Life Sciences in Space Research 000 (2016) 1–4

Contents lists available at ScienceDirect

Life Sciences in Space Research

journal homepage: www.elsevier.com/locate/lssr

Corrigendum to “Monte Carlo simulations of the secondary neutron ambient and effective dose equivalent rates from surface to suborbital altitudes and low Earth orbit”

Samy El-Jaby

Radiological Protection Research and Instrumentation, Canadian Nuclear Laboratories, Canada

ARTICLE INFO

Article history:
Received 18 March 2016
Accepted 22 March 2016
Available online xxx

Keywords:
Ambient dose equivalent
Effective dose equivalent
Secondary neutron
Suborbital altitude
Low Earth orbit
Galactic cosmic radiation
MCNPX

ABSTRACT

A recent paper published in Life Sciences in Space Research (El-Jaby and Richardson, 2015) presented estimates of the secondary neutron ambient and effective dose equivalent rates, in air, from surface altitudes up to suborbital altitudes and low Earth orbit. These estimates were based on MCNPX (LANL, 2011) (Monte Carlo N-Particle eXtended) radiation transport simulations of galactic cosmic radiation passing through Earth’s atmosphere. During a recent review of the input decks used for these simulations, a systematic error was discovered that is addressed here. After reassessment, the neutron ambient and effective dose equivalent rates estimated are found to be 10 to 15% different, though, the essence of the conclusions drawn remains unchanged.

1. Correction

In the original methodology, the Badhwar–O’Neill 2010 (BO’10) (O’Neill, 2010) GCR model was used to approximate the primary radiation environment. The discrete BO’10 data was approximated as a histogram-based distribution. This was accomplished by first averaging the flux and energy values of the discrete data. These averaged quantities then formed the histogram-based source distributions sampled. During implementation, an additional energy bin from 0 MeV up to the first energy bin was also unintentionally sampled. So, for example, where the true spectra for one of the ion species may start from 1 MeV, the sampled distribution actually extended down to 0 MeV. This error was recently identified by the author and exploratory simulations were carried out to quantify the impact on the neutron ambient and effective dose equivalent rate estimates provided. Furthermore, in the simulation results presented here, the discrete BO’10 data spectra were directly incorporated into the histogram-based, MCNPX input distributions without the averaging procedure. To expedite a resolution to this matter, simulations were repeated with less particle histories than originally carried out and no variance reduction was used.

E-mail address: samy.el-jaby@cnl.ca

2. Results

The GCR, proton-induced neutron flux given has changed slightly. This is shown in Fig. 1 and Fig. 2 which compare original and current estimates (replaces Fig. 4 and Fig. 5, respectively, El-Jaby and Richardson, 2015). There is also minimal change in the relative contributions to the total neutron flux, by the differing primary ion species. These are shown in Fig. 4 (replaces Fig. 6, El-Jaby and Richardson, 2015). For instance, for 0 GV cutoff rigidity at surface altitudes, protons are now found to contribute 70% to the total neutron flux while helium nuclei are found to contribute 22%. In Section 3.1 of the original publication, these values were 76% and 22%, respectively (El-Jaby and Richardson, 2015). For the same rigidity at suborbital altitudes, protons are now found to contribute 77% rather than 75%, and helium nuclei 18% rather than 19% (El-Jaby and Richardson, 2015). At suborbital altitudes and 16 GV cutoff rigidity, proton contributions are now less by 1%, while helium nuclei contributions remain the same (El-Jaby and Richardson, 2015).

Estimates of the neutron ambient and effective dose equivalent rates have also changed. Figs. 3(a) and (b) compare prior estimates of the neutron ambient and effective dose equivalent rate as a function of altitude, against current estimates (replaces Fig. 7, El-Jaby and Richardson, 2015). The amended results suggest that the estimated neutron ambient and effective dose equivalent rates are 10 to 15% different than those first published (El-Jaby and Richardson, 2015). For instance, where the peak neutron ambient

http://dx.doi.org/10.1016/j.lssr.2016.03.003

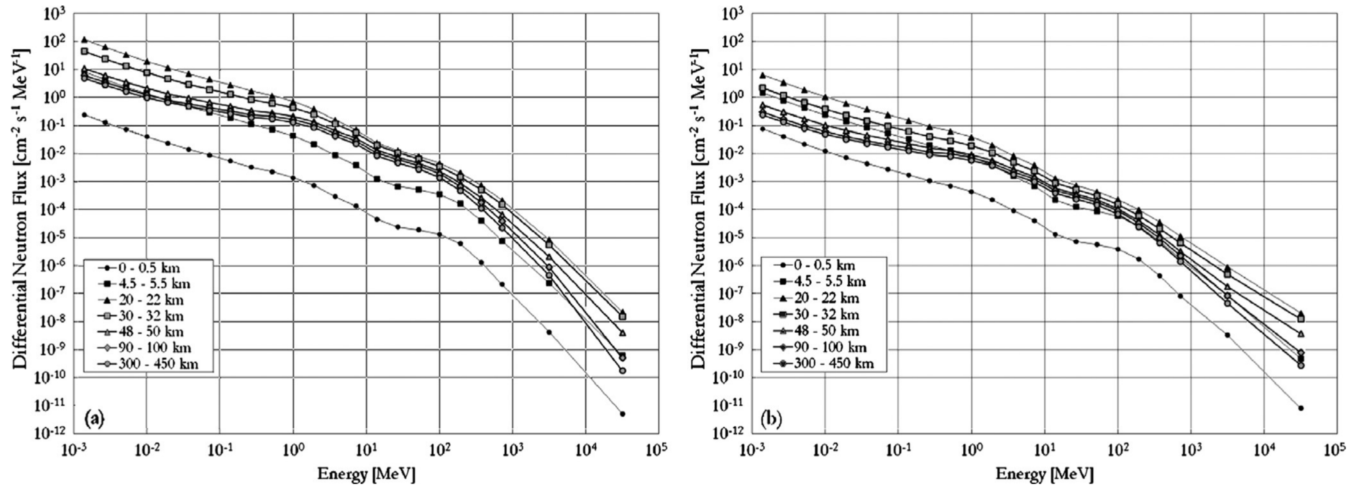

Fig. 1. GCR proton-induced neutron spectrum at representative altitudes and (a) 0 GV (near poles) and (b) 16 GV (near equator) cutoff rigidities. (New estimates shown only.)

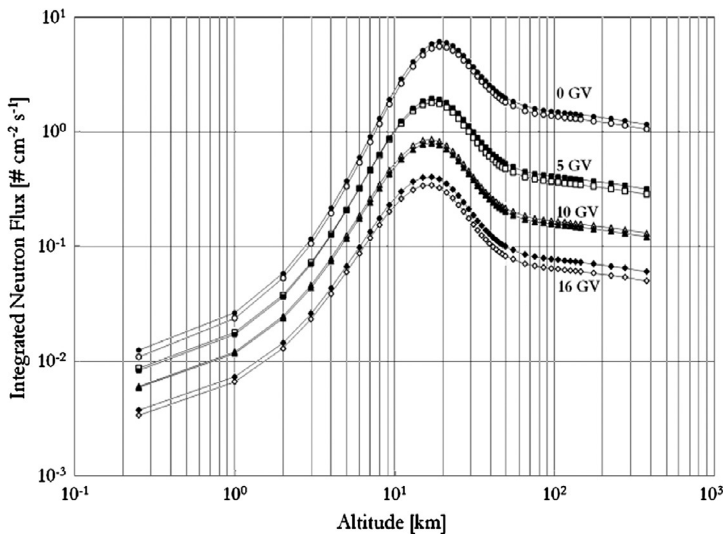

Fig. 2. Integrated GCR proton-induced neutron flux as a function of altitude and cutoff rigidity going from 0 GV (near poles) towards 16 GV (near equator). (Solid markers represent original estimates (El-Jaby and Richardson, 2015); Void markers represent new estimates.)

dose equivalent rate at 0 GV was purported to be $9\,\mu\mathrm{Sv\,hr}^{-1}$, it is now nearer to $8\,\mu\mathrm{Sv\,hr}^{-1}$. Similarly, the peak neutron effective dose equivalent rate at 0 GV now approaches $5\,\mu\mathrm{Sv\,hr}^{-1}$ rather than $\sim 5.5\,\mu\mathrm{Sv\,hr}^{-1}$ (El-Jaby and Richardson, 2015). The remaining dose rates for the different cutoff rigidities have changed minimally from those reported in the text in Section 3.2 (El-Jaby and Richardson, 2015).

The amended results were also re-benchmarked against the measured neutron spectra (Goldhagen et al., 2004; Clem et al., 2004). These are given in Fig. 5 (replaces Fig. 8, El-Jaby and Richardson, 2015). The new estimates are shifted down from original estimates yet still agree well with measured values. Moreover, improved agreement is now achieved for Fig. 5d. It had previously been unclear as to why the quality of this particular benchmark was relatively poor compared to the others (see Section 4, pg. 7, El-Jaby and Richardson, 2015). These corrections seem to have addressed that outstanding issue. The final benchmark compared the neutron ambient dose equivalent rate as a function of cutoff rigidity against FLUKA simulation results (Roesler et al., 2002) at an altitude of 10 to 12 km. This is shown in Fig. 6 (replaces Fig. 9, El-Jaby and Richardson, 2015). The original neutron ambient dose equivalent rates slightly overestimated the FLUKA results for cutoff rigidities less than 4 GV. In the reassessed values, the FLUKA results are now underestimated for cutoff rigidities of 2 GV and less, but agree well beyond this value. Moreover, although at 0 GV it is under-predicted, the difference remains within 10% of the FLUKA results.

3. Conclusion

To conclude, estimates of neutron ambient and effective dose equivalent rates in air are different from those first reported by 10 to 15%. The aim of the original paper was to provide an estimate of the neutron ambient dose equivalent rate and effective dose equivalent rate, in air, from surface up to suborbital and orbital altitudes. The substance and essence of the conclusions drawn in the original paper remain valid.

Acknowledgments

This work is supported by Atomic Energy of Canada Limited administered Federal Science and Technology program.

Please cite this article as: S. El-Jaby, Corrigendum to “Monte Carlo simulations of the secondary neutron ambient and effective dose equivalent rates from surface to suborbital altitudes and low Earth orbit”, Life Sciences in Space Research (2016), http://dx.doi.org/10.1016/j.lssr.2016.03.003