Statistical Prediction of Solar Particle Event Frequency based on the Measurements of Recent Solar Cycles for Acute Radiation Risk Analysis

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Introduction

- Large solar particle events (SPEs) present significant acute radiation risk (ARR) during extra-vehicular activities (EVAs) or in lightly shielded space vehicles for space missions.
- Acute radiation sickness can impair performance and result in failure of the mission: Improved forecasting capability and/or early-warning systems and proper shielding solutions are required to stay within NASA's short-term dose limits.
- Statistical prediction of SPE occurrences for ARR analysis: We developed a non-homogeneous Poisson process model fitted to a database of proton fluence measurements of SPEs.

Approaches

- Randomness of SPE occurrence: Using SPEs' onset dates for the past 5 solar cycles: Propensity of SPE occurrence defined as a function of mission period and time within a solar cycle(1).
- Randomness of each event size of SPE, Φ_E: Using historical database of measurements of protons with energy (E) >30, >60, and >100 MeV: Simulation of total Φ_E distribution in a mission period(2).
- Transport properties of the shielding materials and the astronaut's body tissues: NASA BRYNTRN code system(3)
- Shielding distribution by vehicle geometry on space missions: Initial representative shield configurations of spacesuit and equipment room of a spacecraft as 0.3 and 5.0 g/cm^2 Aluminum, respectively.
- Body shielding distribution at the sensitive organs of astronaut: Computerized anatomical man (CAM) model(4)
- ARR analysis: Symptoms of acute radiation response using RIPD code(5) from the blood forming organ (BFO) dose(6)

Exposure limit by NASA(7)	Organ dose, Gy-Eq
30-d limit at Skin	1.5
30-d limit at Eye	1.0
30-d limit at BFO	0.25
Minimum BFO dose for ARR	0.5

ARR Sickness at Severity Level(5)

Severity Level	Upper Gastrointestinal Distress (UG)	Fatigability and Weakness (FW)
1	No effect	No effect
2	Upset stomach, clammy and sweaty, mouth waters	Somewhat tired with mild weakness
3	Nauseated, considerable sweating, swallows frequently to avoid vomiting	Tired with moderate weakness
4	Vomited once or twice, nauseated, and may vomit again	Very tired and weak
5	Vomited several times, including the dry heaves, severe nauseated, and will soon vomit again	Exhausted with almost no strength

References

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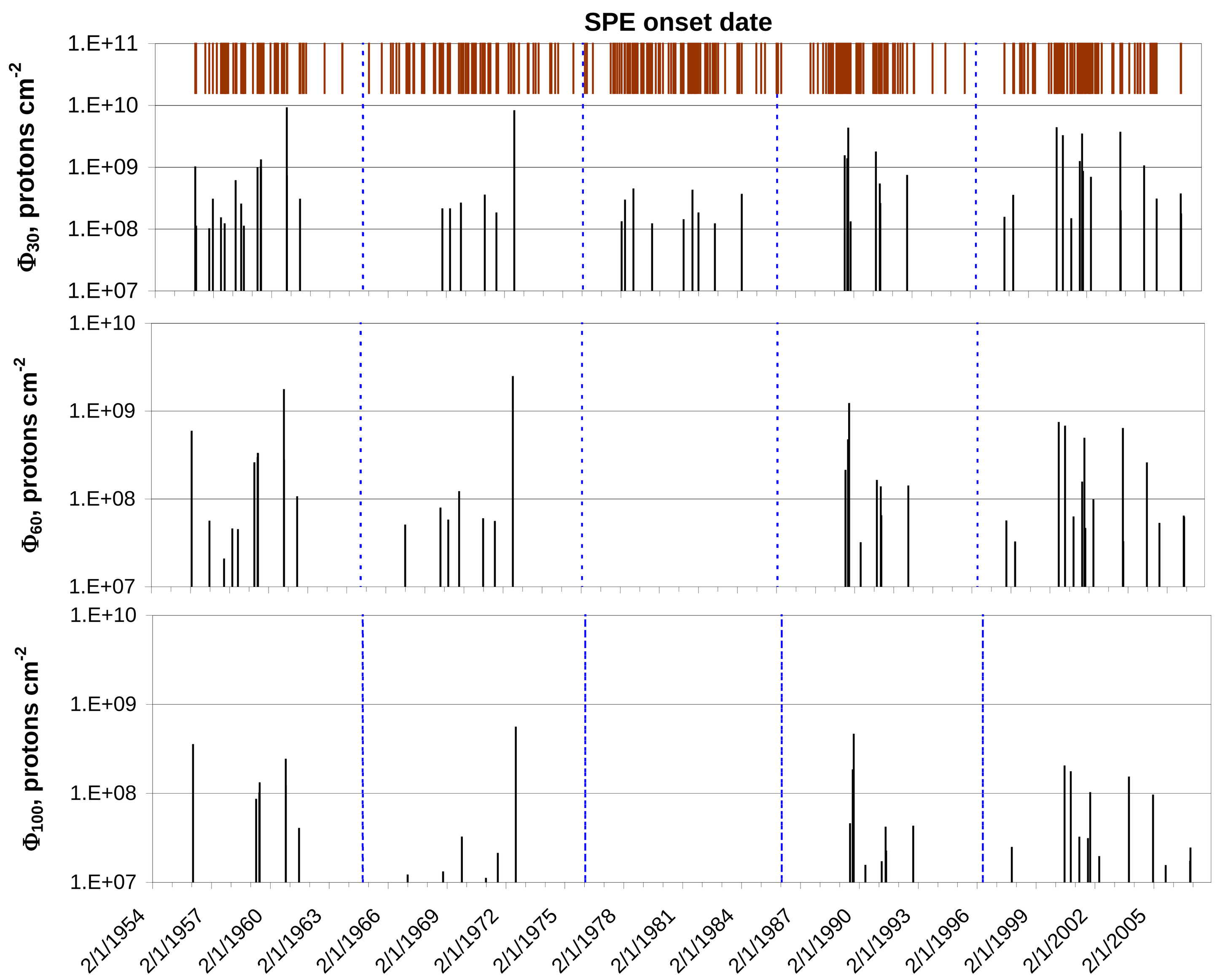
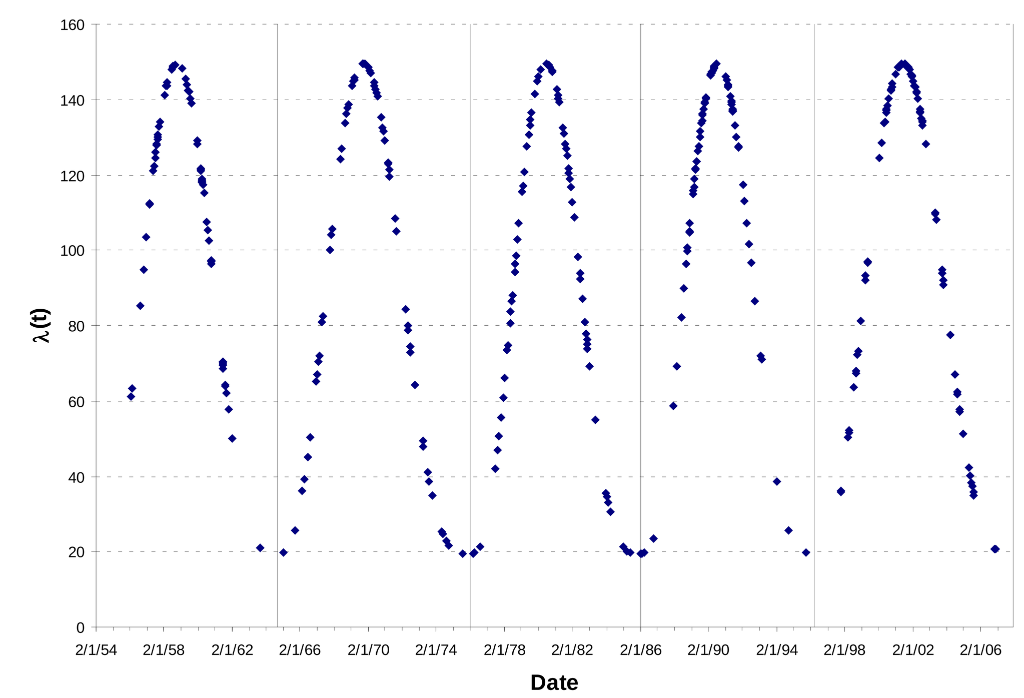
SPE Database for the Past 5 Solar Cycles and Model-Based Prediction of SPE Frequency



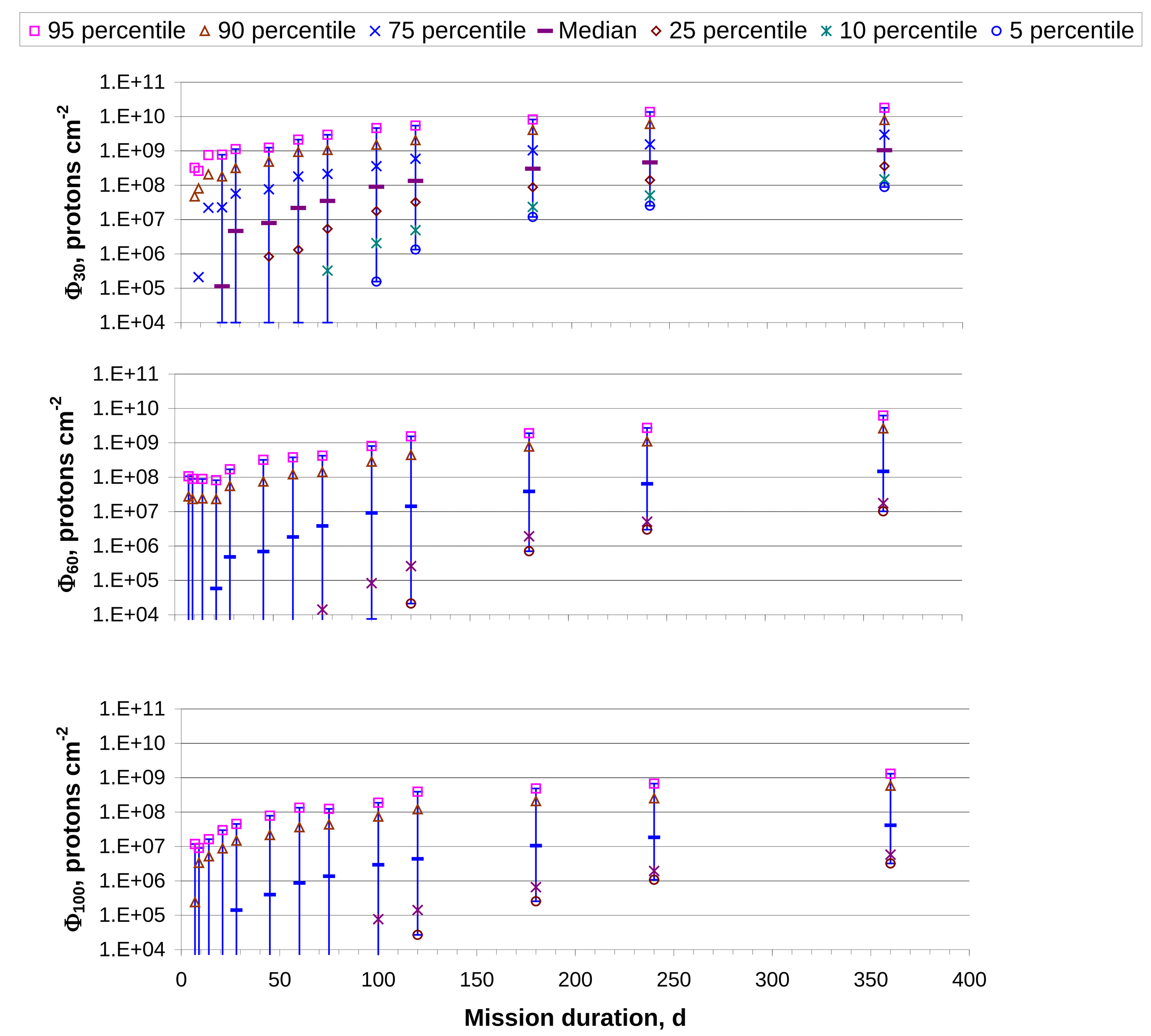
Propensity of SPEs: Hazard Function of Offset β Distribution Density Function

$$\lambda(t) = \frac{\lambda_0}{4000} + \frac{K}{4000}\frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)}\left(\frac{t}{4000}\right)^{p-1}\left(1-\frac{t}{4000}\right)^{q-1}$$

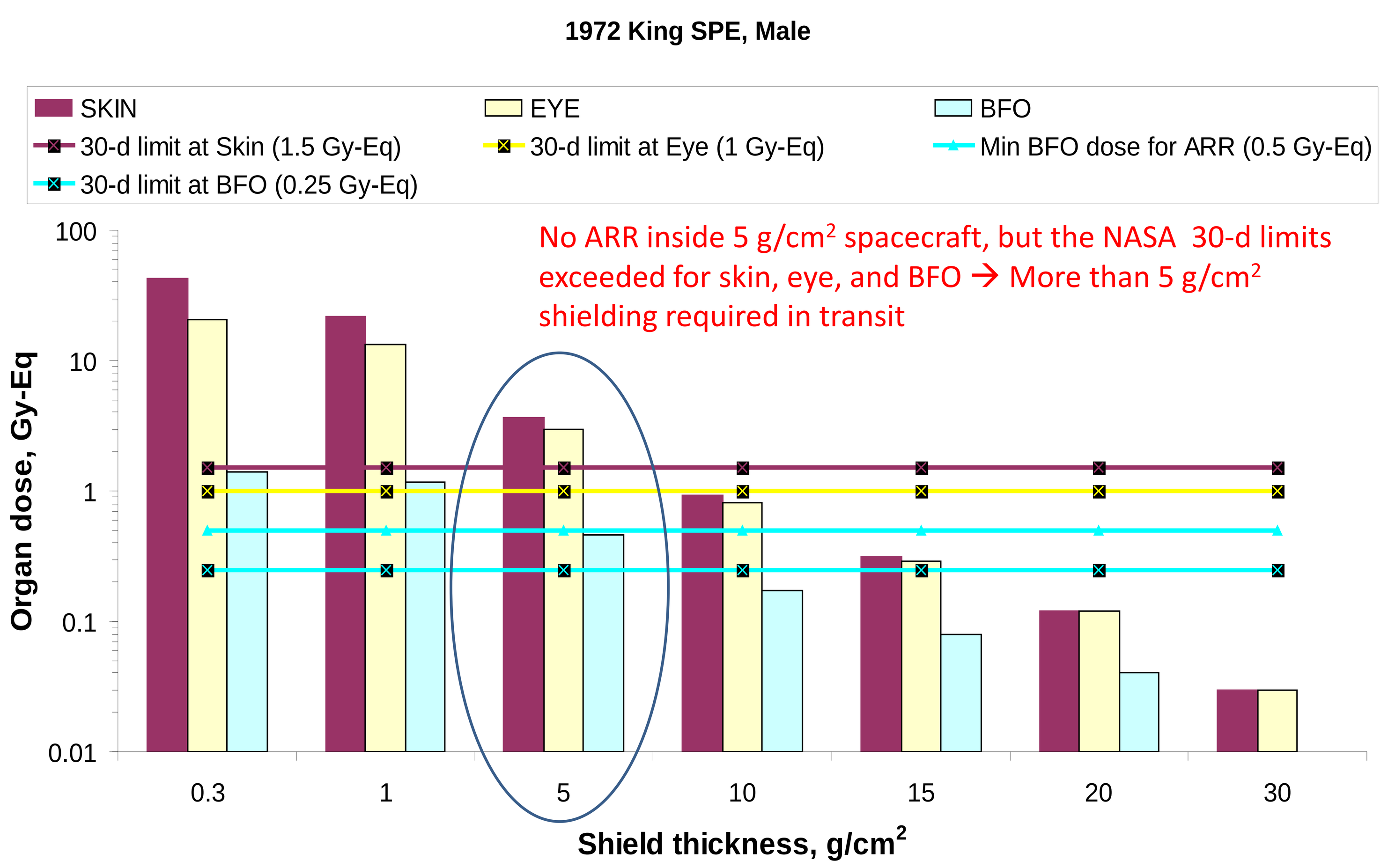
$$(0 \le t \le 4000)$$

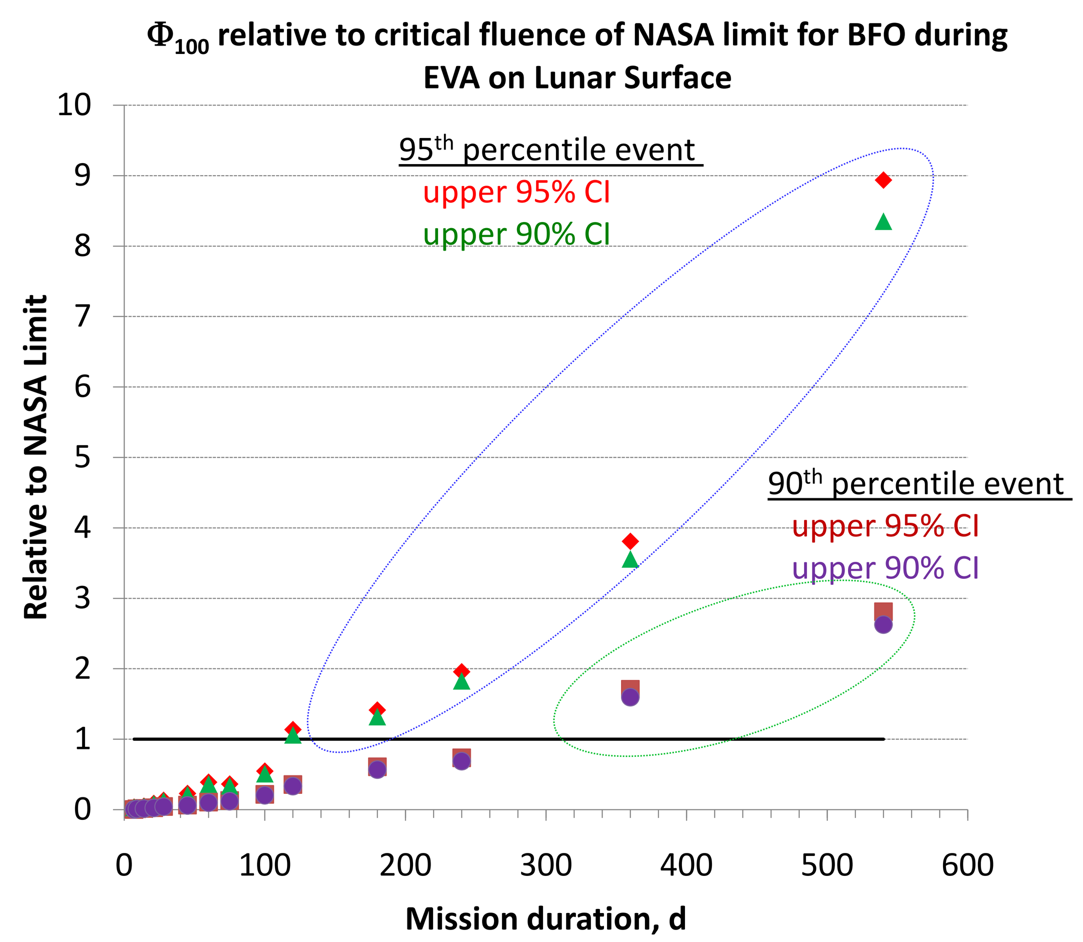


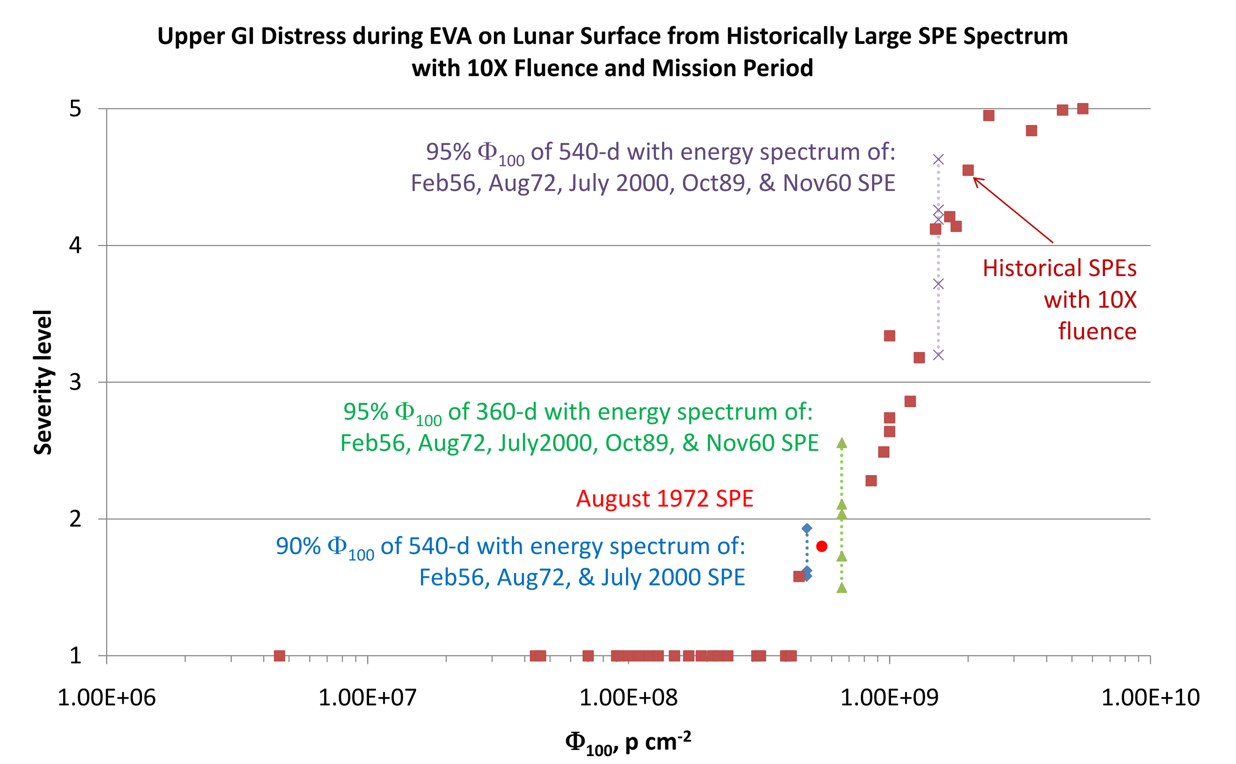
Simulated Distribution of SPE Fluence at 30, 60, and 100 MeV for Mission Period

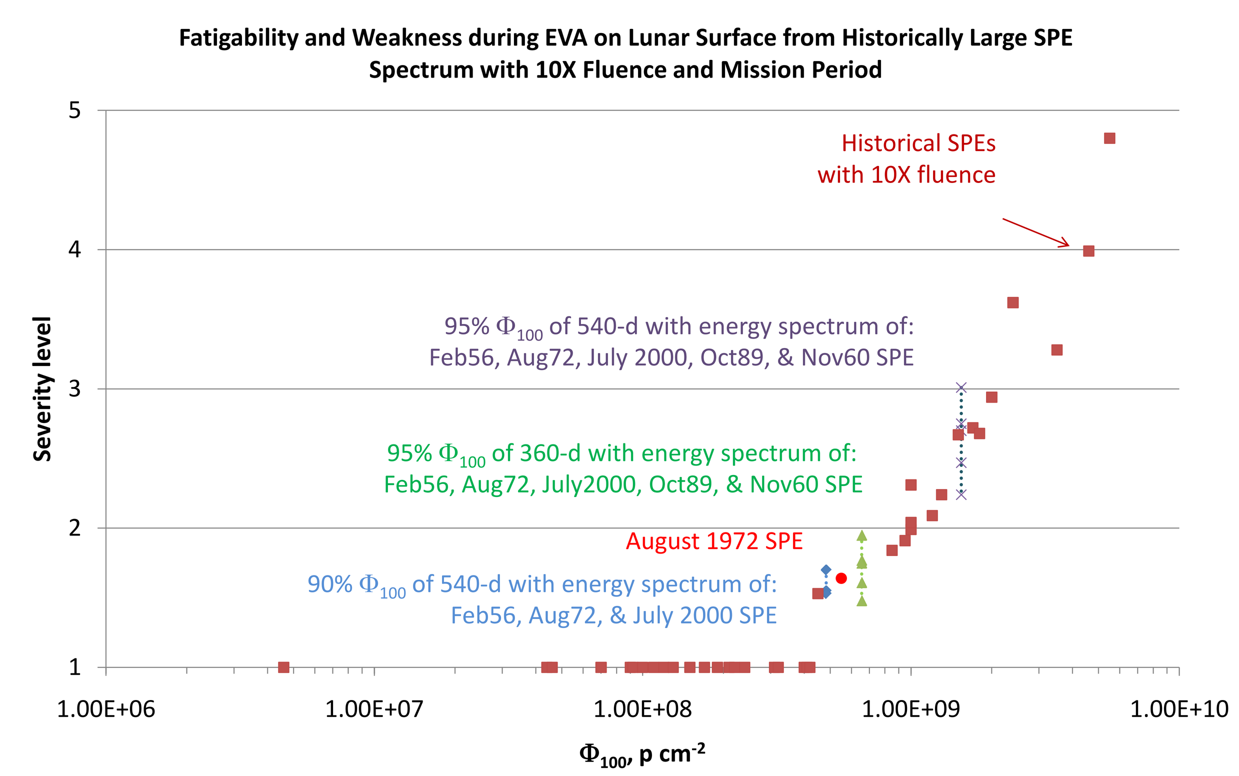


Exposure Limit and Acute Radiation Risk Analysis from SPEs









Conclusion

- Propensity for SPE occurrence and particle fluence for a given mission period were estimated from a non-homogeneous Poisson process model based on observations of SPEs in recent solar cycles.
- Results of BFO dose estimation as a function of mission period and the probability of exceeding the NASA 30-d limits with upper 95% and 90% confidence interval (CI):
  - Space mission longer than 120 days: BFO dose during EVA exceeds the NASA 30-d limit (upper 90% CI) from the exposure to 95th percentile events.
  - Space mission longer than 300 days: BFO dose during EVA exceeds the NASA 30-d limit (upper 90% CI) from the exposure to 90th percentile events.
- ARR analyses were made from the likely organ-dose rates of:
  - Historically observed energy spectra of large SPEs and 10 times intensity of those SPEs
  - 90th and 95th percentile events for several mission periods using various energy spectra of large SPEs

→ The ability to accurately measure high energy protons (50-300 MeV) in real time is a crucial issue for crew protection.