Secondary Neutron Production in space (and ion therapy)

Where they come from,
Why they are important, and
The current state of the data.

Hunter Ratliff
Department of Computer science, Electrical engineering and Mathematical sciences
2 March 2022
Where do secondary neutrons come from in space?

› 2 radiation sources in deep space
  › Solar energetic particles (mostly p\(^+\), some He)
    › Acute risk - solar particle events
  › Galactic Cosmic Rays (GCRs, all ions)
    › Chronic risk - constant GCR flux

› GCR energies peak around 0.1-1 GeV/n

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- GCR energies peak around 0.1-1 GeV/n
- Neutrons produced in fragmentation reactions with target material (shielding / tissue)
- Secondaries cause heavier GCR components to have similar dosimetric contribution to lighter components, despite decreased abundance.
- Ion therapy sees similar ion species, energies, and target materials of interest.

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Why is knowledge of these secondary neutrons important?

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› MSL-RAD (detector onboard the Curiosity rover) observed dose equivalent rates of:
  › 1.84 mSv/day in transit [3]
  › 0.64 mSv/day on the surface [4]
› A realistic manned mission would result in exposure close to or exceeding career limits.

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Simulated dose equivalent as a function of Al shielding thickness in an enclosed environment [2]
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› These neutrons are also important for ion therapy doses and proposed range verification and imaging systems [5].

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What data on secondary neutrons is currently available?

› Both angular & energy dependencies are important since neutrons can scatter at large angles.

› 2 primary categories of interest:

› Double-differential cross sections $\frac{d^2\sigma}{dE d\Omega}$

› Thin target to isolate single interactions
  › Known $E_{\text{beam}}$ inducing every reaction

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- More target \( \rightarrow \) more interactions \( \rightarrow \) more secondaries \( \rightarrow \) better statistics

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› Only lower E He ion measurements exist
› C and Al targets well sampled
› Targets containing O, H, and Fe not very well / not at all represented

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- Existing cross section measurements have minimum neutron energies from 3 MeV to 20 MeV.
  - Further knowledge of the production of lower-E neutrons is desirable.
Thank you!
Dose by secondary vs shielding thickness for He component of GCR

Dose to BFO by primary/secondary Z for various geometries

FIGURE 8 | Effective dose contributions as a function of external GCR energy behind 20 g/cm² of aluminum exposed to solar minimum GCR. Reprinted from Slaba and Blattner [46].

Dose attributed to GCR He by energy slice vs Al shielding thickness

[FIGURE 11] GCR He energy ranges contributing to the 1 year NASA male effective dose for different thickness, using fluence to dose conversion factors from ICRP Publication 123.