An update on Monte Carlo simulations of the radiation environment at space tourism altitudes

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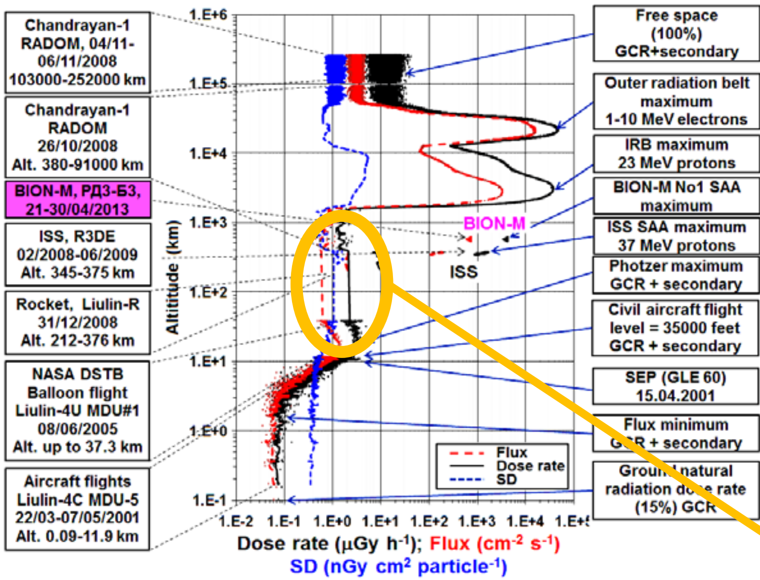
"Space shuttle Endeavour is featured in this photo by an Expedition 22 crew member on board the International Space Station"
https://www.nasa.gov/multimedia/imagegallery/image_feature_1592.html

Monte Carlo Simulations of the Radiation Environment at Suborbital Altitudes

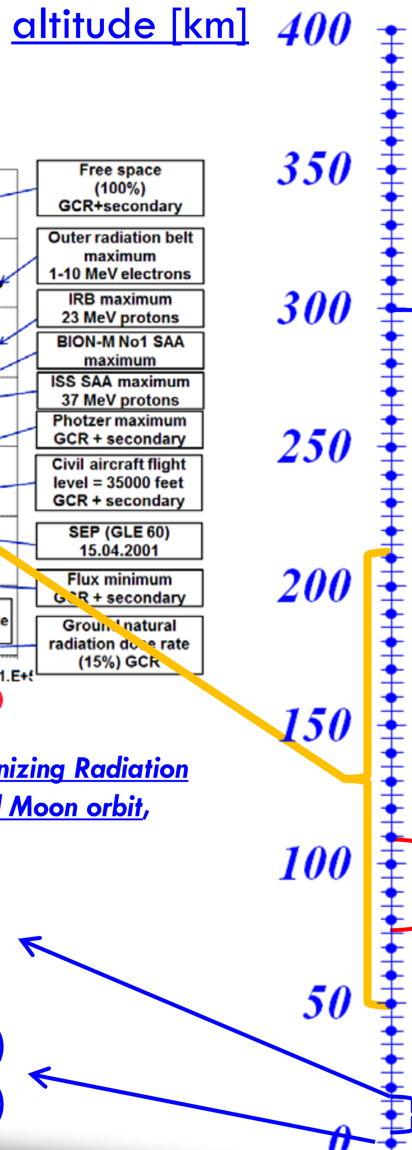
The 19th WRMISS, Polish Academy of Arts and Sciences, Kraków, Poland (2014), *Samy El-Jaby, Richard Richardson*

With space tourism expected in the near future, it is important to improve our understanding of the radiation environment at these alititudes!

(see WRMISS-19)



T.P. Dachev, Altitudinal Distribution of the Ionizing Radiation Exposure between the Earth Surface and Moon orbit, WRMISS 2013.



LEO (~300 – 400 km)
(~ 60 mSv per 140 day mission on ISS)

Overall, the air is thinner at suborbital altitudes and we'd expect greater dose moving up to LEO.

However, what is the composition of that dose? What's the radiation environment look like?

Suborbital altitudes (~80 – 110 km)

Commercial Aircraft (~7 – 14 km)
(~ 1 – 6 mSv y^{-1} occupational dose)

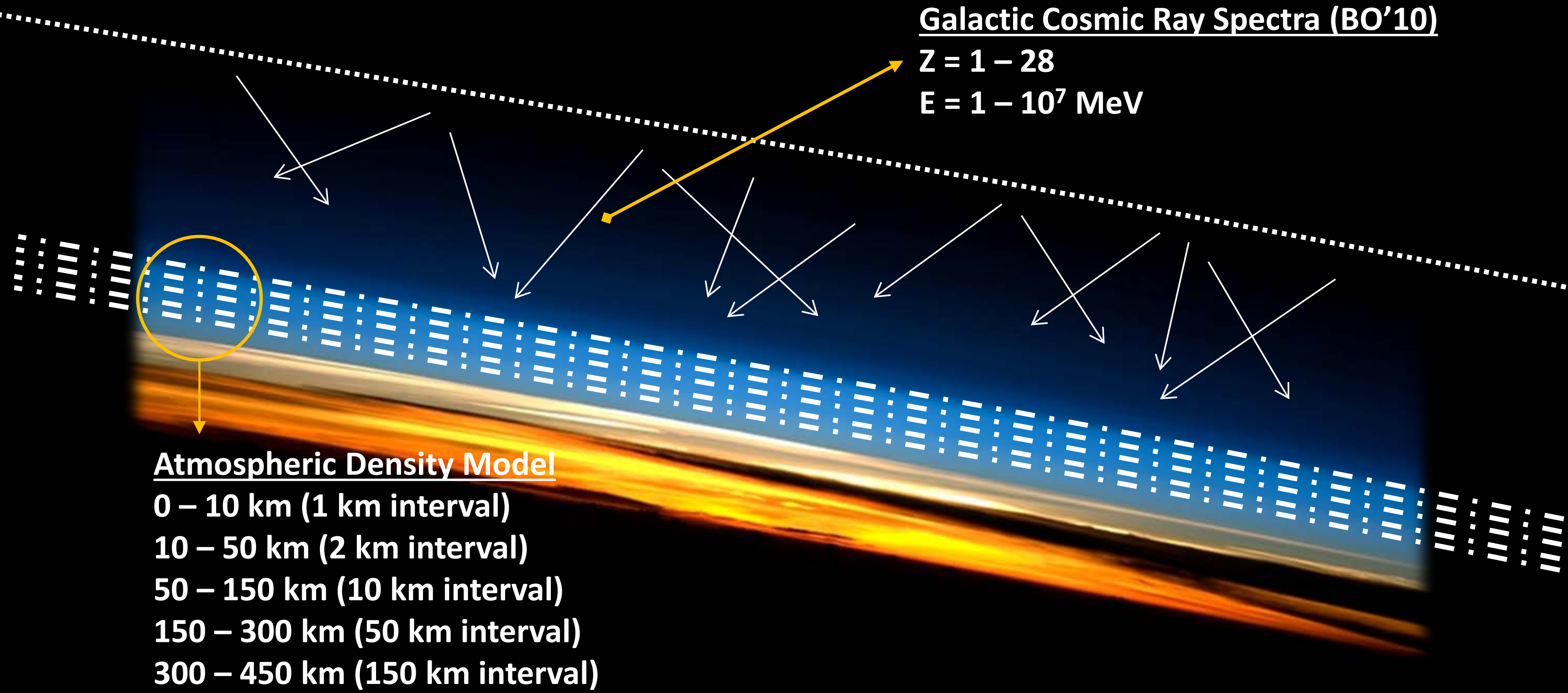
Pftozer Maximum (~20 km)

Surface altitudes (~0 km)
(~ 3 mSv y^{-1} nat. rad.)

(see WRMISS-19)

Geometrical Model

MCNPX 2.7.0 (Monte Carlo N-Particle eXtended) Radiation Transport Code



(see WRMISS-19)

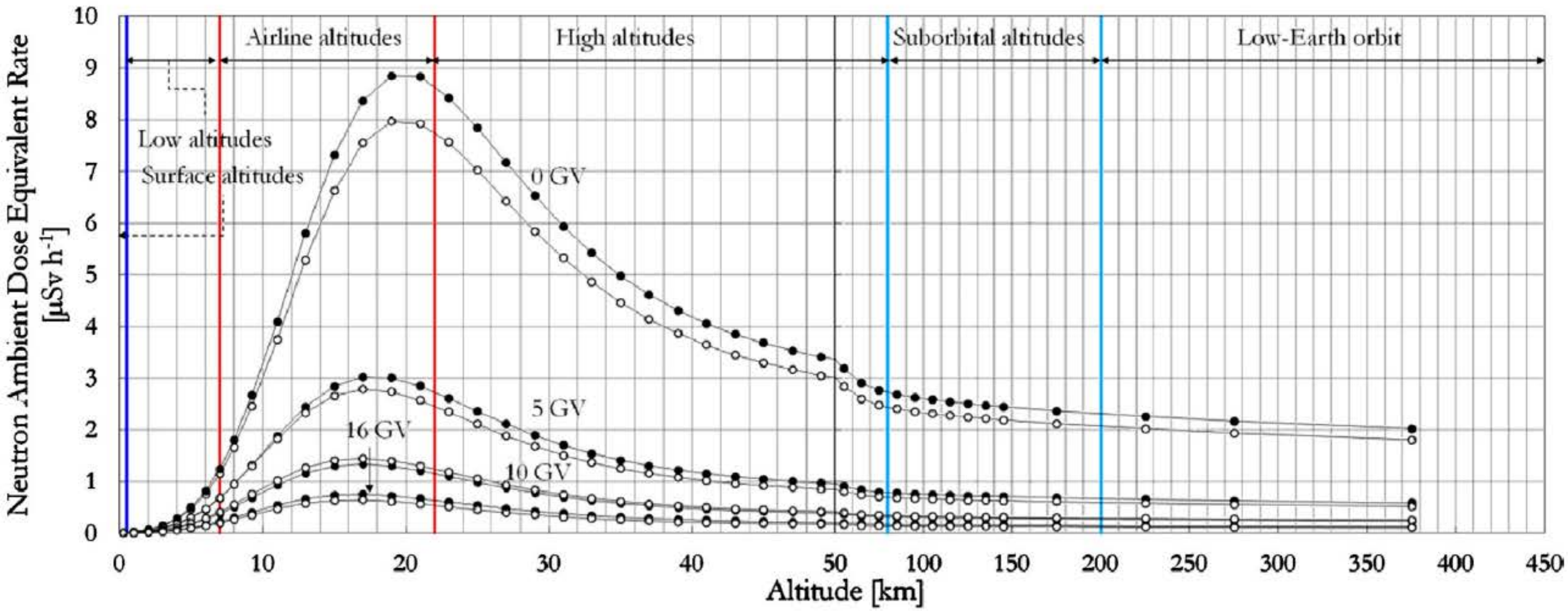
Geometrical Model

Key Points In Approach:

- ***ALL GCR ions transported (individually) at 0 GV and 16 GV.***
- ***GCR-protons transported at 1 - 5, 7, 10 GV.***
- ***% contribution of GCR-proton induced neutrons then scaled using information from runs at 0 GV and 16 GV.***
- ***Variance reduction techniques used to speed up simulations!***

October 14, 2012 Felix Baumgartner jumped from 39 km altitude!

Updated Results Since WRMISS-19!



Solid markers represent original estimate! New estimates now 10 – 15% less!

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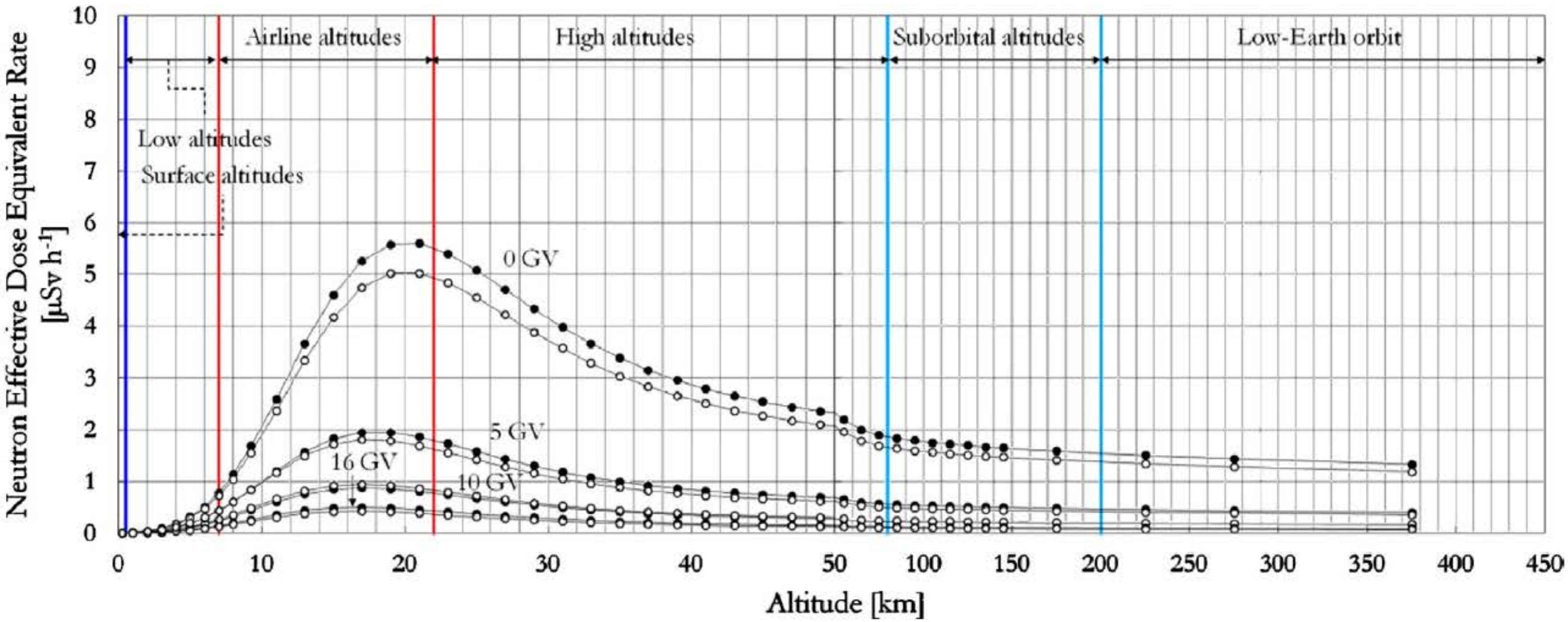
Updated Results Since WRMISS-19!



Solid markers represent original estimate! New estimates now 10 – 15% less!

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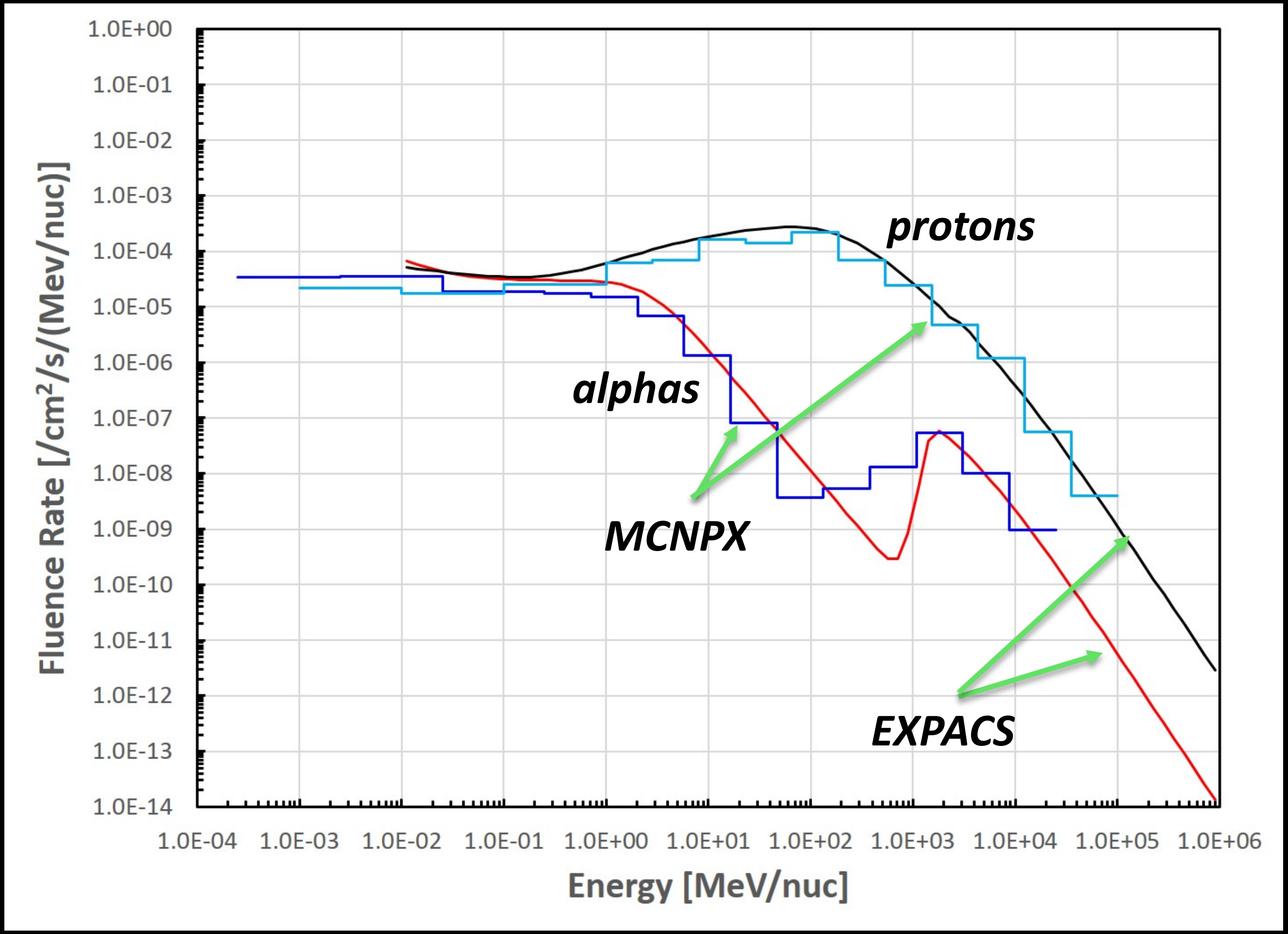
Additional Work Undertaken Since WRMISS-19

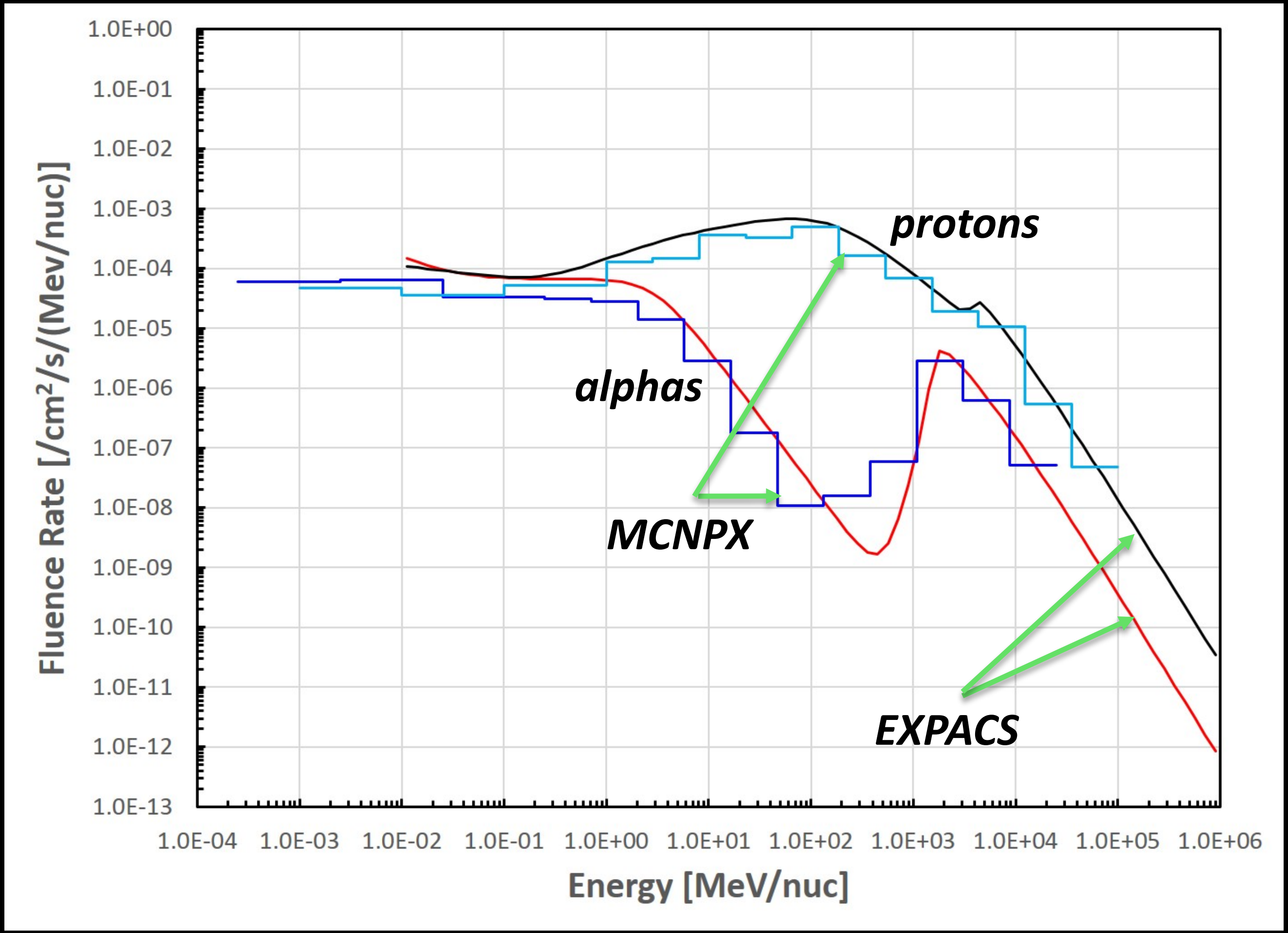
- *Used the same inputs and methodologies as previously described for secondary neutron production during WRMISS-19.*
- *Looking only at 5 GV cutoff rigidity. This was chosen to approximate anticipated space tourism launch locations (i.e. New Mexico, USA).*
- *Examined only secondary protons and alphas produced.*

Preliminary Results (secondary fluence rate @ 5GV & 10 km)



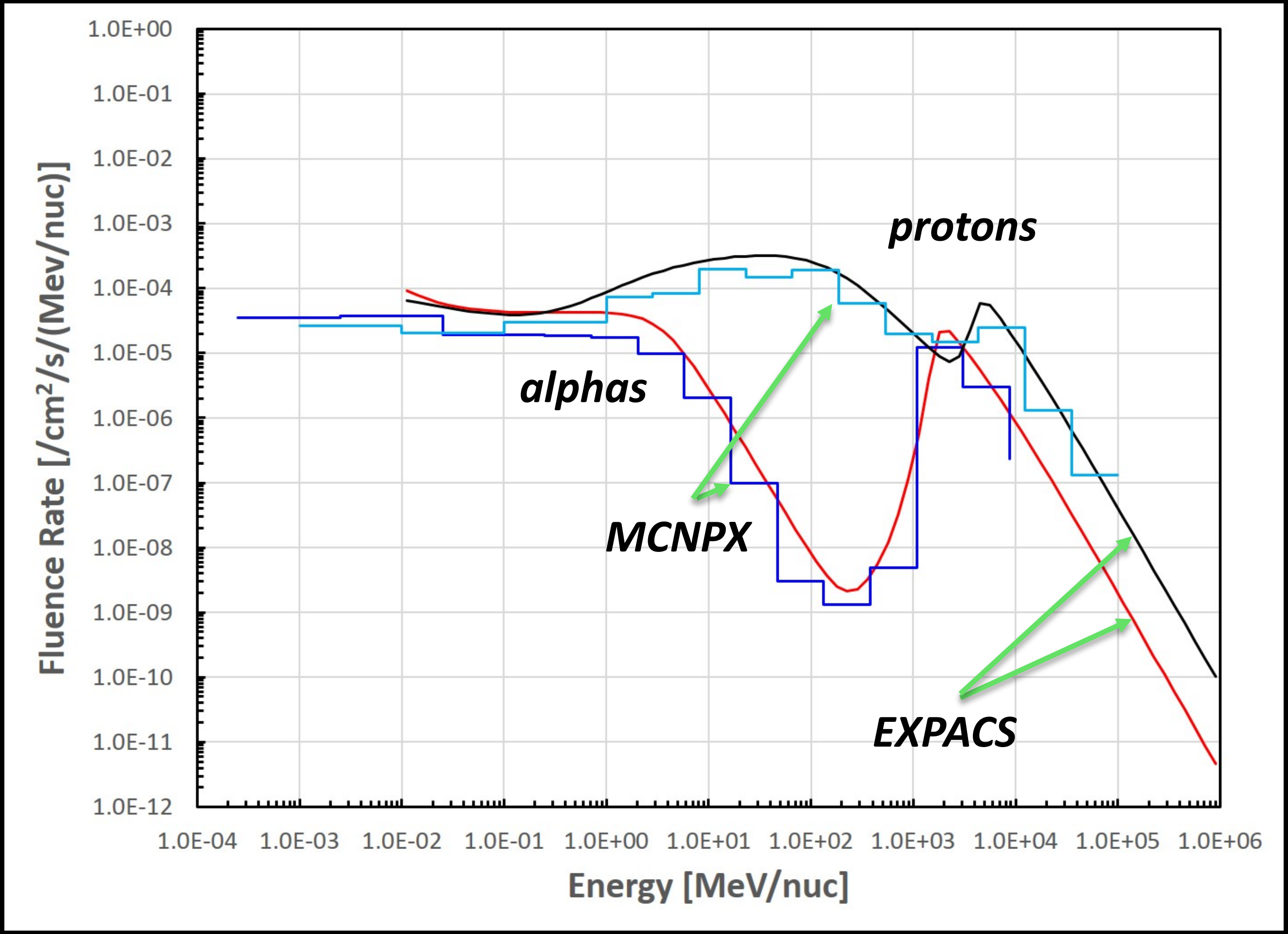
T. Sato, Analytical model for estimating terrestrial cosmic ray fluxes nearly anytime and anywhere in the world: Extension of PARMA/EXPACS, PLOS ONE, 10(12): e0144679. (2015)

Preliminary Results (secondary fluence rate @ 5GV & 20 km)



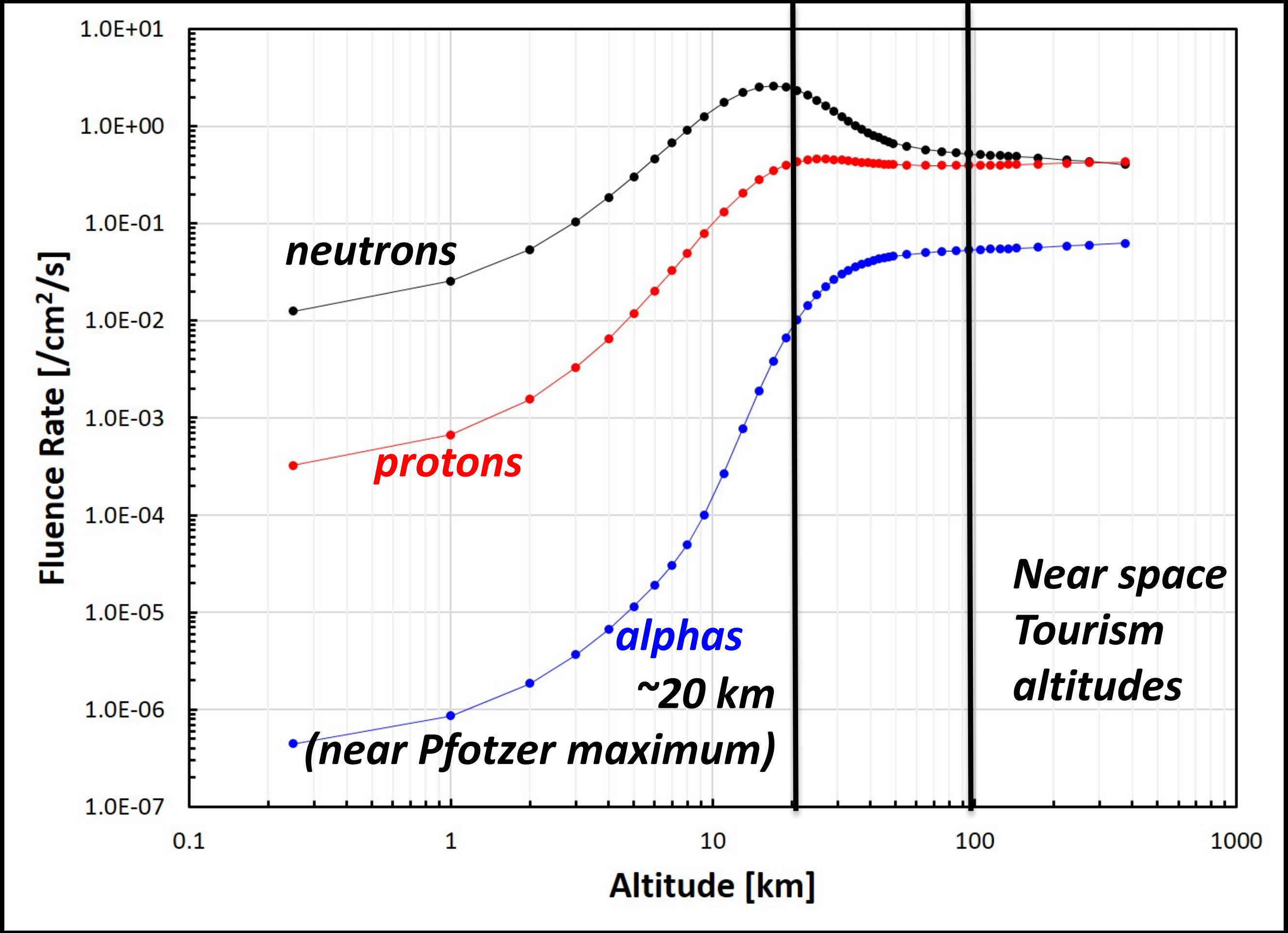
T. Sato, Analytical model for estimating terrestrial cosmic ray fluxes nearly anytime and anywhere in the world: Extension of PARMA/EXPACS, PLOS ONE, 10(12): e0144679. (2015)

Preliminary Results (secondary fluence rate @ 5GV & 50 km)

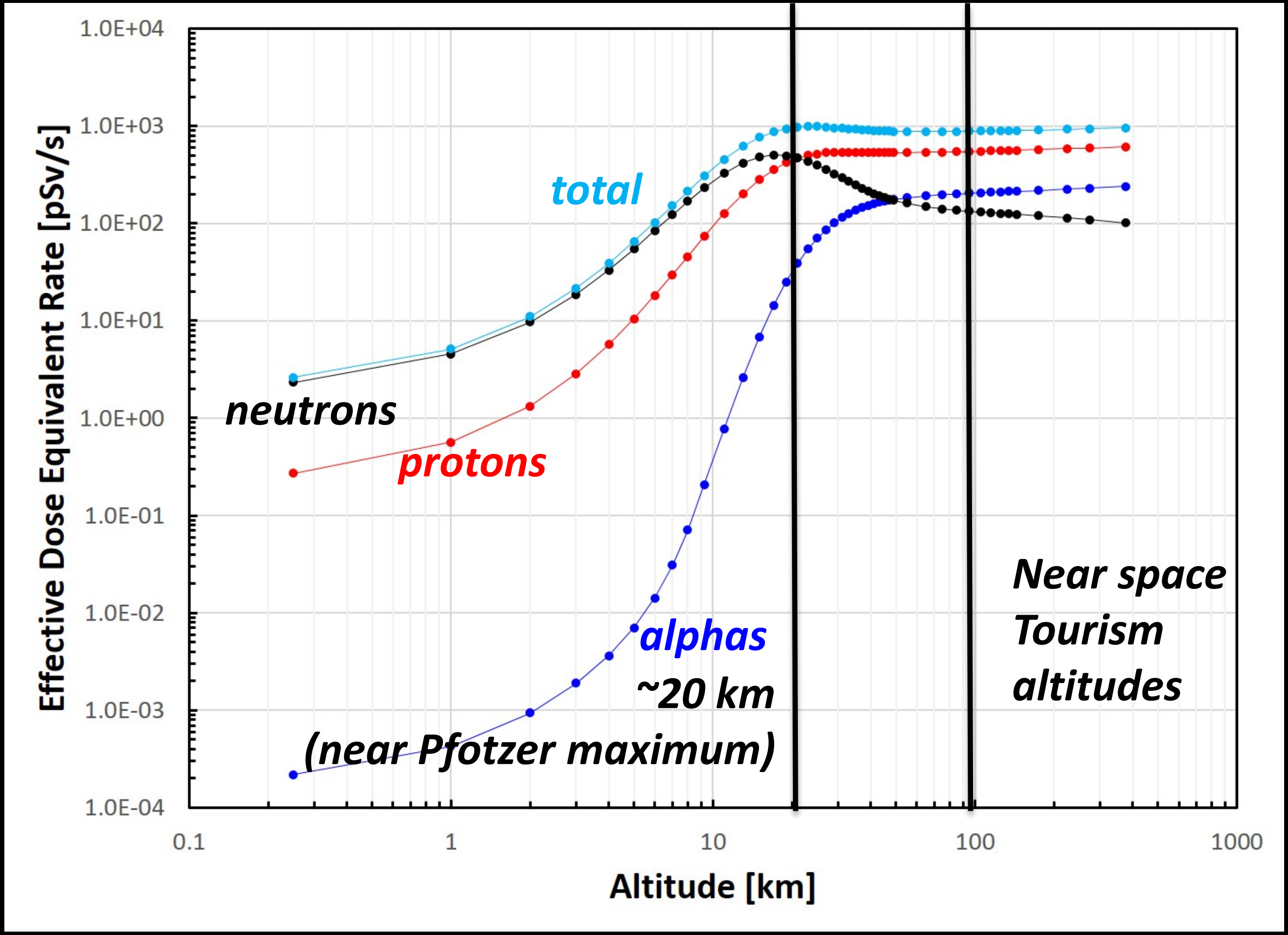


T. Sato, Analytical model for estimating terrestrial cosmic ray fluxes nearly anytime and anywhere in the world: Extension of PARMA/EXPACS, PLOS ONE, 10(12): e0144679. (2015)

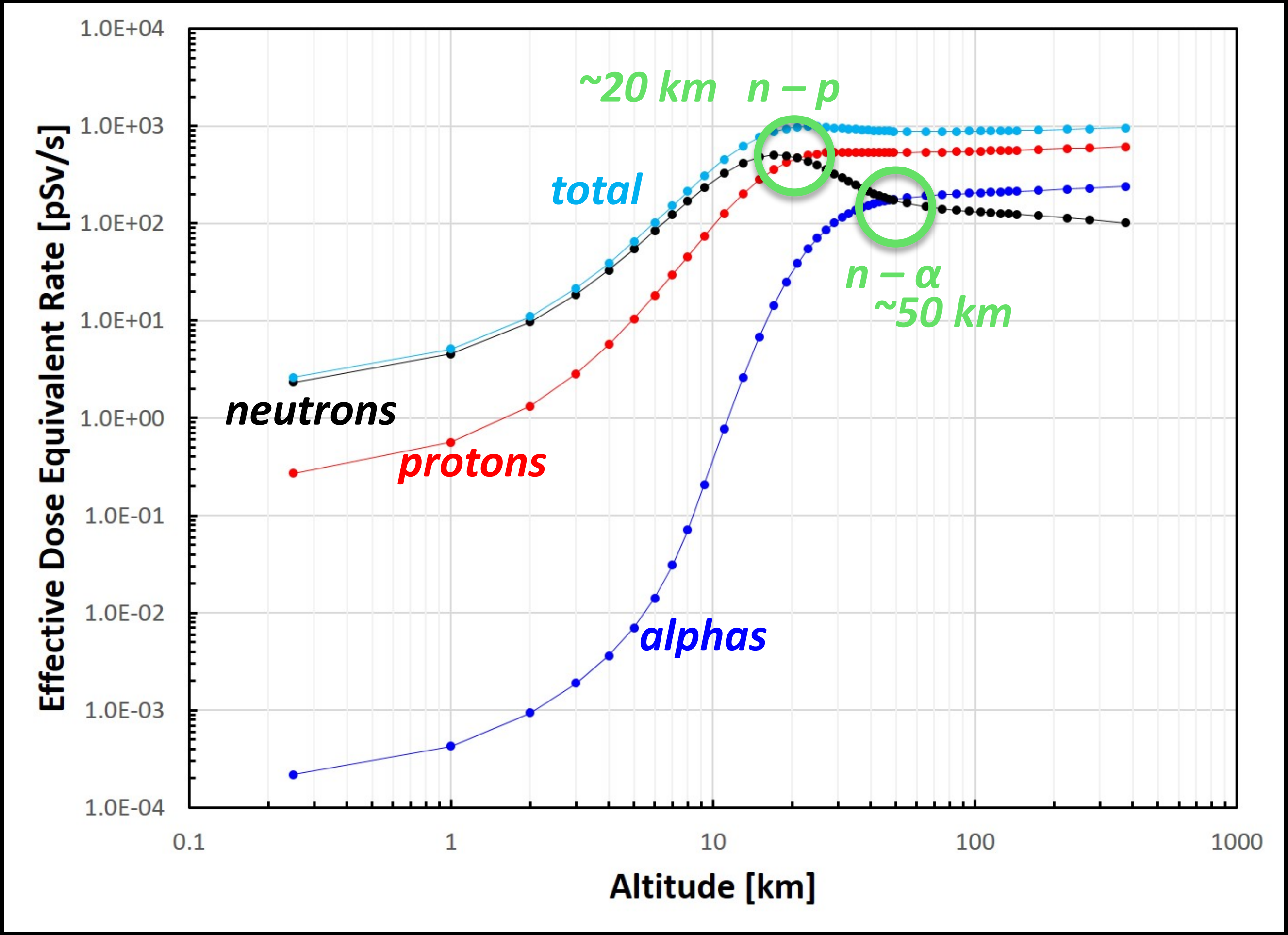
Preliminary Results (energy integrated fluence rate @ 5GV)



Preliminary Results (eff. dose eq. @ 5GV)



Preliminary Results (eff. dose eq. @ 5GV)



Benchmark Against FLUKA + LUIN H*(10)

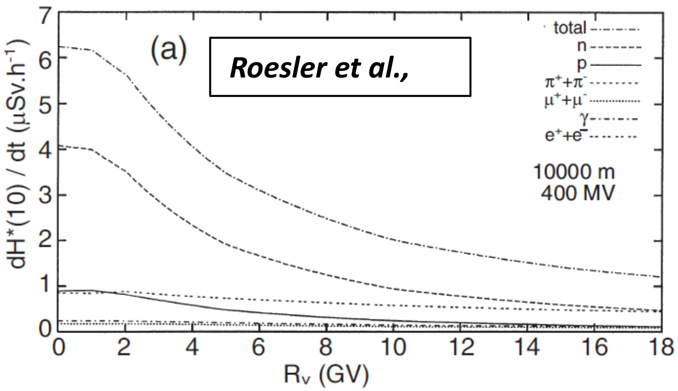


Figure 18. Ambient dose equivalent rate as a function of the vertical rigidity cut-off of the primary particle spectrum for (a) different types of particles at 10,000 m above sea level and a solar modulation of 400 MV, (b) different solar modulation parameters and a height above sea level of 10,000 m, and (c) different heights above sea level and a solar modulation of 400 MV. Figures (b) and (c) show the total ambient dose equivalent rate.

Radiation Protection Dosimetry
Vol. 98, No. 4, pp. 367–388 (2002)
Nuclear Technology Publishing

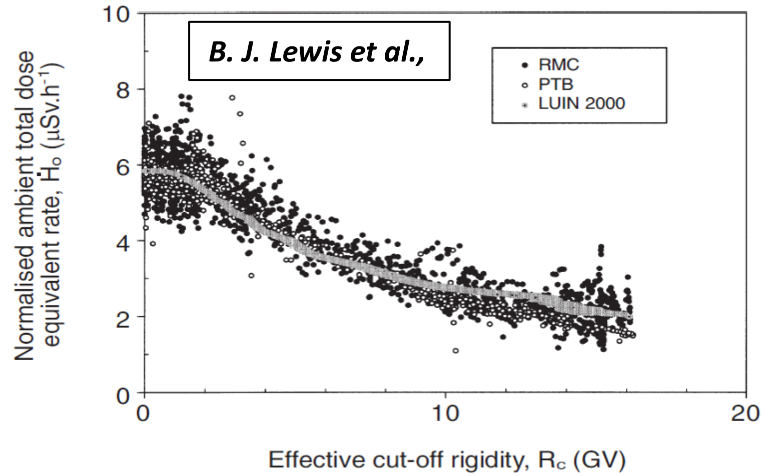


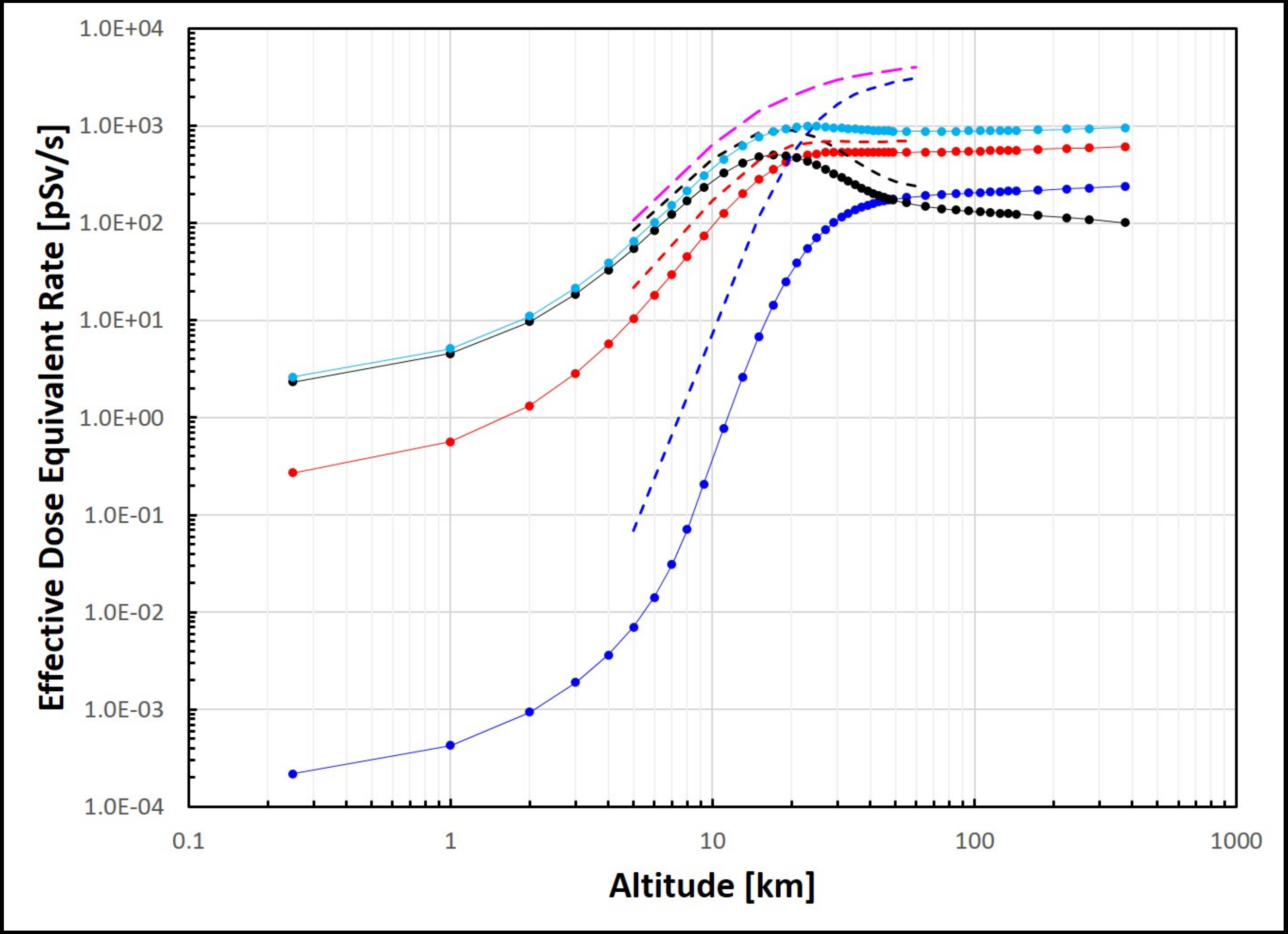
Figure 12. Comparison of the experimental data at RMC and PTB (normalised to U = 640 MV and 10.6 km) with the LUIN 2000 code predictions. The vertical cut-off rigidity values are based on the IGRF 1995 table values for a five degree by five degree world grid.

Radiation Protection Dosimetry
Vol. 93, No. 4, pp. 293–314 (2001)
Nuclear Technology Publishing

@ 11 km, effective dose in this work estimated to ~1.6 μSv/h.

Ambient dose equivalent rate at 5 GV, at ~10 km, is ~3 - 4 μSv/h.

Benchmark Against EXPACS @ 5GV



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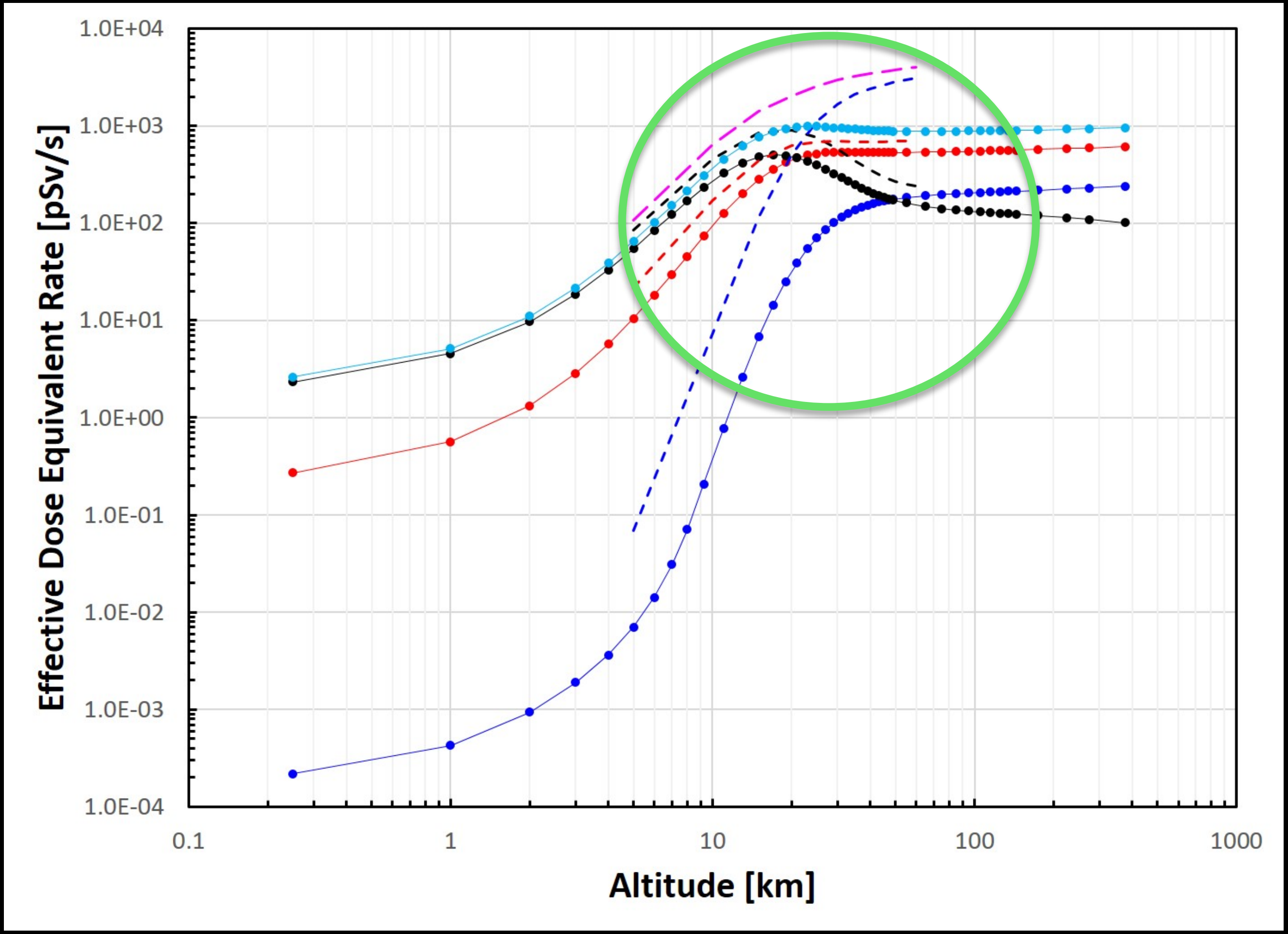
Benchmark Against EXPACS @ 5GV



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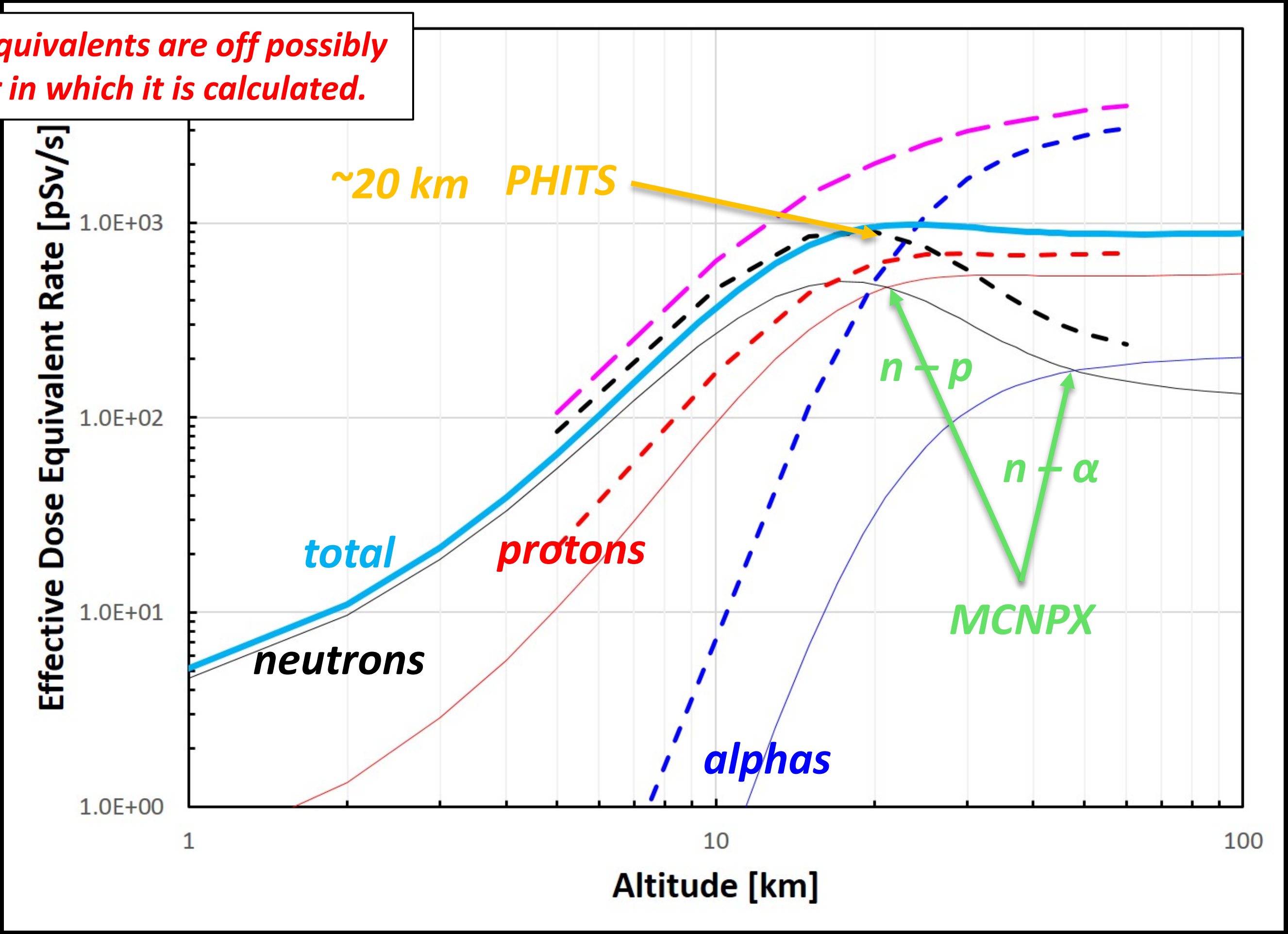
Benchmark Against EXPACS @ 5GV

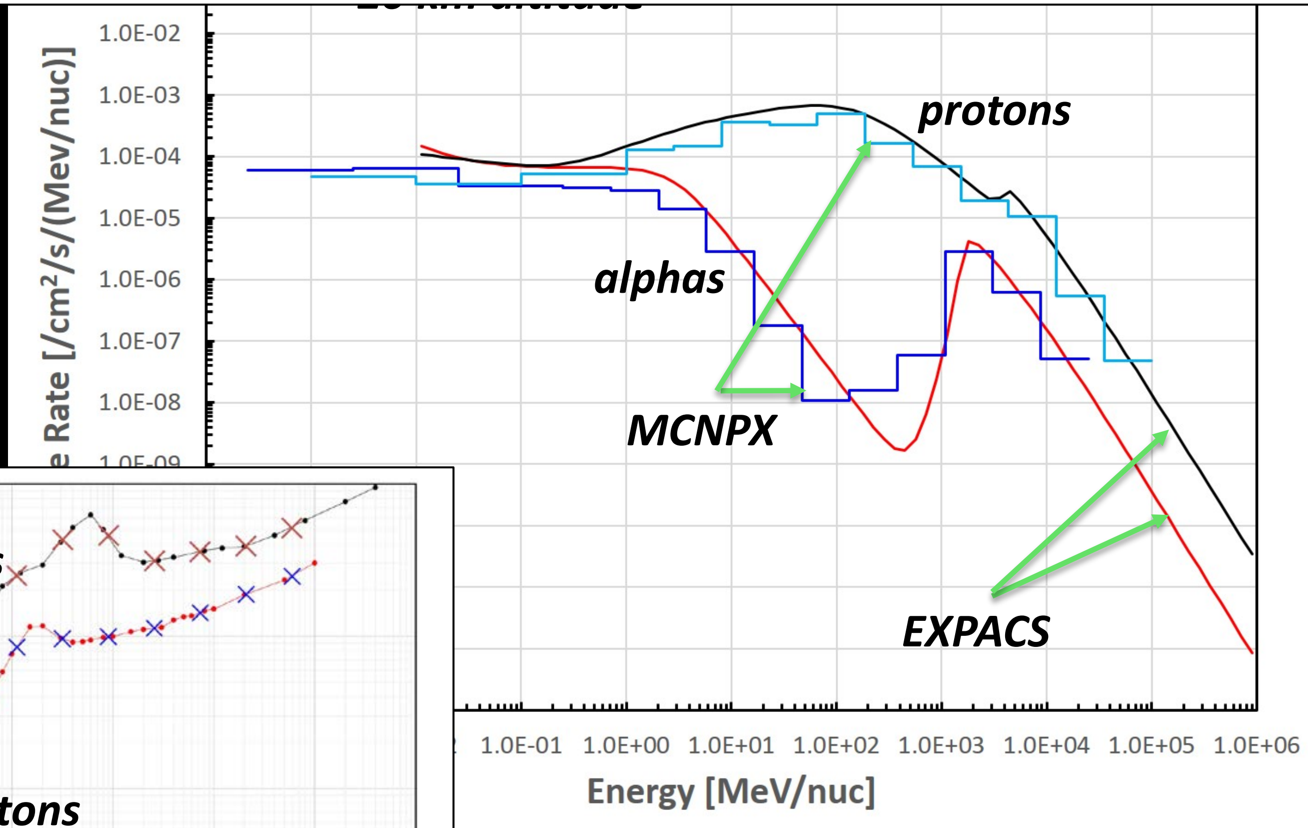
Effective dose equivalents are off possibly due to manner in which it is calculated.

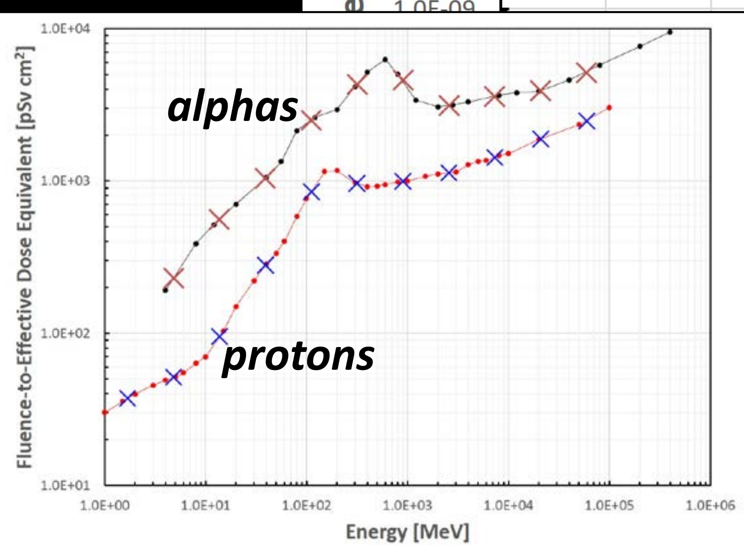


T. Sato, Analytical model for estimating terrestrial cosmic ray fluxes nearly anytime and anywhere in the world: Extension of PARMA/EXPACS, PLOS ONE, 10(12): e0144679. (2015)

Benchmark Against EXPACS @ 5GV & 20 km

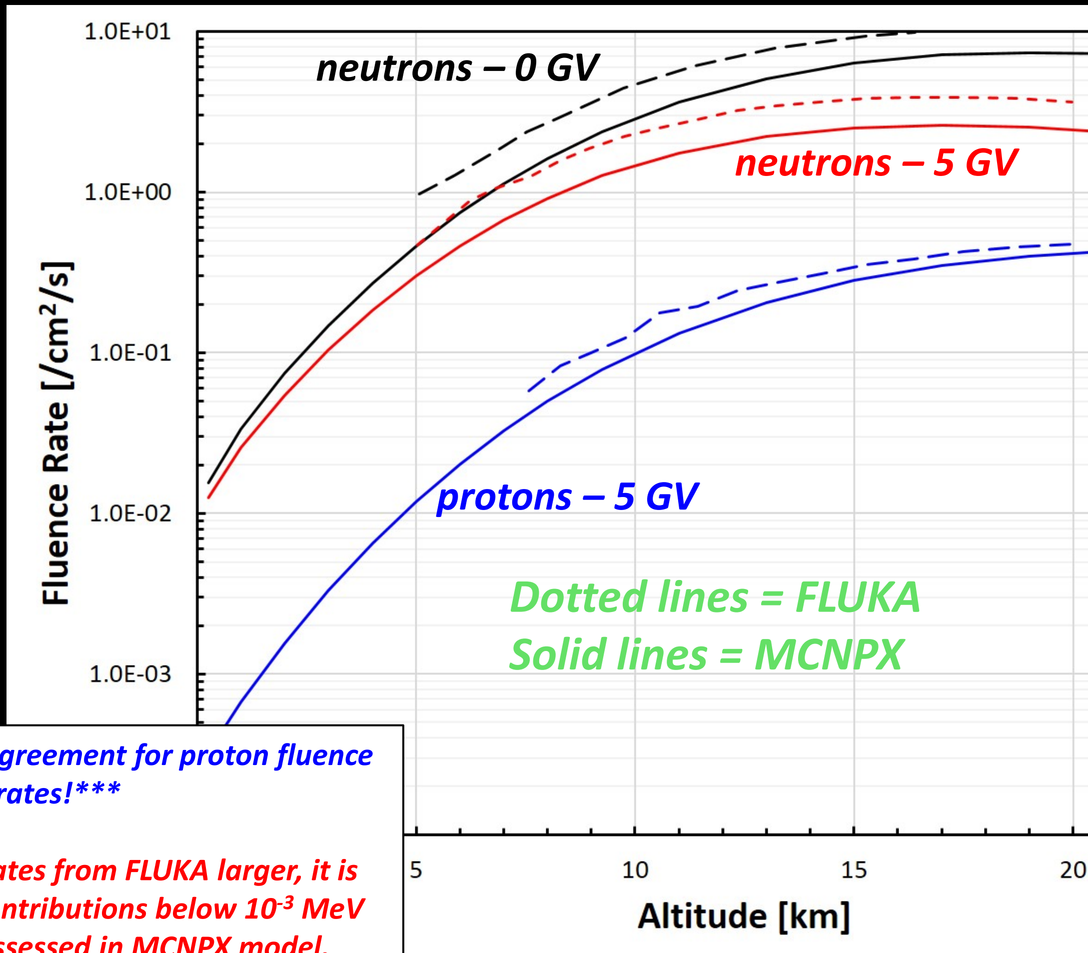
For example, based on the secondary spectra produced at 20 km, the total alpha flux is consiberably lower than proton flux, by approximately an order of magnitude at higher energies. We therefore expect proton dose to be larger using the below conversion factors.





T. Sato, Analytical model for estimating terrestrial cosmic ray fluxes nearly anytime and anywhere in the world: Extension of PARMA/EXPACS, PLOS ONE, 10(12): e0144679. (2015)

Benchmark Against FLUKA



Roughly good agreement for proton fluence rates!

Neutron fluence rates from FLUKA larger, it is believed, due to contributions below 10^{-3} MeV which are not assessed in MCNPX model.

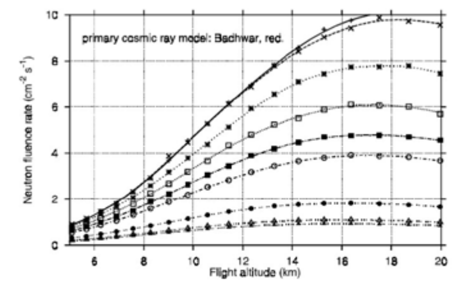


Figure 10. Fluence rate as a function of atmospheric depth for neutrons at solar minimum activity and cut-off rigidities of 0, 1, 2, 3, 4, 5, 10, 15 and 17 GV (from top to bottom).

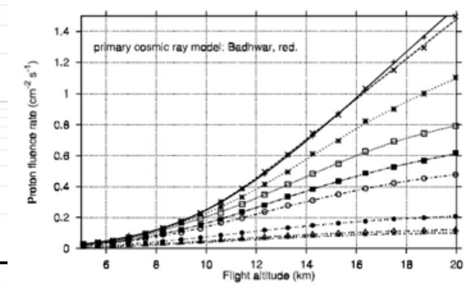


Figure 12. Fluence rate as a function of atmospheric depth for protons at solar minimum activity, and different cut-off rigidities as in Figure 10.

H. Schraube et al., Aviation route dose calculation and its numerical basis, International Radiation Protection Association, http://www.irpa.net/irpa10/cdrom/01230.pdf

Previous Secondary Neutron Benchmarks (MCNPX)

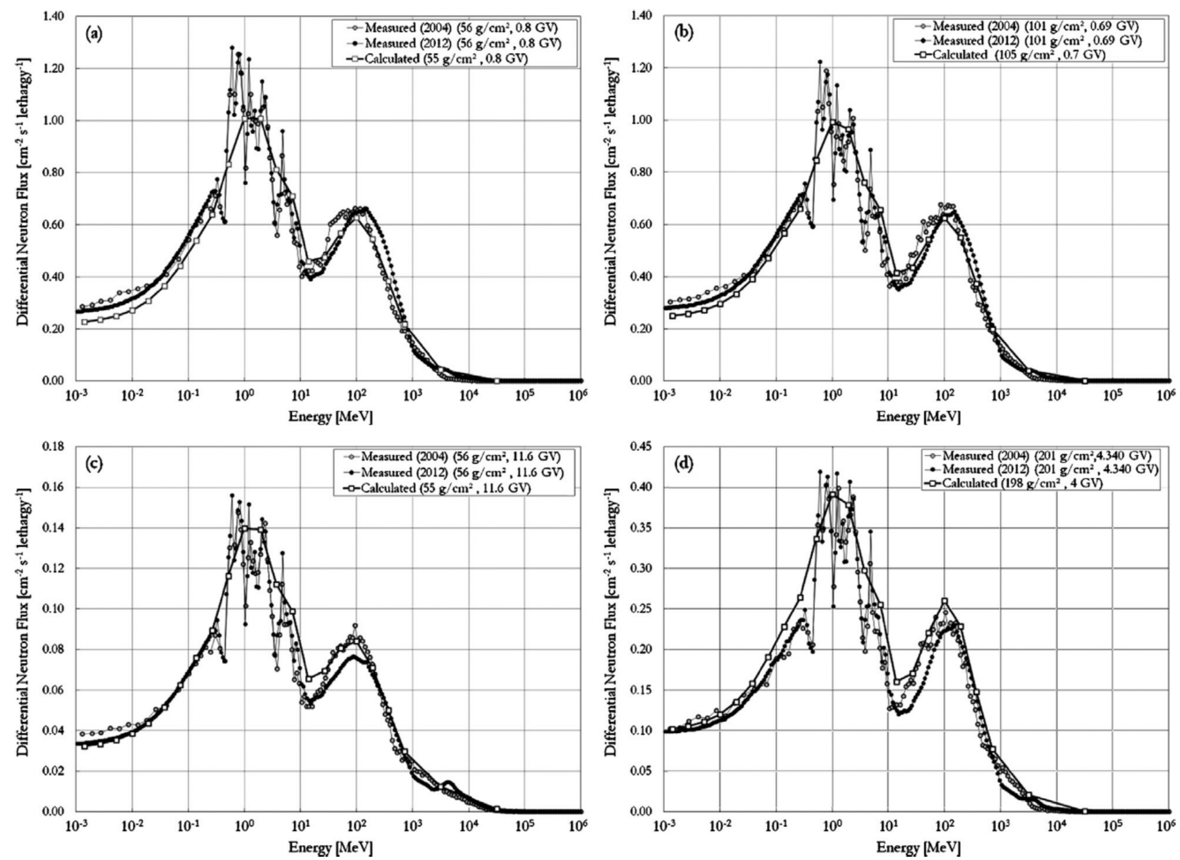


Fig. 5. Measured cosmic-ray neutron spectrum at (a) 56 $g\,cm^{-2}$ (~20 km) and 0.8 GV cutoff rigidity (Goldhagen et al., 2004; Clem et al., 2004), (b) 101 $g\,cm^{-2}$ (~17 km) and ~0.7 GV cutoff rigidity (Goldhagen et al., 2004; Clem et al., 2004), (c) 56 $g\,cm^{-2}$ (~20 km) and 11.6 GV cutoff rigidity (Goldhagen et al., 2004; Clem et al., 2004), and (d) 201 $g\,cm^{-2}$ (~13 km) and 4.3 GV cutoff rigidity (Goldhagen et al., 2004; Clem et al., 2004) as compared to calculated spectra. (New estimates shown only.)

Figures show MCNPX differential fluence rates, per unit lethargy, vs measured results at various cutoff rigidities and altitudes in previous work shown in WRMISS-19. MCNPX simulations for secondary neutrons agreed with measured values at varying altitudes.

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Summary

Secondary proton and alpha differential fluence rates benchmarked against PARMA/EXPACS (PHITS) well up to 50 km (compares well!).

Integrated proton fluence rate benchmarked against FLUKA (compares well!).

Need to further investigate effective dose equivalent rates however!

Future Work

Secondary scatter through shielding for neutrons, protons, alphas.

Generalize the model for all cutoff rigidities.

Assess heavy-ion flux and exotic particles.

Re-assess effective dose calcualtions.

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I would like to acknowledge the project team: Fawaz Ali, Shayne O'Brien, Sheila Kramer-Tremblay, Eugene Masala, Ankur Chaudhuri.

I'd also like to acknowledge the support of Amanda Barr, Chental Kuehl, Kristina Archer, Nick Priest, Joanne Ball, and Fred Beranek, Brent J. Lewis and Leena Tomi!

Thank you to the WRMISS-21 organization committee!

International Space Station is featured in this image photographed by an STS-132 crew member on board the Space Shuttle Atlantis, May 23rd 2010
https://commons.wikimedia.org/wiki/File:International_Space_Station_after_undocking_of_STS-132.jpg