Monte Carlo Modeling of the Fastscan Whole Body Counter Response

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Summary

Monte Carlo N-Particle (MCNP) was used to make a model of the Fastscan for the purpose of calibration. Two models were made one for the Pickering Nuclear Site, and one for the Darlington Nuclear Site. Once these models were benchmarked and found to be in good agreement, simulations were run to study the effect different sized phantoms had on the detected response, and the shielding effect of torso fat was not negligible. Simulations into the nature of a source being positioned externally on the anterior or posterior of a person were also conducted to determine a ratio that could be used to determine if a source is externally or internally placed.

1. Introduction

All workplaces have a responsibility to their employees to ensure a safe and healthy working environment. When there is the potential for the exposure to radioactive material, it is necessary to check regularly for radioactive contamination. One of the ways to accomplish this goal is to have workers use a whole body counter (WBC). Ontario Power Generation has two Fastscan WBCs at the Pickering and Darlington locations; which is used to check for internal contamination. Currently, these Fastscans are calibrated using a Bottle Manikin Absorber phantom (BOMAB). The purpose of this project was to create a Monte Carlo model that would allow calibration curves to be simulated for a wide variety of different sized phantoms. This paper will discuss the benchmarking of the model, the comparison of different sized anthropomorphic phantoms, and the front/back ratio of detected dose.

1.1 Fastscan

The Fastscan has two large NaI detectors (7.6 cm width, 12.7 cm depth, and 40.6 cm height) which are located in the detector tower[1]. The detector tower is positioned at the front of the unit, which is attached to the front of a frame of the WBC. The detectors are stationary, and during monitoring an individual stands within the frame facing the detectors. Since the detectors are static, it simplifies the Monte Carlo model. The frame and detector shielding are made of steel with a thicknesses of approximately 10 cm.

1.2 Source Terms

The point source that was used in the Darlington experiments is a mixed ^{241}Am, ^{137}Cs, and ^{60}Co quality control (QC) point source. A BOMAB is a type of phantom that is used to simulate the composition of human tissue when calibrating WBCs. It approximates the dimensions of reference man where the reference man, defined by ICRP 89, weighs 70 kg and is 170 cm tall[2].A BOMAB has ten sections that are filled with liquid containing a reference source. In the Pickering experiment the BOMAB was filled with ^{57}Co, ^{60}Co, ^{137}Cs, and ^{40}K.

Table 1: Activities for the Darlington Point Source and Pickering BOMAB

Point Source Radionuclides	Point Source Activity on Measurement Date (Bq)	BOMAB Radionuclides	BOMSB Activity on Measurement Date (Bq)
^{241}Am	130671	^{57}Co	4397
^{137}Cs	24494	^{137}Cs	4098
^{60}Co	32337	^{60}Co	4485
		^{40}K	5000

2. Method

2.1 Benchmarking

The simulations were carried out using the MCNP transport code[3]. When modelling the Fastscan two f8 (pulse height) tallies were used to mimic detector response. The peaks were widened to represent the detector response using a Gaussian broadening (GEB) card.

Models were made for both the Darlington and the Pickering Fastscans. The Darlington model was found to be in agreement the majority of the time to within ±5%, with the biggest deviation being ±11%, while the Pickering model is accurate to ±10%. The Pickering model was benchmarked using data from a BOMAB experiment, while the Darlington model used a point source that was moved to five varying heights in the Fastscan. The ratio of experimental count rate to simulated count rate was compared to determine if the MCNP model was in agreement with the experimental results. The background was subtracted from both the experimental and simulation results before the results were compared [4]. Figures 1 and 2 show the comparisons of these ratios.

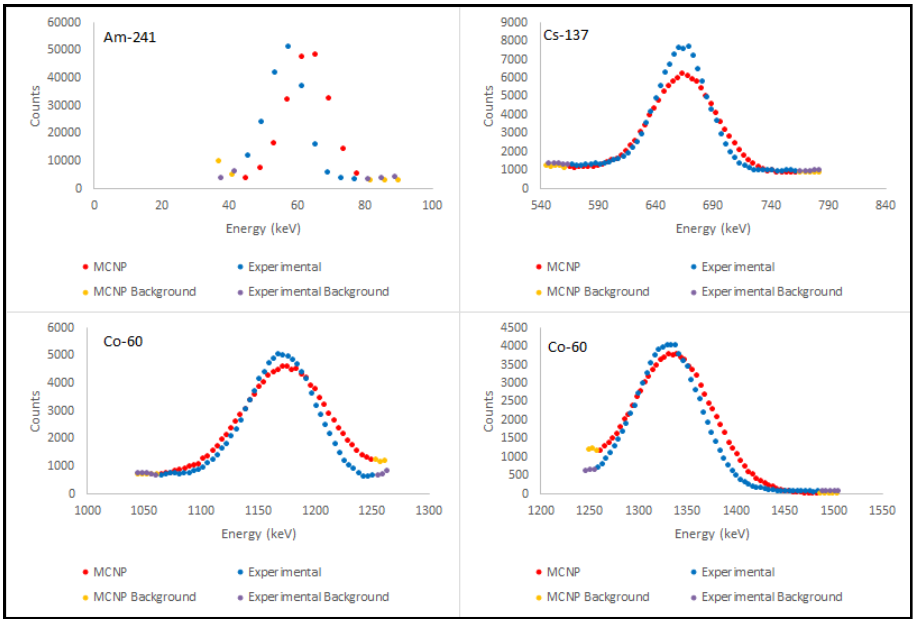

Figure 1Comparison of the Simulation and Experimental Results for the Point Source at 127 cm.

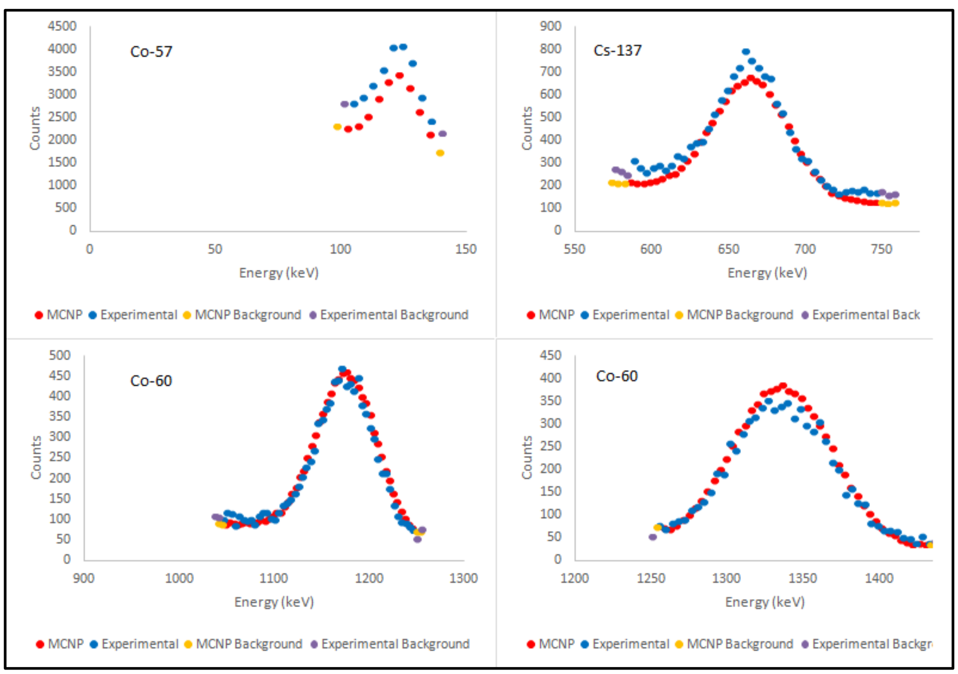

Figure 2 Comparison of the Simulation and Experimental Results for the BOMAB.

2.2 Excel Spreadsheet

To increase the models ease of use a graphical user interface (GUI) was made using Excel. BodyBuilder, a software that generates anthropomorphic phantoms of varying ages and body fat compositions, was linked to the spreadsheet to allow the user to create phantoms of varying heights and weights. The GUI allows the user to choose between the Darlington and Pickering Fastscans and if they wish to run a point source, BOMAB, or anthropomorphic phantom. MCNP can run through the GUI so there is no need to run it through the command prompt, and the output files can be graphed to compare ratios with the click of a button. Currently the GUI uses MCNP6, but it can be also be adapted to use MCNPX. Every effort was made to ensure the simplicity of the GUI for its future users.

2.3 Phantoms of Varying Heights and Weights

Simulations were run for male phantoms of three differing heights, 162cm, 170cm, and 179cm. Each of these heights were run three times with extra torso fat of 0cm, 2cm, and 4cm. The fat was distributed evenly around the torso. The source used was the same point source used in the Darlington point source benchmarking experiments, and it was placed in the centre of the chest for the simulations. An extra 4cm of torso fat was found to shield 25-30% of the emitted gammas with lower energy gammas being shielded more than higher energy gammas.

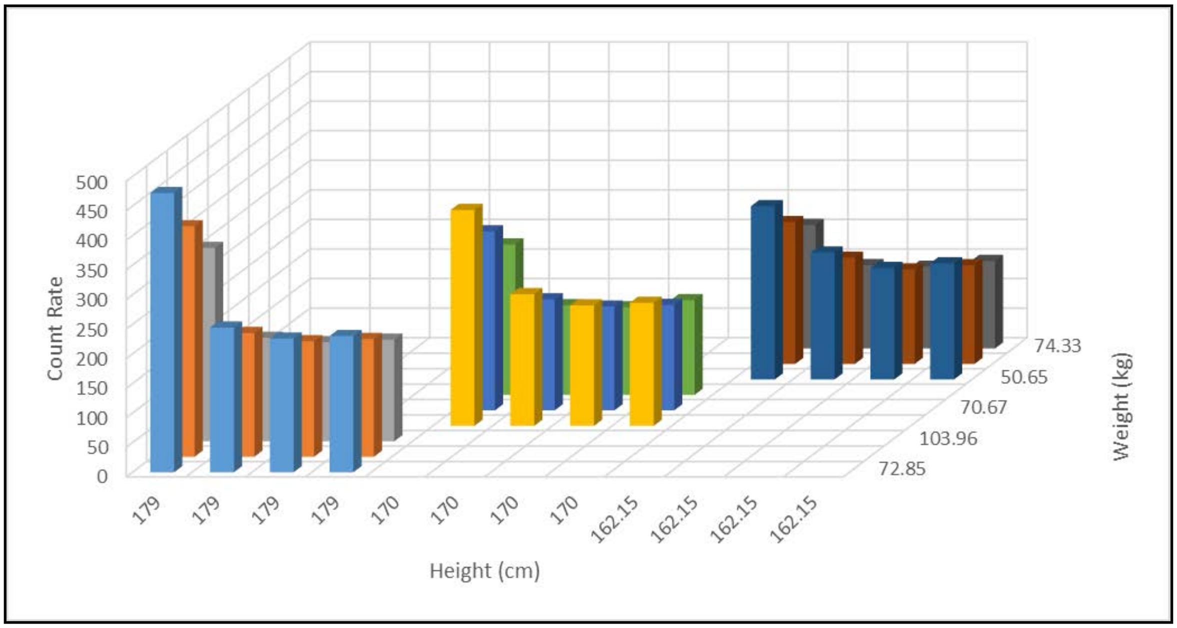

Figure 3 Male Phantoms of Varying Heights and Weights and Their Associated Count Rate

2.4 Front/Back Ratio

The ratio of count rates when there is an external source on the front to when there is an external source on the back changes depending on the fat of the scanned individual. It is not a linear relation, since as a person gets wider the distance between the front of the person and the detectors gets closer, and the distance between the back of the person and the detectors get further away. As seen in Figure 4 the ratio increases as gamma energy increases, and as torso fat increases the ratio increases with a polynomial trend. This is due to the inverse-square law.

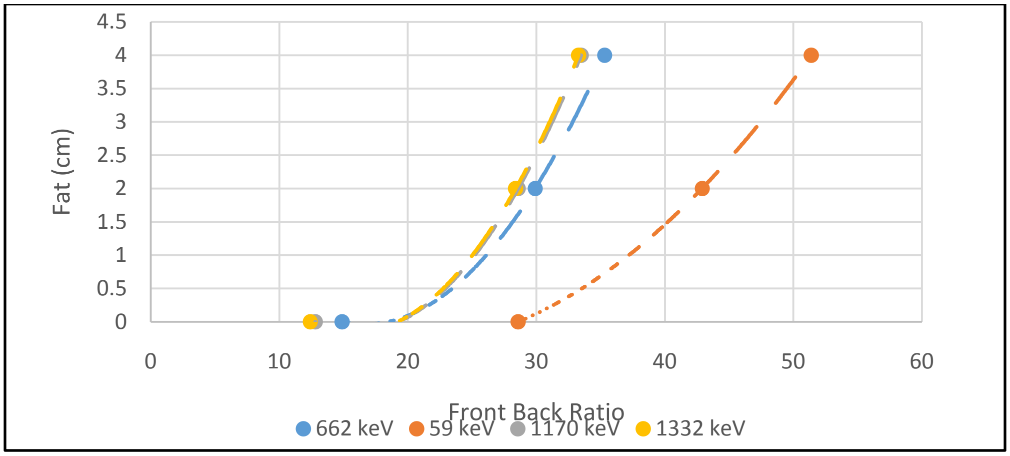

Figure 4 Male Phantom 179 cm of Varying Extra Torso Fat

3. Conclusion

In conclusion, both the Darlington and the Pickering models were found to be in good agreement since the deviations did not exceed ±20% [3]. The Excel spreadsheet makes the models user friendly, and ensures that knowledge of MCNP is not needed to run these simulations. The shielding provided by torso fat is not negligible, and a person that is obese can shield 25-30% more gammas than the average person. Further work has to be done with the front-back ratios to determine at what cut-off point a ratio can be used to determine if the contamination is internal or external.

4. References

[1] Canberra, “Apex-InVivo Productivity Software User's Manual V1.0 (7065586),” Canberra Industries, 2009.

[2] ICRP, “Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values,” *Annals of the ICRP - ICRP Publication 89,* vol. 32, no. 3-4, 2002.

[3] X-5 Monte Carlo Team, MCNP — A General Monte Carlo N-Particle Transport Code, Version 5 Volume I: Overview and Theory, Los Alamos, NM: Los Alamos National Laboratories, 2003.

[4] G. Knoll, Radiation Detection and Measurement, Hoboken, NJ: John Wiley & Sons, Inc, 2010.