Thyroid Screening of Members of the Public with Portable NaI Detectors after a Radionuclide Release from a Nuclear Power Plant

J. G. Hunt

Instituto de Radioproteção e Dosimetria - CNEN – Av. Salvador Allende s/n - Rio de Janeiro - RJ - 22780-160. john@ird.gov.br

Abstract

After an accident in a nuclear power plant or spent fuel pond with releases to the environment, members of the public with possible internal contamination with radioactive isotopes of iodine should be screened so that those cases where a more detailed evaluation and medical follow-up is necessary may be identified. In the case of the screening of large numbers of the public, this can be performed with a quick measuring protocol using hand held unshielded NaI based detectors giving results in cps. The screening detector geometry was simulated using the Monte Carlo code Visual Monte Carlo, and the results showed that for a geometry with the NaI detector near the skin in front of the thyroid, the interference of the gamma radiation coming from the other radionuclides released in the accident either deposited in the lung or in the whole body is sufficiently low to allow the thyroid screening criteria to be established. The screening criteria were developed using 5, 10 and 15 year old hybrid phantoms and for the adult male based on the ICRP reference voxel phantom

Key words: Thyroid scanning, NPP accidents, Monte Carlo, voxel phantoms,

1) Introduction

The massive release of radionuclides from a nuclear power plant (NPP) or spent fuel pool may result in the intake by members of the public and emergency workers of fission and activation products. The resulting body burdens may reach levels where medical treatment and follow-up is required. As part of the emergency response planning, members of the public who may have inhaled or ingested the radionuclides should be screened as a part of the "public processing" for internally deposited radionuclides[1].

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

In this paper, the internal contamination of individuals with a wide range of radionuclides such as that seen after a large scale accident at a nuclear Power plant (NPP) or spent fuel pond is simulated, and the measurement in counts-per-second (cps) of unshielded hand-held equipment is simulated using the Monte Carlo technique.

2) Materials and methods

In order to represent the various age groups of the public, four phantoms were used for this study. The voxel phantoms used were the ICRP male reference phantom[2] and the 5, 10 and 15 year old male hybrid phantoms produced by the University of Florida (UF)[3]. Figure 1 shows the UF "family" of hybrid phantoms.

The Monte Carlo program used is Visual Monte Carlo (VMC) in-vivo, see http://www.vmcsoftware.com/Index.html[4,5]. The emission of photons by fission products in the thyroid, lung and the whole body were simulated, the photons were transported through the phantom and then detected in a NaI detector. Instead of binning the counts in the photopeak, as is usually the case in gamma spectrometry, the total cps count in the NaI crystal was simulated. If the photon suffered one or more Compton interactions or a photoelectric interaction in the NaI, then one count was added to the total counts.

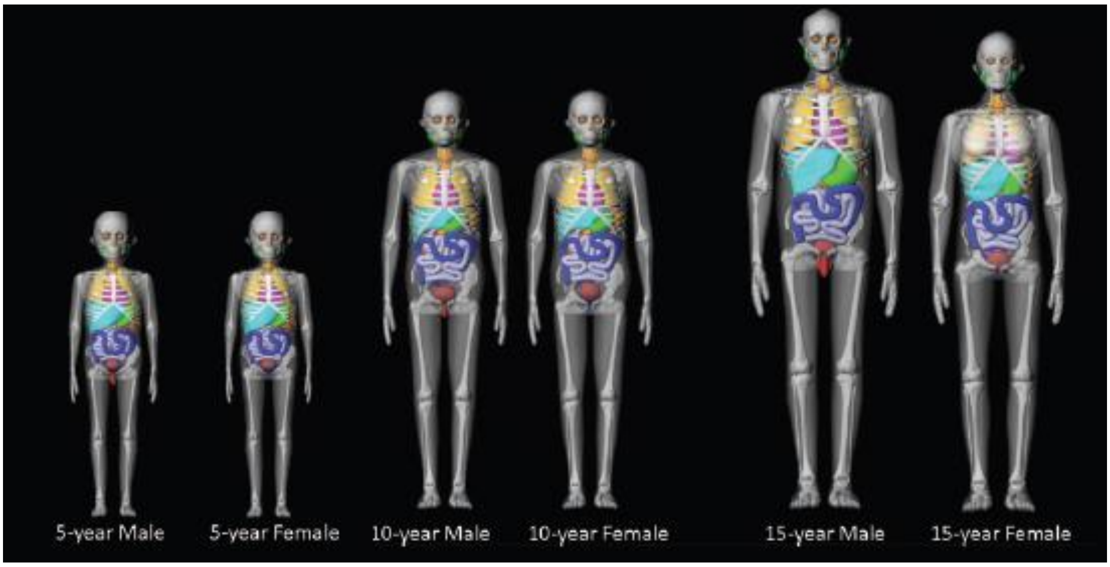

Figure 1: the University of Florida family of 5, 10 and 15 year old hybrid phantoms

The detector used in this paper was the Identifinder NHG Ultra with a NaI crystal with 35 mm diameter and 51 mm height. The same work has also been performed in a more complete study using NaI detectors of geometry 1” x 1” (2.54 mm diameter x 2.54 mm height) and 2” x 2” (5.08 mm diameter x 5.08 mm height) as seen in hand-held equipment such as the Canberra SG-1R or SG-2R. None of the NaI crystals were considered to be shielded or collimated.

During a severe accident at a NPP, a number of radionuclides are emitted, some of which have the thyroid as the critical organ, some remain in the lung for some time, while others are quickly transported to the soft tissues.

In order to quantify the interference in the cps measured by the hand-held detector due to radionuclides in each of these three body regions, calibration factors for each radionuclide in each body region were calculated.

3) Results

3.1 Calibration factors for iodine isotopes in the thyroid

Simulations were run for the four phantoms with ^{131}I, ^{132}I, ^{133}I and ^{135}I in the thyroid. The results for the identifinder are given in Table 1 and the graphics are shown in Figure 2.

Table 1: Calibration factors for radio-iodines in the thyroid measured with an Identifinder placed over the thyroid and at a distance of 0.2 cm from the skin.

Calibration factors for radio-iodines in the thyroid counted at the thyroid with an Identifinder (cps/kBq)				
Radionuclide	**5 y**	**10 y**	**15 y**	**Adult**
I-131	57	56	48	33
I-132	120	119	103	71
I-133	105	102	85	53
I-135	43	43	37	26

The 5 and 10 year phantoms show similar values of cps. The ICRP adult phantom shows lower calibration factors as the thyroid in this phantom is deeper below the skin surface.

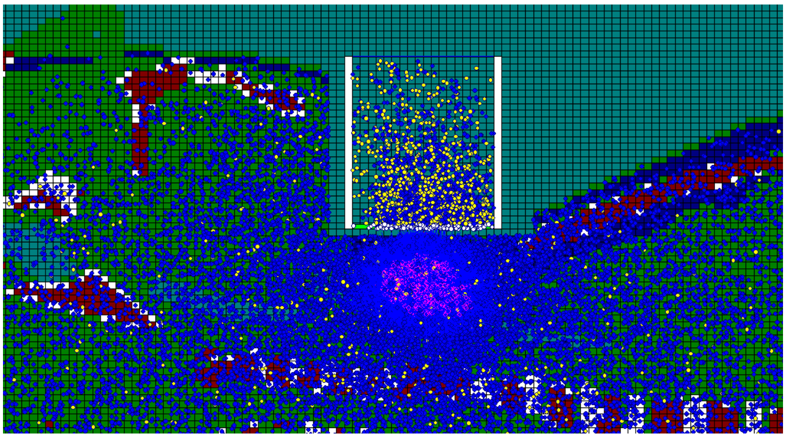

Figure 2. The Identifinder placed over the thyroid, detecting photons emitted from ^{131}I deposited in the thyroid of the 5 year old male

3.2 Calibration factors for whole body radionuclides counted at the thyroid

The presence of ^{134}Cs, ^{136}Cs and ^{137}Cs in the whole body causes a "background" or "cross-fire" cps in the NaI detector positioned at the thyroid. Simulations were carried out for the ICRP male adult to determine some values for the "cross-fire". The results are given in Table 2.

Table 2: Calibration factors for a cesium contamination of muscle, fat and soft tissues (whole body) with the Identifinder placed over the thyroid for the adult phantom.

Calibration factor for *Identifinder* at thyroid for radionuclides in the whole body (cps/kBq)	
Radionuclide	**Adult**
Cs-134	1.8
Cs-136	2.4
Cs-137	0.69

3.3 Calculation of interference of lung radionuclides on measurements at thyroid

The radionuclides deposited in the lung are relatively close to the detector at the thyroid position and will cause a measurable "cross-fire". In order to determine the magnitude of this cross-fire, the contamination of the lung was simulated and the cps evaluated in the detector placed at the thyroid, see Table 3 and Figure 3.

Table 3. Calibration factors for radionuclides in the lung with an Identifinder placed over the thyroid.

Calibration factors for radionuclides in lung counted at the thyroid with an Identifinder (cps/kBq)				
Radionuclide	**5 y**	**10 y**	**15 y**	**Adult**
Zr-95	4.9	3.9	3.7	3.1
Mo-99	7.7	5.5	5.2	4.3
Ru-103	5.7	4.3	4.2	3.4
Ru-105	6.7	5.3	4.8	3.9
Te-127m	0.30	0.13	0.12	0.13
Te-129m	0.24	0.09	0.07	0.10
Te-131m	21	16	14	12
Te-132	13	9.4	8.2	6.9
Ba-140	13	9.4	9.4	7.5
Ce-141	4.6	3.2	3.0	2.5
Ce-143	6.5	4.6	4.2	3.5

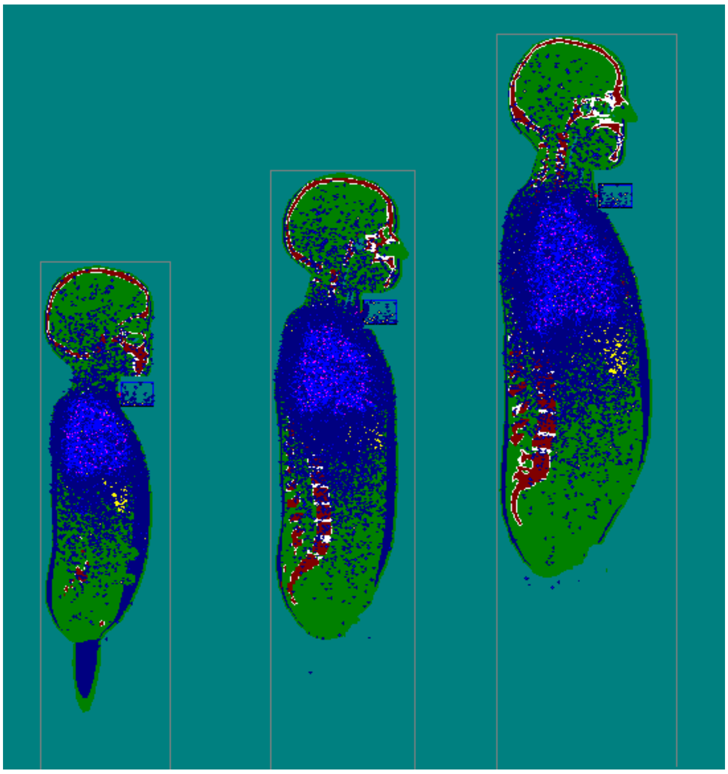

Figure 3. Simulating gamma radiation emitted from ^{99}Mo in the lungs, with the detector placed at the thyroid position of the 5, 10 and 15 year male

4) Release of radionuclides in the case of a severe nuclear power plant accident

In the case of a severe NPP accident, a mixture of isotopes of iodine, cesium and other fission products are released. Taking the radionuclides released during the Chernobyl accident and the release fractions established in UNSCEAR as a reference[6], and assuming for a given member of the public a ratio of inhaled activity to released activity of 10^{-15} the end result is as given in Table 5, assuming that all the radio-iodines inhaled end up in the thyroid.

Table 5. For the 5, 10, 15 and adult phantoms, with the detector at the thyroid, the total cps emitted due to the radio-iodines in the thyroid, the radio-cesium being deposited in the whole body, and the insoluble radionuclides being deposited in the lungs.

	Released	Inhaled	Tissue or organ	cps at thyroid with identifinder			
	PBq	kBq		5y	10y	15y	adult
I-131	1760	1.76	Thyroid	100	99	84	58
I-133	910	0.91	Thyroid	96	93	77	48
			subtotal	**196**	**192**	**161**	**106**
Cs-134	47	0.047	Soft tissues				0.08
Cs-136	36	0.036	Soft tissues				0.09
Cs-137	85	0.085	Soft tissues				0.06
			subtotal				**0.23**
Zr-95	84	0.084	Lung	0.41	0.33	0.31	0.26
Mo-99	100	0.1	Lung	0.77	0.55	0.52	0.43
Ru-103	200	0.2	Lung	1.139	0.87	0.83	0.68
Te-129m	240	0.24	Lung	0.057	0.022	0.017	0.024
Te-132	1150	1.15	Lung	15	11	9	8
Ba-140	240	0.24	Lung	3.1	2.2	2.2	1.8
Ce-141	84	0.084	Lung	0.39	0.27	0.25	0.21
			subtotal	**20**	**15**	**14**	**11**

The following conclusions may be derived from Table 5: (a) for the same activity of radioiodine in the thyroid, the cps measured for the 5 and 10 year olds is double that of the adult, due to the fact that the thyroid is closer to the skin surface for these two ages. (b) The radioisotopes of cesium distributed over the whole body do not contribute to the cps measured by the identifinder located at the thyroid. Not only is the inhaled activity much lower for the radio-cesium, but also the spread of the radio-cesium over the whole body significantly reduces the calibration factors in cps/kBq. (c) The radionuclides deposited in the lung contribute around 10% of the cps measured by the identifinder located at the thyroid in relation to the direct count of the iodines deposited in the thyroid, for all ages. (d) The inhalation of 1.76 kBq of ^{131}I will lead to an equivalent dose to the thyroid of approximately 0.4 mSv and the inhalation of 0.91 kBq of ^{133}I will lead to an equivalent dose to the thyroid of approximately 0.05 mSv for type F and 5 µm AMAD. For the adult, the inhaled activity required to produce a 100 mSv equivalent dose to the thyroid would show around 30,000 cps on the identifinder at the thyroid. The identifinder maximum range is 100,000 cps

5) Validation

The Monte Carlo calculations used in this paper were validated using the thyroid phantom developed at the IRD which had been used previously as part of an IAEA regional intercomparison exercise for in-vivo thyroid measurement[7]. ^{133}Ba was used as a substitute for ^{131}I as it has a photo-peak at almost exactly the same energy as ^{131}I (356 keV) and a half-life of 10.5 years.

The ICRP male phantom was used in VMC, and the head and thorax was removed so as to simulate as far as possible the cylindrical geometry of the thyroid phantom. The ^{133}Ba in the thyroid was measured with the *Identifinder* NHG-ULTRA at three distances and the results are given in the Table 6 and Figure 4.

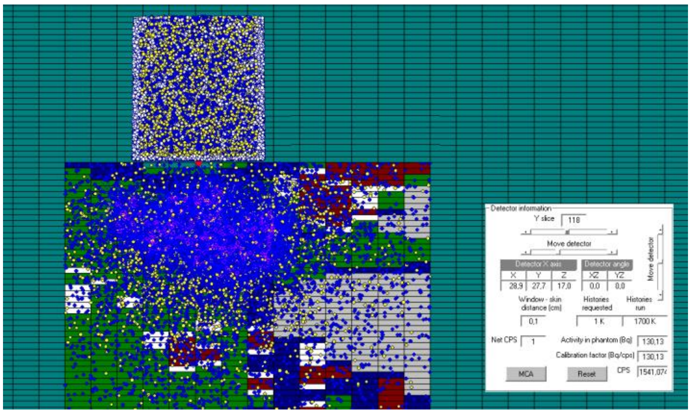

Figure 4: Simulation of Identifinder placed over thyroid of adult phantom counting ^{133}Ba in the thyroid

Table 6. Validation results for ^{133}Ba in the thyroid with an *Identifinder* placed at three distances from the skin surface.

Distance to surface thyroid phantom (cm)	Identifinder measurement (net cps)	VMC calculation	Ratio of *Identifinder* cps to VMC cps
0.1	1200	1310	0.92
4.8	410	366	1.1
9.8	170	153	1.1

A loss of signal through the photomultiplier and electronics of the Identifinder of 85% was considered in this paper. An electronic efficiency for NaI detectors between around 75% - 90 % has been verified in previous VMC validation work.

The ICRP male phantom thyroid and the thyroid phantom are different in their geometry as the phantom thyroid is represented by a sheet of paper cut into a shape resembling a butterfly, which is placed into a tissue equivalent plastic cylinder resembling the human neck.

6) Uncertainties

There are three main sources of uncertainty:

a) The highest source of uncertainty is the difference between the phantom used and the real person. The uncertainty in the calculation of the calibration factors is estimated to be around ±20% for the thyroid and ±30% for the lung and whole body counting.

b) The second source of uncertainty is the NaI detector "electronic efficiency". For the Identifinder, this is estimated to be 85%. That is, for every 100 photons that cause a

Compton or photoelectric interaction in the NaI crystal, only 85 photons are detected by the photo-multiplier and converted into one “count” on the detector. The variation of this “electronic efficiency” between detectors of the same model and manufacturer is estimated to be around ± 15%.

c) The Monte Carlo method employed generates uncertainties at a maximum of ± 10%

Compiling these uncertainties leads to a propagated uncertainty of around 40%.

7) Conclusions and future work

It is possible to estimate the activity of the radio-iodines in the thyroid with an unshielded NaI detector. The cross-fire cps coming from radionuclides deposited in the lung and whole body is around 10% of the cps coming from the iodine isotopes in the thyroid for all ages.

Calibration factors have been calculated for the Identifinder NHG Ultra with a NaI crystal with 35 mm diameter and 51 mm height, and other NaI crystal geometries have also been simulated. NaI crystals of this size already show very high cps (>10,000) for thyroid activities which would cause an equivalent dose above 100 mSv. Possibly a 25.4 mm x 25.4 mm NaI detector would be the most indicated, or a thin NaI detector such as a 9 mm diameter x 2 mm thick crystal.

8) Acknowledgements

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9) References

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