Recreating the enhanced neutron environment of GLE 77 at TRIUMF

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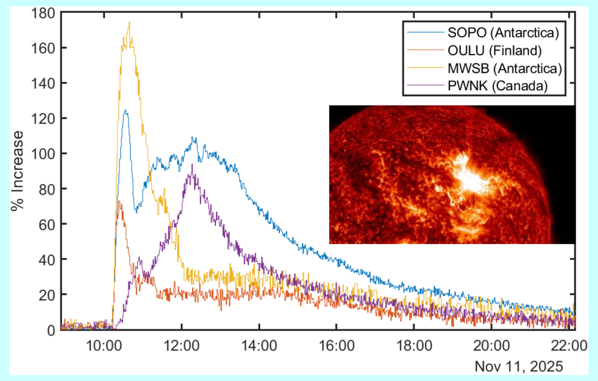
Ground Level Enhancement #77 – Armistice Day 2025

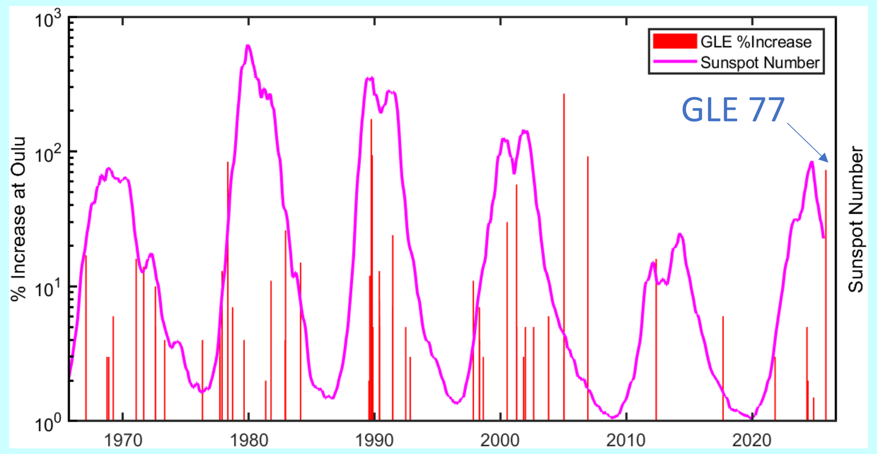
- At the eleventh hour* of the eleventh day of the eleventh month of 2025 – the Sun unleashed an X5.1-class solar flare from Active Region 14274.
- Athens Neutron Monitor Station (ANeMoS[1]) issued a GLE alert at 10:14 UT – just 10 minutes after the peak of the X-ray event and 15 minutes ***before*** NOAA-SWPC's >100 MeV GOES proton alert.
- Ground level neutron monitors recorded up to ~175% increase in count rate[2], the largest event for 20 years.
- Models and measurements imply dose rates >75 µSv/h, more than 10x the galactic cosmic ray background[3], however no radiation alerts were issued by ICAO.

*Paris time



Left: Increases in select ground level neutron monitors during GLE 77. The event was very anisotropic in the early phase, with Antarctic monitors seeing the biggest increases.

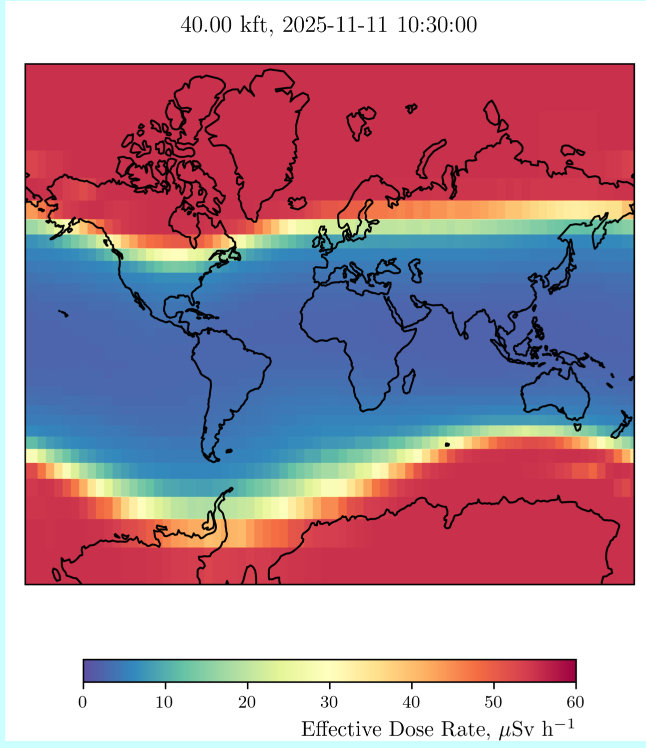
Below: GLE intensities since 1966, as recorded at the Oulu ground level neutron monitor. GLE 77 was the largest event for 20 years.



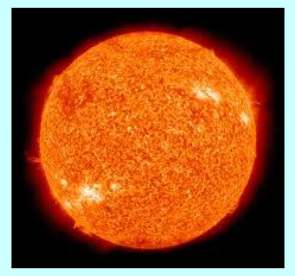
Aircraft Radiation Environment during GLE 77

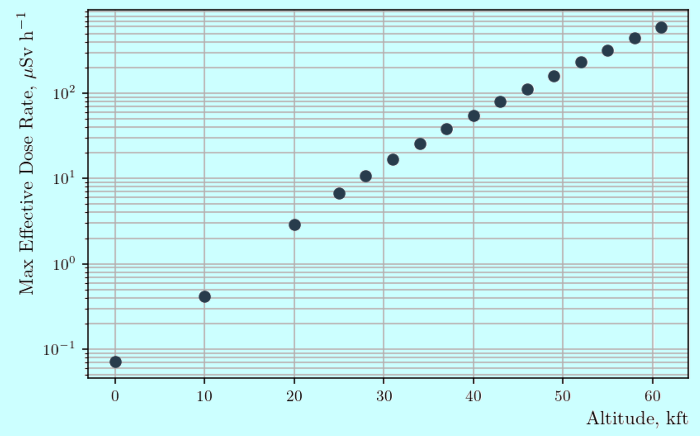
- Several atmospheric radiation tools provided nowcasts of the in-flight dose environment during GLE 77 – e.g. MAIRE-S[4], WASAVIES[5], SiGLE[6].
- Peak dose rates are estimated at ~60 – 100 µSv/h at 40,000 feet, (possibly up to 200 µSv/h with anisotropy effect).
- Corresponding >10 MeV neutron flux is ~20 – 60 n/cm²/s, leading to single event upset (SEU) rates of up to 200 SEUs/Gbyte/h in avionics*.

*assuming 10^{-13} cm²/bit



Nowcast of GLE 77 effective dose rate at 40 kft from the University of Surrey's MAIRE-S model.





GLE 77 peak effective dose rate at zero cutoff rigidity as a function of altitude (using MAIRE-S).

TRIUMF's Neutron Irradiation Facility (NIF)

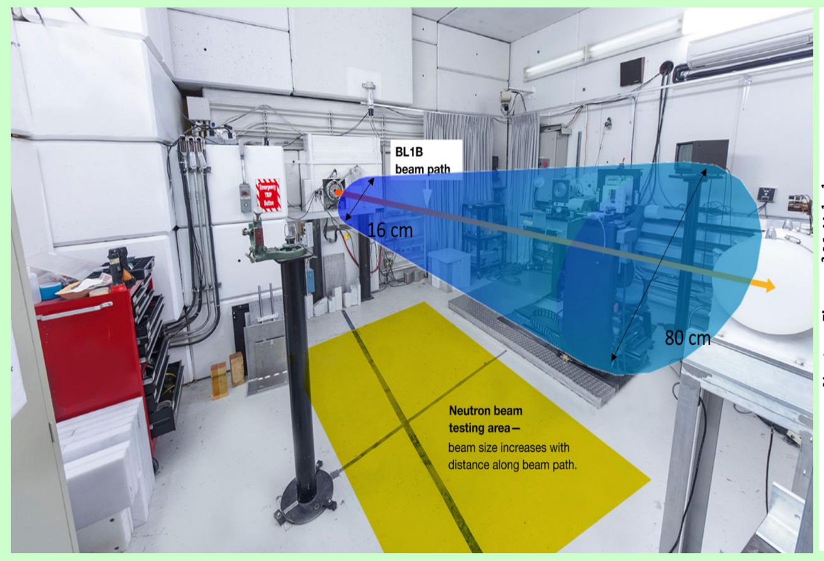
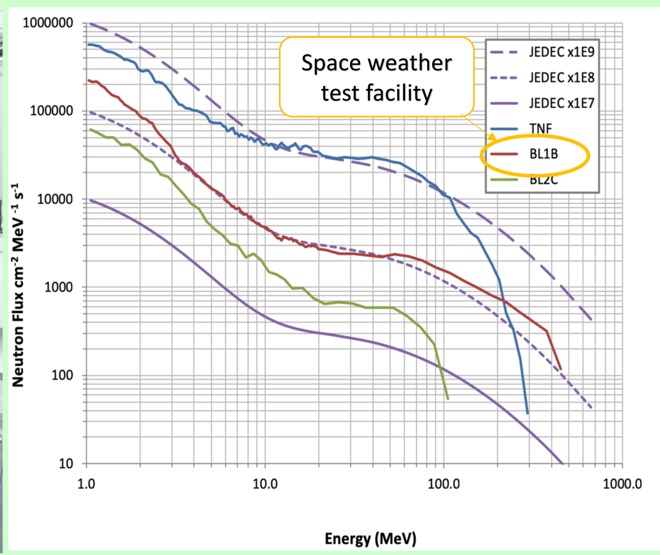


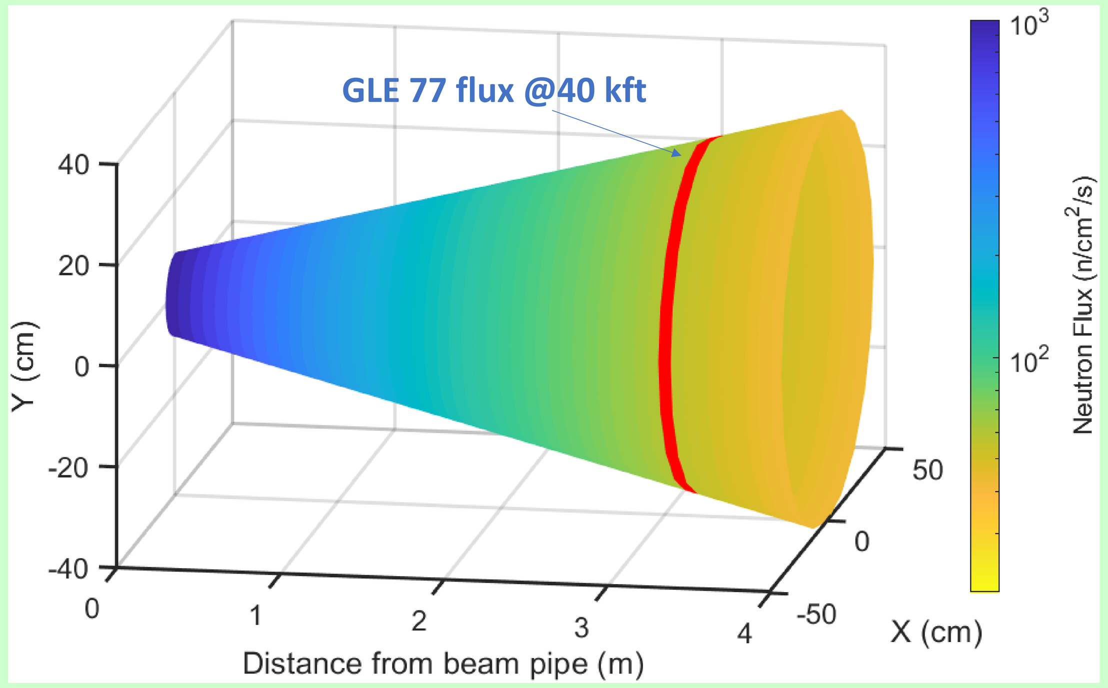
Illustration of the conical neutron beam within the BL1B experimental area. The beam diameter at the front, for maximum flux, is 16 cm. The beam diameter at the back is 80 cm, which facilitates system-level testing.



Spallation neutron spectra at TRIUMF facilities relative to the ground level neutron environment defined by JEDEC standard JESD 89A[8].

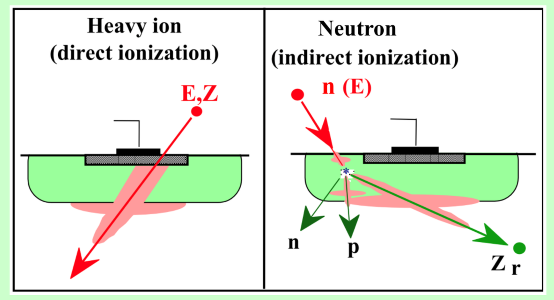
- The TRIUMF lab, in Vancouver, has proton and neutron irradiation facilities (PIF & NIF) for single event effects (SEE) testing[7].
- Maximum neutron flux is **one billion** times greater than the GCR ground level environment.
- Wide-area (BL1B) space weather test facility provides capability to vary flux to match GLE aviation environments.

GLE 77 at the Space Weather Test Facility



>10 MeV neutron flux as a function of distance from the front of the experimental area. Fluxes depicted are based on ~0.01 nA of primary proton beam current (0.2% of facility maximum 5 nA). At this intensity, the GLE77-equivalent test location (shown by a red ring) is ~3 metres from the beam pipe (front of test area) and ~65 cm in diameter.

- Spallation reactions between ~500 MeV protons and a lead target produce an atmospheric-like conical neutron field up to 80 cm diameter.
- Recreating GLE 77 peak neutron flux (at flight altitude) requires <1% of maximum beam current.
- System-level single event effects (SEE) testing in GLE environments can be accommodated.
- Lower fluxes are also achievable for ground level SW environments.



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

Extreme GLEs

- The largest GLE on record occurred on 23rd February 1956 (GLE 5), leading to a ~50x increase in ground level neutron flux and up to 2000x at 40,000 feet (12 km)[9].
- GLEs up to **100 times larger** than Feb '56 (5000 times larger than GLE 77!) are inferred from isotopes in ice cores and ancient tree samples[10, 11].
- Part 6 (Space Weather) of IEC 62396 (Process management for avionics - Atmospheric radiation effects) specifies an extreme environment of 30 times Feb '56 for single event effects (SEE) testing[12].

GLE Size (cf. Feb '56)	Maximum available diameter (cm)	Required Beam Current (nA)	>10 MeV Neutron Flux (n/cm²/s)	Bit error rate (SEUs/GB/h)
0.02 (GLE 77)	80	0.015	60	200
1 (GLE 5)	80	0.75	3,000	10,000
30 (IEC)	40	5	9 x 10^4	3 x 10^5
100	20	5	3 x 10^5	1 x 10^6

Selected GLE test environments and their relative magnitudes. GLE 5 is the Feb '56 event. "IEC" refers to the extreme space weather level specified by avionics test specification 62396-6. Bit error rate assumes an SEU cross section of 10^{-13} cm²/bit for >10 MeV neutrons.

Conclusion

- The Armistice Day event (GLE 77) in 2025 was the largest GLE for 20 years.
- TRIUMF's space weather test facility can recreate the aviation radiation environment during GLE 77, and for extreme space weather events up to five thousand times larger.
- SEE rates in avionics during extreme GLEs could be 5 orders of magnitude higher than GCR background rates. Ground level testing can mitigate this risk to aircraft safety.

Contact Us

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

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