The Use of a High-resolution Radionuclide Identifier as a Portable Whole Body Monitor

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ABSTRACT

A portable radionuclide identifier (Detective^{TM}, Ortec, USA) has been calibrated so that it could be used following a radiological incident to measure radionuclides in whole body and also ^{131}I in thyroid. The system could be very quickly deployed as comparatively little equipment is required and the transportation can easily be achieved by one person. The rapid deployment would allow preliminary measurements to be made before the more sensitive HPA-RPD Transportable Whole Body Monitor is available. An evaluation has shown that, for a range of gamma-emitting radionuclides which could be released following a radiological incident, the instrument can detect activities in the body from intakes that would result in effective doses of less than 1 mSv. It therefore has sufficient sensitivity to be of value for monitoring. It is not sufficiently sensitive to be used for measurement of commonly encountered actinides in the body.

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CONTENTS

1 INTRODUCTION

This report describes the use of a portable radionuclide identifier as a portable whole body monitor and ^{131}I in thyroid monitor. Such an instrument would be used following a radiological incident involving the release of radioactive material, where a rapid response is necessary, and monitoring of people is required close to the incident. This work is based on that of Kramer et al (2005) who have previously described the role of the Detective^{TM} for portable whole body monitoring.

The instrument and how it would be deployed following an incident are described.

The method of efficiency calibration (i.e. the determination of calibration factors relating count rate to activity) and the measurement geometries which would be used are given. The efficiency of the system for measuring activity in whole body is shown for adults and children. The efficiency for adults of different statures has been investigated, as has the effect of activity being localised in the chest of the subject. The efficiency for measurement of radionuclides in the thyroid has also been determined.

The sensitivity of the instrument has been calculated in terms of minimum detectable activity for a range of radionuclides. An appendix lists the equipment which is required to deploy the Detective^{TM} in response to an incident.

2 DETECTOR

The detector used is the Ortec Detective^{TM} portable radionuclide identifier. A picture of this instrument with its battery charger is shown in figure 1. The Detective^{TM} is a compact instrument measuring 320 mm long, 160 mm wide and 320 mm high. The weight is 10.6 kg.

This instrument is primarily designed for identification of radionuclides using gamma emissions. The instrument consists of a coaxial high-resolution hyper-pure germanium detector (approximately 50 mm diameter x 30 mm long). The detector is cooled electrically using a low power Stirling cooler. This is important for transport reasons as liquid nitrogen is not required. The detector will operate for about 3 hours on an internal battery and can also be powered from a vehicle battery, through the ‘cigarette lighter socket’ during transport. An external battery is also available which will provide sufficient power for 8 hours of operation. The instrument has integral data acquisition electronics and can acquire and store spectra. More details about this instrument can be found on the Ortec website (http://www.ortec-online.com/psis.htm)

The instrument does not have software to analyse spectra, but can be connected to a laptop PC running suitable software. For this investigation, Ortec Maestro^{TM} MCA emulation software was used to import spectra from the Detective^{TM}. These were in then imported into Canberra Genie^{TM} software for analysis.

Figure 1 The Ortec Detective$^{\mathrm{TM}}$ portable radionuclide identifier (shown with battery charger)

3 MEASUREMENT GEOMETRIES

The use foreseen for this instrument is the screening of large numbers of people. This screening will identify people who require urgent treatment and also those who require more accurate measurements. To achieve this, the measurement geometries used need to be as simple as possible. Measurement geometry is the term used to describe the positioning of the Detective$^{\mathrm{TM}}$ relative to the person being measured. In addition, it is advantageous to keep the amount of equipment required to a minimum, to allow rapid deployment.

For whole body measurements, it was decided to have the person seated rather than standing as this produces a more reproducible counting geometry and also a slightly improved counting efficiency. In order to minimise the error in measured activity resulting from different body sizes and errors in detector positioning, a person to detector distance of 500 mm was chosen. This is also the distance used at the Human Monitoring Laboratory in Canada for similar work (Kramer et. al., 2005).

The detector is placed on a table which can be set at various heights. To allow maximum throughput, the number of detector positions needs to be kept to a minimum. For measurement of most people, the tabletop is set 720 mm from the ground. This sets the axis of the cylindrical crystal 880 mm from the ground. The subject sits on a chair with a seat height of 430 mm. This chair is a lightweight design and easily transported. This measurement geometry is shown in figure 2. This geometry is suitable for measurements of people older than 1 year. For very young children (< 1 year old) the table height is adjusted to 570 mm (detector centre-line 730 mm above the ground). This second geometry is necessary to maintain a reasonable counting efficiency for small children.

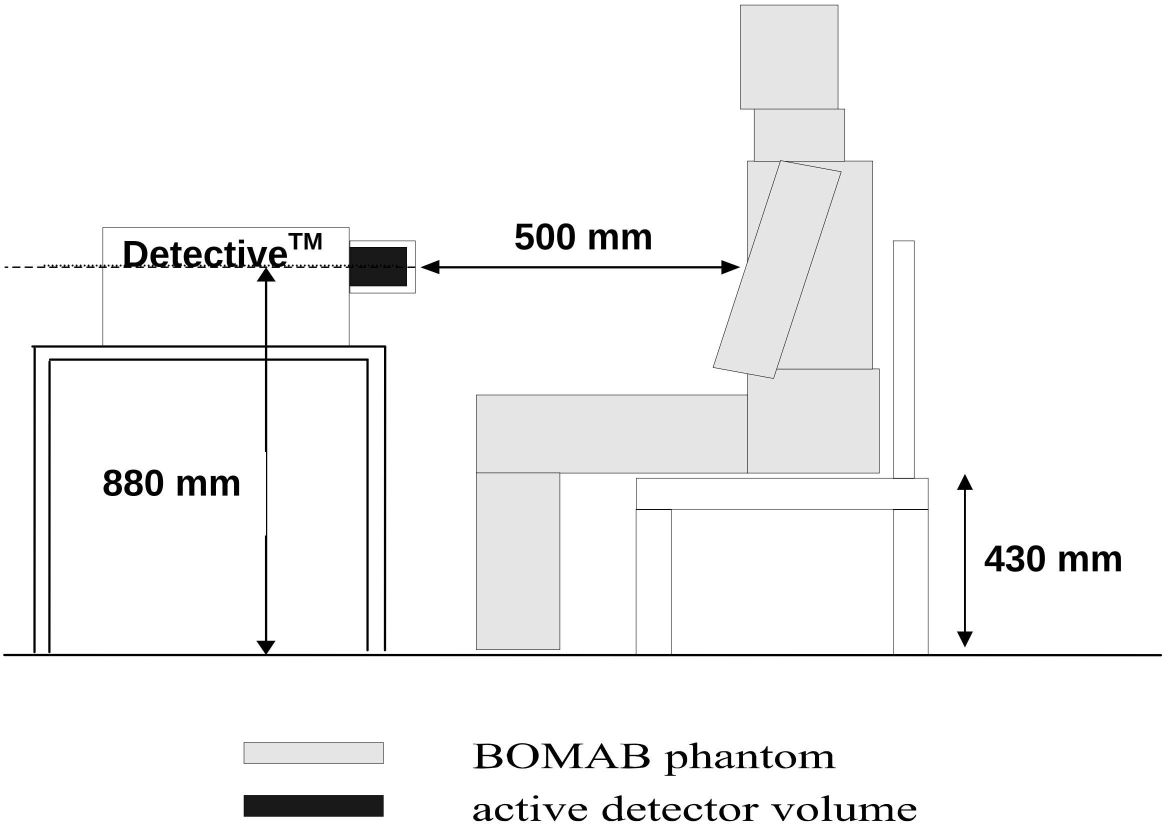

Figure 2 Counting geometry for adults and children (more than 1 year old)

For iodine in thyroid measurements the detector is positioned 200 mm from the neck of the subject. This distance reduces the errors produced by variable thyroid size and position, and is more acceptable to the subject than a closer detector position.

No collimation was used for any of the measurements in order to maximise the counting efficiency. Also, no shielding was used around the subject, to keep the system weight as low as possible.

4 CALIBRATION FOR WHOLE BODY AND CHEST MONITORING

The Detective^{TM} was efficiency-calibrated for whole body activity measurement in the energy range 88 keV to 1836 keV using a mixed radionuclide standard uniformly distributed in a BOMAB phantom (ICRU, 1992). The mixed radionuclide standard used (QCYB41, AEA Technology-QSA, UK), which is traceable to national laboratory standards, contains the following nuclides: ^{133}Ba, ^{57}Co, ^{139}Ce, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{65}Zn and ^{88}Y. The energy range covered by this standard is from 81 keV to 1.8 MeV. This mixture was chosen in preference to other mixed radionuclide standards because it may be diluted with 0.5M HCl. Other radionuclide mixtures require 4M or 6M HCl to avoid activity becoming attached to the container walls. The standard BOMAB phantom is approximately the same size and weight as ICRP Reference Man (ICRP, 1975). In order to be able to represent adults of other statures additional BOMAB phantom parts were used to either replace or augment sections of the standard phantom. In this way phantoms were made to represent tall and light, tall and heavy, short and light and short and heavy adults, each phantom representing the 25th and 75th quartile for adults of all ages for weight, and the heights are close to the minimum and maximum found in all adults (ICRP, 1975). The information taken from ICRP Reference Man is in broad agreement with the later publication ‘Basic Anatomical and Physical Data for Use in Radiological Protection’ (ICRP, 2002). Efforts were made to ensure that the proportion of mass in the head, arms and trunk was as realistic as possible. The phantom construction details are described in an earlier paper (Youngman, 2002).

In addition, phantoms were constructed from standard phantom parts to represent children of average height and weight at ages birth, 3, 6 and 9 months, and 1, 2, 4, 8, 14 and 16 years. Again, efforts were made to represent accurately the proportion of mass in the head, arms and trunk, although this was only partially achieved for children younger than 4 years. The phantom construction details are also given in the earlier paper (Youngman, 2002).

The total activity of radionuclides in the standard BOMAB phantom was approximately 80 kBq and a count time of approximately 100,000 seconds was used for calibrations.

The whole body counting efficiencies for a standard adult and for children are shown in Figure 3a and 3b. The curves shown are 4th order polynomial functions produced by fitting the efficiency at each gamma-ray energy. As would be expected the counting efficiency generally decreases with increasing age and therefore subject height. It should be noted that the range of counting efficiencies is quite small. It is therefore possible to use a single calibration file for subjects of all ages for whole body measurements. If for example the values for an adult were used for all subjects the maximum error would be approximately a factor of 2 if small children were measured using this calibration. This approach would tend to overestimate whole body activity for children and would therefore avoid underestimation of dose. If more accurate activity measurements are required, then ages 14 and over should be determined using the adult calibration factors. Similarly, activity calculations for ages 8-14 should be determined using the 14 year old calibration factors, ages 2-8 using the calibration factors for an 8 year old, and age less than 2 using the calibration factors for a 2 year old. Children less than 6 months old should be counted using the factors determined for new born babies. These counting efficiency factors are smaller than would be expected because even with a table height of 570 mm the detector axis is well above the subject. Because of the uncertainties on whole body counting efficiencies, there is no justification for using calibrations to represent narrower age groups.

Figure 4 shows the effect of different adult statures on whole body counting efficiency. It can be seen that heavily built adults have lower counting efficiency than standard or light adults.

To simulate activity being localised in the lungs the chest section of each BOMAB phantom was counted with the other sections replaced with identical pieces containing distilled water. It was only possible to simulate activity in the chest for the largest BOMAB phantoms, as the smaller phantoms do not have a distinct chest. The calculated counting efficiency is shown in figure 5. It can be seen that the effect of activity being concentrated in the chest has little effect on whole body counting activity at gamma-ray energies above about 500 keV. At lower energies the proximity of the thighs to the detector means that the efficiency of counting the whole body is greater than when the activity is localised in the chest. This behaviour is different from the HPA transportable whole body monitor (Youngman, 2002) where the use of a collimator means that the detector is less sensitive to activity in the legs of the subject.

5 CALIBRATION FOR RADIOIODINE IN THYROID MONITORING

Calibration factors for determining activities of iodine radionuclides in the thyroid were obtained using the same mixed radionuclide standard that was used for whole body calibrations. The mixture was dispensed into two 6 ml plastic vials representing the two lobes of the thyroid. The phantom used is a solid cylinder of tissue equivalent resin in which there are pairs of holes drilled at various distances from the surface so that the effect of thyroid depth can be investigated. The thyroid phantom replaced the neck section of a BOMAB phantom filled with distilled water for the efficiency measurements. The thyroid counting efficiencies for two thyroid depths, appropriate for people older than 14 years (thyroid depth 3.6 cm) and less than 14 years (thyroid depth 1.8 cm) are shown in Figure 6.

6 TRANSPORT

The transport of the whole body monitoring system is straightforward. The small overall weight, electrical rather than liquid nitrogen cooling and the absence of sophisticated detector supports and shielding allow the equipment to be readily loaded and transported in an ordinary car. The system components are listed in appendix A. The system could be loaded in less than one hour, and set up in a similar time. This can be compared with the existing HPA-RPD transportable whole body monitor, which requires a team of four to transport and takes approximately 5 hours to load, and 2 hours to assemble (Youngman, 2002). The existing system also requires two dedicated trailers and two vehicles equipped with tow bars. This system uses detectors cooled with liquid nitrogen and therefore a small quantity of this must also be transported.

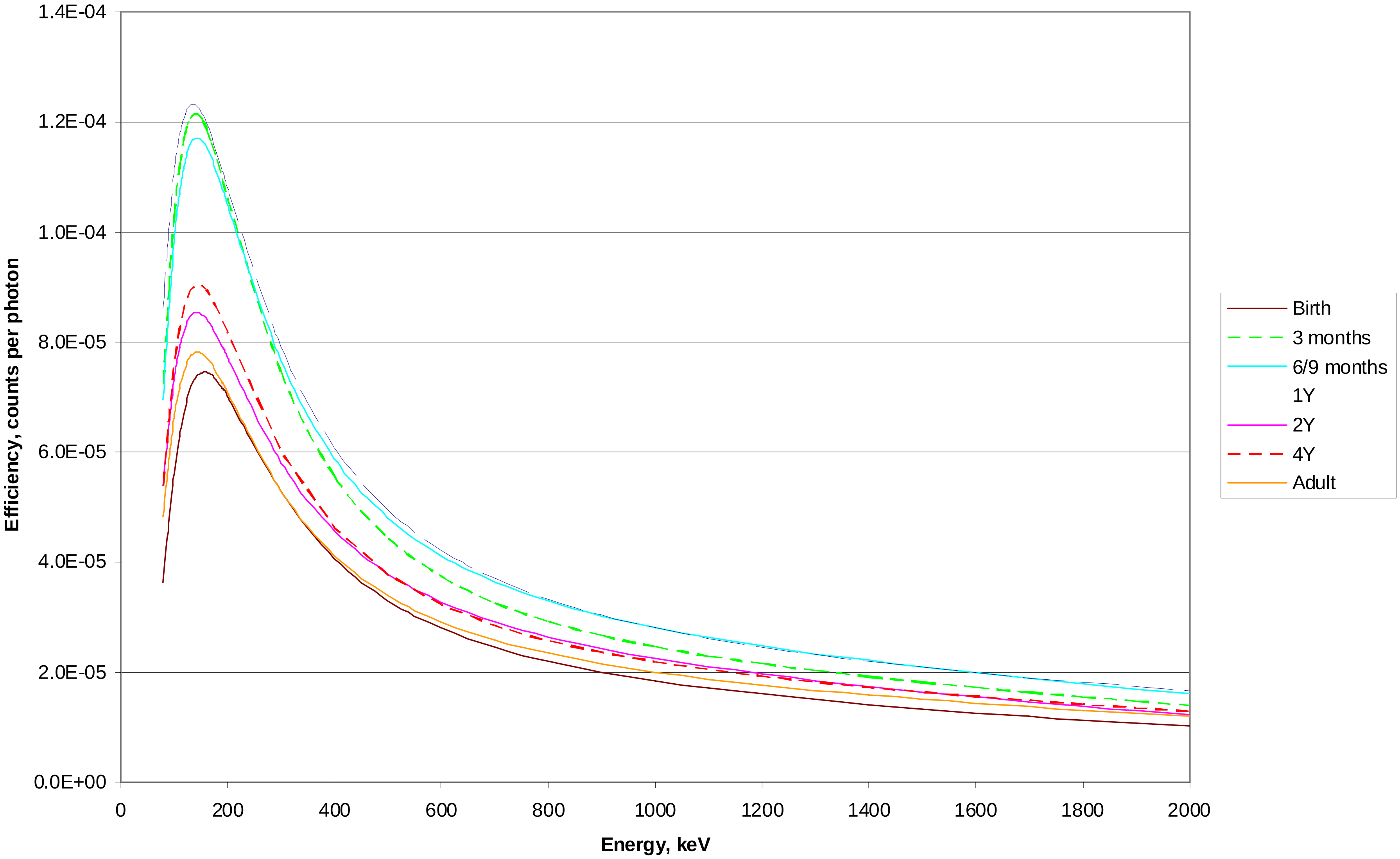

Figure 3a Whole body counting efficiency for standard adult and younger children

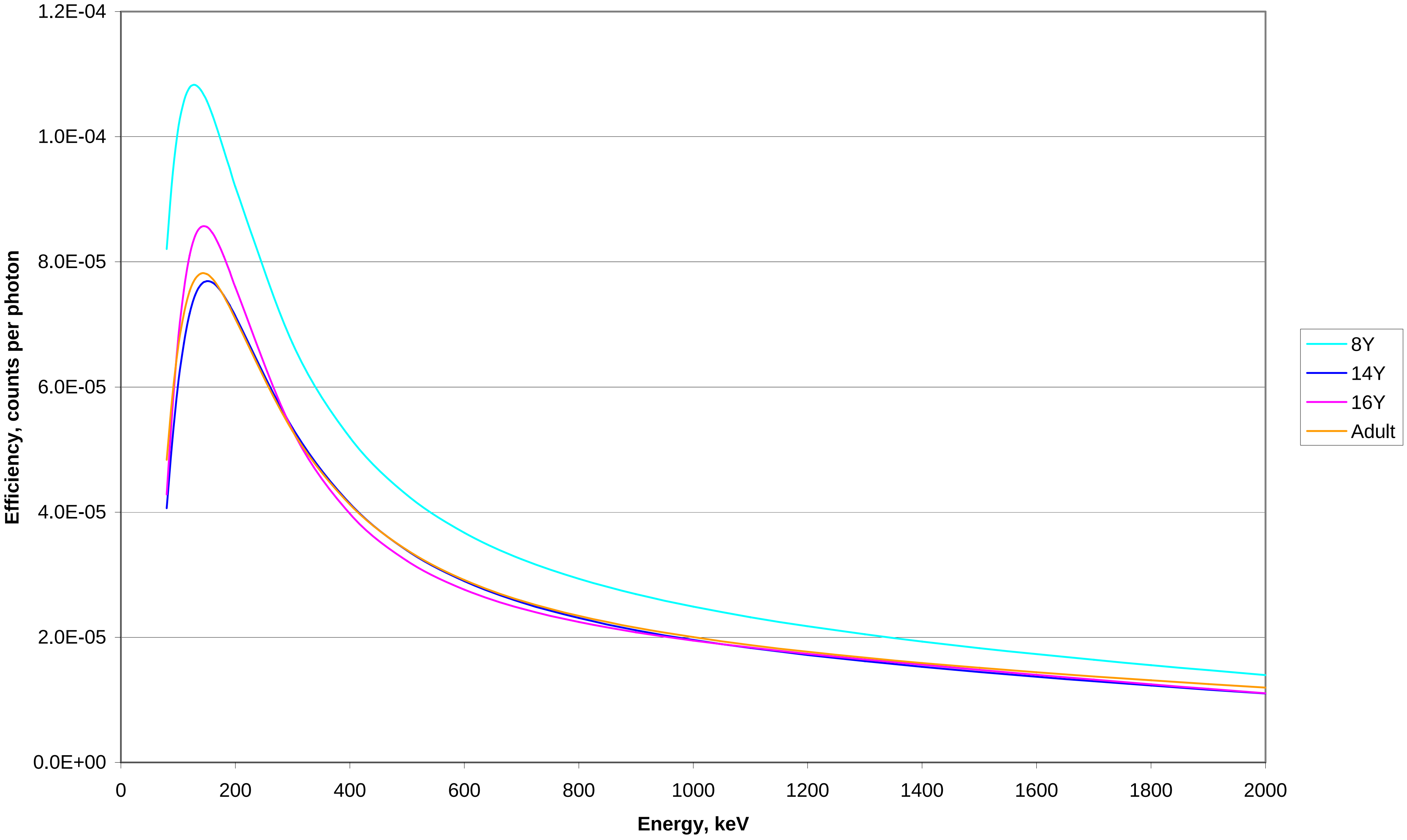

Figure 3b Whole body counting efficiency for standard adult and older children

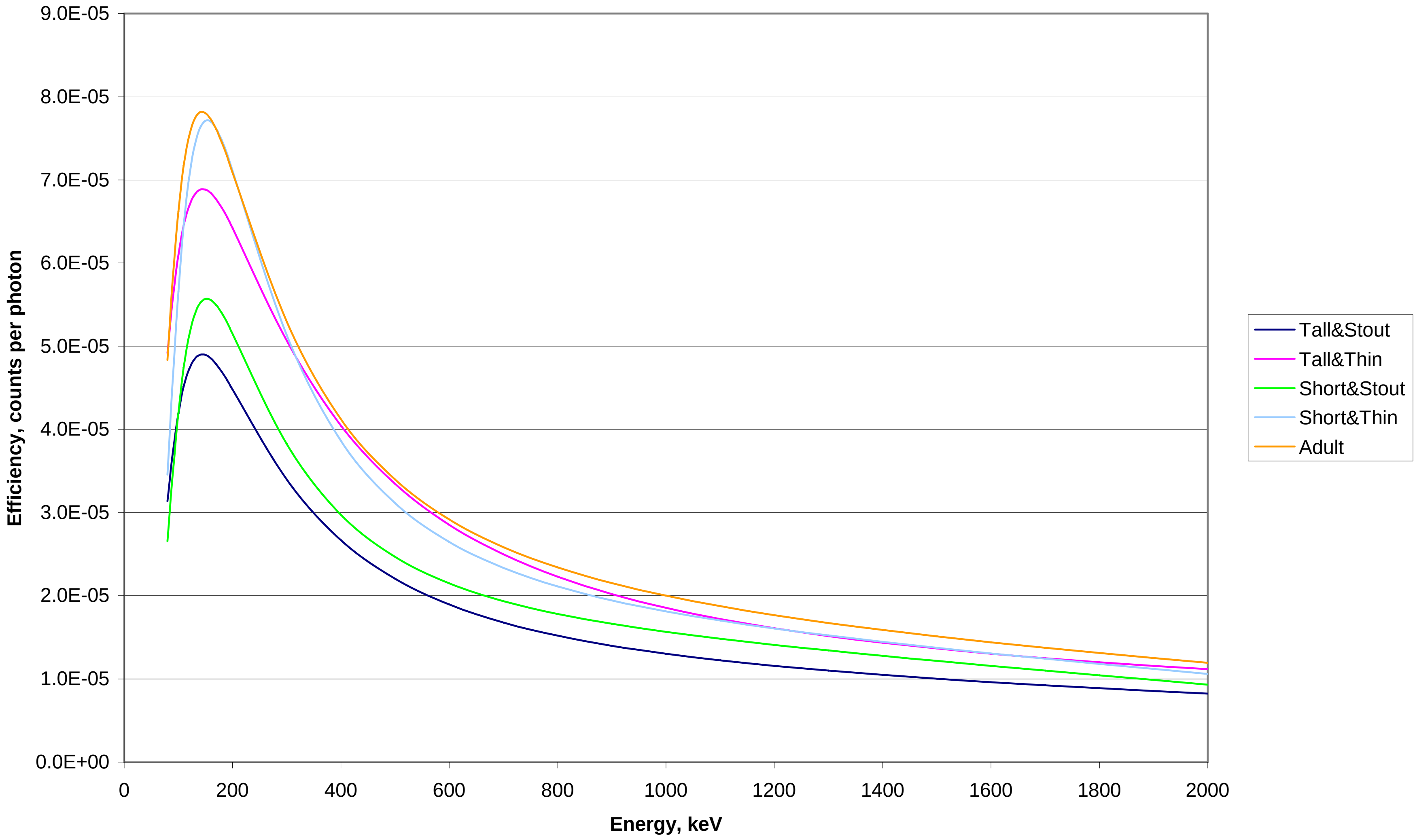

Figure 4 Whole body counting efficiency for different sized adults

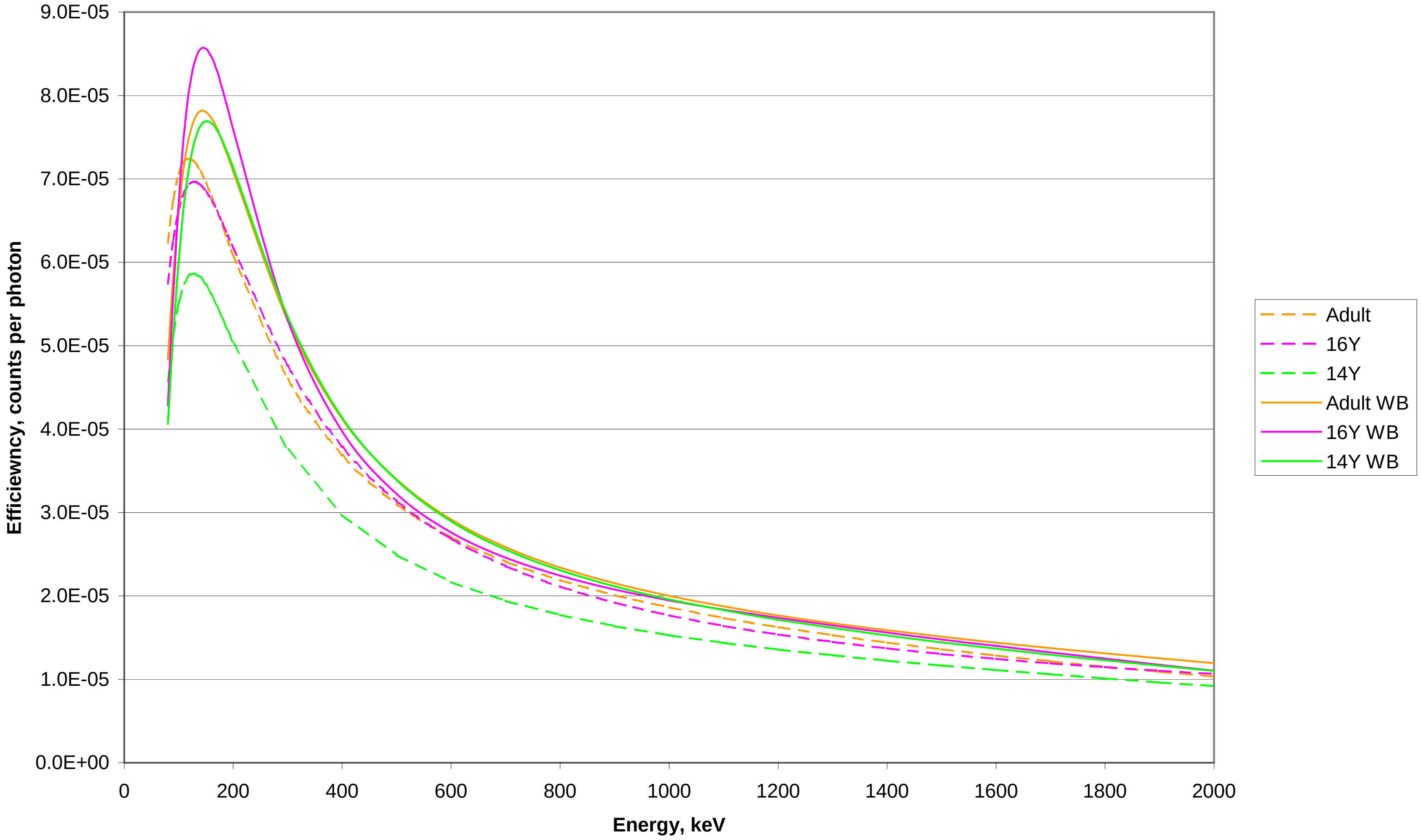

Figure 5 Counting efficiency for activity localised in the chest for standard adults and older children (whole body (WB) counting activity is shown for comparison)

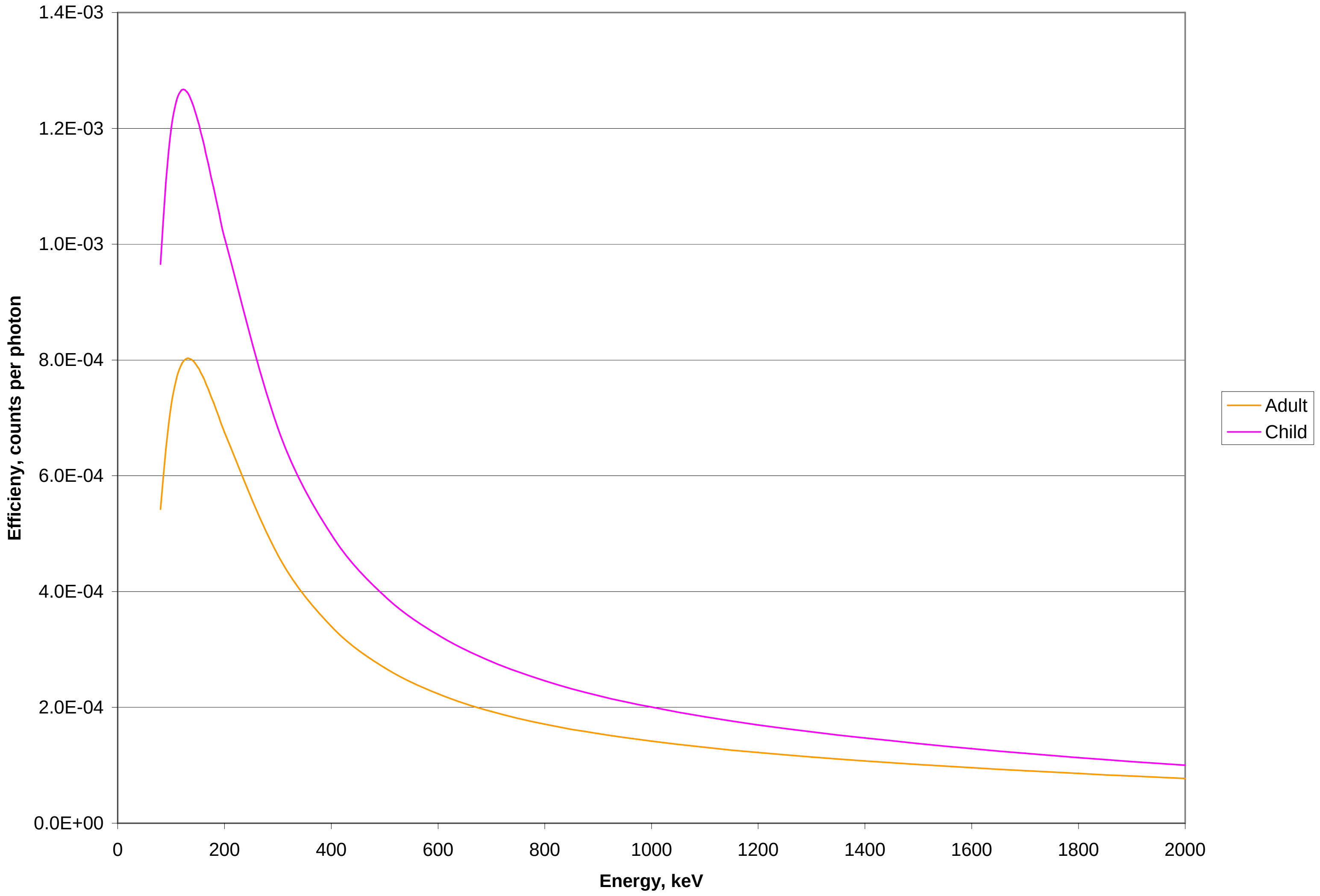

Figure 6 Counting efficiency for activity in the thyroid

7 PERFORMANCE

The performance of the Detective^{TM} as a whole body monitor (or iodine in thyroid monitor) has been determined by calculating the effective dose which corresponds to the minimum detectable activity (MDAs). The MDA is the activity which, if present in the subject, would, on average, be detected by 95 out of 100 measurements. This was done for eight radionuclides (table 1) which could be released in a radiological incident. This table gives the MDAs calculated for a 5 minute count in a normal room environment, for a 1 year old child and an adult. MDAs for the RPD transportable whole body monitoring system (tWBM), (Youngman, 2002) are included for comparison.

Table 1 Minimum detectable activities (MDA) for whole body (or ^{131}I in thyroid) measurement for the Detective^{TM} and the Transportable whole body monitoring system

		MDA, kBq			
		Detective^{TM}		Transportable WBM	
Nuclide	Energy of principal emission (keV)	Age 1 year	Adult	Age 1 year	Adult
^{60}Co	1332	3.2	4.4	0.16	0.38
^{75}Se	265	6.1	9.1	0.31	0.81
^{99}Mo + ^{99m}Tc	140	5.3	8.3	0.31	0.78
^{131}I	364	0.55	0.80	0.014	0.023
^{137}Cs	662	4.2	6.0	0.18	0.48
^{169}Yb	198	11	17	0.59	1.6
^{192}Ir	468	4.3	6.4	0.18	0.48
^{241}Am	60	33	66	3.8	12.2

As expected MDAs for the unshielded Detective based system are higher than for the tWBM. Table 1 shows that MDAs for the Detective based system are of the order of a factor of 10 higher than the tWBM for whole body measurements of an adult. For whole body measurements of a 1 year old child the MDAs are about 20 times higher, and for measurements of ^{131}I in thyroid the MDAs are about 30 times higher.

The intake which corresponds to these MDAs was calculated assuming intake by inhalation 5 days before measurement, and assuming an AMAD of 1µm and light exercise (ICRP 71). For ^{131}I it was assumed that the phase was particulate. The committed effective dose, (E(50), which corresponds to this intake has also been calculated. Table 2 shows the intakes and doses for a 1 year old and for an adult. The doses for a child are higher despite the smaller MDAs because of the higher dose coefficients for children. It can be seen that for many radionuclides the Detective^{TM} can detect intakes which correspond to doses of less than 1 mSv. The exception is for intakes of ^{241}Am where the minimum detectable dose is about 20 Sv. As ^{241}Am is the most easily measured of the commonly encountered actinides (because of the 60 keV gamma-ray emission) using external counters, the monitoring system described here would not be of any value for directly determining intakes of actinides. If the actinide formed part of a well characterised mix of radionuclides it may be possible to use a more easily measureable radionuclide as a tracer for the actinide. For in vivo measurements of actinides, well shielded facilities using HPGe detectors optimised for detection of low energy photons are usually required; such as those housed at HPA-RPD in Chilton.

Table 2 Intakes and committed effective doses, E(50), corresponding to a whole body (or thyroid) content equivalent to the MDA (table 1) for a 1 year old and for an adult, assuming the intake took place 5 days earlier

		1 year		Adult	
Nuclide	Absorption Type	Intake (kBq)	E(50), mSv	Intake (kBq)	E(50), mSv
^{60}Co	M	26	0.88	33	0.32
^{75}Se	F	19	0.11	33	0.03
^{99}Mo + ^{99m}Tc	M	126	0.55	187	0.17
^{131}I	F	3.8	0.61 (12.1)	4.7	0.10 (1.9)
^{137}Cs	F	13	0.07	20	0.09
^{169}Yb	M	105	0.92	144	0.36
^{192}Ir	F	23	0.25	36	0.06
^{241}Am	M	260	18,000	470	20,000

Note: for ^{131}I the committed dose equivalent to the thyroid is also shown in brackets

8 CONCLUSIONS

The Detective^{TM} radionuclide identifier can be used as a portable whole body monitor and also as a ^{131}I in thyroid monitor. The system can detect activities in people which correspond to committed effective doses of less than 1 mSv for many gamma emitting radionuclides. The system could be quickly and easily transported to the vicinity of any incident. A radionuclide identifier based portable whole body monitoring equipment would be a useful complement to the HPA-RPD transportable whole body monitoring and static systems. For many scenarios, the new equipment will have sufficient sensitivity to be used for screening of people, and for other radionuclides the superior sensitivity of the transportable whole body monitor may be required. The transportable system is also less affected by environmental contamination that will reduce measurement sensitivity.

9 REFERENCES

Kramer GH. Personal communication 2006.

Kramer GH, Hauck BM, Capello K. The HML's new field deployable high resolution whole body counter. Health Phys. 89(Supplement 5):S60-S68; 2005.

ICRU (1992). Phantoms and computational models in therapy, diagnosis and protection. Bethesda MD, ICRU Report 48.

ICRP (1975). Report of the Task Group on Reference Man. ICRP Publication 23.

ICRP (2002) Basic Anatomical and Physiological Data for Use in Radiological Protection. ICRP Publication 89, Annals of the ICRP 32 (3-4).

Youngman M J (2002) Transportable In Vivo Monitoring System for Accident Monitoring of Internal Contamination NRPB-W12.

ICRP (1995) Age-dependant Doses to Members of the Public from Intakes of Radionuclides: Part 4 Inhalation Dose Coefficients. ICRP Publication 71, Annals of the ICRP 25 (3-4).

APPENDIX A List of equipment

1. Detective^{TM} portable radionuclide identifier
2. Laptop PC with Maestro MCA emulation software and Genie 2000 Gamma Analysis software
3. USB cable to connect PC and Detective^{TM}
4. Mains charger
5. Battery belt (allowing battery operation for approximately 8 hours)
6. Car cigarette lighter to Detective^{TM} cable (for powering Detective^{TM} during transport)
7. Metal plate to stand Detective^{TM} on during transport (to allow air to circulate underneath when on a soft surface)
8. Caesium-137 source for energy calibration
9. Height adjustable folding table
10. Chair (with seat height of approximately 430 mm)
11. ERIDAS dose calculation software
12. Report forms
13. Plastic film to cover detector (to allow easy removal of contamination)

In addition material for control of contamination may be required (for example, materials for floor covering, plastic bags) and also PPE.