Calibration factors and minimum detectable activities in the lung of radionuclides released in the case of a nuclear power plant accident

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Abstract

Assessing the intake of the high energy gamma emitting radionuclides inhaled after an accident in a nuclear power plant or after the intentional release of radionuclides in public places provides input necessary for the dose calculations for members of the public and for emergency response teams. Low and high energy gamma emitters in the lung may be readily detected and quantified through methods of in-vivo counting. However, physical lung phantoms developed for calibration purposes mostly include low energy gamma emitters, such as members of the ^{238}U, ^{232}Th and ^{235}U series, and ^{241}Am. Furthermore, many of the fission products emitted have half-lives on the order of hours or days. In this paper, the Monte Carlo program Visual Monte Carlo is used to simulate the photon emission of a number of high energy photon emitters in the lung so as to calculate the radionuclides calibration factor for the lung geometry, and to calculate the minimum detectable activity (MDA) of the radionuclide in the lung for a broad energy germanium detector mounted in a low level counting room such as a whole body counter. It turns out that most of the radionuclides evaluated including ^{95}Zr, ^{95}Nb, ^{124}Sb, ^{134}Cs, ^{137}Cs and ^{192}Ir have a MDA of around 10 Bq in the lung, with ^{106}Ru having an MDA of around 40 Bq for this geometry.

Key words: Lung counting, Monte Carlo, voxel phantoms, NPP accidents

1) Introduction

Assessing the intake of radionuclides that may be released during an accident in a nuclear power plant (NPP) or after an incident with a radiation dispersion device (RDD) and later inhaled is necessary for the relevant dose calculations to members of the public and for emergency response teams.

Low and high energy gamma emitters in the lung may be readily detected and quantified by methods of in-vivo counting. However, the physical lung phantoms commercially available have normally been produced for low energy gamma emitters, such as the ^{238}U, ^{232}Th and ^{235}U series and ^{241}Am, although lungs containing ^{152}Eu are available [1]. The half-lives of many of the fission products released in the case of an NPP accident have half-lives in terms of hours or days, which turns impracticable the production of physical phantoms for these specific radionuclides.

In this paper, the Monte Carlo program Visual Monte Carlo in-vivo is used to simulate the photon emission of higher energy photon emitters deposited in the lung, to calculate the calibration factor for the detector, geometry, phantom and radionuclide, and to calculate the minimum detectable activity (MDA) of the radionuclide in the lung.

VMC in-vivo is available for free download from the site http://www.vmcsoftware.com/in%20vivo.html. An up-dated version with a wider list of phantoms VMC in-vivo 2012 will be shortly made available at the site.

2) Materials and methods

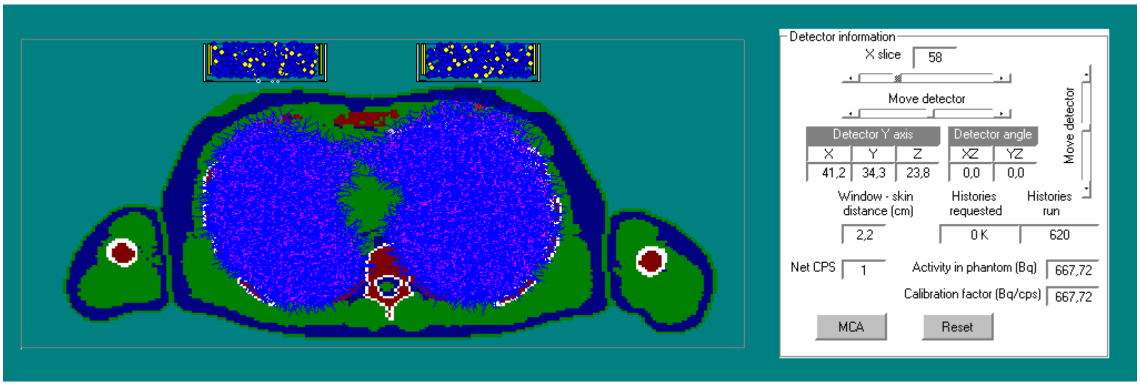
2.1 Counting geometry

The photon emissions of the following radionuclides were simulated: ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{124}Sb, ^{134}Cs, ^{137}Cs and ^{192}Ir. The mathematical phantom used was the ICRP male reference phantom[2]. The detector setup used two BE5030 germanium detectors supplied by Canberra, with the main characteristics given in Table 1.

Table 1. Characteristics of the BE5030 germanium detector

Detector Characteristic	Value
Active diameter of crystal	80 mm
Crystal thickness	29 mm
Window thickness	0.5 mm
Window material	Carbon epoxy
FWHM at 122 keV	623 eV
FWHM at 1332.5 keV	1869 eV

The counting geometry is as shown in Figure 1. The distance between the detector window and the phantom skin surface was 2.2 cm.



Detector information

X slice: 58

Detector Y axis: X 41,2; Y 34,3; Z 23,8

Detector angle: XZ 0,0; YZ 0,0

Window - skin distance (cm): 2,2

Histories requested: 0 K

Histories run: 620

Net CPS: 1

Activity in phantom (Bq): 667,72

Calibration factor (Bq/cps): 667,72

Figure 1. VMC in-vivo simulation of Zr-95 being emitted in the lungs and detected by two BE5030 detectors

The detectors are mounted in a shielded low level counting room supplied by Canberra with 10 cm of steel shielding.

2.2 Visual Monte Carlo in-vivo

The program Visual Monte Carlo in-vivo (VMC)[3,4] was developed at the IRD and has been extensively validated through international intercomparisons using real phantoms and calculations produced by other Monte Carlo programs. The most recent intercomparison was promoted by the CONRAD/EURADOS initiative[5] and involved the assessment of the activity of ^{238}U and ^{235}U in the LLNL lung phantom using an array of four germanium detectors. The results obtained using VMC in-vivo compared with the reference results are shown in Figure 2 below.

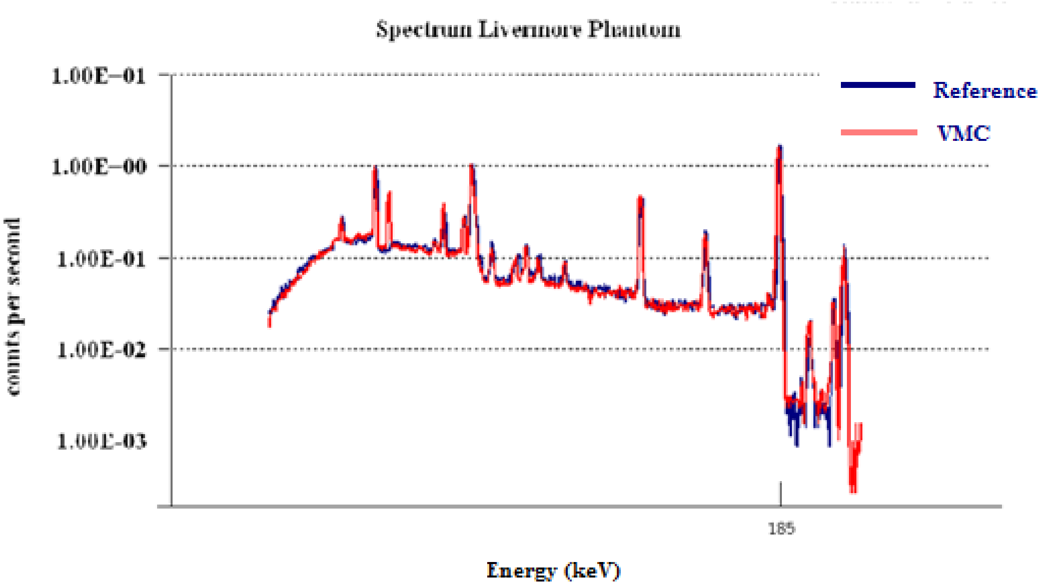


Figure 2. Reference spectrum and VMC in-vivo generated spectrum for the CONRAD/EURADOSE intercomparison

2.3 Minimum detectable activity calculation

To calculate the MDA, the following equation[6] was used:

$$MDA = \frac{4.65 \ \times \ \text{Calibration factor} \ \times (\sqrt{Background\ counts} + 3)}{\text{Counting time (s)}}$$

Where the calibration factor is given in Bq/cps for the photopeak. In this case, a background count of a non-contaminated person for 900 seconds was used.

3) Results

The results of the simulation for individual radionuclides are given in Table 2.

Table 2: Results of the calibration factor and MDA calculations

Radionuclide	**Photopeak energy**	**Yield**	**Calibration Factor[a]**	**BG [b]**	**MDA**
	keV	**%**	**Bq/cps**	**counts**	**Bq**
^{137}Cs	662	85	417	4.8	11
^{134}Cs	605	98	331	4.8	9
^{95}Zr	757	55	716	4.9	19
^{95}Nb	766	99	401	3.5	10
^{106}Ru/^{106}Rh	511	20	1377	8.7	42
^{124}Sb	602	98	330	5.1	9
^{192}Ir	317	87	183	13	6

(a)The cps in the calibration factor is the sum of the cps in the photopeak for the two detector spectra.

[b] The BG is the sum of the background counts from the two detectors for 900 seconds in the same Region of Interest as the photopeak

In a real situation involving the release of multiple radionuclides from a nuclear reactor, the situation is complicated by the creation of a number of Compton edges in the spectrum. To determine the effect of the Compton scattering, a simulation of the lung count using VMC in-vivo was made in which a mixture of the above radionuclides corresponding approximately to the radionuclide mixture released during the Chernobyl accident[7] was simulated. The radionuclide mixture simulated is given in Table 3.

Table 3. Assumed mixture of radionuclides after a release from a NPP accident

Radionuclide	Percentage
^{134}Cs	8.8
^{137}Cs	13.9
^{95}Zr	32.0
^{106}Ru	13.1
^{95}Nb	32.1
^{124}Sb	0.1

The spectrum generated by VMC in-vivo for the radionuclide mixture in the above table deposited in the lung was simulated, and the background spectrum added, see Figure 4 below. This is the spectrum that might be seen in emergency workers involved in the response to a NPP emergency.

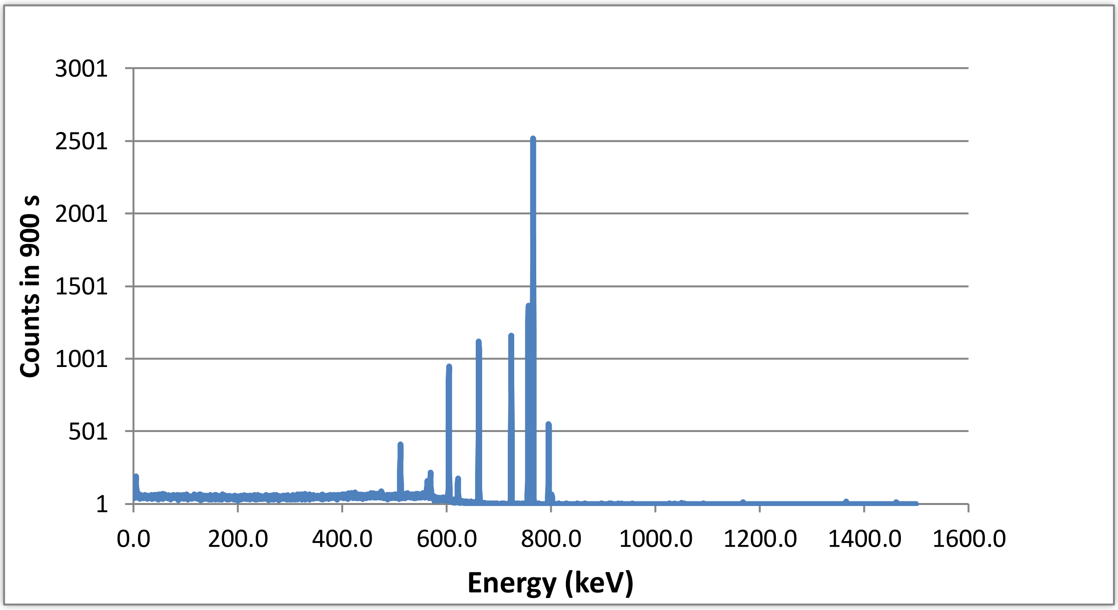


Figure 4. Simulated spectrum of radionuclide mixture plus background. 20.000 Bq total activity of the Table 3 radionuclide mixture counted in the lung geometry for 15 minutes

In the case of the radionuclide mixture, the MDAs are the same; however the 602 keV photopeak of ^{124}Sb is covered by the 605 keV peak of ^{134}Cs.

4) Summary and conclusions

The MDA calculations were performed using the male ICRP reference phantom. The MDAs are lower than those for the same radionuclide in the whole body, as the lungs represent a source with a smaller volume, and the calibration factor is correspondingly lower.

For the female ICRP reference phantom, the lung has a smaller volume and lower photon attenuation so that the corresponding MDAs will be slightly lower for the female than for the male.

The calculation of the calibration factors for the above mentioned radionuclides in the lung may be performed using the software VMC in-vivo which is available for free download from the site http://www.vmcsoftware.com/in%20vivo.html A wide range of detectors and detector geometries may be simulated.

5) References

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