THE LOCAL TISSUE ENVIRONMENT DURING THE SEPTEMBER 29, 1989 SOLAR PARTICLE EVENT

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ABSTRACT

The solar particle event (SPE) of September 29, 1989, produced an iron-rich spectrum with energies approaching 1 GeV/amu with an energy power index of 2.5. These high charge and energy (HZE) ions of the iron-rich SPEs challenge conventional methods of SPE shield design and assessment of astronaut risks. Shield and risk assessments are evaluated using the HZETRN code with computerized anatomical man (CAM) model for astronaut's body tissues. Since the HZE spectra decline rapidly with energy and HZE attenuation in materials is limited by their penetration power, details of the mass distributions about the sensitive tissues (shielding materials and the astronaut's body) are important determining factors of the exposure levels. Typical space suit and lightly shielded structures allow significant contributions from HZE components to some critical body tissues and have important implications on the models for risk assessment. Only a heavily shielded equipment room of a space vehicle or habitat provides sufficient shielding for the early response at sensitive organs from this event. The February 23, 1956 event of similar spectral characteristics and ten times this event may have important medical consequences without a well-shielded region.

INTRODUCTION

Solar particle events have been a concern to space missions outside the Earth's geomagnetic field since the Feb. 23, 1956 solar particle event (SPE) was observed by ground-level measurements and late into the event by an ion chamber on a high-altitude balloon (Schaefer, 1957, Foelsche, 1962). There was an observational gap between 20 MeV and several hundred MeV by the monitoring methods available. Added concern (Foelsche, 1962) followed the more intense intermediate energy events of November 12-13, 1960, in which small numbers of alpha particles and heavier ions were observed in nuclear emulsion stacks aboard sounding rockets (Biswas *et al*., 1962). Following additional SPE observations by satellite, it was clear that the SPE heavy ion component was variable from event to event. A pattern emerged in the analysis of a series of events from 1978 to 1981 in which a typical or baseline SPE compositional spectrum is found and unusually iron rich SPEs appear on occasion (McGuire *et al*., 1986). It was found that the composition was determined by local plasma heating prior to acceleration and is somewhat ordered according to the first ionization potential of the local plasma constituents.

Haffner (1964) found that the alpha component made significant contributions to space exposures since the dose per particle is four times greater and the quality factor is 20 times larger than for protons. Curtis *et al*. (1966) reached similar conclusions for alpha particles and medium mass ion components observed in the November 1960 event and an assumed exponential rigidity spectrum. Curtis also introduced a fractional cell lethality model (FCL) using recently measured human kidney cell inactivation cross sections for heavy ions. Wilson (1975) had used the fractional cell lethality model to demonstrate that distribution effectiveness factors greatly reduce the blood forming organ (BFO) risk estimates in SPEs. The details of the heavy ion biological cross sections have been shown to be a determining factor in evaluation of effectiveness of space radiation shielding (Wilson *et al*., 1995). Following the development of improved heavy ion transport codes (Wilson *et al*., 1991) with an improved alpha particle database (Cucinotta *et al*., 1994), a re-evaluation of the alpha component (*ibid.*) and the heavy ion component (Townsend *et al*., 1994) was made using assumed exponential rigidity spectra. More recently, space-measured heavy ion spectra have been reduced from the IMP-8 and Galileo spacecraft by Tylka *et al*. (1997) and are well fit by an energy power spectrum with index of 2.5. In the present paper, we examine the local tissue environment during the September 29, 1989 SPE which is of great importance to space radiation for several reasons: (1) it is the largest high energy event since February 23, 1956, (2) it is an iron-rich event for which the spectra are well measured, and (3) ten times this event matches the ground level data of the February 1956 event suggesting use of the factor of ten scaled event as a worst case event for spacecraft design.

SEPTEMBER 29, 1989 EXPOSURES

The input spectrum was reconstructed using Nymik's (1995) model for protons, the O and Fe ion spectra of Tylka *et al*. (1997) to evaluate the iron enhancement ratio, and the Solar Energetic Particle Baseline (SEPB) composition of McGuire *et al*. (1986). The Fe/O ratio is approximately 0.2 for this event while values up to 0.56 have been observed (*ibid*.). The SEPB Fe/O ratio is 0.066 (*ibid*.) demonstrating the present event to be a moderately Fe-enriched event. The necessary transport properties of the shielding materials and the astronaut's body tissues are evaluated using the HZETRN code. Three shield configurations (assumed to be aluminum) are considered: (1) space suit taken as 0.3 g/cm^2, (2) pressure vessel as 1 g/cm^2, and (3) equipment room of 5 g/cm^2. The astronaut geometry is taken from the computerized anatomical man (CAM) model (Atwell *et al*., 1993).

The hydrogen ions contribute to skin dose equivalent in a space suit over a wide energy range from 60 keV/amu to 45 MeV/amu as seen in Figure 1. Helium ions mainly contribute over the 0.3 to 10 MeV/amu range resulting from fragmentation of the aluminum shield nuclei. The Li to B ion group show

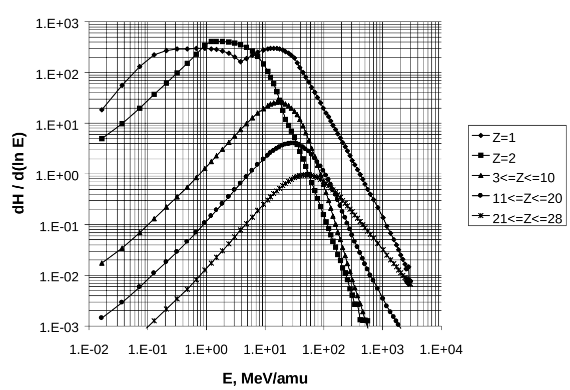

Fig. 1. Skin dose equivalent inside space suit

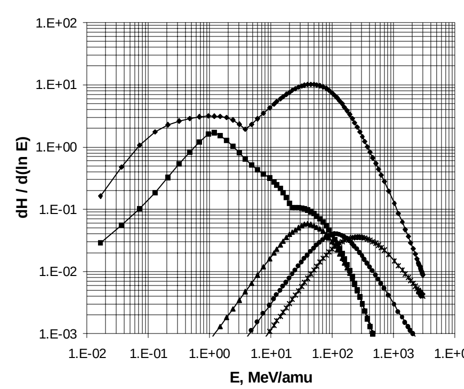

Fig. 2. BFO dose equivalent inside space suit

significant contributions over the range 5 to 30 MeV/amu with heavier ions giving lesser contributions at higher energies (7 to 100 MeV/amu). The higher charge of the ion requires more energy to penetrate to the sensitive tissues. The low-energy primary helium ions attenuate rapidly in shield materials. The helium ions from evaporation events in tissue nuclei dominate at larger shielded depths as seen in Figure 2. Note that the evaporation events in tissue cover a less broad energy range than those events in the aluminum shield. Heavier ions attenuate even more rapidly and contribute little to deep organ exposures. Protons and low energy helium ions are the main contributors in well-shielded areas as for the BFO in a space suit.

The exposures in a pressure vessel are shown in Figures 3 and 4. The hydrogen and helium ions show similar broad energy contributions in the skin exposures with the helium result showing significant attenuation compared to the space suit exposures. The heavier ions are likewise reduced relative to the hydrogen contributions. Again we see the narrowing of the helium ion energy range in the deeper organs. Results for other body organs in various shield configurations are shown in Table 1. The total dose equivalent is significantly reduced in going from the space suit to the pressure vessel, but only the equipment room provides sufficient shielding to satisfy the exposure limitation requirements of 25, 100, and 150 cSv for the BFO, ocular lens, and skin respectively (NCRP, 1989). Even so, the exposure levels in a space suit are expected to cause only nonlethal responses. One would expect at worst, reddening of the skin and depression of the blood levels (*ibid*.).

It has been suggested that the February 23, 1956 event should be approximated by ten times the September 29, 1989 event on the basis of the ground-level neutron monitor records. An event ten times larger than the September 29, 1989 event may have dire consequences unless a well-shielded region is used during most of the exposure. For example, the NCRP (1989) estimates that the mortality threshold is 1.5 Gy for gamma rays which is small compared with 4.2 Sv to the BFO in a space suit for a “February 23, 1956 event” taken as ten times the September 29, 1989. The skin dose in a space suit would be very large and even a dose rate reduction factor of 2 to 3 would leave the exposures high compared to the threshold for moist desquamation (30 Gy for gamma rays). The possibility of infection with an already depressed immune system prior to the exposure followed by the added challenge from the coincident BFO exposure may provide a serious medical problem to the astronauts. Clearly some attention needs to be given to emergency medical planning in deep space missions.

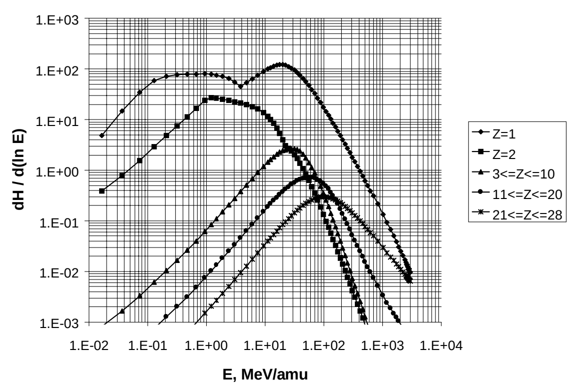

Fig. 3. Skin dose equivalent inside pressure vessel.

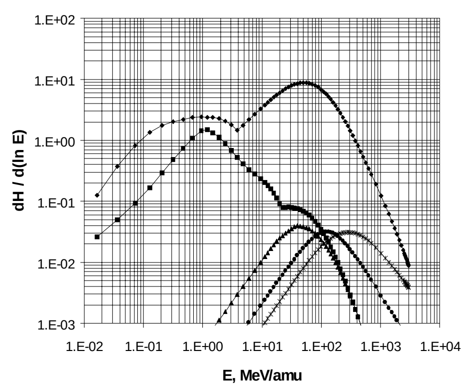

Fig. 4. BFO dose equivalent inside pressure vessel.

Table 1. Dose equivalent from September 29, 1989, SPE (in cSv)

	Skin			Ocular Lens			BFO		
Charge	Space suit	Pressure Vessel	Equipment Room	Space suit	Pressure Vessel	Equipment Room	Space suit	Pressure Vessel	Equipment Room
Z=1	1738	554	57.7	668	318	50.1	37.8	31.4	16.81
Z=2	1149	82	6.6	133	33	4.9	4.0	3.5	2.40
3≤ Z ≤10	53	5	0.2	9	2	0.2	0.1	0.1	0.03
11≤ Z ≤20	9	2	0.1	2	1	0.1	0.1	0.1	0.03
21≤ Z ≤28	2	1	0.2	1	1	0.1	0.1	0.1	0.04
Total	2951	644	64.8	813	355	55.4	42.1	35.2	19.31
NCRP 30-day limit	150			100			25		

CONCLUSIONS

The multiply charged ions play a limited role for this very energetic SPE with moderate Fe enhancement in a lightly shielded space suit and for the least shielded organs. Clearly, the factor of two higher Fe enhancements observed in some events will not radically change this conclusion, especially for greater shielding or organs deeper in the body, such as the BFO. This event in itself would pose a limited health risk although the February 23, 1956 event of similar spectral characteristics and ten times the fluence may have important medical consequences. Still the heavier ions are responsible for only a small fractional contribution to the exposure and primarily affect the skin and ocular lens.

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