness: 0.157 cm
Vacuum	–	0	–

Appendix 2: source specifications

1) ^{241}Am Calibration source: drawing, materials specification, recommended spectrum



material	chemical formula	density (g/cm ³)
polystyrene	(C ₈ H ₈) _n	1.06
acrylonitrile-butadiene-styrene (ABS)	(C ₈ H ₈ ·C ₄ H ₆ ·C ₃ H ₃ N) _n	1.05

Emission spectrum of ^{241}Am

Type of emission	Energy (keV)	Yield (%) §
X	13.93	13.2
X	17.61	18.61
X	21	4.82
γ	26.35	2.4
γ	59.54	35.9

§ Number of photons emitted per 100 nuclear disintegrations

PMMA plate, density = 1.19 g/cm³

	H	C	O
weight %	0,08	0,6	0,32

2) Recommended X/γ spectra of the enriched uranium lungs' radionuclides

The values hereafter given are a tentative synthesis from the following references:

- Radionuclide Transformations Energy and Intensity of Emissions, ICRP publication 38, Pergamon Press (1983)
- Nuclear Decay Data for Dosimetric Calculations, ICRP Publication 107, Elsevier (2007)
- Radionuclide-Handbook for laboratory workers in Spectrometry, radiation protection and medicine, Institut für Spektrometrie und Strahlenschutz, (2001)
- Mini Table de radionucléides, Laboratoire National Henri Becquerel, EDP sciences éditeur, (2007).

The beta spectra of uranium daughters are not given. Nevertheless they can be found with the RadToolBox software from NRC (<http://www.nrc.gov/about->

nrc/regulatory/research/radiological-toolbox.html), alternatively some spectra of interest can be obtained at <http://www.doseinfo-radar.com/BetaSpec.zip>.

U-235

Emission type	Energy (keV)	Yield (%)§
X	90.33	3.57
X	93.79	5.77
γ	96.09	0.066
X	105.28	0.66
X	106.07	1.29
γ	109.16	1.87
γ	143.76	10.96
γ	163.33	5.08
γ	182.61	0.34
γ	185.72	57.2
γ	194.94	0.63
γ	202.11	1.08
γ	205.31	5.01
X/g	not listed	18.934

§ Number of photons emitted per 100 nuclear disintegrations

U-234

Emission type	Energy (keV)	Yield (%)§
γ	53.2	0.123
γ	120.9	0.04
X/g	not listed	10.537

Th-230

Emission type	Energy (keV)	Yield (%)§
γ	67.67	0.38
γ	143.87	0.049
X/g	not listed	8.12

Th-231

Emission type	Energy (keV)	Yield (%)§
γ	25.64	14.5
γ	58.57	0.48
γ	81.23	0.89
γ	84.2	6.6
γ	89.95	0.94
X/g	not listed	76.34

Th-234

Emission type	Energy (keV)	Yield (%)§
γ	63.29	4.11
γ	92.38	2.73
γ	92.8	2.69
γ	98.4	0.24
γ	112.81	0.23
X/g	not listed	9.48

Pa-234m

Emission type	Energy (keV)	Yield (%)§
γ	95.06	0.15
γ	98.93	0.24
X/g	not listed	2.6

Appendix 3: voxel phantom technical specification and use

Voxel Size

For all the provided phantoms the voxel size is 0.2x0.2x0.2 cm.

Number of Voxels

The number of voxels of each phantom is as follows:

Phantom	Number of voxels according to direction		
	Head-Feet (Z)	Left-Right (X)	Anterior-Posterior (Y)
P0 (no plate)	255	239	139
P4 (large plate)	255	239	148

Color code associated with organs and tissue

Each voxel is associated with a unique unsigned 8-bit value which defines the tissue or organ as follows:

<i>Bit value</i>	<i>Tissue/Organ</i>
0	Exterior air
51	Left lung
102	Right lung
153	Muscle (body)
204	Extra-thoracic plate (if any)
255	Bone

Material specification

The compositions (weight percent) given above should be used to define the phantom's tissues and organs.

	<i>Air</i>	<i>Bone</i>	<i>Griffith Lung</i>	<i>Muscle</i>	<i>Plate</i>
H		6.38	8	9.03	9.24
C		47.2	60.8	59.37	60.73
N	75.5	2.12	4.2	3.3	3.85
O	23.2	31.3	24.9	26.6	25.4
Ar	1.3				
Ca		13	2.1	1.7	0.78
density (g/cm ³)	1.205x10 ⁻³	1.26	0.26	1.06	1.06

Reference frame

The reference coordinate system is chosen with its origin on the dorsal, head, right (of the phantom) corner of the box containing the phantom. The X axis goes from the phantom's right to left, the Y axis goes from the dorsal to the ventral side, and the Z axis goes from the head to the feet. The detector positions are given in this reference frame. The reference frame is illustrated in Fig. 2.

Format available

Binary data

The files P0.dat and P1.dat contain unformatted unsigned 8 bits integer. Extraction of the data from this file depends on the programming language you use. Most languages have functions or primitives enabling to read and store data once the dimension of the array have been provided. My advice is to read the data using a "for loop" like this

```
for i=1 to 255 do
  read and store the ith 239*139 elements in P0.dat
OR
  read and store the ith 239*148 elements in P4.dat
endfor
```

Ascii data

The folders P0ascii and P4ascii contain 255 ASCII files representing the 255 axial (i.e. transverse) slide. The files are named P0_xxx.txt or P4_xxx.txt; xxx takes values from 001 to 255 and increases from head to feet. The number of lines in each file equals the number of voxel in the anterior-posterior direction. The number of elements per line is 239 (left-right direction), elements are separated by a space, and they are the bit value coding for the tissue.

The *first line* in a file P0_xxx.txt represents the *bottom line* of the corresponding image, as illustrated above. The left part of a line represents the left part of the image (thus the right of the phantom...).

