Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 580 (2007) 694–697
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

In situ gamma spectrometry measurements for the verification of simulated irradiation conditions at MAYAK PA work places

M. Smetanin[a], E. Vasilenko[a], M. Semenov[a], G. Takoudis[b], S. Xanthos[b], A. Clouvas[b,*], J. Silva[c,b]

[a]MAYAK PA, Lenin Street 31, 456780 Ozyorsk, Russia
[b]Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece
[c]Universite Pierre et Marie Curie (Paris VI), U.F.R. Physique BC212, 4 Place Jussieu, 7525 Paris cedex 05, France

Available online 17 May 2007

Abstract

Experimental and simulated photon flux energy distributions in different locations of a MAYAK PA work place are compared. The experimental photon fluxes are deduced by in situ gamma spectrometry measurements with a portable Germanium detector. The method used for the conversion of the in situ gamma ray spectra to photon flux energy distribution is the spectral stripping method. This method requires the simulation of the portable Germanium detector, which has been performed with the MCNP code of Los Alamos and the GEANT code of CERN. The calculated (simulated) photon flux energy distributions were performed with the MCNP code. The results obtained from the comparison of the experimental and calculated photon flux energy distributions are presented and discussed.

PACS: 87.50.N, P; 02.50.N; 07.85

Keywords: Radiation protection; Gamma spectroscopy; Monte Carlo simulations; MAYAK PA

1. Introduction

The Mayak Worker and Techa River Cohorts in the Southern Urals are internationally recognized as being emerging major sources of information on health risks associated with significant exposure to radiation. The general objective of the project "Southern Urals Radiation Risk Research" (integrated project FP6-516378) is to improve the quantification of the risks of radiation, based on epidemiological studies of exposed cohorts in the Southern Urals. One of the subprojects is aimed at quantifying individual external dose values for Mayak PA workers by film dosimetry, electron paramagnetic resonance measurements of teeth (EPR) and fluorescence in situ hybridization measurements of chromosomal aberrations in lymphocytes (FISH). Reconstruction of occupational dose from film dosimetry, absorbed dose in tooth and FISH requires as input numerical-simulated irradiation conditions at work place and in particular the knowledge of the photon energy spectra. Investigation of irradiation conditions were performed at work places in the divisions of the reactor, plutonium and radiochemical facilities of MAYAK PA. All divisions include 7493 work places in 615 work areas, which are divided into eight groups of work areas, each with comparable radiation sources and irradiation parameters. For each group numerical simulation of irradiation conditions exists and will be used for evaluation of external occupational dose values from film dosimetry, EPR measurements of teeth and FISH measurements. Verification of simulation of irradiation conditions are done by in situ gamma spectrometry measurements and Monte Carlo computations at those work places of the groups of work areas, which did not significantly change since 1950.

As a first step, in the present work, experimental and simulated photon flux energy distributions in different locations of a Mayak work place are compared.

*Corresponding author. Tel.: +30 2310 996353; fax: +30 2310 996302.
E-mail address: clouvas@eng.auth.gr (A. Clouvas).

0168-9002/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2007.05.124

The experimental photon fluxes are deduced by in situ gamma spectrometry measurements with portable Germanium detector. The method used for the conversion of the in situ gamma ray spectra to photon flux energy distribution is the spectral stripping method. This method requires the simulation of the portable Germaniun detector, which has been performed with the MCNP code of Los Alamos and the GEANT code of CERN. The calculated (simulated) photon flux energy distributions were performed with the MCNP code. The results obtained from the comparison of the experimental and calculated photon flux energy distributions are presented and discussed.

2. Materials and methods

2.1. In situ gamma spectrometry measurements

The in situ gamma spectrometry measurements were performed in a work place of MAYAK PA. The dimensions of the room, the location of the ^{137}Cs source and the different positions in the room where the in situ gamma spectrometry measurements have been performed are shown in Fig. 1.

The source of 257 mCi ^{137}Cs (location "2" in Fig. 1) is inside a cylinder (stainless steel) of thickness of 5 mm. In front of the source (location "1" in Fig. 1) there is a lead barrier. The dimensions of the lead shield are $550 \times 500 \times 50$ mm. The in situ gamma spectrometry measurements were performed in three positions (location Nos. 1, 2, 3 in Fig. 1) with a 10% n-type portable Germanium detector. In addition, background measurements without the ^{137}Cs source were performed at the same positions as with the point source .The duration of each in situ gamma spectrometry measurement with the ^{137}Cs source was 600 s and the duration of each background measurement was 3600 s.

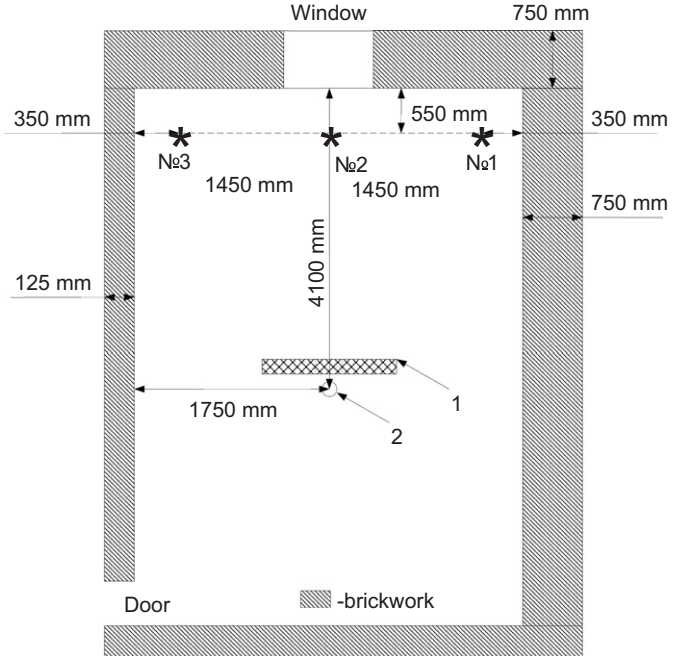

Fig. 1. MAYAK PA work place (Nos. 1, 2, 3): the positions where the in situ gamma spectrometry measurements have been performed: (1) lead barrier; (2) 257 mCi ^{137}Cs source.

2.2. Monte Carlo computations

The Monte Carlo simulations were performed using the MCNP code. The simulated geometry introduced in the MCNP code is relatively simple and simulates the work place (Fig. 1) used in the in situ gamma spectrometry measurements. Standard densities for lead, stainless steel, bricks, air, etc. were used. The ^{137}Cs point source position as well as the detector positions were the same as the experimental ones. In each simulation, 50 million photons were emitted isotropically from the point source. For the determination of the photon flux energy distribution, the point detector, which is a standard tally of the MCNP code, was used. The point detector gives the energy distribution of the photon flux directly, normalized per starting photon. In order to compare the simulated and the experimental photon flux energy distributions, the simulated photon flux energy distributions normalized per starting photon, were multiplied by the number of photons emitted per second by the ^{137}Cs source.

2.3. Spectral stripping procedure

The scope of this work is the comparison between experimental and simulated photon flux energy distributions. The stripping spectral method used in the present work to convert the in situ gamma ray spectrum to photon flux energy distribution is comprised of three steps and to a certain extent is similar to the one we have reported previously [1,2] for other Germanium detectors.

1. First, the in situ background spectrum (measured with no ^{137}Cs source) is subtracted from the in situ gamma ray spectrum (measured with the ^{137}Cs source). The resulting spectrum is only due to counts induced by the interaction with the germanium crystal of photons emitted by the gamma point source and reaching the detector unscattered or after scattering in the different materials (e.g. lead barrier, walls, etc.).
2. Second, the resulting spectrum is stripped of the partial absorption energy events leaving only the events corresponding to the full absorption energy of a gamma ray. The partial absorption events are the result of Compton scatter in the Germanium crystal.
3. Finally, the resulting spectrum, which represents in this stage both primary and scattered photons, can then be converted to photon flux energy spectrum by applying the full absorption efficiency curve of the detector.

The full absorption efficiency curve of the detector was determined by calibrated point sources and by Monte Carlo simulations (with the GEANT and MCNP code) for

different incident photon energies and angles. As the gamma radiation in MAYAK work places can have different angles of incidence in the detector, it was important to study first the response of the detector over the angles of incidence. It was found experimentally, that for photon energies higher than 200 keV the Germanium detector has a uniform response over the angles of incidence.

Fig. 2 compares the experimental energy dependence efficiency (for photon normal incidence) with the simulated ones. The difference between the experimental and simulated energy efficiency dependence is small, which means that our simulations are good. However, well-simulated spectra must not only predict the full absorption peak count rate (efficiency of the detector) but also the partial absorption of photon energies in the detector, in other words the shape of the continuum. In Fig. 3, the experimental and simulated spectra for ^{137}Cs point source placed in front of the detector is presented. It should be noted that for presentation reasons the figure is expanded in the vertical scale and is shown only the continuum spectra and not the full absorption peak. The simulations reproduce satisfactorily the experimental spectra.

In order to execute step 2 of the stripping procedure, we generated about 57 spectra for incident photon energies from 100 up to 670 keV with steps of 10 keV. For all other energies, the response function of our Ge detector is determined by interpolation between two simulated spectra. Using the simulated shapes for the partial absorption continuum, step 2 includes a computerized stripping operation .The stripping is initiated at the highest energy (662 keV) due to the presence of the ^{137}Cs source and involves subtracting the simulated continuum of counts, which is lower in energy for this specific photon energy. The operation continues for succeeding lower energies down to 100 keV. After performing the stripping routine, the resultant spectrum is converted to incident flux by applying the full absorption efficiency of the detector (step 3 of the stripping procedure).

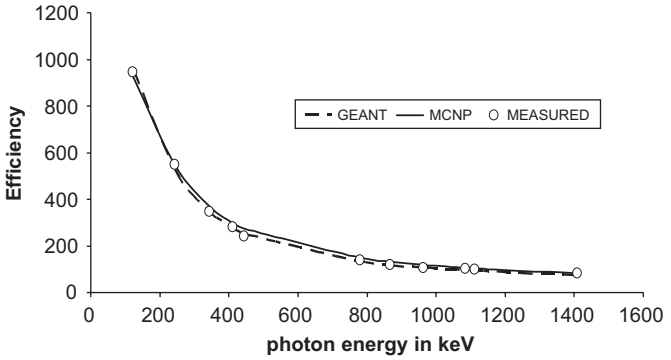

Fig. 2. Experimental and simulated energy dependence efficiency. The efficiency is given in counts per minute per photon per cm^2 and per second.

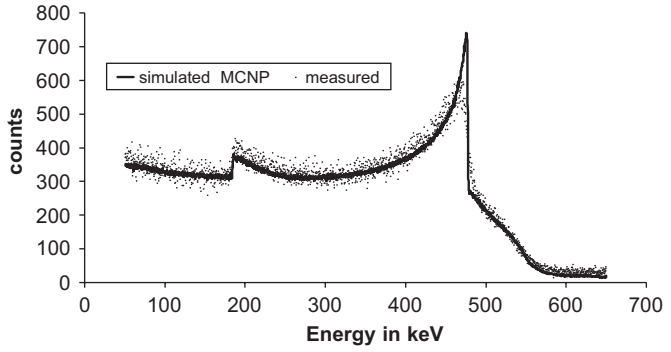

Fig. 3. Experimental and simulated spectra obtained with a ^{137}Cs point source in front of the detector. For practical reasons only the shape of the continuum is shown.

3. Results and discussion

In Table 1 the measured and calculated (MCNP) unscattered photon fluxes (energy 662 keV) are presented in the three locations (Nos. 1, 2, 3) shown in Fig. 1.

There is a good agreement between the experimental and calculated values. In Fig. 4 for location No. 2 the experimental and simulated scattered photon flux energy distributions (120–660 keV) are compared. As we are interested in the comparison of the energy distributions, the two curves were normalized to the unscatterd peaks. A good agreement between experimental and simulated curve

Table 1
Measured and calculated (MCNP) unscattered photon flux (photons/cm^2/s) in the three locations shown in Fig. 1

Location	Unscattered flux	
	Measured	MCNP
No. 1	3.4±0.5	3.9
No. 2	7.0±1.0	7.7
No. 3	4.8±0.7	4.2

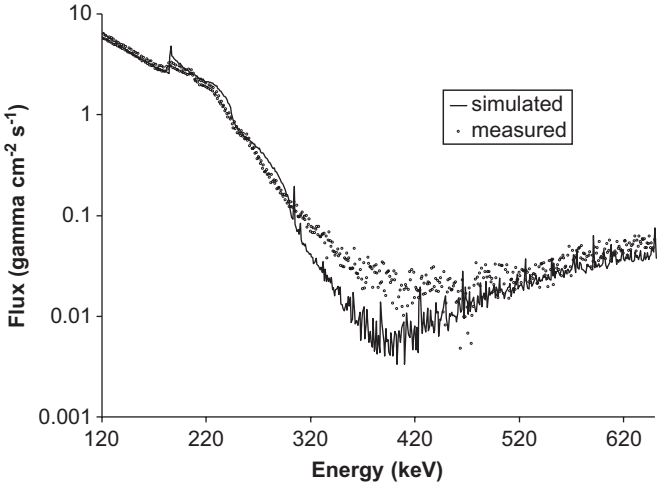

Fig. 4. Experimental and simulated scattered photon flux energy distribution.

is observed (less than 10% difference for the majority of the photon energies). The difference between the total experimental and simulated scattered flux is 4% (445 photons $cm^{-2} s^{-1}$ compared to 429 photons $cm^{-2} s^{-1}$). The same differences were found also for the other two locations.

As a conclusion, the main result of this work is the good agreement between the photon flux energy distributions deduced (a) by Monte Carlo simulations with the MCNP code and (b) experimentally by in situ gamma spectrometry measurements in a MAYAK PA work place. This conclusion is important for the verification of simulation of irradiation conditions at the MAYAK PA work places.

Acknowledgments

This work was performed in the framework of the SOUL project FP6-516378. The authors would like to thank Zoel Gkilo (Joelle Guilhot) for her participation in the experimental work.

References

[1] A. Clouvas, S. Xanthos, M. Antonopoulos-Domis, J. Silva, Health Phys. 74 (1998) 216.
[2] A. Clouvas, S. Xanthos, G. Takoudis, C. Potiriadis, J. Silva, Health Phys. 88 (2005) 154.