The Monte Carlo Method: Versatility Unbounded In A Dynamic Computing World
Chattanooga, Tennessee, April 17–21, 2005, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2005)

COMPARING SIMULATION AND MEASUREMENTS RESULTS OF ANGULAR TEPC RESPONSE IN STANDARD RADIATION FIELDS

M. Autischer
Austrian Research Centre Seibersdorf
2444 Seibersdorf, Austria
michael.autischer@arcs.ac.at

Graz University of Technology
8010 Graz, Petersgasse 25, Austria

P. Beck and S. Rollet
Austrian Research Centre Seibersdorf
2444 Seibersdorf, Austria
peter.beck@arcs.ac.at; sofia.rollet@arcs.ac.at

A. Ferrari
CERN
1211 Geneva 23, Switzerland
alfredo.ferrari@cern.ch

ABSTRACT

The TEPC (Tissue Equivalent Proportional Counter) instrument has been used as the reference instrument for cosmic radiation measurement at flight altitudes by several institutes [1]. For radiation protection reference measurements, it is essential to characterize the instrument's response under these radiation conditions, in terms of radiation particle, energy and angular direction. Investigations for a portable TEPC have been done in photon and neutron standard radiation fields. This paper presents a comparison of measurement results with simulations carried out with the Monte Carlo transport code FLUKA. Further a comparison of parallel beam and isotropic irradiation is described and discussed. It can be concluded that FLUKA provides reasonable characterization of the TEPC response for a wide range of radiation conditions.

Key Words: TEPC, Fluka, Photon, Neutron, Angular dependency

1 INTRODUCTION

The tissue equivalent proportional counter (TEPC) is a standard measurement instrument widely used for aircrew dosimetry [1]. The instrument's response should be characterized in well defined radiation fields. The TEPC used by the Austrian Research Centre Seibersdorf (ARCS) is a spherical detector with an inner diameter of 125 mm, with a tissue equivalent plastic wall (A150). The sphere is filled with pure propane at low pressure of 933.2 Pascal and corresponds to a tissue volume of 2μm in diameter. The detector itself and the required electronics are mounted in a metallic cylinder. The complete assembly is surrounded by a polyethylene foam filled portable trolley of aircraft hand-baggage dimension and referred to as "Hawk" [2]. With this instrument it is possible to obtain reliable measurement of the absorbed dose in tissue and its distribution as a function of lineal energy *y* within five orders of magnitude.

For aircrew dosimetry the instrument is positioned inside an aircraft where the radiation field is supposed to be isotropic [3]. Since most of the characterization measurements of the instrument were done using parallel beams, it is useful to find out if there are any differences in the detector's response between these two types of radiation fields. The asymmetry in the instrument's assembly and the resulting variation of the shielding effect depending on the incident angle can influence its behavior in various radiation fields. Using a 3 dimensional numerical simulation of the full detector assembly allows complete investigation of effects as described above. The Monte Carlo Transport Code FLUKA [4] has been used to analyze the energy deposition inside the detector with respect to different source distributions and incident angles.

1.1 TEPC Simulation

The FLUKA Monte Carlo Transport code is able to simulate the transport and the interaction of a variety of particles in any target material over a wide energy range from 20 TeV down to 1 keV (and down to thermal energy for neutrons). As other MC codes, FLUKA can score the average energy deposition inside a material over many different histories but it has also the capability to score it on an event by event basis, allowing the possibility to calculate the dose distribution as a function of lineal energy. A geometrical model of the instrument assembly, as shown in Figure 1, is described using the 3D combinatorial geometry capability of FLUKA. All the Hawk's elements such as the case, the foam, the metallic surrounding, the electronic part, the batteries and the detector with their exact composition and density are described in the model. Taking into account the attenuation of the particles inside these different materials and the reactions in the TEPC and its surrounding, the energy deposition inside the internal gas is calculated. Because of the low pressure of the gas it is necessary to use up to 10^7 source particles for each run and up to 20 runs to get a reasonable statistical accuracy of the simulation results.

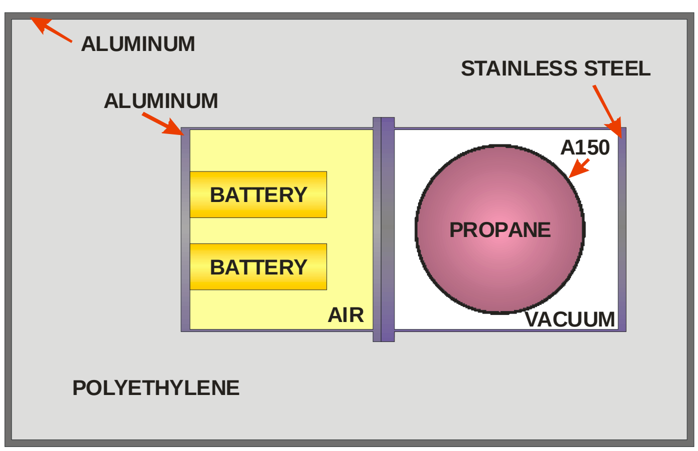

Figure 1: FLUKA simulation geometry.

Due to shielding effects of components inside the assembly, the energy deposition inside the gas depends on the incoming direction of the beam. To simulate this effect, a rectangular broad parallel beam of 15 centimeters times 15 centimeters is used. This beam dimension completely covers the extension of the TEPC sphere. The use of a broader beam is not necessary and therefore a waste of calculation time [5]. As a standard direction, the zero degrees direction is used. At 90 degrees the source beam is crossing the detector electronics before it reaches the detector and for irradiation with an incident angle of 270 degrees, the beam is coming exactly from the opposite as shown in Figure 2.

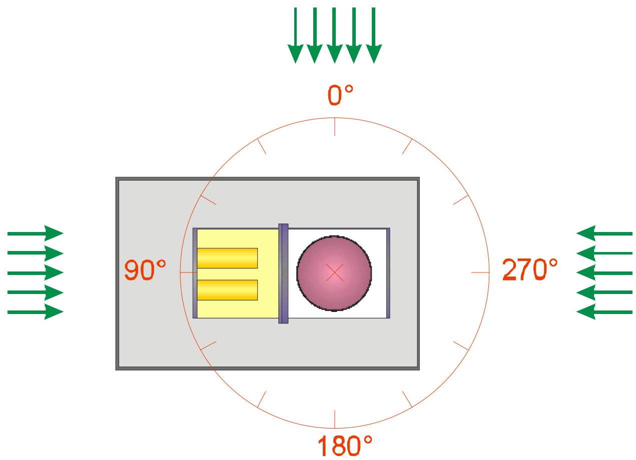

Figure 2: Definition of the beam directions.

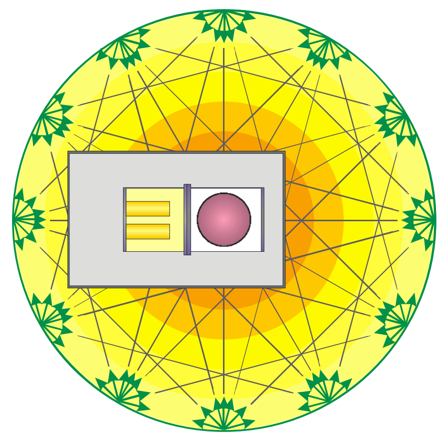

Figure 3: Schematic view of the used isotropic source.

For the simulation of the isotropic field a special source with the characteristics of a black body was created. For this source a sphere with a diameter of 80 centimeters which covers the complete simulation geometry is used. The isotropic source particles start from the surface of this sphere with an inward direction. To obtain a field as defined for an isotropic souce, the directions of the source particles must be cosine distributed. A schematic plot of the appearance of this source is shown in Figure 3.

1.2 Photon angular dependency

The first comparison between the simulation and measurements was done for photon sources. All the measurements were performed in the Dosimetrie und Eichlabor (DEL) of ARCS. ^{60}Co and ^{137}Cs sources were used for the photon measurements. The photon energy of ^{137}Cs is corresponding to 662 keV. ^{60}Co emits photons of two different energies, one at 1.17 MeV and the other one at 1.33 MeV. For the simulations of ^{137}Cs, 662keV has been used as a source's input energy. For ^{60}Co simulation, 1.25 MeV has been used as the mean of the two energies.

The relative energy deposition per source particle inside the gas normalized to the 0° beam direction as a function of the beam direction is shown for ^{60}Co and ^{137}Cs in Figure 4. Results of measurements done at the same angular incidences are also shown in this figure. For comparison, the simulated response to an isotropic source is shown as a dashed line (red ^{137}Cs and blue ^{60}Co).

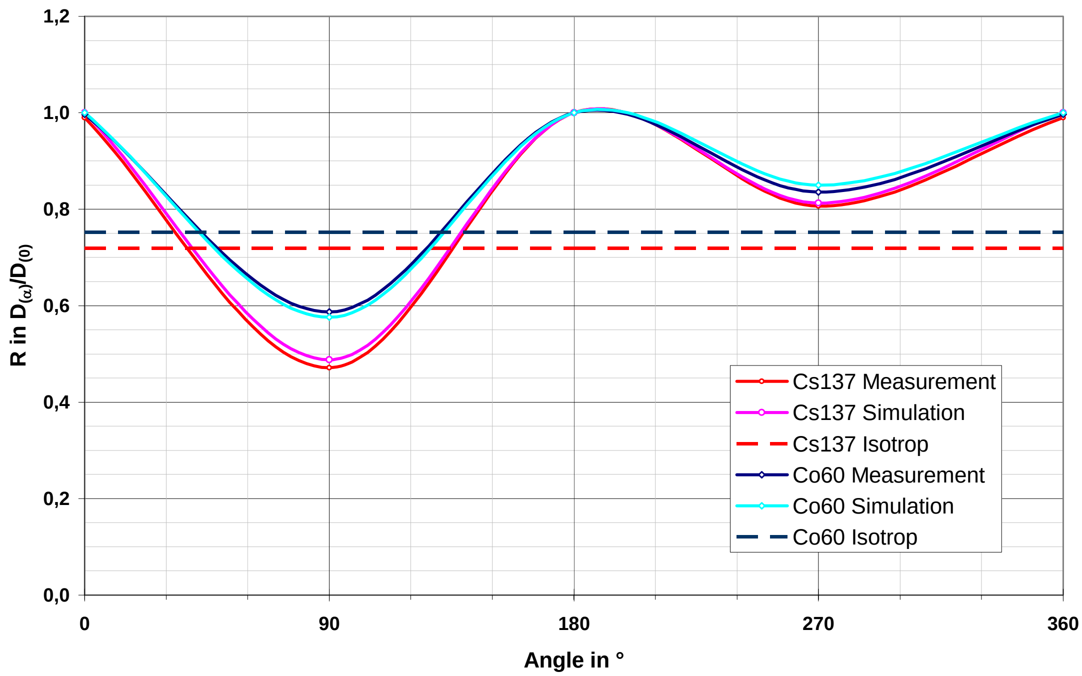

Figure 4: Relative energy deposition of different neutron source energies as a function of the incoming beam direction. For comparison the values for the isotropic field are added as dashed lines.

The simulations show good correspondence with the measurement results. The symmetry of the energy deposition at 0° and 180° is clearly visible. The bigger reductions of more then 50% at 90° for ^{137}Cs and about 40% for ^{60}Co are due to shielding effects of the detector electronics. At 270° the decrease of the response is due to the thicker front panel of the metallic cylinder. The shielding effect is higher for lower photon energies.

For an isotropic field we can see the same correlation of source energy and detector response. Here reductions of the response to 72% for ^{137}Cs and to 75% for ^{60}Co are calculated. For ^{60}Co and ^{137}Cs the shielding effect caused by the assembly is shown in Table I. The errors in Table I are statistical uncertainties of the simulation runs.

Table I. Ratio of the energy deposition in the gas of the TEPC for the isotropic field compared to a parallel beam at 0° for photon sources.

Particle	Energy	Ratio	Error
Photons (^{137}Cs)	662 keV	0.72	1 %
Photons (^{60}Co)	1.25 MeV	0.75	1 %

Since the energy deposition inside the gas of the TEPC is coming from electrons and photons entering the detector, the energy distribution of these particles has been investigated. A comparison of the energy distributions for a beam at 0° and the isotropic field are shown in Figure 5 and Figure 6 for ^{137}Cs.

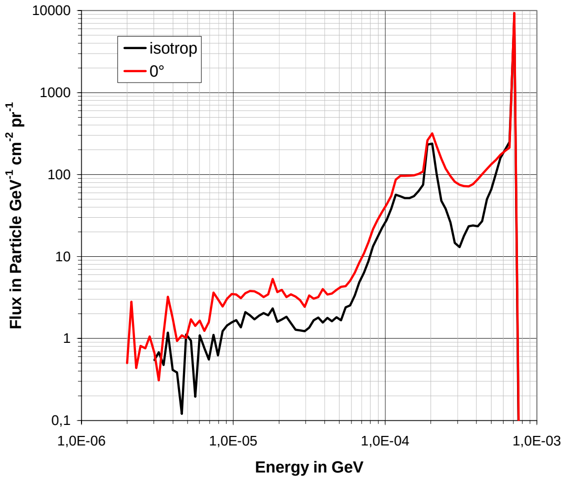

Figure 5: Photon flux per source particle inside the TEPC for ^{137}Cs as a function of energy. Comparison of a parallel beam and isotropic field.

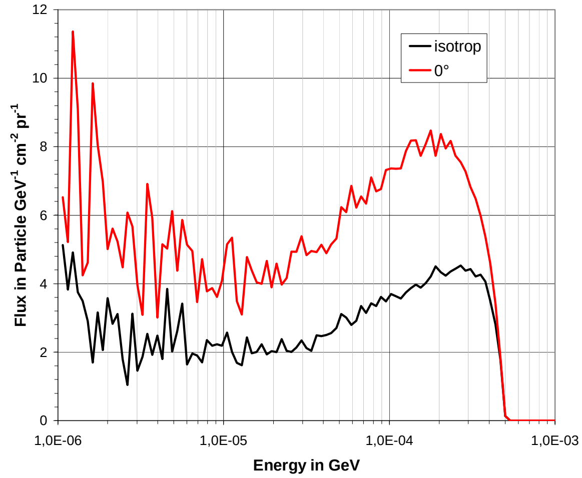

Figure 6: Electron flux per source particle inside the TEPC for ^{137}Cs as a function of energy. Comparison of a parallel beam and isotropic field.

The shielding effect of the TEPC assembly causes slightly different spectra for electrons and photons inside the gas. For the electrons the effect is more or less constant with a factor of 0.5 over the whole energy range, but for the photons the effect changes with the photon energy. The highest effect is discovered for the region of 200keV to 600keV.

Since the characterization of a radiation field can be shown in a microdosimetric spectra a comparison of several spectra is done. A normalized microdosimetric spectrum gives the probability of energy deposition per lineal energy. The lineal energy is given by dividing the average deposited energy in each energy interval by the mean chord length of the microdosimetric volume [6, 7]. The comparisons of these microdosimetric spectra are shown for ^{137}Cs in Figure 7 and for ^{60}Co in Figure 8.

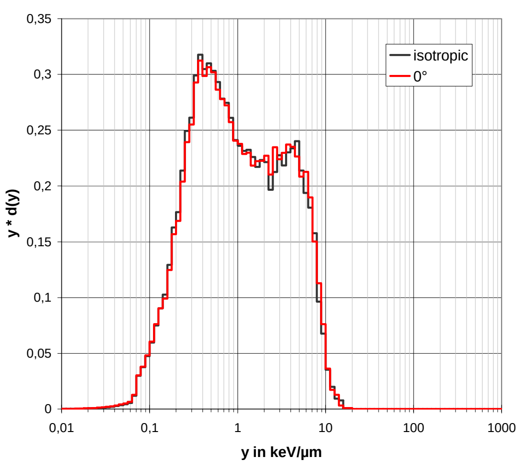

Figure 7: Comparison of the normalized microdosimetric spectra of parallel beam and isotropic field conditions for a ^{137}Cs source.

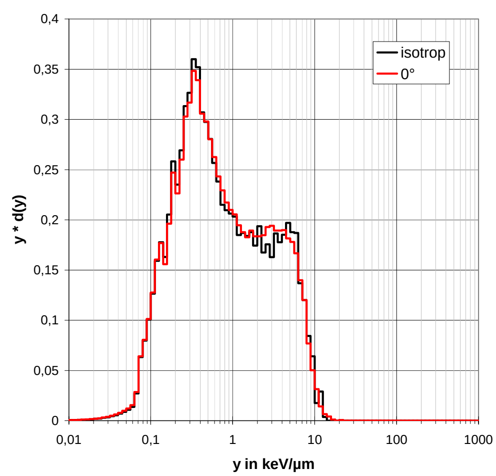

Figure 8: Comparison of the normalized microdosimetric spectra of parallel beam and isotropic field conditions for a ^{60}Co source.

The microdosimetric spectra of ^{137}Cs only show small differences in the lineal energy region of 4keV/µm. The spectra of ^{60}Co show bigger differences in the same area, where the spectrum of the isotropic source field is lower than the spectrum of the parallel beam.

1.3 Neutron angular dependency

The simulations of the dependency of the incoming beam direction for neutrons were done with the same procedure as for the photon simulations. The following neutron energies have been considered to compare to measurements done previously: 0.5 MeV, 1.2 MeV, 5 MeV and 61 MeV. Since all the calibration measurements were done only in the 0° beam direction, no comparison with the measurements of the angular dependency can be shown here. The plot in Figure 9 shows the energy deposition in the gas normalized to the simulation at 0° direction for all these neutron energies. In the same figure the values of the isotropic field conditions are added.

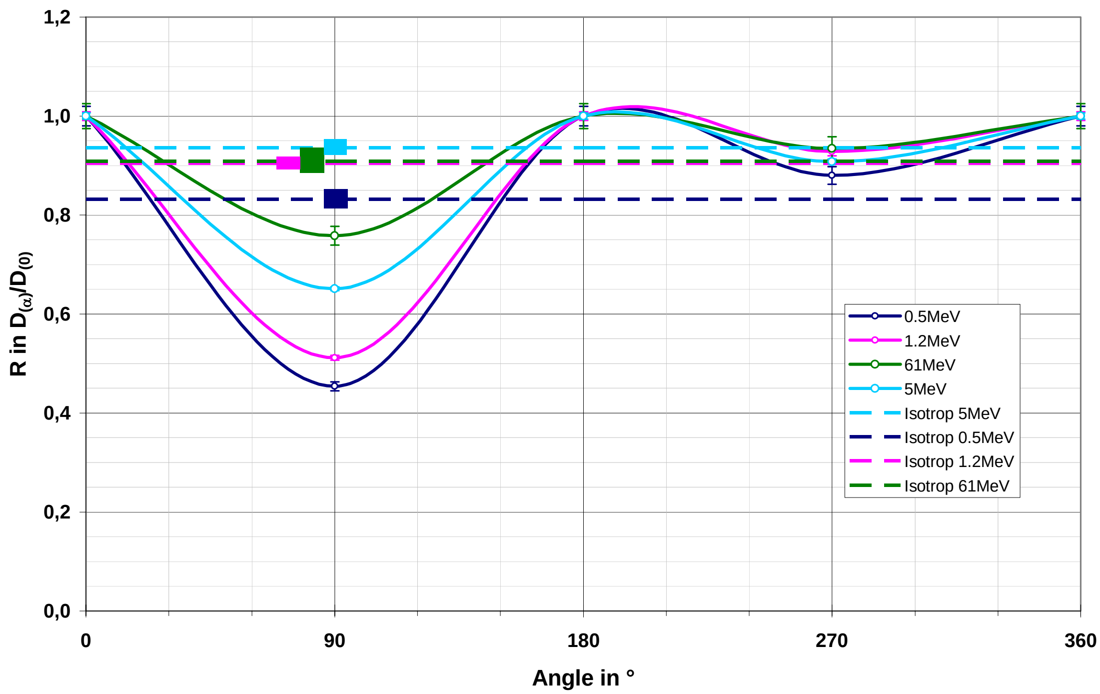

Figure 9: Relative energy deposition of different neutron source energies as a function of the incoming beam direction. For comparison the values for the isotropic field including their error bars are added as dashed lines.

The shielding at 90° beam direction is strongly dependent on the energy of the source neutrons. The range of the shielding effect for the used neutron energies goes from 45% for the lowest energy up to 75% for the highest energy. At 270° the variation of the different neutron energies is also visible but not as significant as at the beam direction of 90°.

For the used neutron energies the shielding effect caused by the assembly is shown in Table II. The errors in the table are statistically uncertainties of the simulation runs. For neutron sources the shielding effect is less than for the photon sources. Especially for higher neutron energies the effect stays in a small range around 90%.

Table II. Ratio of the energy deposition in the gas of the TEPC for the isotropic field compared to a parallel beam at 0° for neutron sources

Particle	Energy	Ratio	Error
Neutrons	0.5 MeV	0.83	2.3 %
Neutrons	1.2 MeV	0.91	1.4 %
Neutrons	5 MeV	0.93	1.6 %
Neutrons	61 MeV	0.91	2.7 %

2 CONCLUSIONS

The Monte Carlo Code FLUKA can provide the response of a whole instrument assembly, including the calculation of the angular dependency for many radiation conditions and different types of source particles. The detector response to an isotropic source compared to a parallel beam can also be investigated by simulation.

3 REFERENCES

1. EURADOS Working group 5, "Exposure of Aircraft Crew to Cosmic Radiation", *Report to EURADOS and the Article 31 Group, and references therein*; in print
2. Far West Techn. Inc., "Environmental radiation monitor with 5 inches tissue equivalent proportional counter, Operations and repair manual", December (2000).
3. P. Beck, A. Ferrari, M.Pelliccioni, S. Rollet and R. Villari, "FLUKA Simulation of TEPC Response to Cosmic Radiation", *Presented* at International Conference on Radiation Shielding (ICRS-10) and 13th Topical Meeting on Radiation Protection and Shielding (RPS-2004) Funchal, Madeira Island (Portugal) 9-14 May, 2004. To be published in *Rad. Protec. Dosim*.
4. Fasso, A., Ferrari, A., Ranft, J., Sala, P.R., "FLUKA: Status and Prospective for Hadronic Applications" *Proc. of the MonteCarlo 2000 Conference*, Lisbon, October 23–26 2000, Springer-Verlag Berlin, p. 955-960, (2001).Beck, P., Ambrosi, P., Schrewe, U., O'Brien, K., "ACREM, Aircrew Radiation Exposure Monitoring", *OEFZS Report*, OEFZS-G-0008, November 1999
5. Beck, P., Ferrari, A., Pelliccioni, M. and Rollet, S., "TEPC simulation with FLUKA", *ARC Report.*, ARC-G-0004, (2003)
6. Rollet, S., Beck, P., Ferrari, A., Pelliccioni, M. and Autischer, M., "Dosimetric considerations on TEPC FLUKA-simulation and measurements", *Radiat. Prot. Dosim.*, **110** 833-837, (2004).
7. ICRU Report 51, "Quantities and Units in Radiation Protection Dosimetry"; *Bethesda, MD, USA: International Commission on Radiation Units and Measurements*, (1993)