RADIATION EXPOSURE FROM NEUTRONS IN SPACEFLIGHT AND AVIATION

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Background

- Radiation exposure in aviation and space is elevated due to
  - Galactic Cosmic Radiation (GCR)
  - trapped particles in the radiation belts
  - solar energetic particles
- GCR: atomic nuclei with energies > 100 MeV/n
- Radiation belt: protons (inner belt) and electrons (inner and outer belt)
- Solar energetic particles: electrons and protons (up to hundreds MeV, rarely GeV)

  → **Neutrons are part of the secondary radiation field**

- This talk:
  - aviation, Low Earth Orbit (LEO/ISS), lunar surface
  - GCR, radiation belt

Neutrons in Aviation

- GCR (and rarely high energy solar particles)
- Secondary neutrons from interactions with the atmosphere
- Total dose rates up to 10µSv/h
  - 40% - 60% from neutrons

EURADOS, “Cosmic Radiation Exposure of Aircraft Crew”, Final report of the EURADOS WG 5, 2004.

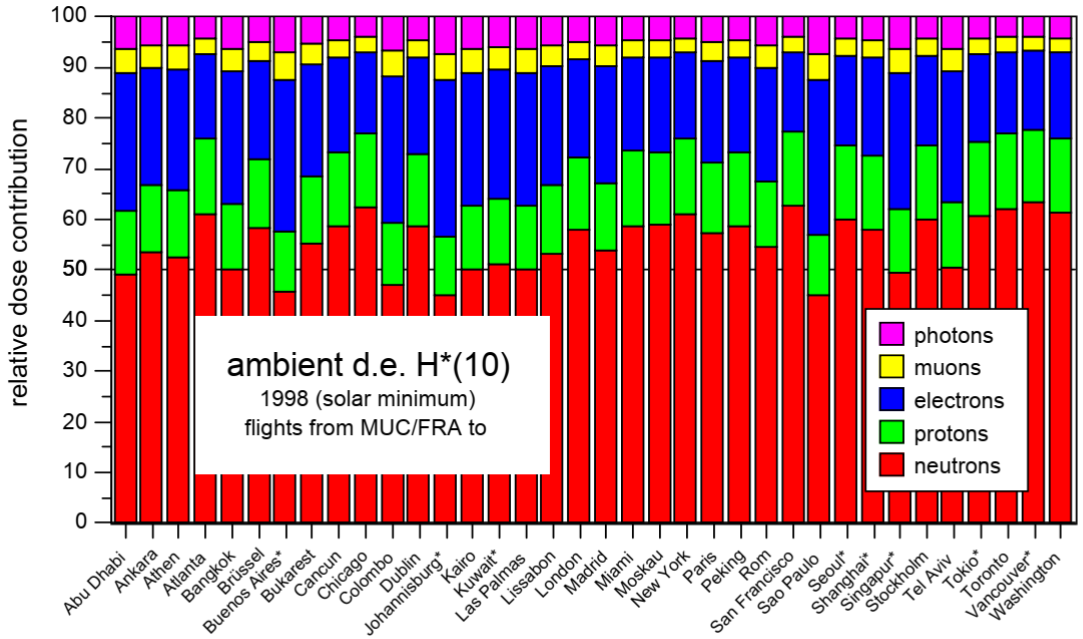
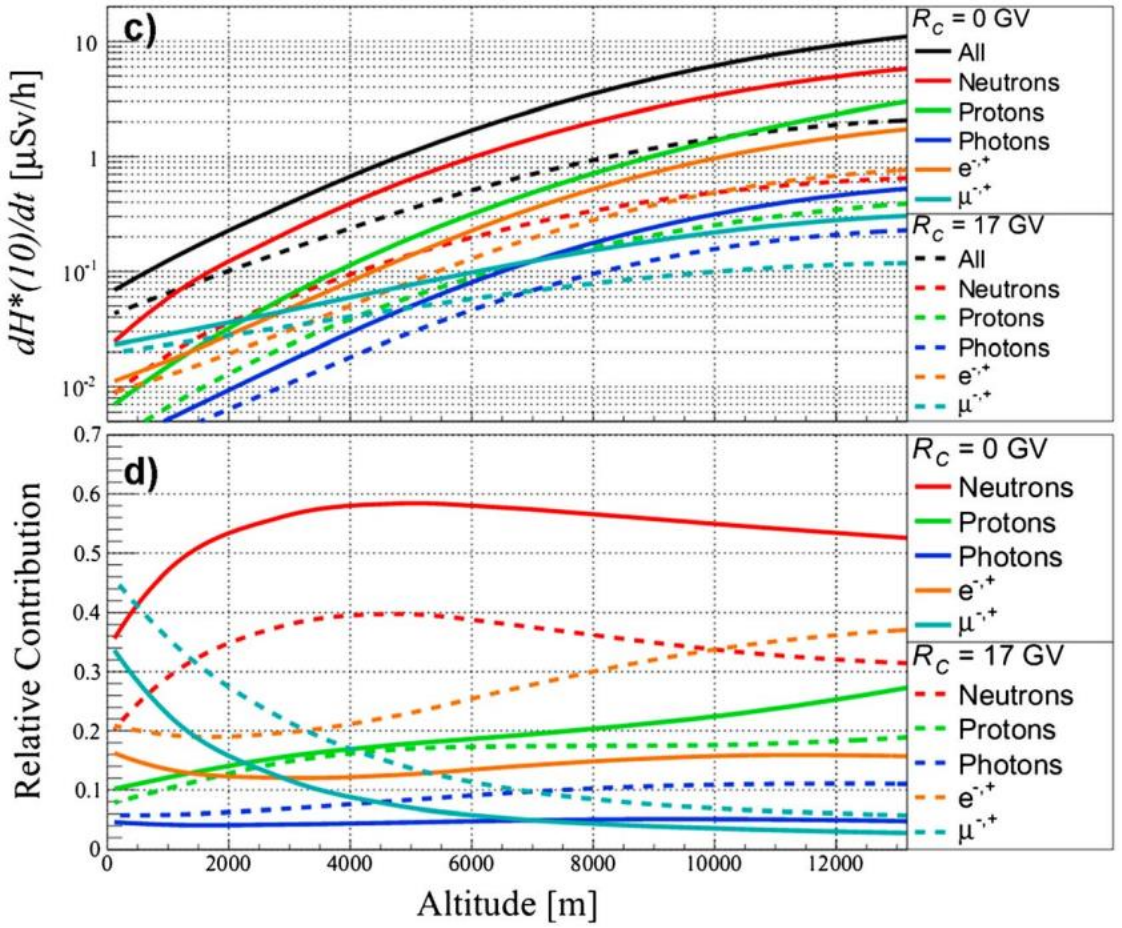


Figure II.6 Relative contribution to ambient dose equivalent for various destinations near solar minimum condition (1998) for 37000 ft flight altitude.

Neutrons in Aviation

- GCR (and rarely high energy solar particles)
- Secondary neutrons from interactions with the atmosphere
- Total dose rates up to 10 µSv/h
  - 40% - 60% from neutrons
- Neutron contribution decreases
  - with increasing altitude
  - with increasing magnetic shielding

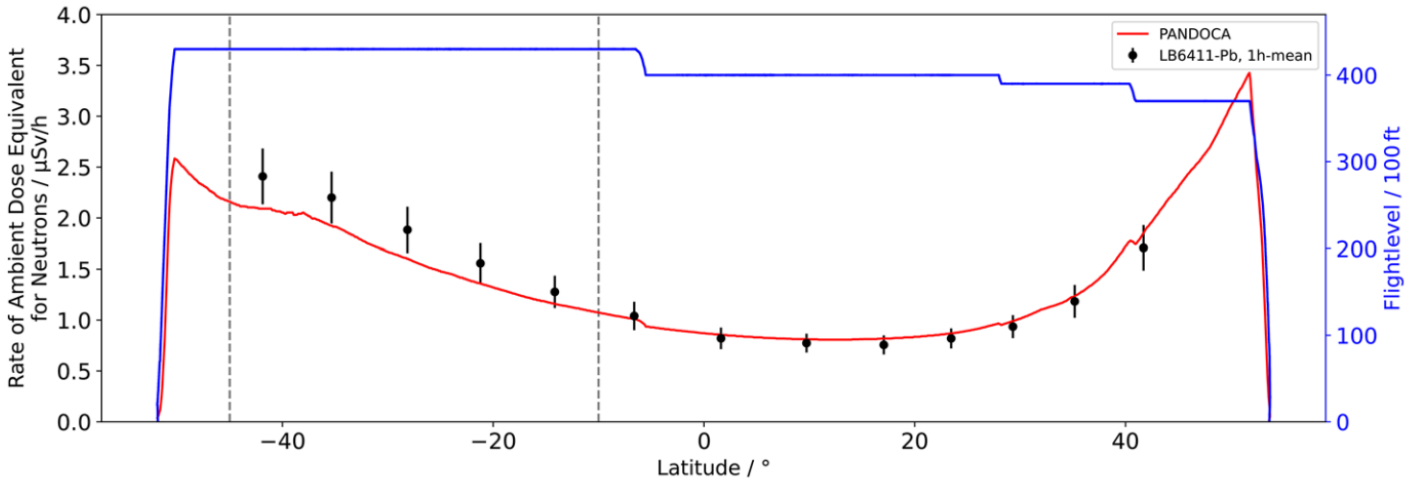
Matthiä et al., Numerical calculation of the radiation exposure from galactic cosmic rays at aviation altitudes with the PANDOCA core model, Space Weather, 2014, doi: 10.1002/2013SW001022



Neutrons in Aviation – Measuring flight to Falkland Islands
Ambient dose equivalent *H*(10)*

- Measurement *H*(10)*:
  - total: 51±3 µSv
  - neutron: 23±2 µSv (45%)
- Model/PANDOCA *H*(10)*:
  - total: 54 µSv
  - neutron: 22.5 µSv (42%)

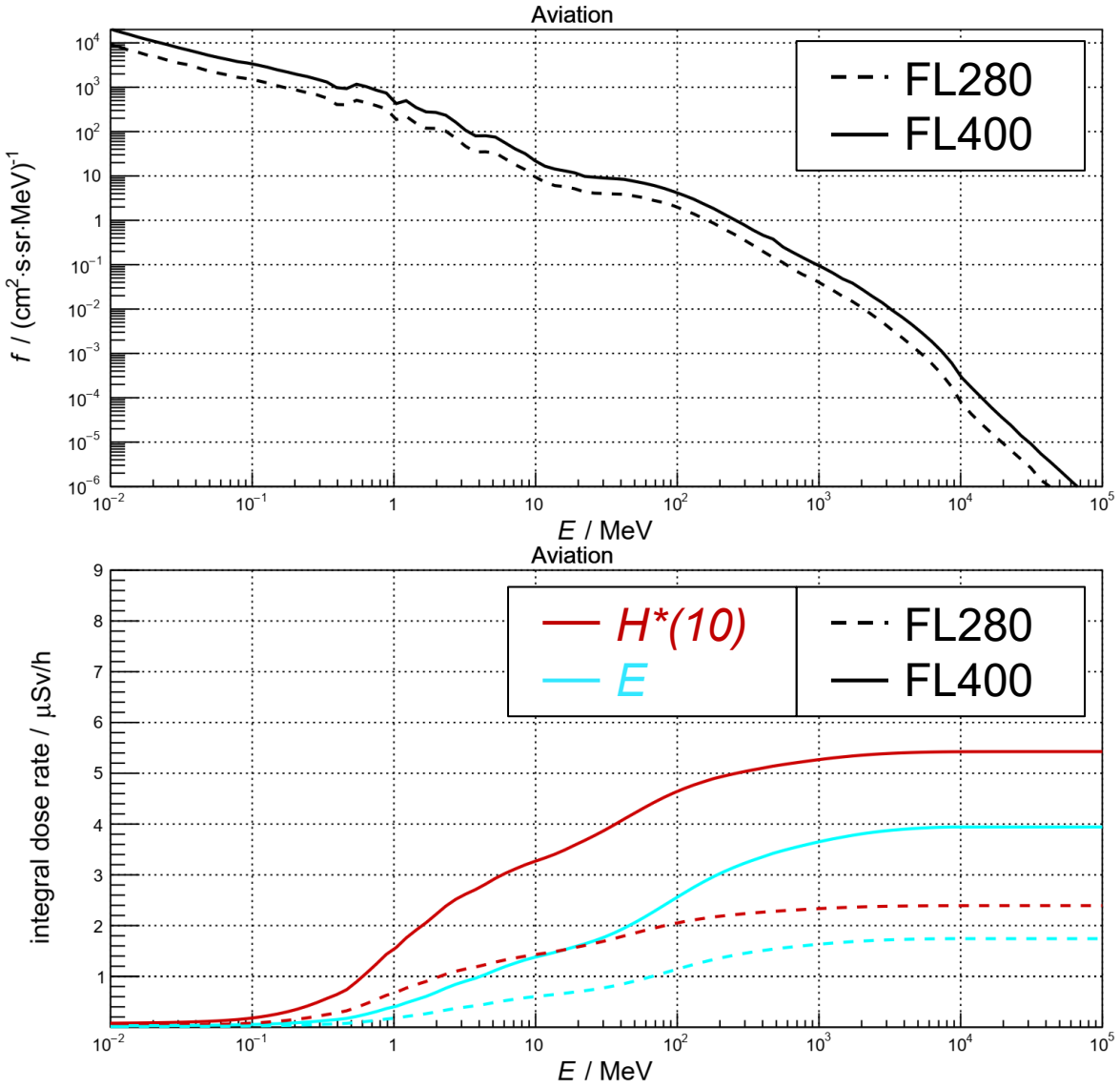
Meier et al., Impact of the South Atlantic Anomaly on radiation exposure at flight altitudes during solar minimum. Scientific Reports, 2023, doi: 10.1038/s41598-023-36190-5



Ambient dose equivalent rate vs. latitude measured with neutron dose rate monitor LB6411-Pb

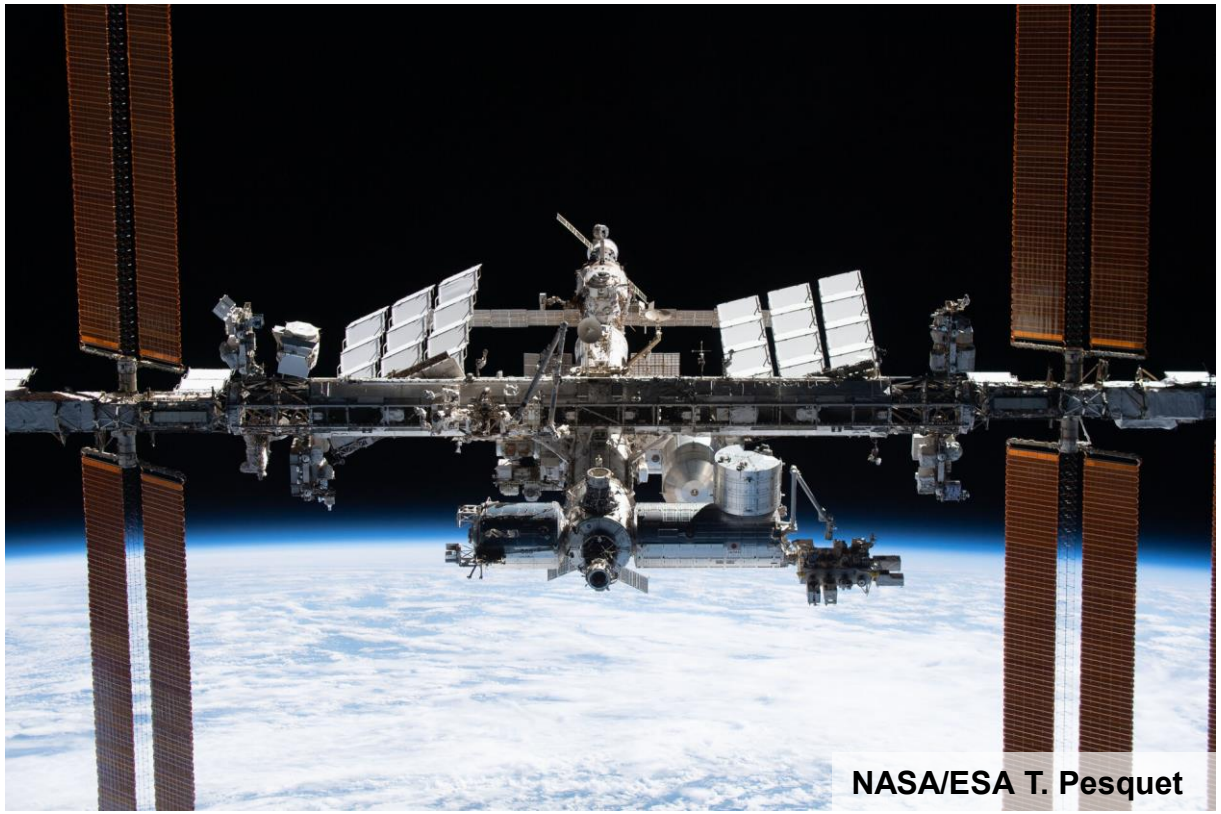
Neutrons in Aviation – Neutron spectra at different altitudes (model)

- Energies ~ 0.1MeV – few GeV contribute
- Ambient dose eq. *H*(10)*: 2.5 – 5 µSv/h
- Effective dose *E*: 2 – 4 µSv/h



Neutrons in Low Earth Orbit
International Space Station (ISS)

- GCR, trapped particles (radiation belts)
- Neutrons from interactions with ISS, cargo etc.

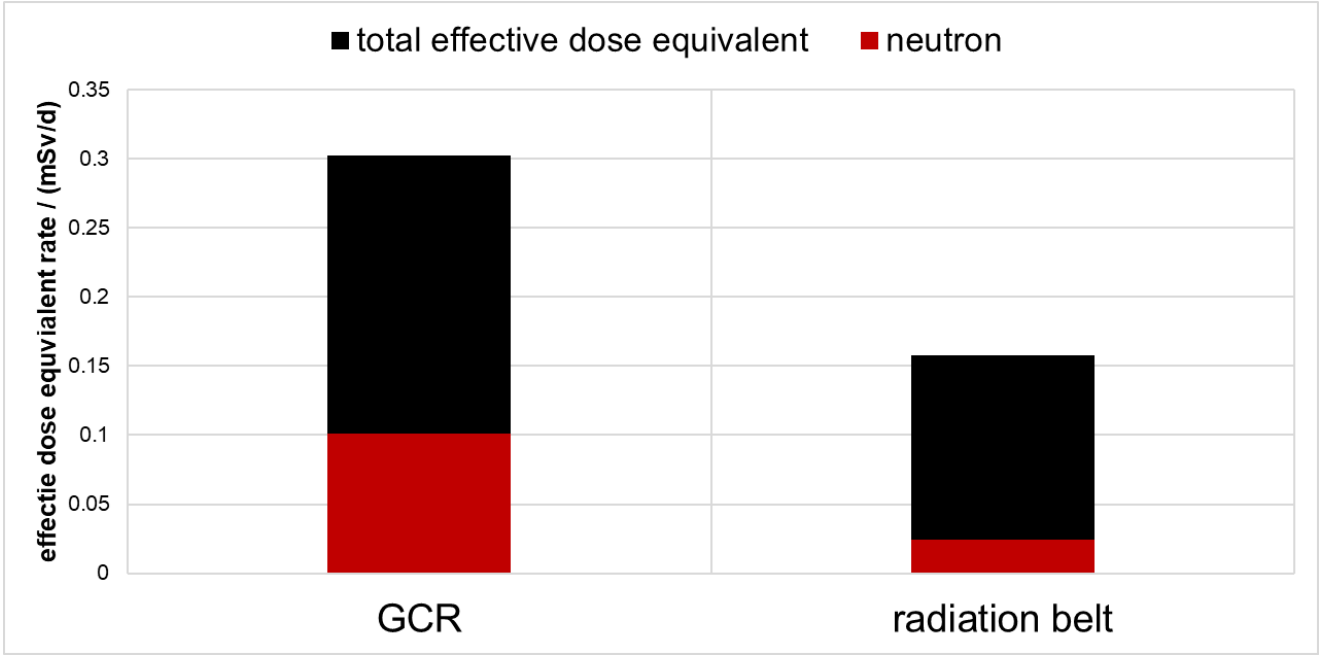


Neutrons in Low Earth Orbit International Space Station (ISS)

- GCR, trapped particles (radiation belts)
- Neutrons from interactions with ISS, cargo etc.
- GCR (COLUMBUS lab.)*
  - total ~ 0.3 mSv/d
  - neutrons ~ 0.1 mSv/d (33%)
- Radiation belt (COLUMBUS lab.)*
  - total ~ 0.16 mSv/d
  - neutrons ~ 0.02 mSv/d (12%)

*model calculations of the total effective dose equivalent for solar minimum

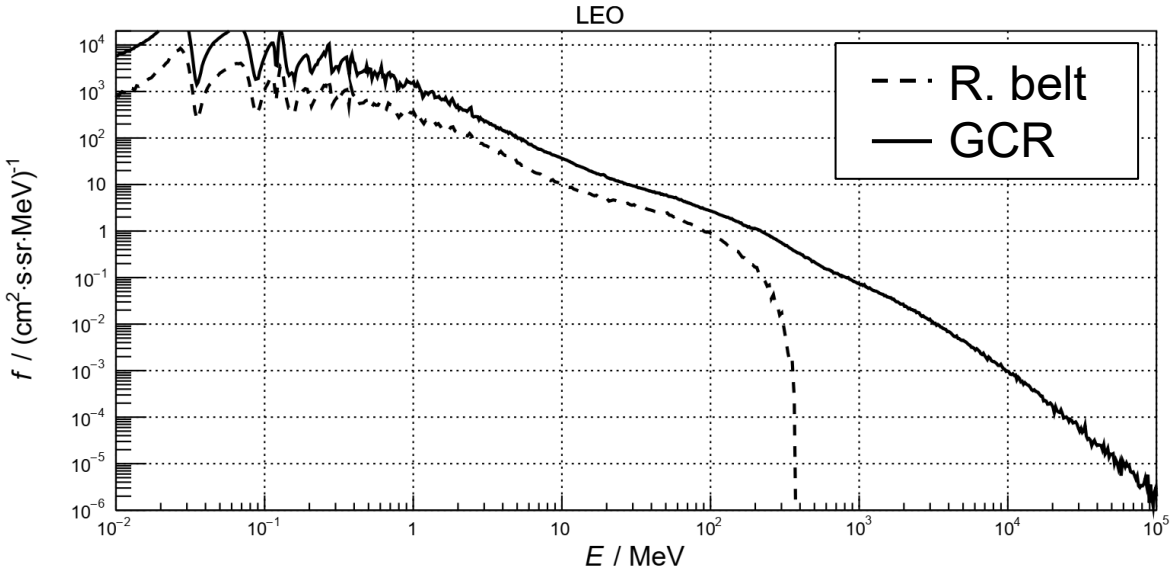
Berger et al., Long term variations of galactic cosmic radiation on board theInternational Space Station, on the Moon and on the surface of Mars, JSWSC, 2020, doi: 10.1051/swsc/2020028

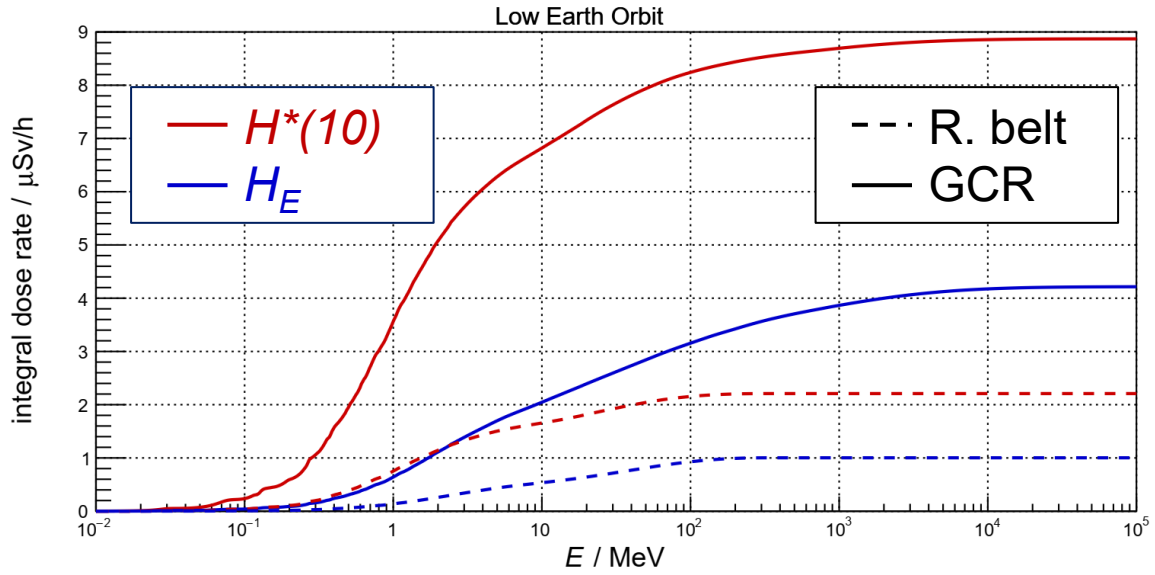


Neutron spectra in Low Earth Orbit International Space Station (model)

- Radiation Belt:
  - energies ~0.1MeV – 100 MeV
  - ambient dose eq. *H*(10)*: ~2 µSv/h
  - effective dose equivalent H_E: ~1 µSv/h

- GCR:
  - energies ~0.1MeV – few GeV
  - ambient dose eq. *H*(10)*: ~9 µSv/h
  - effective dose equivalent H_E: ~4 µSv/h





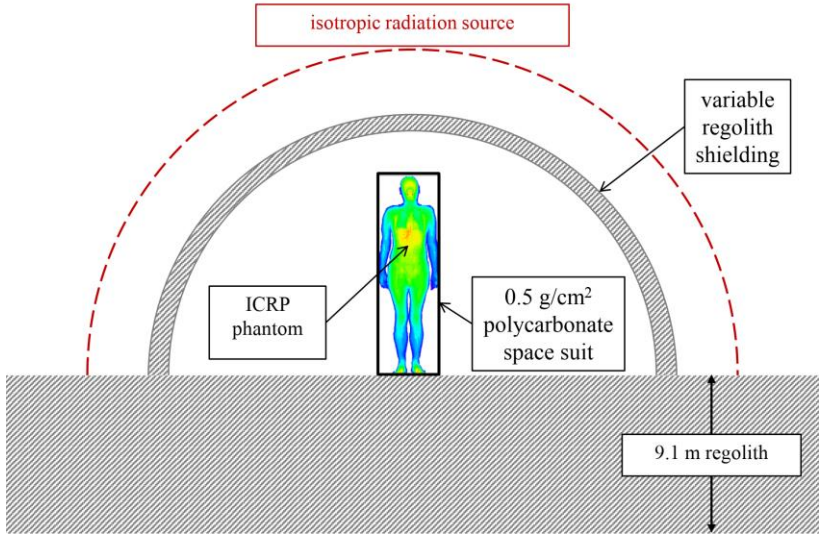
Neutrons on the Lunar Surface

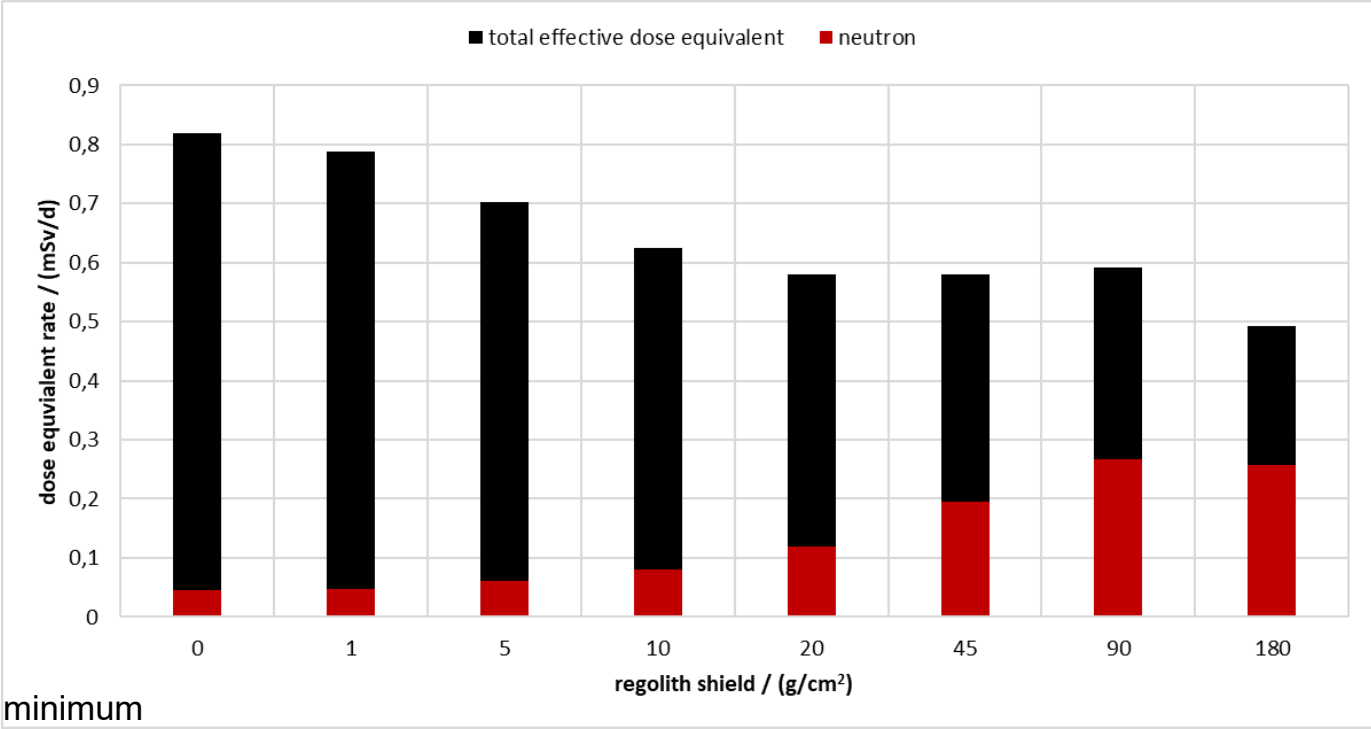
- GCR, solar energetic particles
- Albedo neutrons from interactions with regolith, potentially habitats

Neutrons on the Lunar Surface

Matthiä & Berger, Radiation exposure and shielding effects on the lunar surface, Space Weather, 2024, doi: 10.1029/2024SW004095

- GCR, solar energetic particles
- Albedo neutrons from interactions with regolith, potentially habitats
- GCR (space suit)*
  - total ~ 0.8 mSv/d
  - neutrons ~ 0.05 mSv/d (6%)
- Neutron contribution up to ~50%



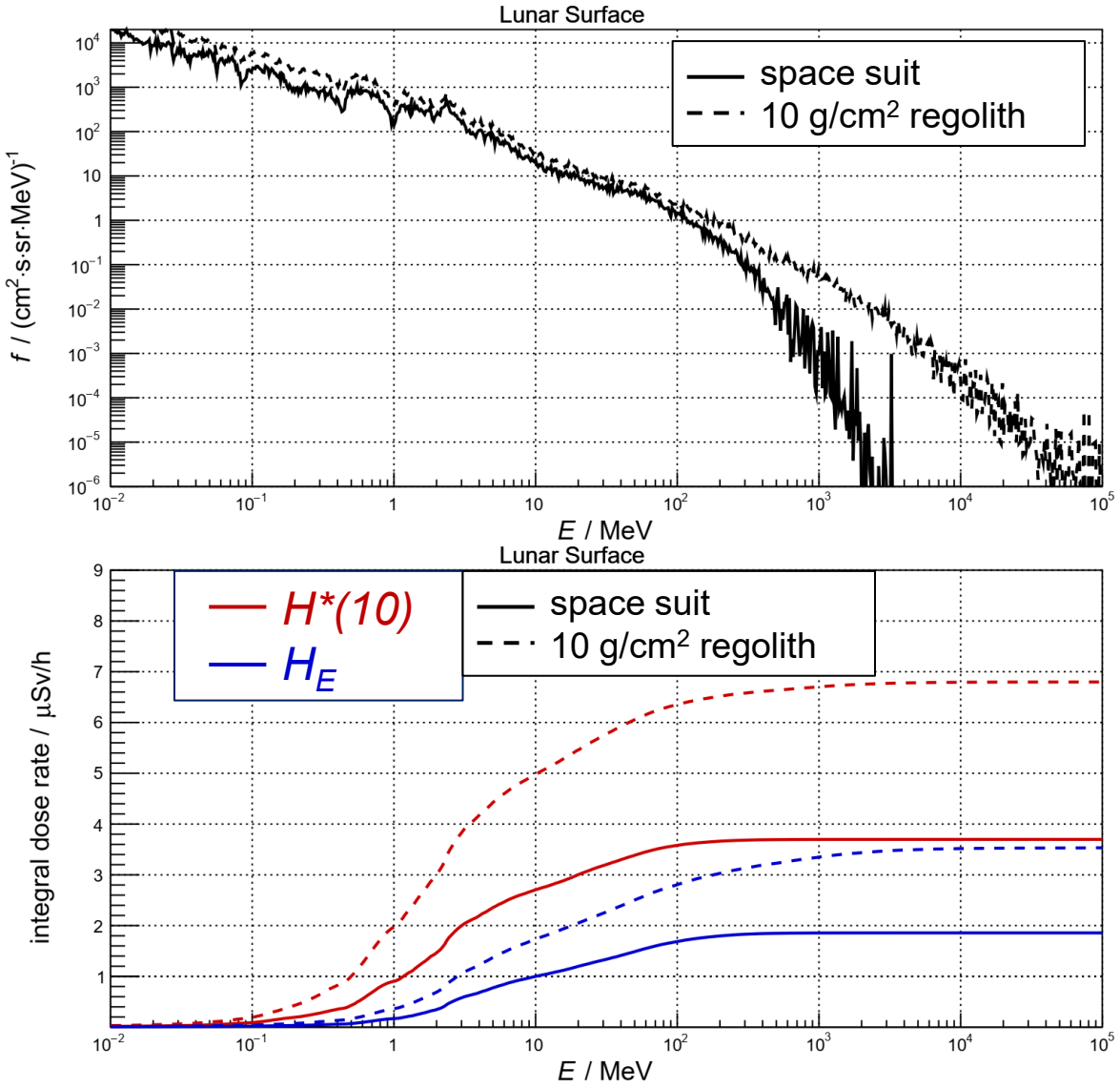


*model calculations of the total effective dose equivalent for solar minimum

Neutron spectra on the Lunar Surface (model)

- Space Suit:
  - ~ only albedo neutrons
  - energies ~0.1MeV – 100 MeV
  - ambient dose eq. *H*(10)*: ~4 µSv/h
  - effective dose equivalent H_E: ~2 µSv/h

- Habitat (10g/cm^2 regolith):
  - energies ~0.1MeV – few GeV
  - ambient dose eq. *H*(10)*: ~7 µSv/h
  - effective dose equivalent H_E: ~3.5 µSv/h



Summary

- Neutrons are one of the most important components of the mixed secondary field from cosmic radiation

- Neutrons contribute 5% to 60% to the total dose ($H^*(10)$, E, H_E) from GCR
  - Aviation: up to ~5 µSv/h
  - Space: up to ~10 µSv/h

- Relevant energy range ~0.1 MeV to hundreds/thousands GeV

- Importance of neutrons increases with shielding (atmospheric/spacecraft/habitat)

Impressum

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