

A Fresh Look at Radiation Exposures from Major Solar Proton Events

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ABSTRACT

Solar proton events (SPEs) represent the single-most significant source of acute radiation exposure during space missions. Historically, an exponential in rigidity (particle momentum) fit has been used to express the SPE energy spectrum using GOES data up to 100 MeV. More recently, researchers have found that a Weibull fit better represents the energy spectrum up to 1000 MeV (1 GeV). In addition, the availability of SPE data extending up to several GeV has been incorporated in analyses to obtain a more complete and accurate energy spectrum representation. In this paper we discuss the major SPEs that have occurred over the past five solar cycles (~50+ years) in detail – in particular, Aug 1972 and Sept & Oct 1989 SPEs. Using a high-energy particle transport/dose code, radiation exposure estimates are presented for various thicknesses of aluminum. The effects on humans and spacecraft systems are also discussed in detail.

INTRODUCTION

Major solar proton events have been observed with some scientific understanding since they were first postulated by Forbush /1/ in the early 1940s. As the scientific community moved into the “Satellite Era,” more accurate satellite observations were made. To date, more than 400 SPEs have been recorded. Some of these SPEs have been energetic enough to penetrate the earth’s atmosphere producing secondary particles, namely neutrons, and measured with neutron monitors at the surface of the earth. These extremely energetic SPEs are called Ground

Level Enhancements (GLEs), and these are the solar particle events that pose the greatest concern for deep space missions.

Early solar particle measurements via satellites were made using particle detectors on the IMP (Interplanetary Monitoring Platform)-series satellites. More recently, SPE measurements have been made by the NOAA (National Oceanic & Atmospheric Administration) using the GOES (Geostationary Operational Environmental Satellite)-series satellites. The SEM (Space Environment Monitor) package contains the MEPAD (Medium Energy Proton And Alpha Detectors) instrument detector package, which measures solar protons in seven energy channels up to energies >100 MeV. Later, an additional instrument package was added, HEPAD (High Energy Proton Alpha Detector), which contains four proton detectors (P8, P9, P10 & P11) with energy thresholds of 370-480, 480-640, 640-850 & >850 MeV, respectively.

Dating back to 1963 /2/ the energy spectrum of an SPE was described in terms of an exponential in rigidity:

$$\phi(>P) = N_0 \times \exp(P/P_0) \quad (1)$$

where ϕ is the integral fluence (protons/cm²), N_0 is a normalization constant, P is the particle rigidity (MV), & P_0 is the characteristic rigidity (MV). P is expressed in terms of the particle energy (MeV) as

$$P = \sqrt{E^2 + 2m_0E}$$

where E is the proton energy (MeV) and m_0 = proton rest mass (≈ 938 MeV).

Xapsos, et al. /3/ showed that a Weibull fit [integral spectral representation: $\phi = \phi_0 \times \exp(-kE^\alpha)$] was an improvement to the exponential in rigidity fit method (ϕ_0 , k and α are Weibull fit parameters; E is the proton energy in MeV). The Weibull fit is applied later in the paper for the September & October 1989 GLE SPEs.

In this paper we show that a Band function (double power law) [and utilizing the high-energy portion of the SPE spectrum inferred from neutron monitor data] provides an even better fit to the data and is an improvement over both the exponential in rigidity and Weibull methods. Tylka and Dietrich /4/ find that the use of a Band function (double power law), which fits the actual SPE particle data out to several GeV based on neutron monitor data, provides the best method. Thus, the Band method also provides for a more accurate SPE radiation exposure assessment. The exponential and other fitting methods use a few lower energy data points (in the 10-100 MeV range - usually from the GOES satellites) and extrapolates out to the GeV regime.

GROUND LEVEL ENHANCEMENTS (GLEs)

Most SPEs that occur have proton energies that extend to the several hundred MeV range. However, there are some that are energetic enough that the proton energies extend to several GeV; these are called GLEs, and can penetrate the earth's atmosphere and magnetic field and be measured at high latitudes at the earth's surface with ground-monitoring stations. When high-energy solar particles interact with the earth's atmosphere they produce secondary particles, some of which are neutrons. These ground stations detect the neutron intensities and one can infer the proton energies (in the GeV range) from these neutron measurements. At the end of the paper, the Appendix (Table 1) lists the GLEs that have occurred since 1956.

Figure 1 is a plot of the neutron flux as observed by several high latitude stations (Courtesy of University of Delaware, Bartol Research Institute). Each station has a known rigidity cutoff (GV) value from which one can infer the high energy portion of

the SPE spectrum. This GLE as shown in Fig. 1 occurred on 20 January 2005.

THREE GROUND LEVEL ENHANCEMENTS

In this section three GLEs are compared for several fitting methods. Absorbed dose and dose equivalent calculations are shown for various thicknesses of aluminum shielding. The computer code HZETRN 2005 /5/ was utilized in making the computations:

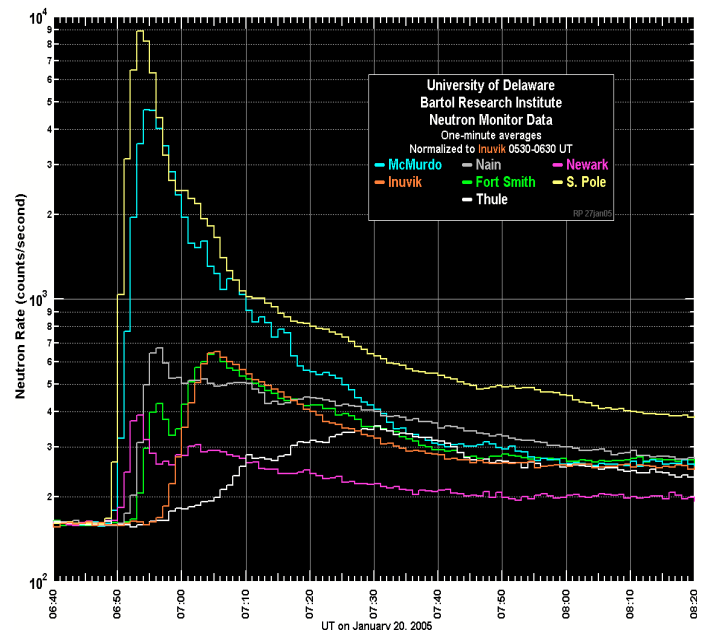


Fig. 1. The 20 Jan 2005 GLE neutron intensities as observed by several high latitude neutron monitoring stations.

4 & 7 AUGUST 1972 GLE SPE – Fig. 2 shows a comparison of the integral spectra for these events

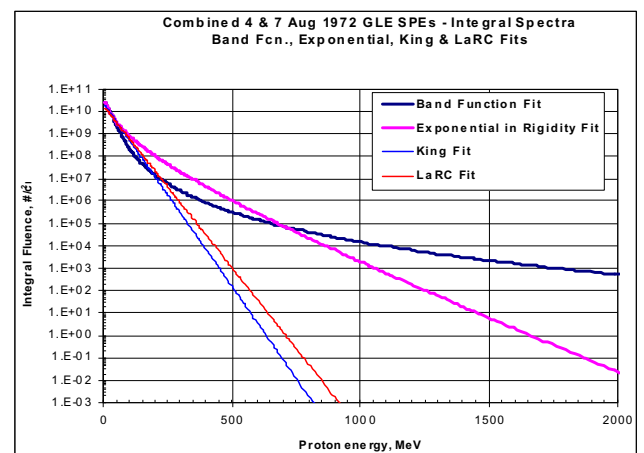


Fig. 2. A comparison of the integral spectra for a Band function, an exponential in rigidity, the King and NASA LaRC functional fits for the 4 & 7 August 1972 GLE SPEs.