Separation of the Secondary Electrons from the Gamma Radiation near the Surface of an Encapsulated Gamma Source Using a Magnetic Field

E. Heritage and E. Waller
[1]University of Ontario Institute of Technology, Ontario, Canada
(eric.heritage@uoit.ca)

A Master's Level Submission

Summary

Secondary electron generation on the surface of encapsulated gamma sources can play a large role in the dose measured near the surface of the encapsulation. An experiment has been designed so that the gamma and electron components of the radiation dose can be measured separately, near the surface of an encapsulated 137-CsCl source. This is done using an electromagnetic field to bend the surface electrons away from the gamma dose measurement. Simulations using the Monte Carlo transport code PHITS show that a magnetic field of at least 75mT is needed to obtain a pure gamma measurement near the source.

1. Introduction

When a gamma emitting source is encapsulated by a high Z material, electrons are generated on the surface of the encapsulating material, due to Compton scattering. These electrons can have a significant impact on the radiation dose that a person would receive, if they were to pick up an encapsulated gamma source. The National Council on Radiation Protection and Measurements (NCRP) Report - 40 contains contact dose conversion factors for encapsulated gamma sources. However, when compared to the physical symptoms observed by physicians, these conversion factors appear to be too high.

2. Background

Many of the experiments regarding the surface electrons generated by encapsulated gamma sources were done in the 1930s, and were related to the application of radium therapy for cancer treatment. In 1931, Benner examined how the intensity of surface electrons generated, varied with encapsulation material [1]. Benner used a magnetic field to deflect the electrons and measured them using an ion chamber. Benner and Snellman conducted physical and biological experiments, measuring the secondary beta radiation from radium needles with platinum and palladium filters, and comparing the biological effect that these needles produced, when placed on human skin and to a rabbit's ears [2]. Wilson also examined the electron component of radiation from encapsulated radium sources, using an ion chamber with thin walls, so that the secondary beta radiation was measured along with the gamma radiation [3]. All of these experiments were done using Ra-226 sources, which are no longer commonly used. Industrial sources that are currently used include Co-60, Cs-137, and Ir-192. These are the sources that are often involved in radiation accidents, when a person mistakenly picks up one of these sources. The contact dose conversion factors for these sources presented in NCRP 40, were extrapolated from the Ra-226 measurements using scaling arguments. The goal of this research is to prove that the contact dose conversion factors in NCRP 40 are too high, and obtain more accurate contact dose conversion factors through experiment.

3. Methods

3.1 Experimental Design

In order to verify that the contact dose conversion factors presented in NCRP 40 are indeed too high, an experiment has been designed to separately measure the gamma and electron components of the dose from an encapsulated gamma source. This experimental setup is a more modern design of the experiment done by Benner in 1931 [1]. The apparatus consists of a stainless steel encapsulated 137-CsCl source, large magnets, and an ion chamber. The ion chamber will be positioned close to the source, to measure the dose from both the gamma rays and electrons together. Then, the magnets will be used to create electromagnetic fields, which bend the surface electrons away from the gamma beam, and the dose from only gamma rays will then be measured.

3.2 Monte Carlo Simulations

Simulations have been done using a state-of-the-art Monte Carlo radiation transport code called Particle and Heavy Ion Transport code System (PHITS). PHITS simulates the motion of various particles in three dimensional space using several nuclear reaction models and nuclear data libraries. PHITS is also capable of simulating the motion of particles under external magnetic fields, which makes it an ideal choice for simulating this experiment. The PHITS simulations are being used to aid in the design of the experimental apparatus, and will ultimately be used to compare with the experimental results. These simulations will be useful in determining the strength of the magnetic field that is needed to bend all of the surface electrons away from the gamma beam. They will also be useful in determining the specific positioning of the encapsulated source, and ion chamber.

The encapsulated 137-CsCl source that will be used in this experiment has an activity of 1mCi, and is contained in an A3000 capsule from Eckert & Ziegler. The PHITS model of this encapsulated source can be seen in Figure 1. The encapsulation is made of 304 Stainless Steel, and contains a cylindrical 137-CsCl source that has a diameter of 0.125 inches and a height of 0.09 inches (cell 103 in Figure 1). There is a pocket of air inside the encapsulation (cell 104 in Figure 1) where there is an Allen key socket.

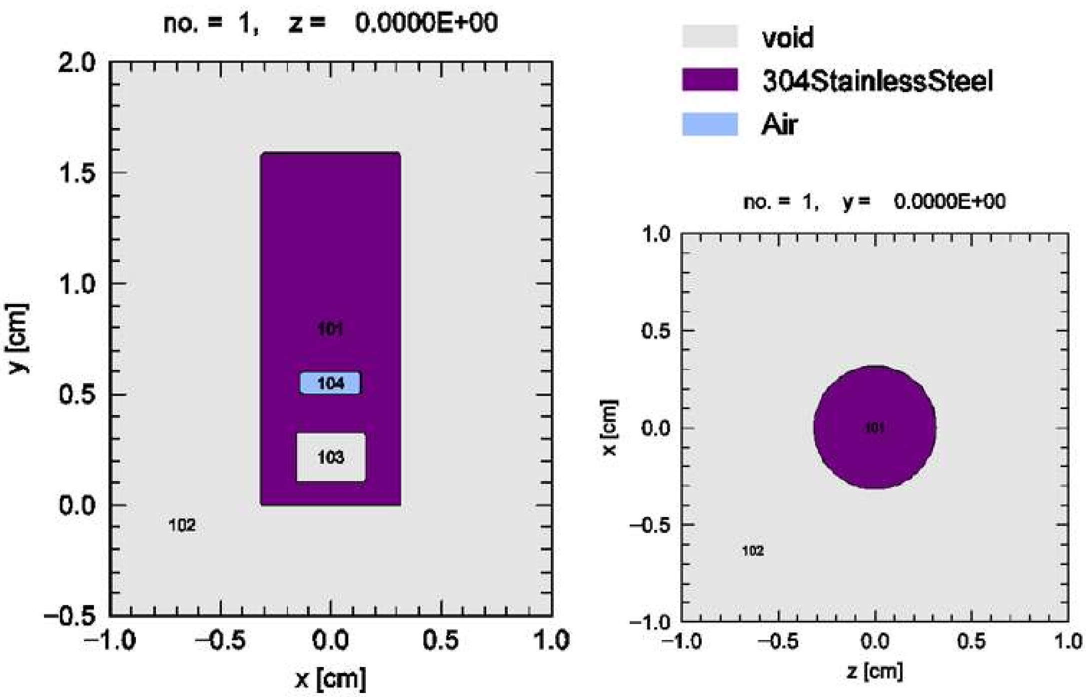

Figure 1 Geometry of encapsulated 137-CsCl source

4. Results of PHITS Simulations

Several PHITS simulations were run with the encapsulated 137-CsCl source in magnetic fields of varying strength. The purpose of these simulations were to determine the magnetic field strength needed to bend the secondary electrons tracks enough that a pure gamma dose measurement could be taken by an ion chamber placed near the encapsulated source.

For each magnetic field strength, maps of the photon fluxes and electron fluxes were created. The maps of the photon flux were obviously the same for each simulation, as photons are not affected by a magnetic field. Figure 2 shows the PHITS calculation of photon flux for the encapsulated 137-CsCl source.

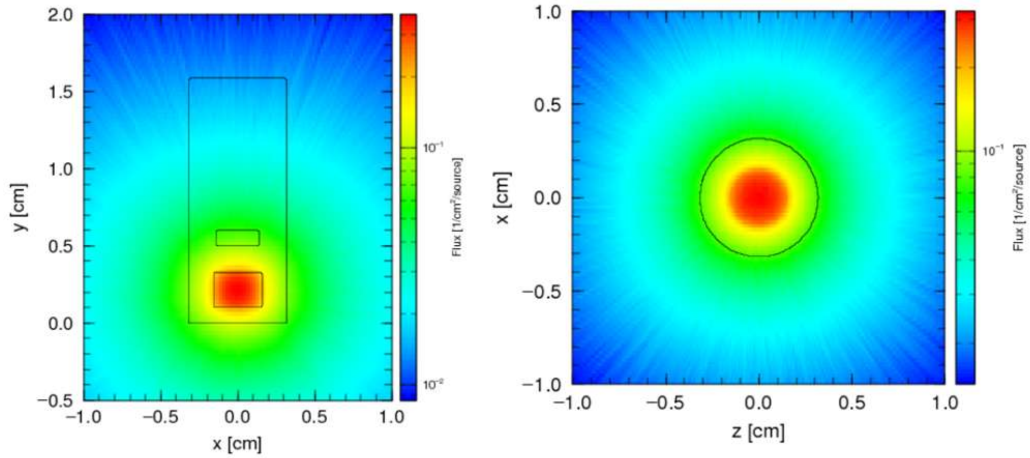

Figure 2 Photon flux from encapsulated 137-CsCl source

A cylindrical region of radius 10cm and length (along the z axis) of 10 cm was created in PHITS with the encapsulated source at its center. It is in this region that a magnetic field was applied in the positive y direction. The strength of the magnetic field was varied from 0 to 100 mT. The electron flux maps produced for various magnetic field strengths are shown in Figure 3. This figure shows that a magnetic field strength of at least 75mT would be needed to bend the electrons sufficiently, to allow for a pure gamma measurement from an ion chamber placed close to the encapsulated source.

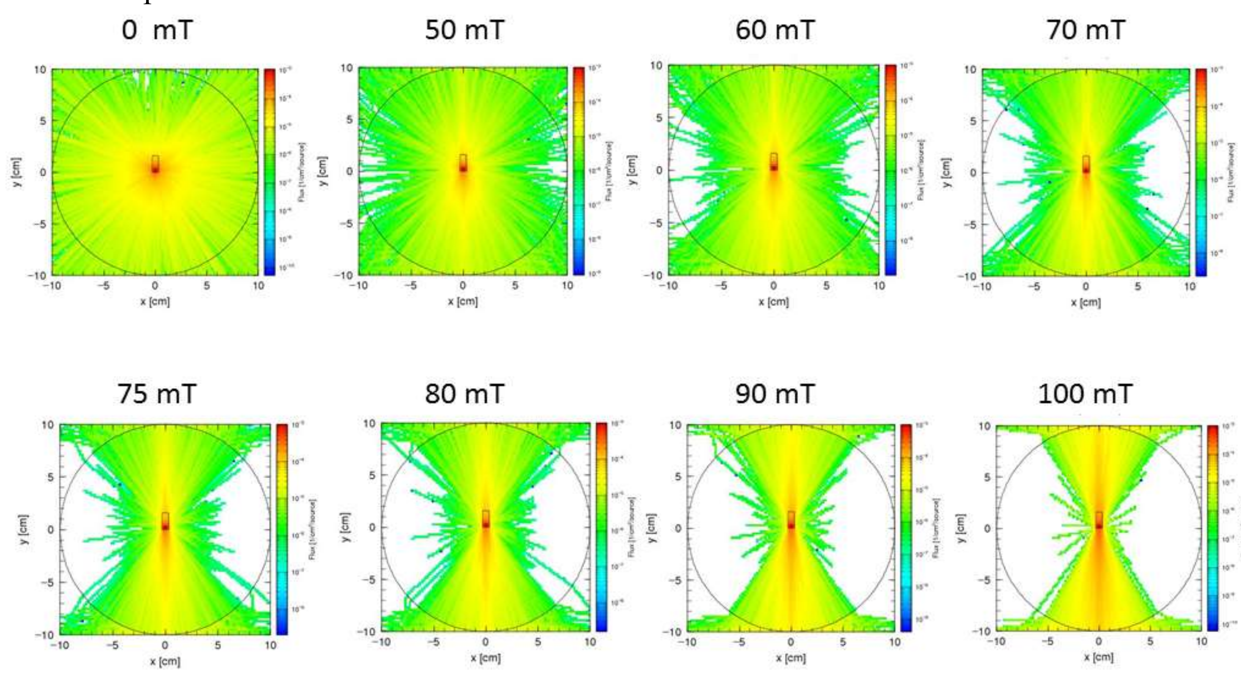

Figure 3 Electron tracks in magnetic fields of various strength

5. Conclusion and Future Work

For the current geometry of the magnetic field (cylindrical volume with a radius of 10cm), a magnetic field of at least 75mT would be needed to bend the secondary electrons away from a gamma beam measurement made close to the encapsulated source. This is a magnetic field strength that will be achievable experimentally. Future work includes calculating the dose rate conversion factor for the 137-CsCl source using PHITS, investigating other possible magnetic field geometries, and then building and running the experiment in the lab.

6. References

[1] Benner, Sven (1931). On secondary β-rays from the surface of radium containers. *Acta Radiol.,* 12: 401-412

[2] Benner and Snellman (1935). On the therapeutic importance of the secondary β-rays. *Acta Radiol.,* 16: 233-241

[3] Wilson, C.W. (1937). The effect of secondary beta radiation on gamma-ray measurements made in air. *Proc. Phys. Soc.,* 49: 338-344