A New mobile whole-body counter for measurement of internal contamination in Finland

Jussi Huikari, Maarit Muikku and Sauli Pusa

STUK - Radiation and Nuclear Safety Authority
P.O. Box 14, 00881 Helsinki, Finland
jussi.huikari@stuk.fi

Abstract

STUK - Radiation and Nuclear Safety Authority has obtained a new mobile whole-body counter to assess the internal exposure of radiation workers and the exposure of the Finnish public. This unit can also be mobilised in emergency situations. The need for assessing internal radiation doses in emergency situations is evident which has been demonstrated after the accidents in e.g. Brasil and Ukraina. In addition, new measurement setup is being developed in order to obtain information of the location of the contamination inside the body.

Keywords: Whole body counter, Monte Carlo simulations, voxel phantoms

1 Introduction

Assessment of internal radiation doses can be done using results from direct measurement of people or indirectly by excreta measurements. Estimations can also be made using air concentration data or activity concentrations in foodstuffs combined with consumption data. The aim of measurements is most often to determine the intake of radioactive substances. The internal radiation dose is then assessed using metabolic and dosimetric models. *In-vivo* measurements are used to assess the internal exposure of radiation workers as well as the exposure of the public. In cases with high internal contamination the purpose of measurements is to help in deciding if medical treatment or other types of measurement for more exact dosimetry is needed. In situations with prolonged exposure repeated measurements are recommended. In emergency situations direct measurements should be done as soon as possible after an alert to give support for decision making and to reassure the general public.

2 Equipment

STUK - Radiation and Nuclear Safety Authority has obtained a new mobile whole-body counter for measurement of internal contamination (Figure 2.1.). The unit has been built on standard Volvo FE 42R truck. The carossery is insulated and equipped with air conditioning, electric and diesel heaters making all year usage comfortable. The monitoring unit uses 230 V AC, which is usually taken from the nearest wall. This external mains is backed up by a UPS system consisting of a powerful sinewave inverter, a sophisticated battery charger, a high speed AC transfer switch and AC distribution in a single light weight and compact enclosure. A battery pack (24 V/400 Ah) has been added in order to maintain measuring devices 24 hours in case of a loss of the external mains. This battery pack is also charged by the alternator of the truck when the engine is running.

Figure 2.1. A new mobile whole-body counter.

The whole-body monitor inside the carossery consists of two HPGe detectors and digital electronics (Dspec Pro [1]). The geometry is a modified chair with a lead made shadow-shield to reduce background in detectors (Figure 2.2. on the left). The detector set-up consists of a coaxial p-type HPGe-detector with a 90% efficiency and GAMMA-X detector which is a coaxial n-type HPGe having an efficiency of 80%. The former detector is placed in the middle of the chair for whole-body measurements and the latter is placed closer to the upper body, providing the possibility to detect iodine accumulated in the thyroid, for example. The GAMMA-X has ultra thin entrance window made of beryllium, providing good efficiency also for low energy γ-rays. The detectors are surrounded by a 5 cm thick lead shield. The typical time used in a routine measurement is 1000 s. Background is determined using the background phantom consisting of 14 pieces of 5 kg sugar bags. If needed the measurement distance can be adjusted by moving the detectors and the lead shield up or down.

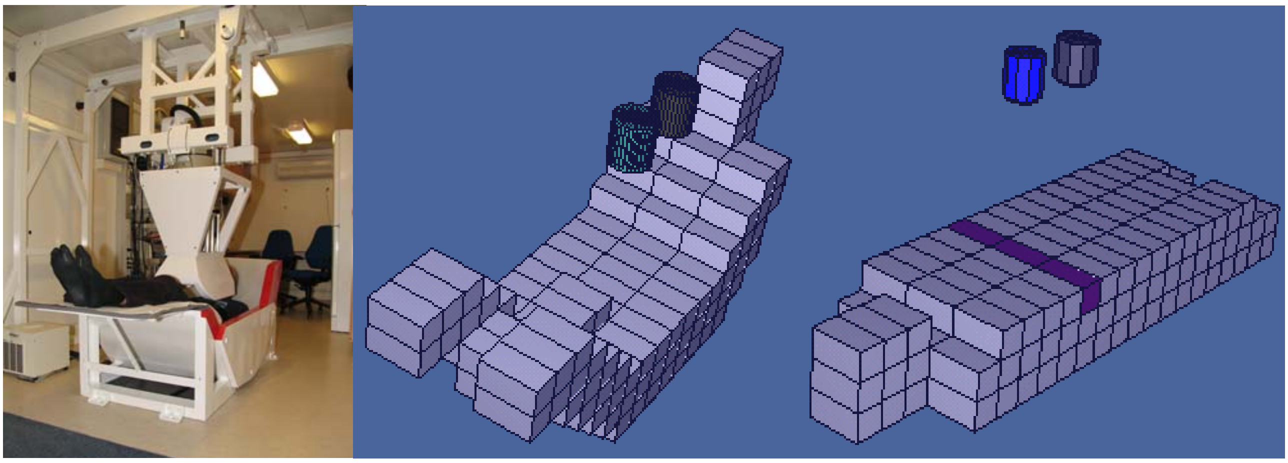

Figure 2.2. Left: Inner view of the truck. Center: MCNPX model of the present setup. Right:New lie-down geometry. Lead made background shields are removed for clarity reasons.

3 Method

The efficiency calibration was performed using the adult St. Petersburg whole-body phantom [2] with ^{60}Co, ^{137}Cs, ^{40}K and ^{152}Eu rods (energy range 122-1460 keV, Figure 3.1). In addition, three St. Petersburg thyroid phantoms with ^{133}Ba capsules were used: adult, teenager (14 years old) and child (6 years old). Barium is used to imitate ^{131}I as its gamma energies are in the same energy range. The body burden of adult persons is determined roughly from knees to nose. The whole-body phantoms from 12 kg to 110 kg corresponding ages from two-year old to adult were used to obtain the correction to the efficiency due to the size of the measured person. The correction factor ranges from 1.4 (12 kg) via 0.9 (90 kg) to 1 (110 kg).

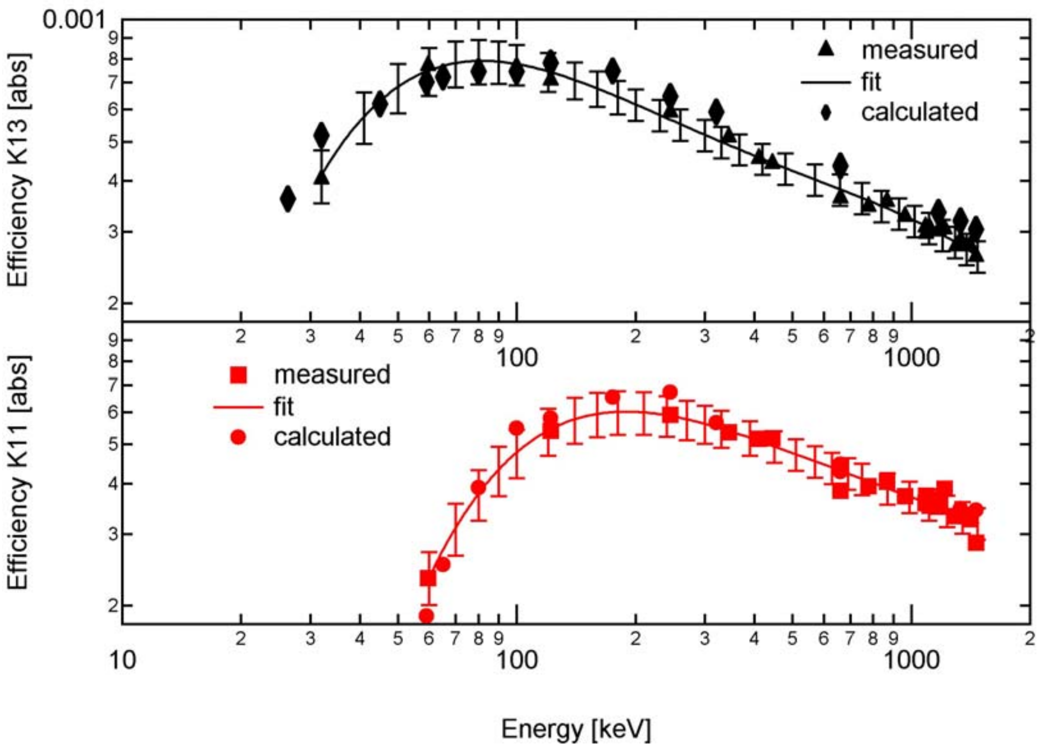

Figure 3.1. Efficiency curves for the p-type HPGe (K11, lower) and n-type GAMMA-X HPGe (K13, upper) detectors.

The uncertainty on the absolute γ-efficiency is 10 % for γ-rays >200 keV and goes up to 15 % towards lower energies. The final uncertainty on the activity measured will be determined by adding quadratically the statistical uncertainty of the identified γ-peak and that of the efficiency. For the most of the cases, uncertainties on the branching ratios and half-lives of the nuclei can be neglected. The minimum detectable activities (MDAs) [4] for the most commonly detected artificial nuclei, ^{137}Cs and ^{60}Co have been determined to be of the order of 100 Bq. The minimum detectable activities for the most of the common radionuclides found in nuclear power plants, industry or radiomedicine are sufficient from the point of view of radiation protection. As the MDA depends on the background level it should be determined when the background changes. In emergency situations the MDAs can be higher due to the higher background from the environment. However, as the MDA increases as a function of square root of background rate, the equipment will be able to handle it. *In-vivo* monitoring can also be used to follow prolonged exposure e.g. after a nuclear or radiological accident. Presently, the efficiency calibration assumes that the radionuclides are homogenously distributed in human body.

4 Mathematical calibrations and new set-up

STUK has launched the project in order to upgrade the measuring unit. The main goal of the project is to obtain better treatment for the radionuclides that are not homogenously distributed in the body, like freshly inhaled radionuclides in the emergency situations. Other goals are to improve ergonomics for the person being measured and to gain more information about the location of the contamination in the body in the cases where intake path is not known. In addition, lower detection limits for some specific nuclei (like ^{241}Am, ^{123}I) which emit only low energy (<200 keV) gamma rays will be necessary to achieve. To begin with, Monte Carlo simulations will be used with voxel phantoms. The code selected is MCNPX[5].

The simulations were started by reproducing the calibration for the present setup where good measurements are available (Figure 3.1.). Next, more comfortable lie-down geometry was studied (Figure 2.2.). The calculated detection efficiency for ^{60}Co is presented in Figure 4.1. With this arrangement, the overall efficiency will be better by a factor of 1.7 as the detectors can be closer. However, the detection efficiency will improve only for the region below the detectors.

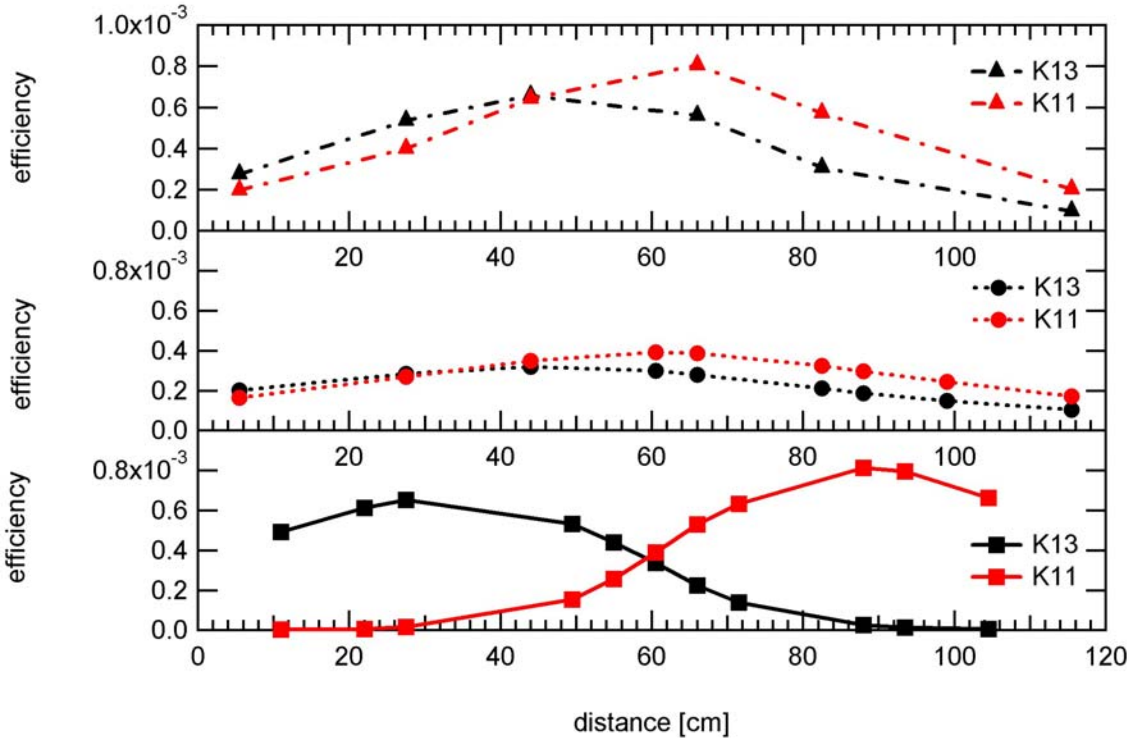

Figure 4.1. MCNPX simulation results for a polyetylene brick phantom. Each point has been calculated such a way that 30 cm long cylinder of ^{60}Co was placed in different locations perpendicular to longitudinal axis of the phantom (Figure 2.2.). Top: Detectors were 15 cm apart and 26 cm away from the phantom. Middle: detectors 15 cm apart and 41 cm away. Bottom: detectors 37 cm apart and 26 cm away and there are lead collimators around each crystal narrowing the solid angle.

This can be compensated by using the sum spectrum for species like ^{137}Cs, which is known to be evenly distributed. For non-even distributions localisation of the activity can be done by comparing the measured two spectra. As can be seen in Figure 4.1., spatial resolution will be just enough to determine whether the activity is in lungs only or has it already been transferred further, like to liver as ^{60}Co would do.

5 Conclusions

In-vivo measurements are used to assess the internal exposure of radiation workers as well as the exposure of the public. The new mobile whole-body counter obtained by STUK - Radiation and Nuclear Safety Authority in Finland fulfils the requirements defined by the dose registration limits of radiation workers. In emergency situations it will be necessary to perform also direct measurements on people for reassurance of the public even if such measurements would not be necessary from a strict radiation protection point of view. The new measurement unit being developed will provide fast and reliable method for both screening and dose assessment purposes. The gamma ray detection efficiency for the whole energy range will be greatly increased. A significant improvement will be the new feature of localisation of the internal contamination. In addition, it will give more precise information about possible ^{131}I accumulation in the thyroid. The new setup presented here will be studied further in STUK and also calibrations with well defined calibration phantoms will be necessary before commissioning.

References

[1] DSPEC Pro, Digital gamma-ray spectrometer, Hardware user’s manual, ORTEC part no. 794380, manual revision C 2005, IL USA.

[2] Kovtun, A.N., Firsanov, V.B., Fominykh, V.I. and Isaakyan, G.A. Metrological parameters of the unified calibration whole-body phantom with gamma-emitting radionuclides. Radiation Protection Dosimetry 89(3-4), 239-242 (2000).

[3] Moilanen A, HPGe-ilmaisimia käyttävän kokokehomittauslaitteiston kalibrointi ja testaus (in Finnish). Helsinki University of Technology, Espoo 2007.

[4] Glenn F. Knoll, Radiation Detection and Measurement, 3rd ed., 1999, ISBN 0-471-07338-5

[5] *Pelowitz, D., 2005. MCNPX™ User’s Manual, Version 2.5.0.* Los Alamos National Laboratory, Los Alamos, New Mexico, USA.