TRIUMF
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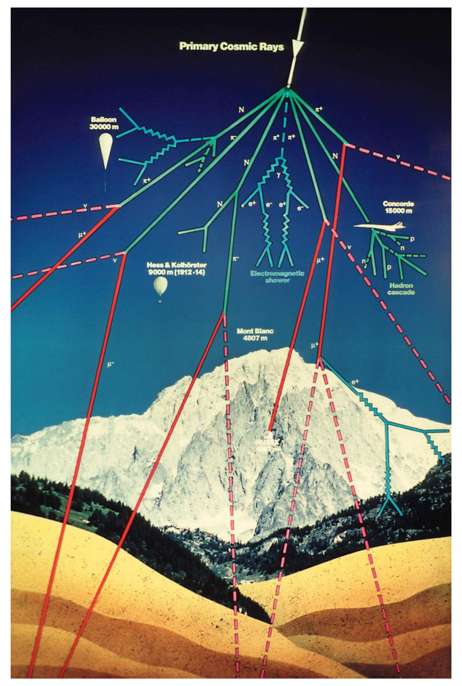
Discovery, accelerated

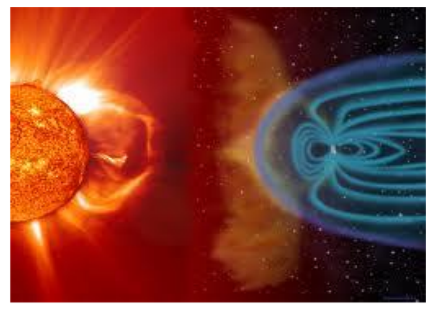
System-level Avionics Testing for Extreme Space Weather Conditions at PIF & NIF

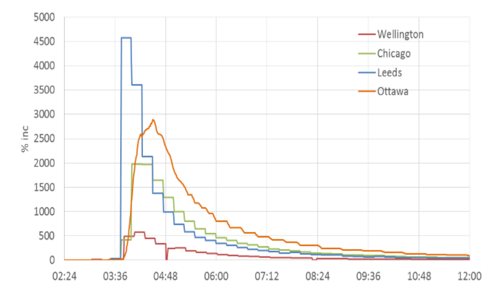
Atmospheric Radiation



- Galactic cosmic rays (GCR), through interactions with the atmosphere, produce secondary particles, including **neutrons**, across a wide energy range.
- Neutron flux builds up to a maximum at 60,000 feet (18 km) but is reduced by two or three orders of magnitude at sea level.
- Neutrons can deposit charge in sensitive volumes of semiconductors, leading to a variety of single event effects (SEE) in avionics systems.
- Solar Energetic Particle Events (SEPEs) may lead to ground level enhancements (GLEs) that can increase atmospheric neutron flux by several orders of magnitude.
- GLE events usually occur **without warning.**

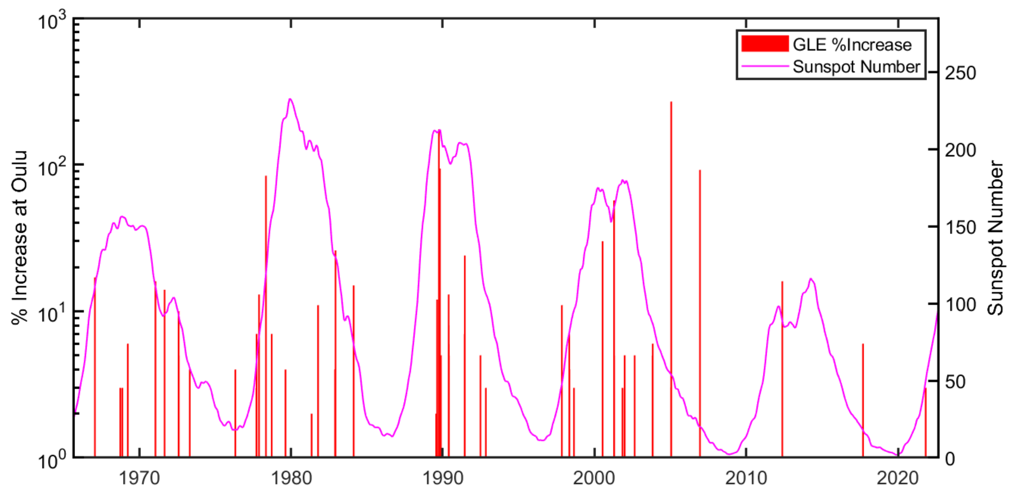
Ground Level Enhancements (GLEs)





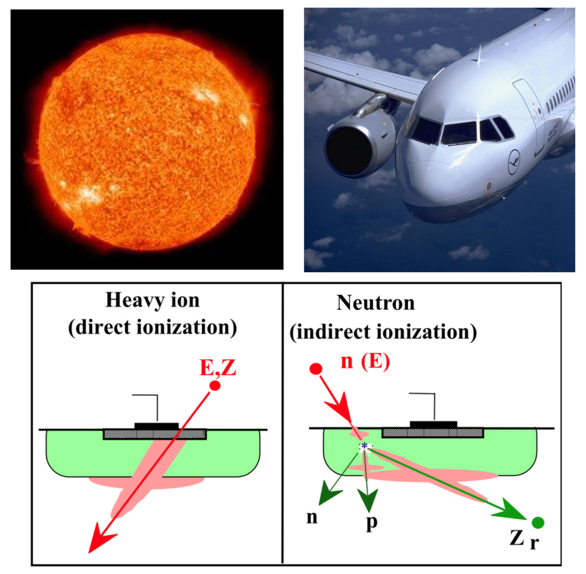
Ground level neutron monitor measurements of the largest GLE on record - 23rd February 1956.

- There have been 73 GLEs since the 1940s, the latest in 2021.
- The largest GLE on record occurred on 23rd February 1956, leading to a ~50x increase at ground level and a ~1000x increase at 40,000 feet (12 km).
- GLEs up to **100 times larger** than Feb '56 are inferred from isotopes in ice cores and ancient tree samples.



GLE intensity measured by percentage increase at Oulu neutron monitor station (Finland) since 1966 on a logarithmic scale. The solar cycle (in terms of sunspot number) is also shown.

Single Event Effects in Avionics



Single particles affect electronics via either direct ionization (e.g., cosmic ray heavy ions in space) or indirect ionization (e.g., atmospheric neutrons).

- Neutrons can cause a variety of single event effects in aircraft electronics - Single Event Upset (SEU), Single Event Latchup (SEL), Single Event Gate Rupture (SEGR), Single Event Burnout (SEB).
- The International electrotechnical commission (IEC) technical standard 62396 provides guidance on atmospheric radiation effects in avionics [1].
- IEC 62396 Part 6 defines two levels of extreme atmospheric space weather:
  - ESW Level 1: **1000 x** GCR background (based on GLE in Feb 1956)
  - ESW Level 2: **30,000 x** GCR background (based on ice core and tree records)

TRIUMF's Neutron Irradiation Facility (NIF)

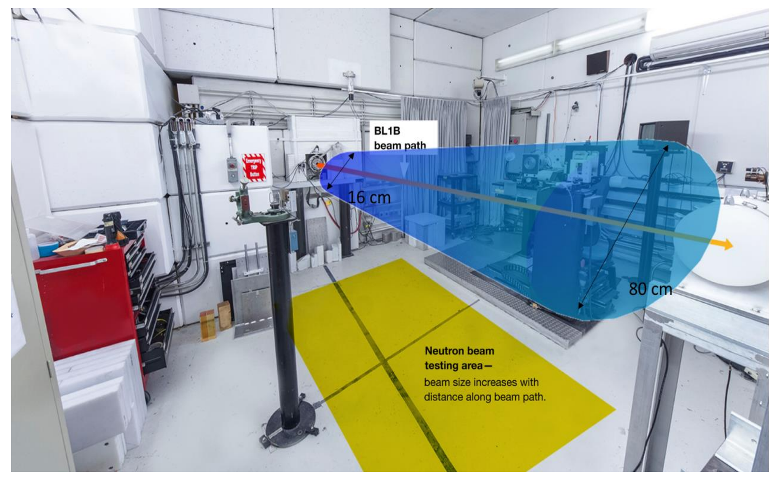
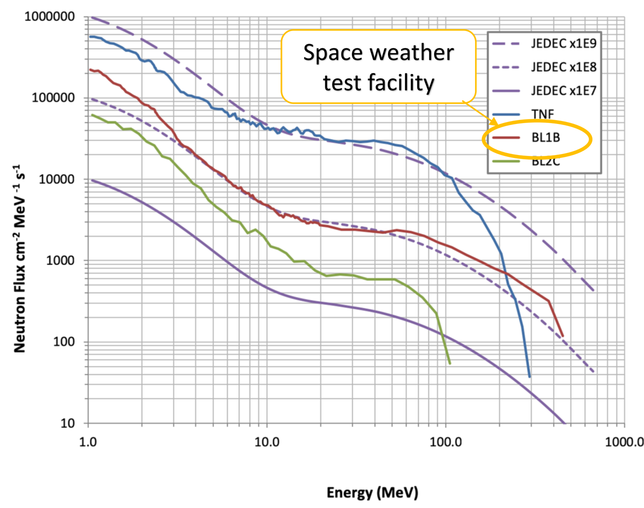


Illustration of conical neutron beam within BL1B experimental area. The beam diameter at the front, for maximum flux, is 16 cm. The beam diameter at the back is 80 cm, which facilitates system-level testing.

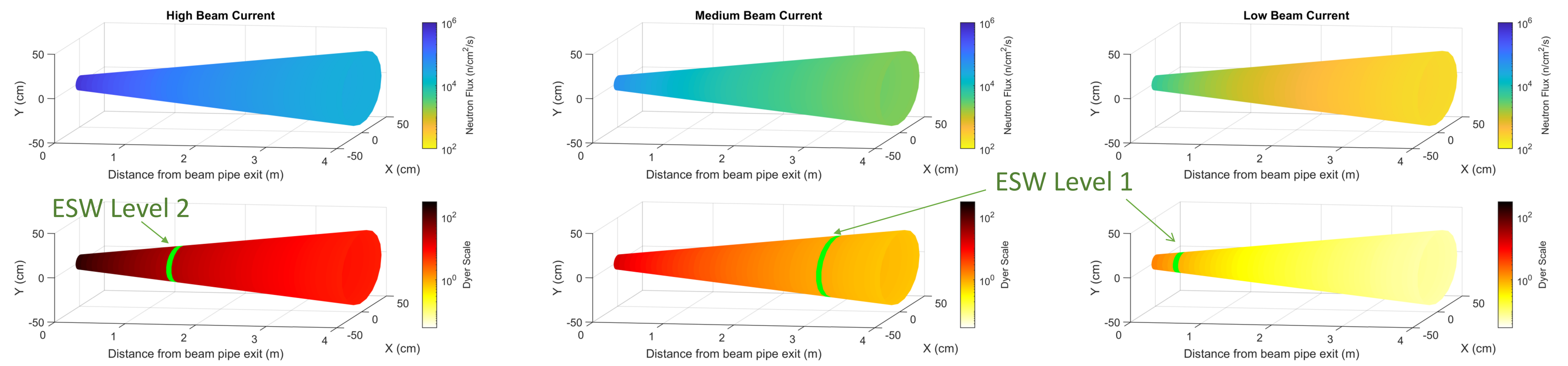
- The TRIUMF lab, in Vancouver, has proton and neutron irradiation facilities (PIF & NIF) for single event effects (SEE) testing.
- Maximum neutron flux is **one billion** times greater than on the ground.
- Flux can be 'tuned' to match extreme space weather conditions covering both IEC ESW levels.



Spallation neutron spectra at TRIUMF facilities relative to the ground level neutron environment defined by JEDEC standard JESD 89A [3].

Recreating extreme GLE conditions at TRIUMF

- The "Dyer scale" relates GLE intensity to the Feb 1956 event (i.e., IEC ESW Level 2 is 30 on the Dyer scale) [2].
- By varying primary beam current and test position, we recreate ESW aviation environments to cover a range of GLE intensities from 0.06 to 160 on the Dyer scale. This covers all relevant GLE scenarios for SEE in avionics.



Neutron intensity plots with common colour scales for three primary beam currents. Upper plots show neutron flux within a conical beam area from 16 cm diameter on the LHS to 80 cm diameter on the RHS. Lower plots show flux relative to the Feb '56 GLE (the Dyer scale) at 40,000 feet altitude. The full range is 0.06 – 160 on the Dyer scale, encompassing both IEC ESW levels.

Conclusion

- Avionics are vulnerable to single event effects (SEE) from atmospheric neutrons during extreme GLEs.
- GLEs cannot be forecast or shielded against and occur with no warning. Studying their impact via ground testing is the **only** way to ensure SEE do not lead to system failure during extreme space weather events.
- Airlines and avionics manufacturers are (currently) **not** obliged to demonstrate safe operation during GLEs.
- TRIUMF offers a unique capability to perform system-level testing across a wide range of GLE intensities.

Contact Us

For more information, please visit https://www.triumf.ca/pif-nif or contact one of the TRIUMF irradiation facilities team:

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References

[1] IEC, "IEC62396 Process management for avionics–Atmospheric radiation effects–Part 1: Accommodation of atmospheric radiation effects via single event effects within avionics electronic equipment," 2006.
[2] C. Dyer, A. Hands, K. Ryden, and F. Lei, "Extreme Atmospheric Radiation Environments and Single Event Effects," IEEE Transactions on Nuclear Science, vol. 65, no. 1, pp. 432-438, 2018, doi: 10.1109/TNS.2017.2761258.
[3] J. S. JeSD89A, "Measurement and reporting of alpha particle and terrestrial cosmic ray-induced soft errors in semiconductor devices," JEDEC solid state technology association, vol. 1, no. 6, p. 8, 2006.