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Simulation of internal contamination screening with dose rate meters

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A B S T R A C T

Assessing the intake of radionuclides after an accident in a nuclear power plant or after the intentional release of radionuclides in public places allows dose calculations and triage actions to be carried out for members of the public and for emergency response teams. Gamma emitters in the lung, thyroid or the whole body may be detected and quantified by making dose rate measurements at the surface of the internally contaminated person. In an accident scenario, quick measurements made with readily available portable equipment are a key factor for success. In this paper, the Monte Carlo program Visual Monte Carlo (VMC) and MCNPx code are used in conjunction with voxel phantoms to calculate the dose rate at the surface of a contaminated person due to internally deposited radionuclides. A whole body contamination with ^{137}Cs and a thyroid contamination with ^{131}I were simulated and the calibration factors in kBq per μSv/h were calculated. The calculated calibration factors were compared with real data obtained from the Goiania accident in the case of ^{137}Cs and the Chernobyl accident in terms of the ^{131}I. The close comparison of the calculated and real measurements indicates that the method may be applied to other radionuclides. Minimum detectable activities are discussed.

1. Introduction

The massive release of radionuclides from a nuclear power plant (NPP) or spent fuel pool or from a radiological dispersion device (RDD) may result in the intake of fission and activation products by members of the public and emergency workers. The resulting body burdens may reach levels where medical treatment and follow-up is required. As part of emergency response planning, persons who may have inhaled or ingested radionuclides should be screened as a part of the "public processing" for internally deposited radionuclides (IAEA, 2005).

The screening protocol should take into consideration that the measurements should be made simply and quickly due to the normally large numbers of people to be screened. This can be performed with readily available portable hand-held equipment. The objective of the screening is to determine which individuals should be indicated for more detailed internal individual monitoring and possible medical treatment.

In this paper, the internal contamination of individuals with ^{137}Cs or ^{131}I such as that seen after a large scale accident at a nuclear Power plant (NPP) or spent fuel pond is simulated, and the calibration factors for hand-held dose rate meters in kBq per μSv/h in a given organ or tissue were calculated using the Monte Carlo method. The MCNPx code (Pelowitz, 2011) and the freely available Monte Carlo program Visual Monte Carlo (VMC) *in-vivo* (Gómez-Ros et al., 2008; Hunt et al., 2002) were used for the modelling.

2. Materials and methods

2.1. VMC and MCNPx

Two Monte Carlo programs were used in this work, VMC *in-vivo*, see http://www.vmcsoftware.com/Index.html and MCNPx. In this paper VMC and MCNPx were used to simulate the emission of photons by fission products deposited in the thyroid, lung and the whole body of voxel phantoms, transport the photons through the phantom and "detect" them in a virtual H*(10) per hour dose rate meter. For the virtual detector in VMC the photon energy fluence Ψ over the relevant energy range for the photons that pass through a 1 cm radius sphere positioned at the point of interest are binned. The photon energy fluence is then converted into H*(10) using the values given in Table A.21 of ICRP 74 (ICRP, 1996). In MCNPx the tally F4 was used to bin the photon energy fluence and multiply by the conversion coefficients for the ambient dose equivalent, H*(10) from photon fluence given in Table A.21 of ICRP 74 as well. The resulting values (in Sv/particle) were converted to kBq per μSv/h. The Simulations were done using the MCNPX code version 2.7.d running under MPI (Message Passing

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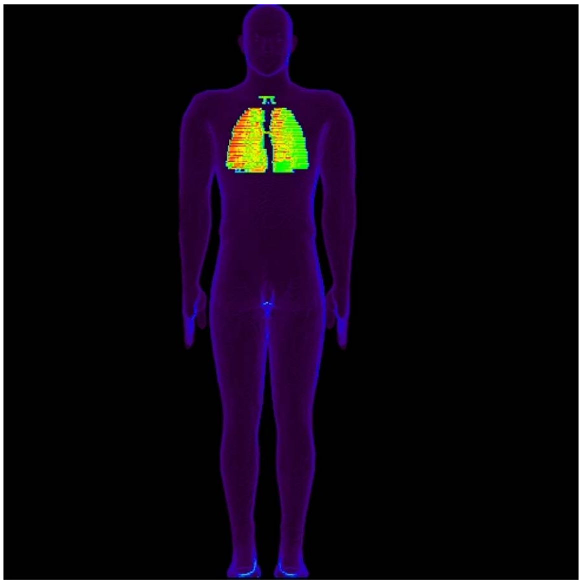

Fig. 1. MaMP Male Mesh Phantom with thyroid and lungs.

Interface) on a computational cluster with 120 processors of the Neutron Laboratory of IRD/CNEN in Brazil.

2.2. The phantoms used in the simulation

The voxel phantoms used in the VMC simulations were the 10 year and 15 year old voxel phantoms produced by University of Florida of body mass 32 kg and 56 kg respectively (Lee et al., 2010) and the ICRP 110 adult male reference phantom of body mass 73 kg (ICRP, 2009).

The MCNPx simulations used the MaMP (Male Mesh Phantom) of 1.76 m and 73 kg of body mass (Fonseca et al., 2014). The freely available library of MaMP and FeMP voxel phantoms were created for virtual Whole Body Counter calibrations. The first versions of these phantoms were without internal organs. Later versions of the MaMP and FeMP voxel phantoms include the thyroid and lungs that allow *in-vivo* calibration calculations to be performed for these organs. Fig. 1 shows the MaMP male phantom with lungs and thyroid. The thyroid of the ICRP male reference phantom has a mass of 20 g and a volume of 19.2 cm^3 however the MaMP voxel phantom has a thyroid of mass 7.3 g and volume of 7.1 cm^3.

2.3. Data from Goiania and VMC simulation

During the 1987 Goiânia accident (IAEA, 1988) daily dose rate measurements were made at a number of predetermined positions on the internally contaminated patients aged from 8 years to adult (Oliveira et al., 1988). Six weeks after the internment whole body measurements for ^{137}Cs were also performed (Hunt and Oliveira, 1990), allowing a comparison to be made between the dose rate at the skin surface and the estimated internal activity. The dose rate measurements were made using a variety of portable equipment which required careful post-accident equipment response studies. In future cases of internal contamination it is recommended that standardized equipment with recent calibration certificates be used. Fig. 2 shows a measurement being made at the neck of a patient at the Goiânia General Hospital. The Whole Body measurements were made by a dedicated set-up at the same hospital, see Fig. 3.

At the time of the Goiânia incident, there was no National Nuclear Energy Commission (CNEN) with resources and training for dealing with this type of incident. The choice of this type of handheld H*(10) dose rate monitor for this evaluation was subject to the availability of suitable equipment and the level of contamination on affected people.

Fig. 2. Dose rate measurement of a patient at the Goiânia General Hospital.

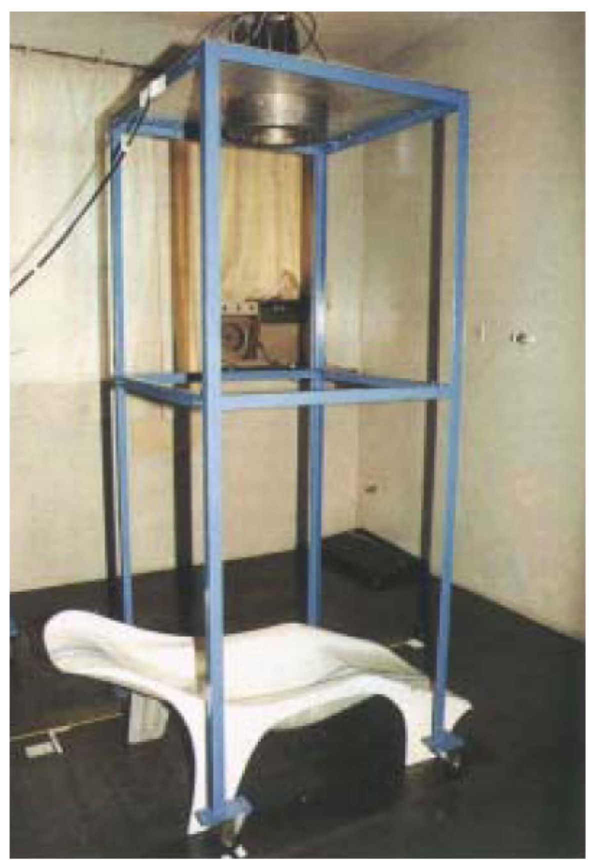

Fig. 3. The Whole Body Counter set-up in the Goiania General Hospital.

For the mass screening of contaminated persons following a radiological accident, a portal monitor would be more effective, but these were not available at the time. Handheld H*(10) dosimeters were the only ones available at this time and they were sufficiently sensitive for the