SOLAR PARTICLE EVENT--REAL TIME (SPERT): A REAL-TIME SOLAR PARTICLE EVENT EXPOSURE ANALYSIS SYSTEM

M.D. Weyland*, M.J. Golightly**, T. Lin*

*Lockheed Martin, Houston, TX, USA
**NASA Johnson Space Center, Houston, TX, USA

ABSTRACT

The planned high-inclination orbit for the International Space Station (ISS) increases the vulnerability of crew and hardware to exposure to increased levels of radiation during solar particle events (SPEs). A new software tool has been developed for automatic real-time modeling of SPE exposure inside ISS or to EVA astronauts. Solar Particle Event--Real Time (SPERT) couples the temporally varying SPE proton spectrum with the continuously varying geomagnetic cutoff at the vehicle location to provide realistic exposure modeling. SPERT includes such features as the ability to use historical or real-time proton flux and spacecraft trajectory information, direct access to GOES proton data stored in the NOAA Space Environment Center's Data Management System, direct access to current vehicle state vector information via a NASA ISP server, user interruption to change scaling and offset values, simultaneous exposure calculations at up to five locations, automatic retrieval of missing information resulting from temporary data loss, and the ability to be started automatically from other space weather monitoring systems. SPERT also features an enhanced proton transport code and a new geomagnetic cutoff rigidity algorithm based on recently calculated rigidities for 450 km altitude. In comparison with dose measurements from Shuttle and Mir, SPERT determines exposures to within a factor of two of measurements.

BACKGROUND

During the last solar maximum in 1989, the space radiation analysis group (SRAG) had six different codes to run, after receiving GOES proton data, to estimate a crew dose following an SPE. In 1990, those codes were combined into a single code with slightly better user prompts. This made the process better, but was still inadequate for making accurate real-time recommendations to flight management during an event. Those methods and codes had far too many user inputs and made too many assumptions to be reliable, as the group discovered during the STS-28 flight. This flight occurred during the August 1989 SPE and due to the lack of fidelity in the SPE codes, SRAG over projected the additional dose contribution to the crew by more than a factor of 1000! This was obviously unacceptable and work began on improving SRAG's SPE analysis system. Over the next 6 years the work moved slowly or was shelved due to organizational changes, moving into solar minimum, and lack of qualified personnel after losing several individuals through retirement or reassignments. The work picked up again in 1996 and is nearing completion at this writing (November 1998).

PROCEDURE

The goals for the new SPE analysis system were to determine crew exposures to ± 15% and be automated to run in near real time. The old method used a single orbit-averaged geometric transmission function which assumed SPE particles are continuously reaching the vehicle. This is not true and does not agree with time resolved measurements. It also uncouples the temporal SPE spectral and geometric cutoff variations. However, for low-Earth orbiting missions, temporal SPE spectral and geometric cutoff variations must remain coupled. In the new code we coupled the temporal variations in the SPE spectra with continuously varying geomagnetic cutoff at the vehicle location. A general description of our method is:

- Every 60 seconds determine vehicle location
- Calculate geomagnetic cutoff energy for protons (E_c) at vehicle location
- If $E_c > 3$ GeV, assume additional dose is zero and move to next vehicle location
- Obtain corresponding integral GOES proton flux (updated every 5 minutes)
  - J(E) > 30 MeV
  - J(E) > 100 MeV
- Convert integral flux to differential flux
- Reduce "free-space" SPE spectrum to account for "Earth shadowing" at low Earth orbit
- Attenuate SPE spectra through vehicle shield distribution
- Calculate dose from attenuated SPE spectra

$$Dose = C\int_{E_c'}^{3GeV} F(E')L(E')\partial E'$$

$F(E')$ = SPE proton spectrum behind shield
$E'_c = E_c - DE$ DE = energy loss through shielding

- Repeat procedure and integrate over desired trajectory period at 60 second intervals.

The code assumes geomagnetically quiet conditions, alpha and heavier particles are ignored, the dose calculation is based on continuously slowing down approximation (CSDA) and ignores secondary particles.

There are 5 different options for the GOES data and trajectory input when running solar particle event – real time (SPERT):

1. Existing GOES proton flux file and trajectory file
2. Existing GOES proton flux file and user input state vector (SPERT will propagate new trajectory file)
3. GOES "real time" proton flux data and trajectory file
4. GOES "real time" proton flux data and user input state vector
5. GOES "real time" proton flux data and "real time" state vector

The fifth option is undergoing testing and is not yet operational, but should be ready for the first International Space Station flight, STS-88, in December 1998. Other work still to be completed on SPERT is a GUI interface for the initialization parameters, linking to the space weather alarm code which will automatically start SPERT when predetermined proton levels have been exceeded at GOES, and a graphical interface for the output.

The code has had two major verification opportunities where there were significant SPE's, low Earth orbiting vehicles, and on-board time resolved instrumentation. The first was the August 1989 event discussed above that was over estimated with the old method by more than a factor of 1000 during the STS-28 flight. The RME III instrument was flying on STS-28 during that flight and clearly shows the additional dose received from solar particles. Using option 1, a Zwickl corrected August 1989 GOES particle file, and an existing as-flown trajectory file from the flight, SPERT was tested for the first time. See Fig. 1. The first particles to reach the vehicle appear to have come between 16:00 and 20:00 according to SPERT, but the doses were so low, the response would have been drowned out by the GCR in the RME III. The next set of high geomagnetic latitude passes begins just after 8:00 on the 13th and landing occurs around 13:00. As can be seen in Fig.1, the first measured solar particles at 8:30 were completely missed by SPERT. The remaining four passes show SPERT with good agreement on the time of solar particles and good agreement on the magnitude of the passes. The cumulative SPERT calculation was within 3% of the measured RME III value inside the locker. This tells us that SPERT is over estimating the dose since one pass was completely missed and another was under by more than a factor of two. This was confirmed when a thinly shielded spot in the Space Shuttle was used. SPERT over estimated the dose by a more than a factor of two for this location. While not within our goal of ± 15%, this was much better than the projection given during the flight (off by more than factor of 1000).

The next opportunity came in November 1997 while SRAG was "flight following" MIR with a U.S. crewmember aboard. The tissue equivalent proportional counter (TEPC) was on board. A major X-ray flare (X9) occurred around 12:00 GMT on November 6th. The MIR space station was phased favorably, with respect to higher geomagnetic latitudes (and lower cutoff energies), to receive solar protons from the event. There was not a good shield file for the MIR available so we gave the standard Space Shuttle shielding file to SPERT. This is represented by DL1 (dosimeter location 1) in Fig.2. Figure 2 shows the calculated (SPERT) dose rate and cumulative dose versuses the measured (TEPC). The magnitude of the SPERT passes (dose rate) is generally higher than measured, but since the duration of the SPERT passes is shorter, the cumulative dose estimation vs. measured was remarkably good.

CONCLUSIONS

SPE dose calculations for the Aug. '89 and Nov '97 events using SPERT yielded relatively accurate values in comparison to Shuttle and MIR based measurements. Orbital phasing relative to SPE flux profile is a significant factor in determining the resulting exposures to low-Earth orbiting spacecraft. More work needs to be done to resolve missing one of the Southern Hemisphere passes and on cutoff routines to be applied during geomagnetic storming. The magnitude and shape of individual passes also needs to be studied to determine where corrections can be made to the world wide grid of geomagnetic cutoffs and/or how SPERT applies them. The authors express their gratitude to Drs. Don Smart and Peggy Shea for providing us with a prepublication version of the world-wide grids of geomagnetic cutoffs and for their guidance in applying them to our analysis.

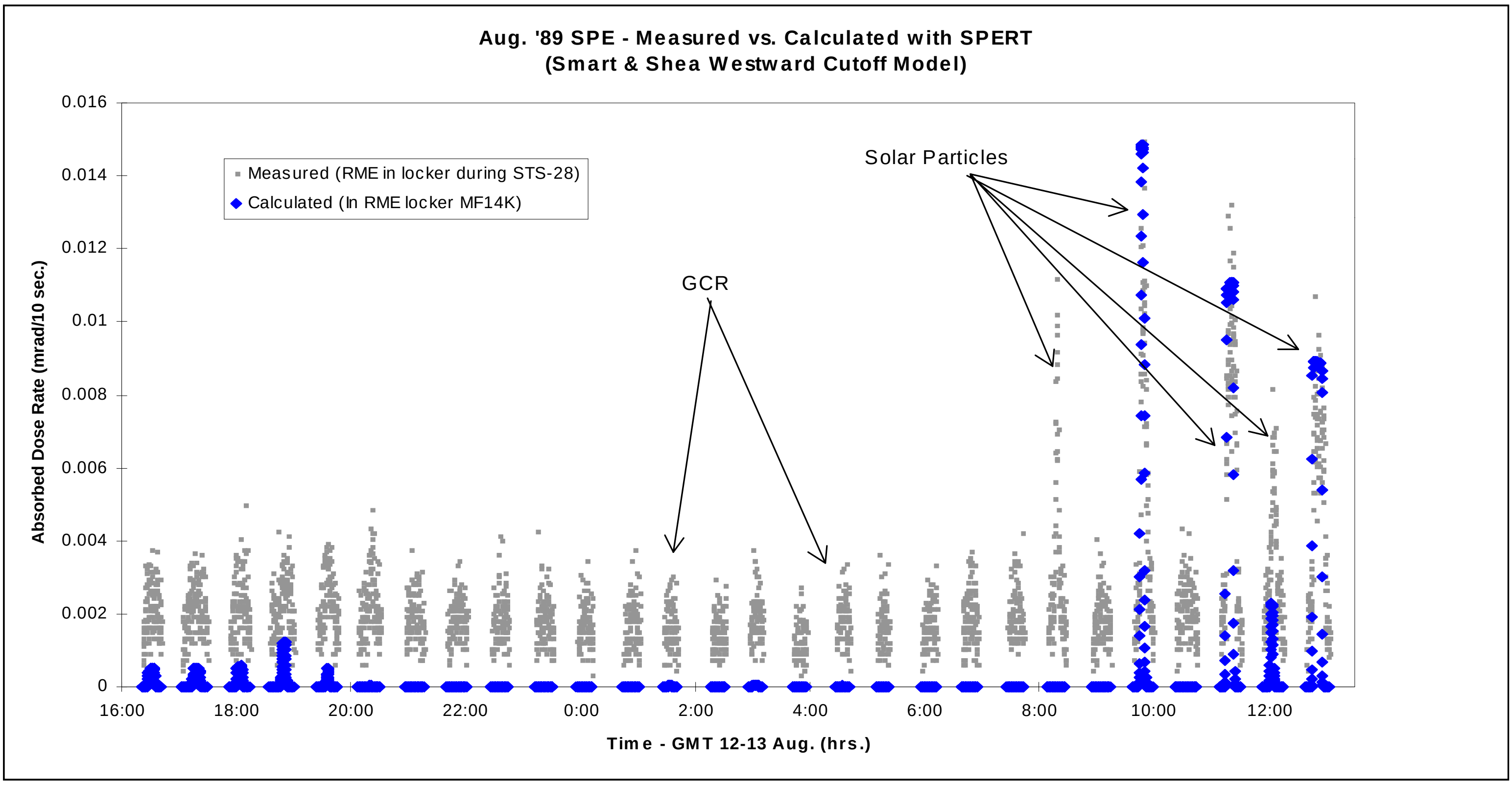

Figure 1

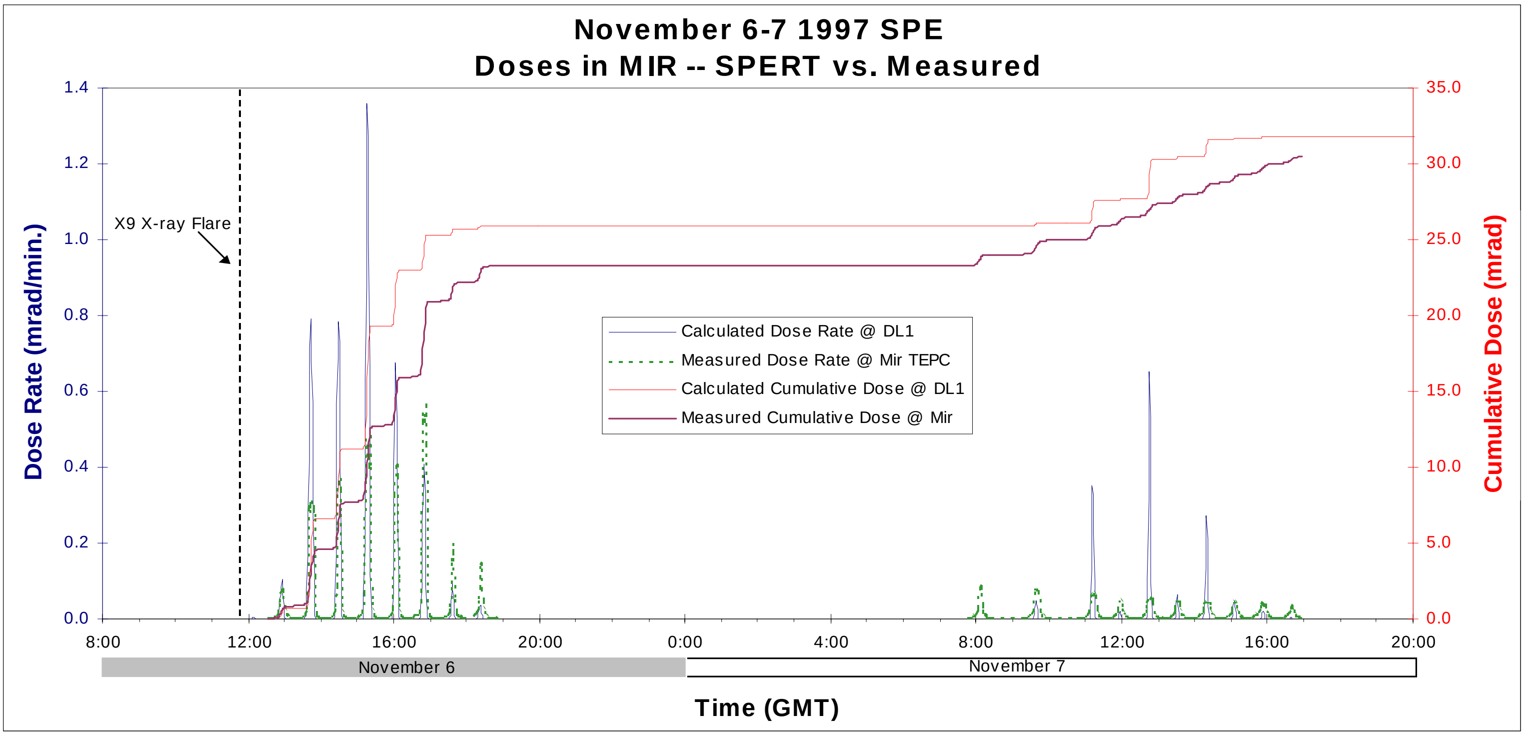

Figure 2