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# Monte Carlo Characterization of an Individual Albedo Neutron Monitor

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## ABSTRACT

**An individual albedo neutron dosimeter is simulated with the Geant4 toolkit. The simulation results are compared with results from an international intercomparison for Monte Carlo codes. The doses are obtained for thermoluminescent dosimeters irradiated free in the air and also on the surface of a water phantom for different neutron energy values. The Geant4 toolkit was not used by any of the participants in this intercomparison, so with these results we can infer the applicability of Geant4 in radiation protection for this type of simulation in neutron fields.**

***Keywords: Geant4, radiation protection, albedo dosimeter.***

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# 1. INTRODUCTION

The radiation protection quantity for whole-body exposure in an ionizing radiation field is defined by the International Commission on Radiological Protection (ICRP) as a weighted sum of the equivalent doses to the tissues and organs of the body, for all kinds of radiation, known as the Effective Dose [1]. By its definition, it is impossible to measure this quantity, therefore estimated by the so-called operational quantities, which are defined by the International Commission on Radiation Units and Measurements (ICRU), such as the ambient dose equivalent, $H^*(10)$, and the individual dose equivalent, $H_P(10)$. The $H_P(10)$ quantity is obtained, in soft tissue, at an appropriate depth, in this case 10 mm, below a specific point on the human body. This specific point is normally taken to be where the individual dosimeter is used. The $H^*(10)$, in a radiation field point, is the value that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth of 10 mm, in the radius that opposes the direction of the aligned field [1,2]. The effective dose evaluation for neutron fields is particularly challenging as the radiation weight, used to calculate the equivalent dose, fluctuates by one order of magnitude according to the neutron energy, assuming values ranging from 2 to 20, according to an ongoing function established by the ICRP. Common neutron sources also usually show an emission spectrum ranging from a thousandth of an electron volt to millions of electron volts.

An established technique for individual neutron monitoring is the albedo dosimeter, where the effective dose is estimated by measuring the fraction of the neutron field that is reflected by the body, or “albedo neutrons”. Different types of dosimeters have been developed using this technique, most of them using thermoluminescent crystals as sensitive material. This makes it necessary to use Monte Carlo techniques to describe the passage of neutrons and secondary particles in the materials that compose these dosimeters.

Concerned about the use of reliable codes in radiation dosimetry, the European Commission took an initiative to promote an intercomparison exercise for Monte Carlo codes applied to radiation protection problems. One of these problems is a specific description of an albedo dosimeter [3], where participants should compare their results for the dosimeter's response with each other and with a reference value. The main objective of this work is to simulate the problem proposed for this exercise with the Geant4 tool, which was not used by any of the participants. By doing so, one can infer the applicability of Geant4 in radiation protection for this type of simulation with neutron fields.

## 2. MATERIALS AND METHODS

Version 10.5 of Geant4 was used for the simulations [4]. They were performed with $10^8$ histories for monoenergetic neutrons with energies ranging from $10^{-8}$ to 20 MeV. High Precision (HP) physics was implemented for neutrons in Geant4 library which describes neutron interactions with thermal energies up to 20 MeV with the thermal scattering option, for neutrons energies below 4 eV. More details on the physics used can be found in Ribeiro and Souza-Santos [5]. The dosimeter response is found by counting the $^6$Li(n,t)$^4$He capture reactions, assuming that the neutron response is proportional to the number of capture reactions of this type [3]. For this count, the event counter (CountEvents()) present in Geant4 was used.

Before starting the albedo dosimeter studies, a LiF-600 and LiF-700 crystals simulation in the open air, was made to verify if the description of the thermoluminescent crystal materials was correct. This simulation calculated the dose in each of the crystals for a plane and parallel neutron beam with energies ranging from 1 keV to 10 MeV. Figure 1 shows the results published by Furuta and Tanaka [6], which values were compared with the ones found in the present work.

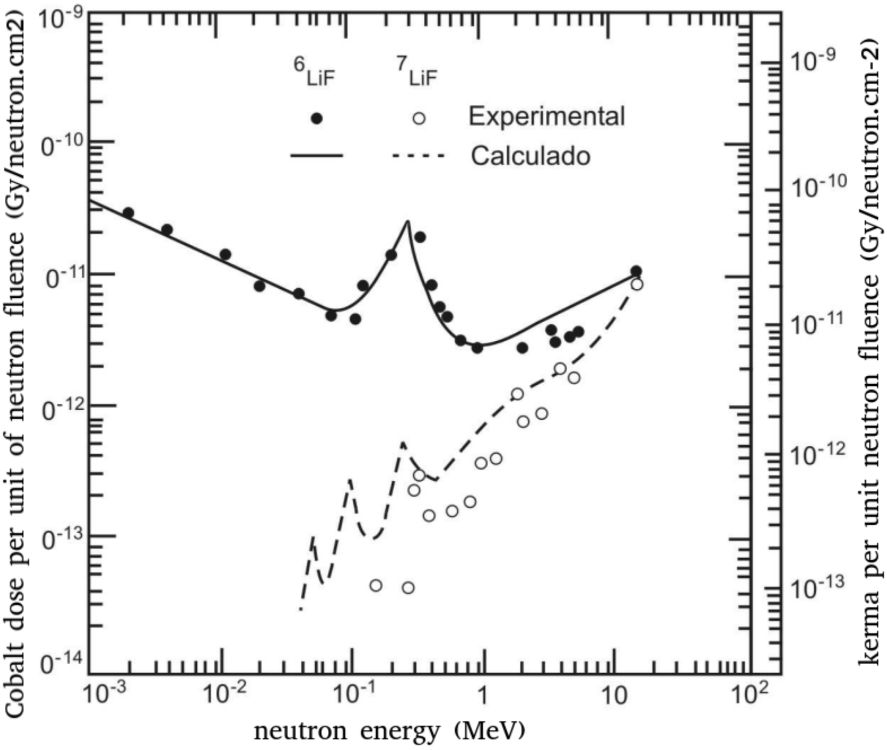

**Figure 1:** *Cobalt dose per neutron fluence unit (Gy.cm2) of thermoluminescent crystals, $^{6}$LiF and $^{7}$LiF, when exposed to a parallel plane neutron beam.*
Source: Furuta e Tanaka,1972 [6].

Then the P4 problem of the intercomparison exercise was solved for the albedo dosimeter. The proposed dosimeter can be seen in Figure 2. In Figure 2B the slab phantom was cut with the magnification given in the dosimeter showing only its front part in the figure, but in the simulation, it was considered as a whole. The dosimeter has a $^{6}$LiF and $^{7}$LiF pair on each side, one pair facing the incident neutron beam and the other pair facing the ISO slab phantom. The results found in this work were compared with those found in the intercomparison [7], in which the MCNP-4C code was used, and are shown in the following section.

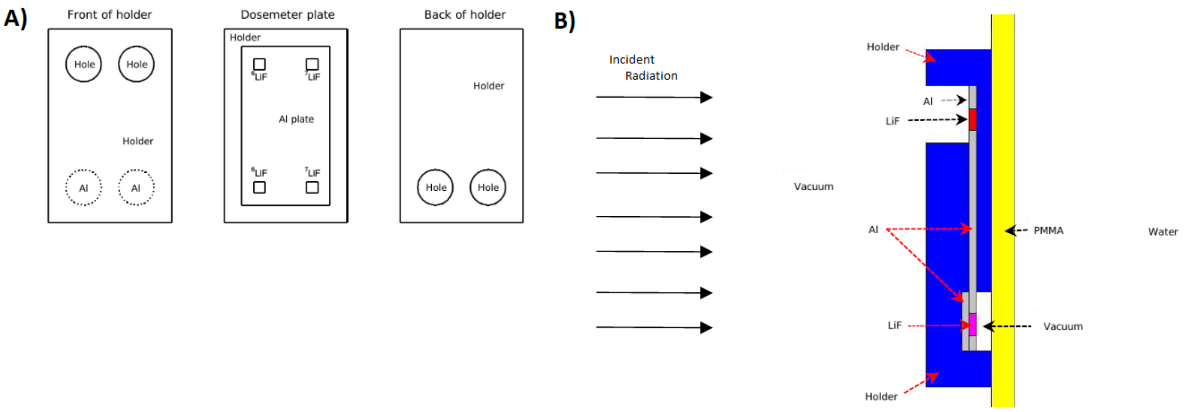

**Figure 2:** *Scheme of the albedo dosimeter of problem P4 of the QUADOS intercomparison (A). Scheme of the side view of the albedo positioned on the front face of the ISO slab phantom (B).* Source: Freitas, 2018 [8].

## 3. RESULTS AND DISCUSSION

Figure 3 shows the comparison of the responses of the $^{6}$LiF and $^{7}$LiF crystals, obtained in Geant4 with the calculated data from Furuta and Tanaka [6], values represented by the solid and dotted lines in Figure 1. The responses were normalized for the reading of the $^{6}$LiF at the energy of $10^{-3}$ MeV.

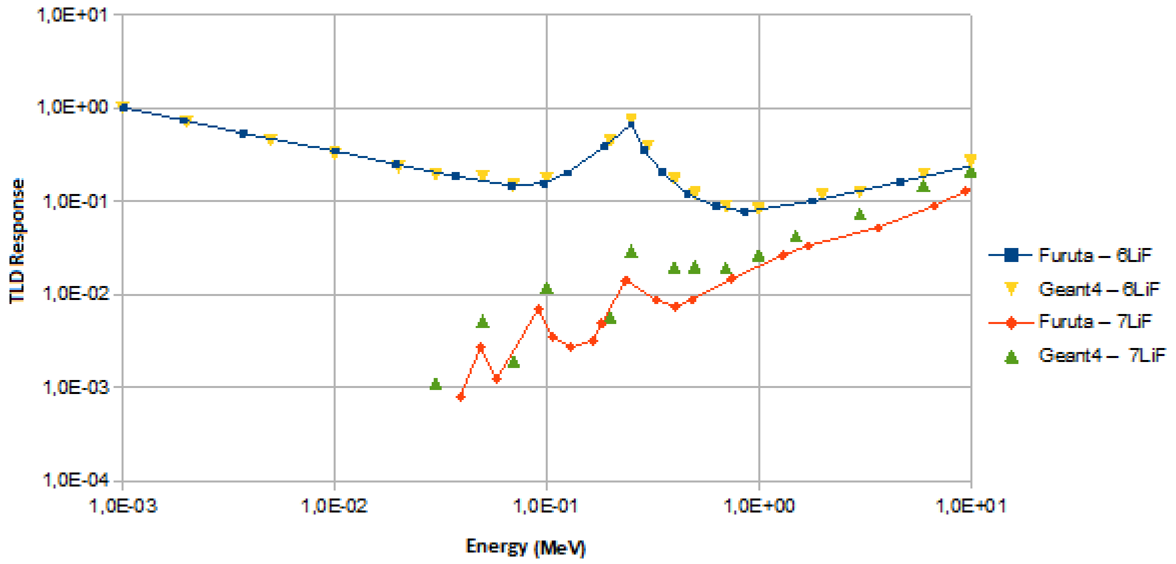

**Figure 3:** *Comparison of normalized responses in 6LiF and 7LiF crystals when exposed to parallel plane neutron beams, free in air.*

Figure 4 shows the results for the intercomparison exercise, problem P4, showing the response of the 4 TLD crystals in the dosimeter. The indices with the letters “i” and “a” that accompany the names of the TLD-600 and TLD-700 in the figure, indicate for “i” the TLDs for the incident neutrons and “a” the TLDs for the albedo neutrons.

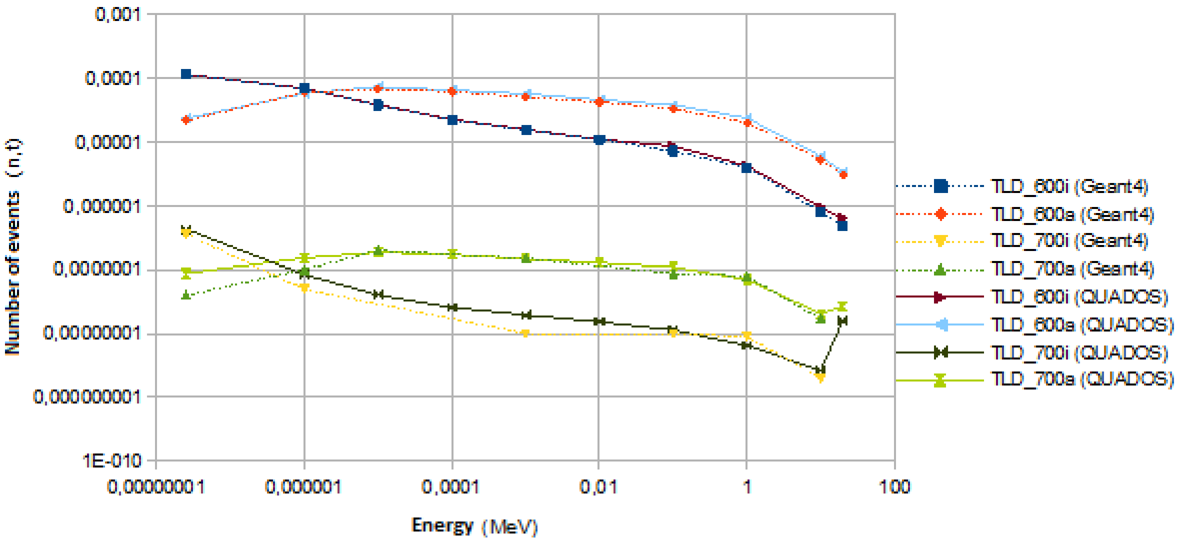

**Figure 4:** *Number of events (n,t) in the albedo dosimeter placed on the surface of the water phantom and radiated by a plane and parallel neutrons beam.*

The Geant4 results show good agreement with the results presented in the intercomparison across the monoenergetic neutron energy range, for all 4 TLD crystals in the albedo dosimeter.

## 4. CONCLUSION

It was shown that the Geant4 tool is suitable for simulating an albedo dosimeter for neutrons with energies ranging from 10-8 MeV to 20 MeV. The results obtained in this work will be used as a basis for response in the simulation for different types of albedo and to deepen the understanding of the interactions between neutrons and individual dosimeters, which will be valuable knowledge in the design of new individual monitoring devices.

## ACKNOWLEDGMENT

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