^{60}Co phase-space files generated using BEAMnrc

B Muir, G Xiong, T. Palani Selvam*and D.W.O. Rogers
Physics Department, Carleton University
Ottawa, K1S 5B6

CLRP-Report CLRP-09-01

Version of 2009-06-12 07:28:05-04 , printed June 12, 2009

Abstract

This report documents the use of BEAMnrc to duplicate the work of Mora et al who used BEAM/EGS4 to model an Eldorado6 ^{60}Co unit. The resultant phase-space files are being contributed to the IAEA phase-space database project.

Contents

*Permanent address: Bhabha Atomic Research Centre, Mumbai, India

I. Introduction

This report describes the updating of the model used by Mora et al[1] to model the Eldorado 6 ^{60}Co radiotherapy treatment unit. Their work was based on the EGS4/BEAM code[2,3] whereas the current state-of-the-art is the EGSnrc/BEAMnrc code[4–6] which is used here. We have started from the input files of Mora et al. Preliminary work was done by Palani Selvam and Guoming Xiong while at Carleton University and the work was finalized by Bryan Muir. This is being done as part of a wider project to distribute phase space files by the IAEA. This project is described at http://www-nds.iaea.org/phsp/phsp.htmlx.

There have been no major changes to EGS4 or EGSnrc that would affect these simulations very much except for the fix of a boundary tolerance problem (it was changed from 10^{-4} cm to 10^{-5} cm in various component modules, in particular JAWS and PYRAMIDS). This change is known to increase the electron contamination considerably. It is not understood how the previous calculations avoided this issue since without this fix, the current broad beam depth-dose curves would substantially underestimate the measured values.

II. Modeling the unit and determining the field size

We used the same semi-realistic rectangular geometry of the collimator assembly as used by Mora et al.[1] This is shown in Fig 1. In our opinion the *description* in the previous paper of how the the field size was set is somewhat misleading. In particular the field is defined by the line from the centre of the source capsule through the outer edge of the last collimator (i.e. OE in the figure) whereas the original paper suggests it was defined by AD. In the input files it is defined by OE, in both the previous study and now. Using this definition, the measured field sizes and the calculated field sizes agree well but using the other definition leads to substantial disagreement with measurements. Fig 1

III. Depth-dose curves

In the paper of Mora et al, in order to study the influence of electron contamination on the dose build up curve, both a broad (35 $\times$35 cm^2) and a narrow (5 $\times$5 cm^2) beam from the

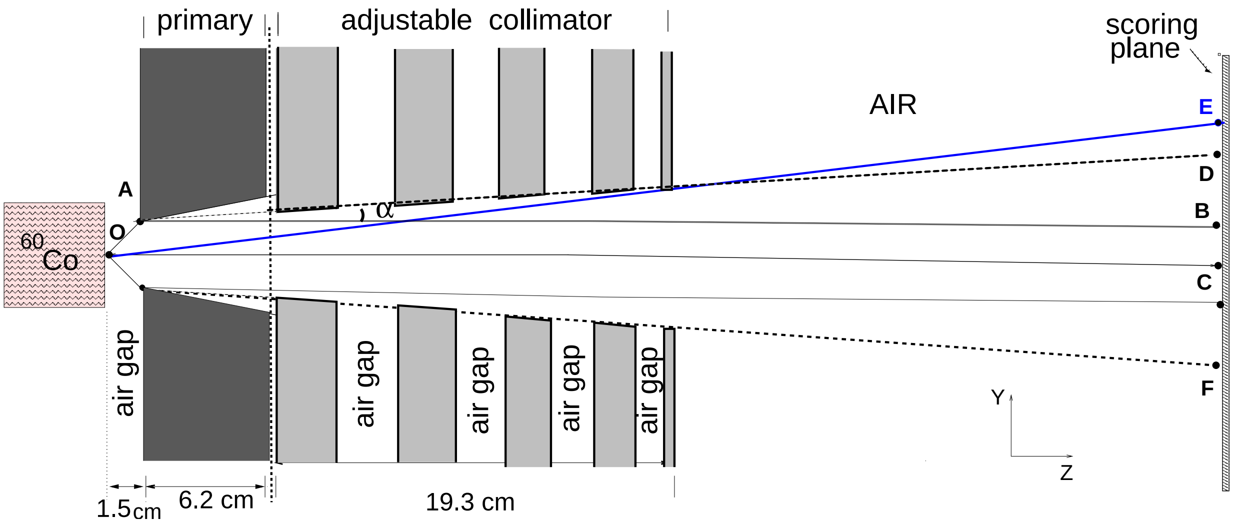

Figure 1: The model of the Eldorado 6 ^{60}Co unit. Field size at the scoring plane is represented by 2×EC rather than DF as suggested in the earlier work.[1]

^{60}Co unit were simulated and then modelled as incident on a homogeneous water phantom. Here we first report the duplication of these two simulations. In the simulations, an SSD of 80.5 cm is used in both narrow and broad beams for determining the field size, but the water phantom is set at a distance of 72 cm from the photon source since this was the experimental arrangement. The dose-depth curves are shown in Fig 2 and Fig 3 for both the broad and narrow beams, respectively. In both Fig 2 and Fig 3, the curves are normalized to the dose at the depth of dose maximum (0.5 cm) in the absence of electron contamination. For both narrow and wide beams the effects of the electron contamination are clearly seen from the difference between the total and photons only dose in the first 3.5 mm from the water surface. These two figures compare the measured data with the experimental work of Attix et al.[7] The agreement with measurement is comparable to that obtained by Mora et al.

Fig 2
Fig 3

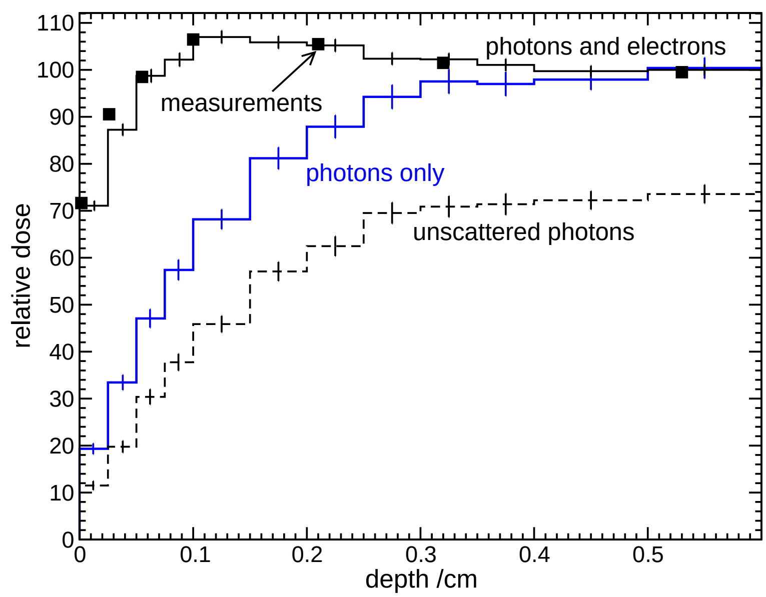

Figure 2: Broad beam depth-dose curves. The SSD is 72 cm and the field size is 35 cm $\times$ 35 cm (defined at SSD=80.5 cm). The calculated total dose is compared with the measured results from Attix et al.[7]

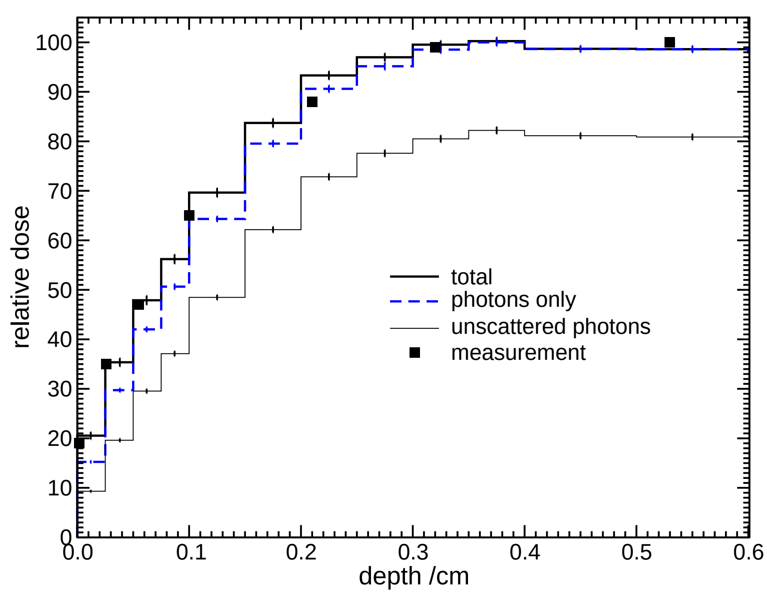

Figure 3: Narrow beam depth-dose curves. The SSD is 72 cm and the field size is 5 cm $\times$ 5 cm (defined at SSD = 80.5 cm). The calculated total dose is compared with the measured results of Attix et al.[7]

IV. Relative air kerma output factors

In Mora et al, the relative air kerma for different field sizes was simulated and the results were consistent with the NRC-measured values. We have simulated this relative air kerma output factor with exactly the same method used previously. The relative air kerma is defined as

$$K_{output}(i) = \left(\frac{K_i}{K_{ref}}\right), \tag{1}$$

where the air-kerma value K_i for each field size i is given by[1]

$$K_i = 1.0032 \int_0^{E_{max}} \Psi_i(E) \left(\frac{\mu_{en}}{\rho}\right) dE, \tag{2}$$

where (μ_{en}/ρ) are mass energy-absorption coefficients, 1.0032 is a constant to convert from collision kerma to total kerma[8] and the energy fluence spectrum is given by

$$\Psi_i(E) = \Phi_i(E)E, \tag{3}$$

with $\Phi_i(E)$ being the photon fluence spectrum for a field size i. As in the paper of Mora et al, the relative air kerma was calculated in two separate steps. We first obtained the phase space file of the fixed primary collimator, and then we used this phase space file for calculating the on-axis (in a 2 ×2 cm^2 region about the beam axis) spectrum for each different field size. In this way we can write:

$$K_{output}(i) = 1 + \frac{K_i^{scatt} - K_{ref}^{scatt}}{K_{ref}}. \tag{4}$$

Mora et al showed that the scattered components contribute no more than 30% of the air kerma and the second term on the right-hand side of Eq. (4) is less than 0.1. Thus the overall uncertainty on $K_{output}(i)$ is much smaller from Eq. (4) than from Eq.(1). One can find a more detailed discussion in the paper of Mora et al. The relative air kerma obtained in this way is shown in Fig 4, and a comparison to the measured data from NRCC (Ken Shortt and Dave Hoffman) is also shown. The field size at SSD=80.5 cm is varied from 6.3 × 6.3 to 30 × 30 cm^2, and the reference field size is 8 × 8 cm^2, as in the experiment. Fig 4

V. Photon spectra

Figures 5, 6 and 7 present the energy spectra of photons and electrons reaching the scoring Fig 5

Fig 6

Fig 7

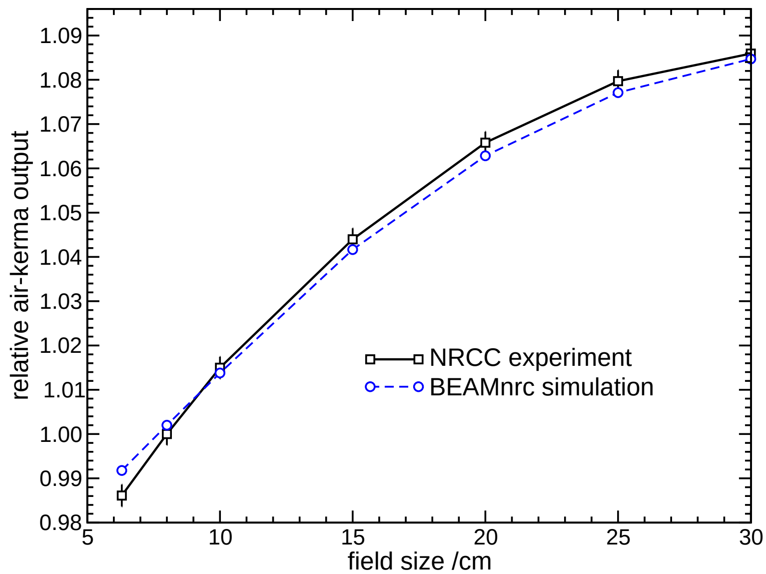

Figure 4: Relative air-kerma output factors vs field size for Eldorado 6 ^{60}Co at NRC. The air-kerma is normalized relative to the 8×8 cm^2 field. The measured data were provided by Ken Shortt and Dave Hoffman then of NRC.

plane at SSD=80.5cm for three field sizes. The full spectra of photons are calculated in a $2{\times}2$ cm^2 region, while the spectra of electrons are in an 8×8 cm^2 region about the axis of the beam and the low-energy peaks are scored in a $5{\times}5$ cm^2 region. The spectra shown in the two full energy range figures are essentially the same as those shown in Mora et al., except that in our results there are some small peaks at the low-energy side of the energy spectrum of photons (Fig 5). See also Fig 6. These small peaks are K-shell fluorescence peaks from Pb and W. The peak at about 58 keV is the Kα_2 line of tungsten (hν=57.981keV) and arises from the primary collimator which is made of 90% tungsten. In the ^{60}Co unit the secondary jaws (leaves) are made of lead and we see x-ray fluorescence lines from Pb for all field sizes (the other two peaks correspond to the Kα_2 (72.804keV) and Kβ_1 (84.936keV) lines of Pb). The EGS4/BEAM code was also able to simulate K-shell fluorescence, but for some unknown reason these lines did not appear in the simulation of Mora et al.

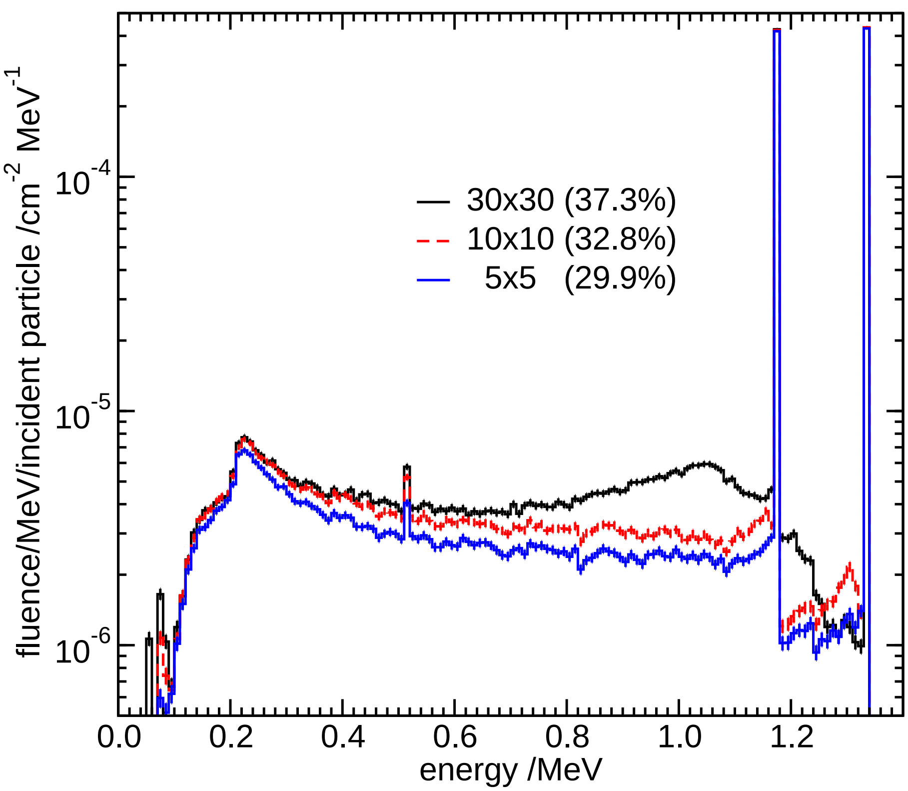

Figure 5: On-axis energy spectra of photons on the scoring plane at 80.5 cm SSD for three different field sizes (5×5, 10×10 and 30×30 cm ^{2}). Energy bins are 10 keV wide and are scored in a 2×2 cm^2 region. The percentage of the total fluence from the scattered photons is shown in the brackets.

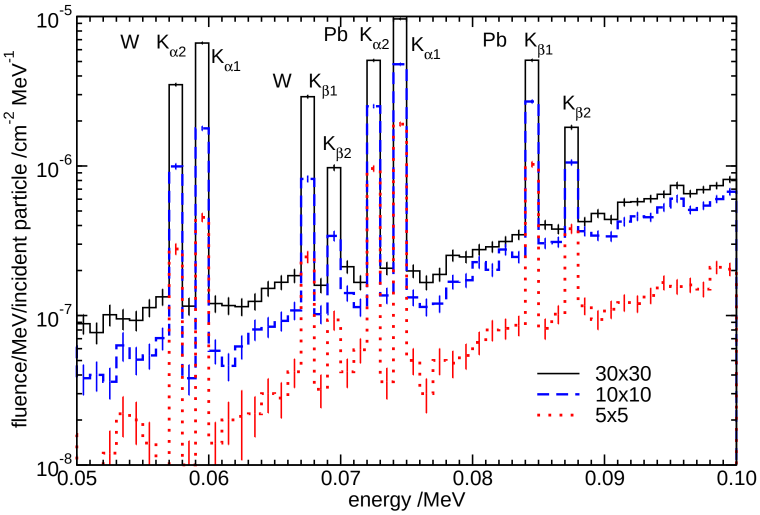

Figure 6: The low-energy peaks appearing in the 5 cm× 5 cm on-axis energy spectra of photons for three different field sizes (5×5, 10×10 and 30×30 cm^2). The peaks correspond to the K-shell x-ray fluorescence of W and Pb.

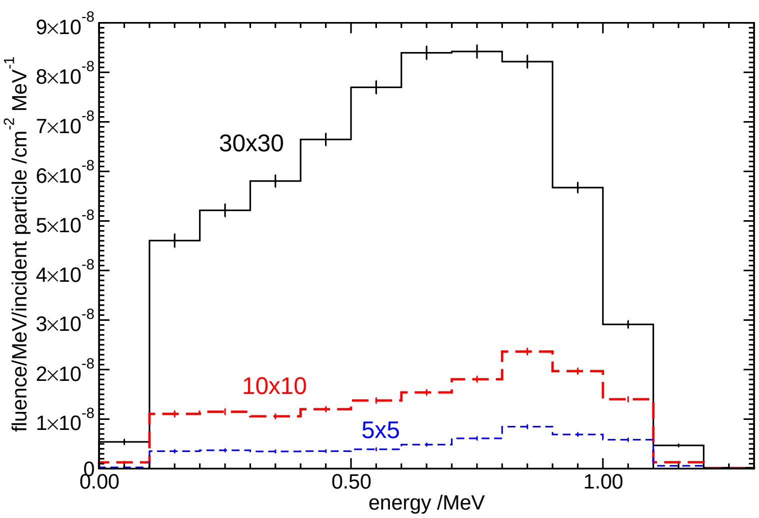

Figure 7: On-axis energy spectra of electrons on the scoring plane at 80.5 cm SSD for three different field sizes (5×5, 10×10 and 30×30 cm^2). The spectra are calculated in a 5 × 5 cm^2 region.

VI. Conclusions

In this report, by duplicating the simulations of Mora et al using BEAMnrc, we have shown that the input files for the ^{60}Co unit used in BEAM simulations with EGS4 are still valid for simulations of BEAMnrc using EGSnrc.

VII. References

1 G. Mora, A. Maio, and D. W. O. Rogers, Monte Carlo simulation of a typical ^{60}Co therapy source, Med. Phys. **26**, 2494 – 2502 (1999).

2 W. R. Nelson, H. Hirayama, and D. W. O. Rogers, The EGS4 code system, Report SLAC–265, Stanford Linear Accelerator Center, Stanford, California, 1985.

3 D. W. O. Rogers, B. A. Faddegon, G. X. Ding, C.-M. Ma, J. Wei, and T. R. Mackie, BEAM: A Monte Carlo code to simulate radiotherapy treatment units, Med. Phys. **22**, 503 – 524 (1995).

4 I. Kawrakow, Accurate condensed history Monte Carlo simulation of electron transport. I. EGSnrc, the new EGS4 version, Med. Phys. **27**, 485 – 498 (2000).

5 I. Kawrakow and D. W. O. Rogers, The EGSnrc Code System: Monte Carlo simulation of electron and photon transport, Technical Report PIRS–701, National Research Council of Canada, Ottawa, Canada, 2000.

6 D. W. O. Rogers, B. Walters, and I. Kawrakow, BEAMnrc Users Manual, NRC Report PIRS 509(a)revK (2006).

7 F. H. Attix, F. Lopez, S. Owolabi, and B. R. Paliwal, Electron contamination in ^{60}Co gamma-ray beams, Med. Phys. **10**, 301 – 306 (1983).

8 D. W. O. Rogers, Fundamentals of High Energy X-ray and Electron Dosimetry Protocols, in *Advances in Radiation Oncology Physics, Medical Physics Monograph 19*, edited by J. Purdy, pages 181 – 223, AAPM, New York, 1992.

VIII. Appendix

VIII.A Sizes of Phase space files

The table below shows the size of the phase space files for beams of different field sizes. These runs are all quite short but can be easily scaled. For example, for 1% photon fluence statistics for a 30×30 cm^2 field one needs a phase space file of $118 * (1.67/1.0)^2 = 329$ MB.

Table 1: The size of phase-space file produced and the 1 s statistical uncertainty on the fluence in an on-axis region of 1×1 cm^2 achieved for a 19.5 minute run using 255,000,000 histories for beams of different field sizes.

Field Size (cm^2)	Photon Fluence 1s (%)	Electron Fluence 1s (%)	PHSP Size (MB)
5x5	1.79	70.77	6
6.3x6.3	1.77	44.82	8
7x7	1.77	38.03	10
8x8	1.76	37.89	12
10x10	1.75	35.42	17
15x15	1.72	30.56	34
20x20	1.69	30.19	57
25x25	1.68	30.87	85
30x30	1.67	25.87	118
35x35	1.67	25.05	155

For the phase space files distributed the actual sizes and statistics are given in table 2.

Table 2: As in table 1 except for the 3 phase space files being distributed.

Field Size (cm^2)	Photon Fluence 1s (%)	Electron Fluence 1s (%)	PHSP Size (MB)
5x5	0.41	17	116
10x10	0.40	11.8	330
30x30	0.38	5.9	2,318

VIII.B LATCH settings

In the creation of the phase space files, the following definitions of the BEAMnrc LATCH bits were used.

Table 3: Defintions of the BEAMnrc LATCH bits which are available in the phase space files.

LATCH bit	description
1	Co inside capsule
2	Fe at back of capsule
3	Fe at side of capsule
4	Fe at front of capsule
5	lead behind capsule
6	lead beside and behind(to side) capsule
7	HEVIMET in primary collimator
8	Pb in outer collimator
9	air in primary & outer collimator
10	air before phantom
8,11, 12, 13, 14	Pb leaves in collimator, closest to farthest from source

VIII.C Location of files

All of the relevant files are on-line at `http://www.physics.carleton.ca/clrp/Co60_phsp`

The files associated with the creation of the phase space files being distributed are named:
`iaea_nophant_forphsp_30x30_at80p5.egsinp` etc
and are stored at CLRP on `/home/drogers/co60/final_runs_input_output/iaea_phsp`
They were run on: `/home/drogers/egsnrc_MP9/BEAM_eldorado6e5_nophant_IAEA/`
and the phase space files stored on `/data/data024/drogers/IAEA_phsp_Co`

The files associated with the depth-dose curve calculations are called:
`35x35_at80p5_dd_water_SSD72cm.egsinp` etc
They are stored at CLRP on
`/home/drogers/co60/final_runs_input_output/percent_depth_dose`
They were run on `/home/bmuir/egsnrc_MP15/BEAM_eldorado6e5_ph`