"Minimizing Space Radiation Exposure During Extra-Vehicular Activity "

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ABSTRACT

Continued assembly of the International Space Station (ISS) requires numerous Extra-Vehicular Activities (EVAs). Prudent radiological safety practices require minimizing additional exposures to crewmen during these periods[1]. The spatial distribution of the "normal" trapped proton and electron radiation sources in low Earth orbit is strongly governed by the geomagnetic field. It is possible to use ISS trajectory information to estimate crew exposures during EVAs and to identify periods that can result in minimal EVA crew exposures through avoidance of these trapped radiation regions. Such exposure minimization planning can also accommodate the unforeseen development of a solar proton event. An EVA exposure estimation tool, EVADOSE, is described and applied to various EVA exposure scenarios. Procedures and parameters that influence EVA exposures are discussed along with techniques to minimize crew exposures.

INTRODUCTION

Astronauts are radiation workers. Special exposure limits are applied that can allow astronauts to receive exposures greater than that allowed for terrestrial radiation workers. As a condition of implementing the higher exposure limits, NASA is required to perform ALARA (As Low As Reasonably Achievable) assessments to maintain crew exposures as low as reasonably possible. The radiation fluences found in low Earth orbit are spatially non-uniform as a result of the geomagnetic field which both protects and adds to the radiation environment. On one hand, the geomagnetic field provides some shielding against the background galactic cosmic radiation (GCR), while on the other hand traps protons and electrons into regions where localized and significantly increased radiation levels are found. This non-uniform distribution of radiation levels causes internal radiation levels to typically vary by a factor of 1000; the range of external levels is even higher. The crew exposure during an extra-vehicular activity (EVA), or space walk, is very dependent upon the amount of time spent in the areas of higher radiation levels. Assessing the spacecraft trajectory against the spatial distribution of the radiation environment presents an opportunity to evaluate and make recommendations to potentially lower the EVA exposure.

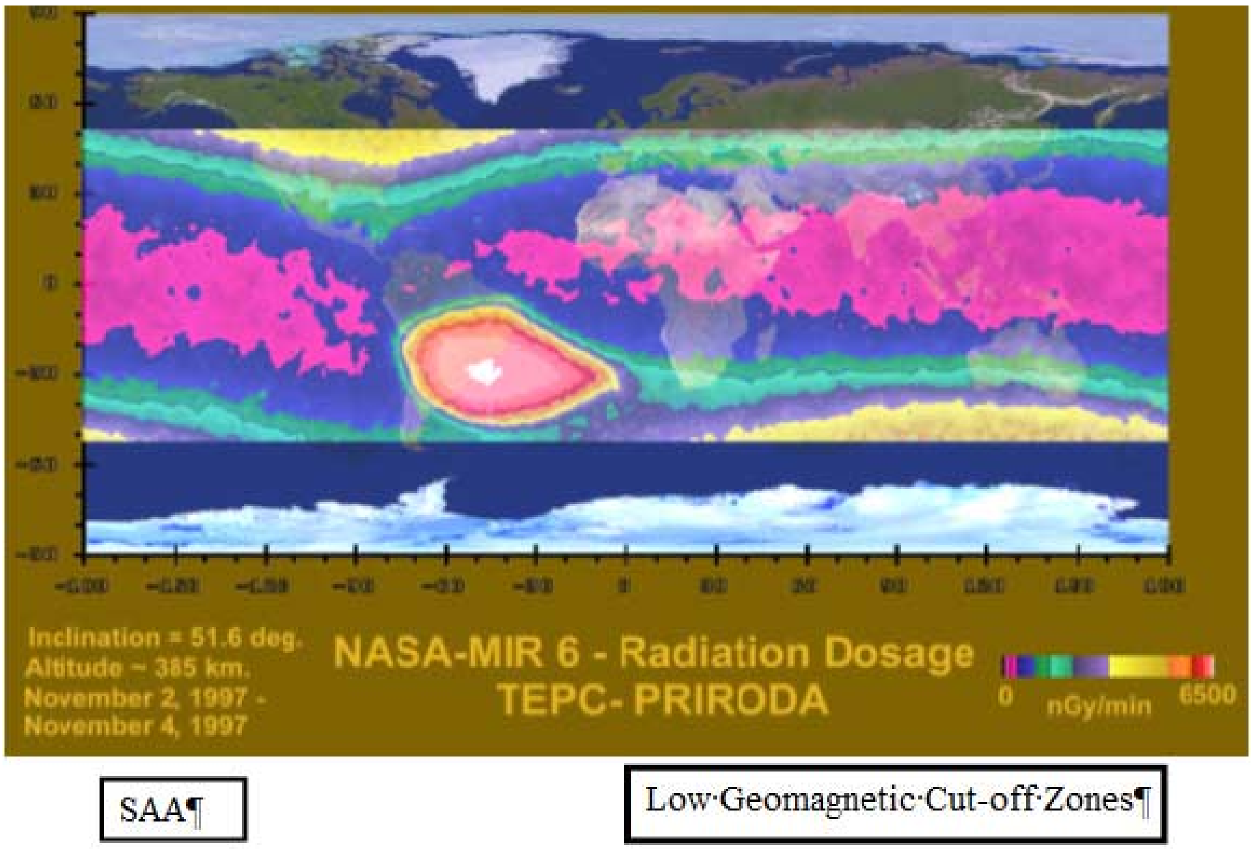

Figure 1 – Typical internal dose rate mapped by ground track

BACKGROUND

Figure 1 illustrates the basic distribution of the radiation environment at a typical ISS altitude. Dose data from an internal radiation monitor, Tissue Equivalent Proportional Counter (TEPC), is plotted against the spacecraft ground track. This distribution is representative of the 'normal' radiation environment. The tilt and offset of the geomagnetic field relative to the Earth's spin axis creates the South Atlantic Anomaly (SAA), which appears as the "bulls-eye" over South America. One third to half the daily dose is encountered in this region. In this chart, the remaining radiation is from GCR. The lowest levels are encountered at the geomagnetic equator due to the protection of the Earth's field. Geomagnetic protection decreases as the spacecraft moves away from the equator. Due to the tilt of the magnetic field, geomagnetic field lines with large dipoles are found over North America and near Australia and provide little protection from the free space environment. These are referred to as 'low cutoff zones'. The yellow areas indicate the GCR reaching maximum levels. Although not measurable inside, trapped electron belts dip to low Earth orbit (LEO) altitudes and are found near these low cutoff zones. Thus, the EVA 'normal' radiation hazards are summarized as 1) GCR, 2) SAA protons and electrons and 3) trapped belt electrons at high latitudes. During off normal situations, additional exposure can occur from Solar proton Events (SPE) or from temporary increases in trapped radiation belts resulting transient magnetic storms.

EVADOSE

In order to estimate the exposure to the crew the program called EVADOSE was developed to assess the trajectory of the EVA spacewalker against the projected external radiation levels encountered during the course of the EVA. EVADOSE is designed to evaluate the difference in exposure between what the crew receives during an EVA and what would have been received if the crewmember remained inside the spacecraft. GCR exposure inside or outside of the spacecraft is very similar and therefore neglected in the analysis. Trapped exposures, however, differ greatly between inside and outside. Transport of protons and electrons through the spacecraft structure and the EVA Suit are evaluated using separate shield files to determine the exposures inside the spacecraft and inside the EVA suit.

Four options for trajectory assessment are provided.

1. Trajectory file – data file of latitude, longitude, altitude, B and L-Shell as a function of time (once per minute).
2. User-supplied State Vector – M50 state vector and associated time of vector to generate a trajectory file.
3. Real-time STS State Vector – current Shuttle state vector and time extracted by polling local Mission Control data Servers to generate a trajectory file.
4. Real-time ISS State Vector – current Space Station state vector and time extracted by polling local Mission Control data Servers to generate a trajectory file.

The input trajectory file serves as an input source of B and L-shell computational routines in conjunction with the source models to determine the flux at any location as a function of time. AP8 & AE8 trapped proton and electron models are used with options to select from either the solar maximum model or the solar minimum version of the trapped models. The differential proton & electron flux at each minute of the EVA is determined. The differential fluxes are summed for the duration of the EVA and used with two radiation transport codes, PDOSE for protons and EDOSE for the electrons to compute the resulting dose.[2] A summary output is provided along with a proton and electron flux vs. time file for EVA exposure optimization.

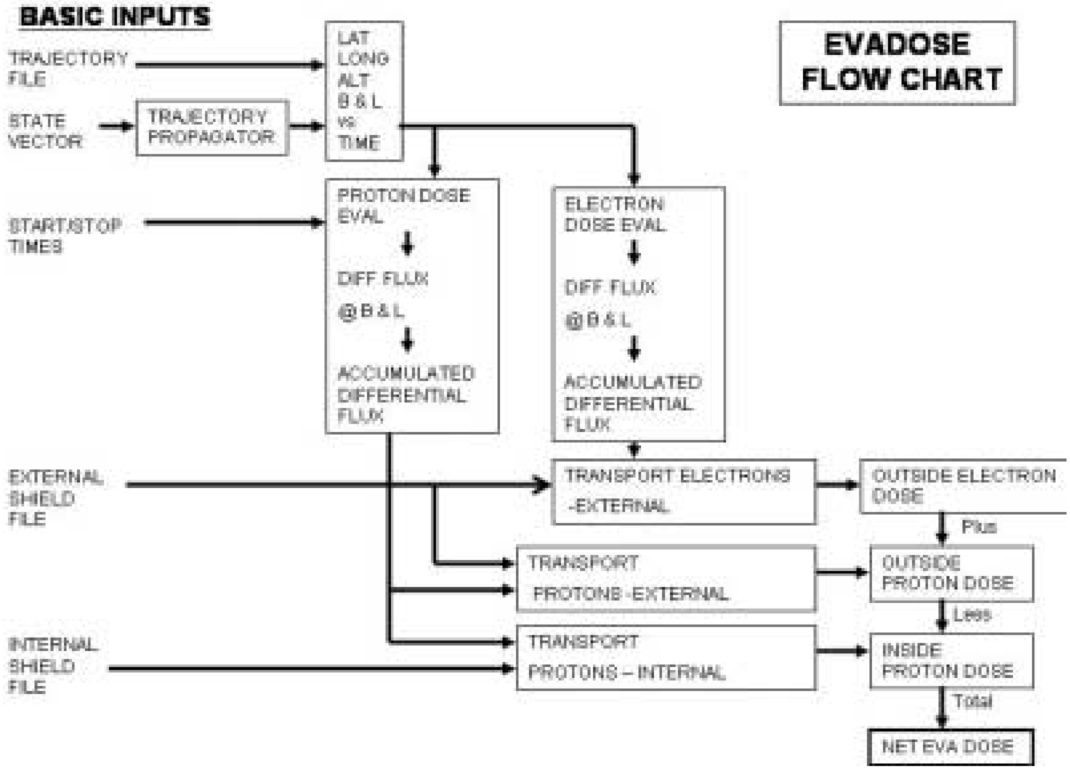

Figure 2 – Basic functional flow chart of EVADOSE

OUTPUT

Specific parameters may be input to produce an estimation of any particular EVA. Generally, before the EVA starts, several cases have been run to estimate the result of starting an EVA early or late. By combining the proton and electron flux versus time output files, a rolling integration of a specific EVA duration is possible. Figure 3 is an example of EVA dose projections for a high inclination Space Station mission. The top half of the graphic depicts the dose rate vs. time. These spikes are due to passes through the SAA or the electron belts. Figure 4 depicts the result from STS-109 a low inclination, high altitude flight which only passes through the SAA. Planned EVAs are marked by green triangles. For any given start time, the lower curve reflects an estimate of the EVA exposure for the targeted duration. In order to minimize exposures, optimal EVA exposure start times should be scheduled in the bottom of ‘valleys’ of the lower curve. Once a day there is a time when the additional dose is at a minimum and it is possible to receive very little extra exposure for the EVA. However, EVA schedules are driven by a large number of requirements so it is not always possible to schedule them for optimally minimum exposure.

For the STS-109 (Hubble Space Telescope Repair Mission) example, the skin exposure versus start time curve appears simplier in comparison to the ISS example in Fiure 3. Since STS-109 represents a low inclination mission, only the SAA region contributes to the EVA exposure.

This type of temporal pattern of EVA exposure vs. EVA start time provides a quick means to advise the mission control team on the impacts of changes in the planned EVA start time on EVA exposures. EVAs have been replanned on occasion based on similar analysis. Although the primary operational focus is on finding the minimum dose levels, the start times and magnitude of the worst case exposures also can be determined.

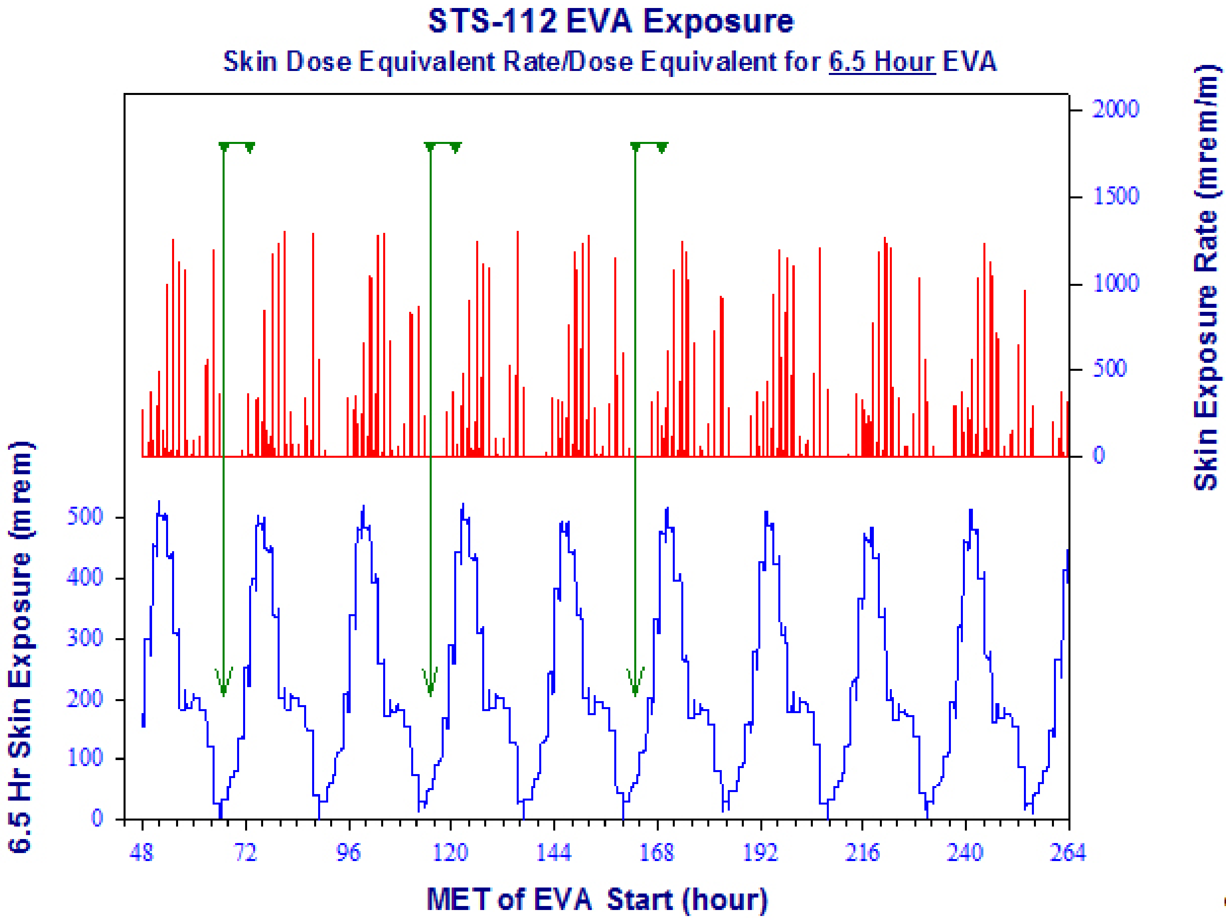

Figure 3 – High orbital inclination EVA assessment (STS-112). Top graph is dose rate vs. mission elapsed time (MET). Bottom graph is integrated EVA dose for a given EVA start time.

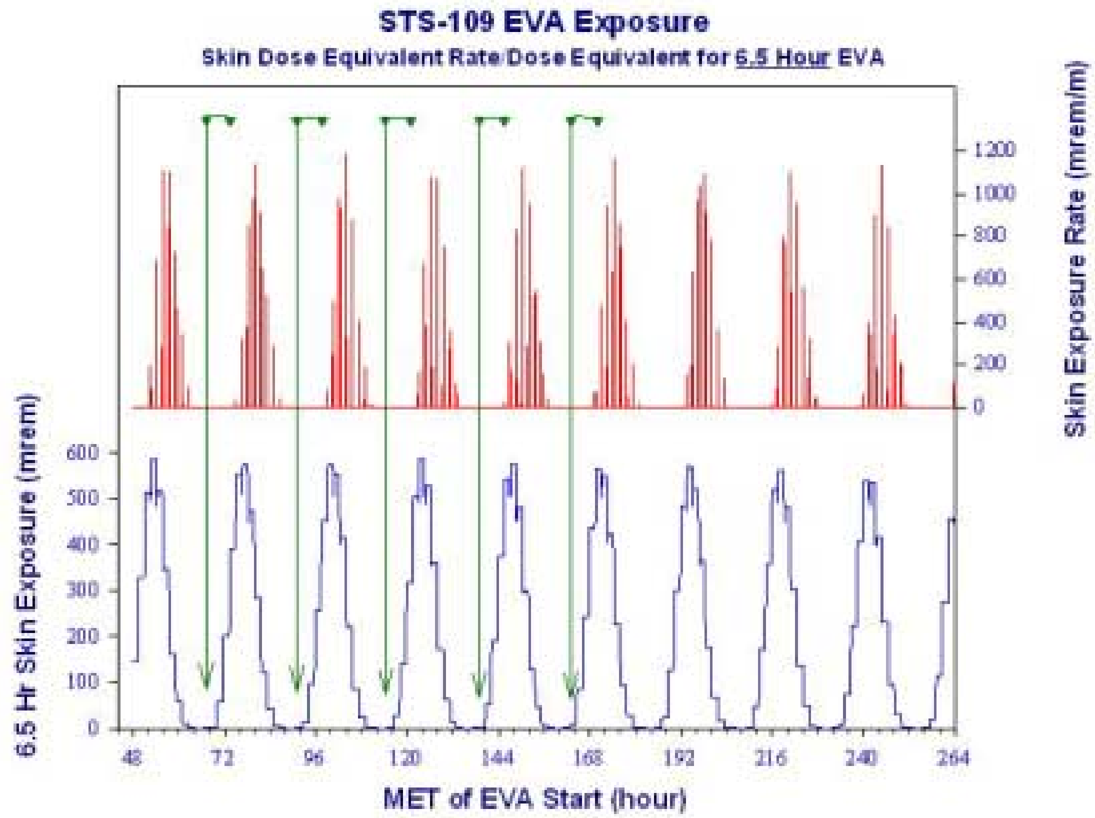

Figure 4 – Low orbital inclination EVA assessment (STS-109).

The above method describes how, based on timing, EVA exposures can be minimized. It is also possible to relate the dose at any given time to a ground track location. The repeating structure of the integral doses above reflects the repeating nature of the trajectory. If the ground track exactly repeated each day, the optimal exposure EVA start time would be the same time each day. Usually, there is a slight precession in the ground track leading to slightly earlier start times each day. Since each EVA start time has an associated trajectory location, it is also possible to associate EVA doses with ground track locations. Figure 5 depicts the ground track start location of EVA below 30 mrem. This information can also be used by planners to locate the trajectory the position for optimal initiation of EVAs. Generally, the optimum locations will start as the spacecraft exits the last daily SAA pass. Such a trajectory will miss the SAA protons and electrons and will be complete before the outer electron belts are encountered. Starting an EVA outside the optimum ground track shown in figure 5 will result in exposures greater than 30 mrem.

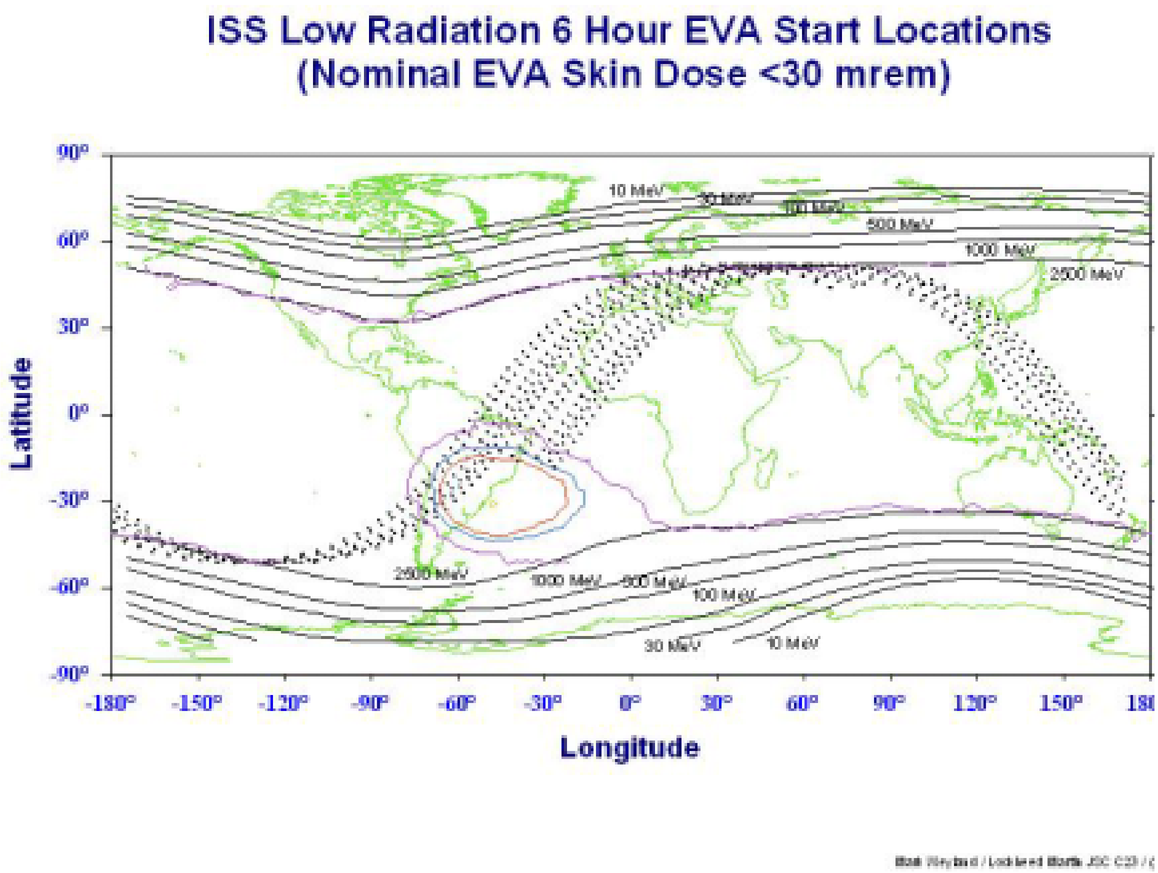

Figure 5 – Ground track locations for initiating a 6 hour EVA less than 30 mrem (solar maximum conditions and ISS altitude/inclination).

SOLAR PROTON EVENTS

Solar proton events (SPE) can also contribute to an EVA exposure. However, EVADOSE is not configured with making dose projections based on SPE fluences. However, when SPEs do occur, the resulting protons intercept typical spacecraft altitudes in the low cut-off areas shown in Figure 1. These two regions also roughly correspond to the trapped electron belts. An EVA planned to miss the electron horns may also avoid SPE exposures. To compare the relative phasing of SPE exposures during a potential EVA, an SPE projection code[2] was used to generate 6.5 hour EVA doses (See Figure 6). A constant flux value approximately one fifth of the maximum flux for the October 1989 event was used with quiet geomagnetic conditions to generate the doses inside the vehicle. Although the calculation is for internal doses, the relative phasing will be the same EVA Exposures. As can be seen in the figure, in a normal day there is about an approximately 4 hour window that will result in a low EVA exposure. A window of time exists such that an EVA can be executed and receive little exposure, even during a large SPE. In this example a simulated very large event was used, resulting in a narrow window to execute a 6.5 hour EVA at minimum exposure. SPE events that are smaller may yield a wider gap depending on many factors such as the magnetic field conditions (Kp), proton rise times, etc. Due to the large variation in SPE events, these situations must be evaluated on a case by case basis. This case is provided to illustrate how EVADOSE can be used in conjunction with other models and not necessarily to represent exact EVA doses from an SPE. Shortening the planned EVA duration will always increase width of the low dose window and lower the corresponding EVA exposures at any given time.

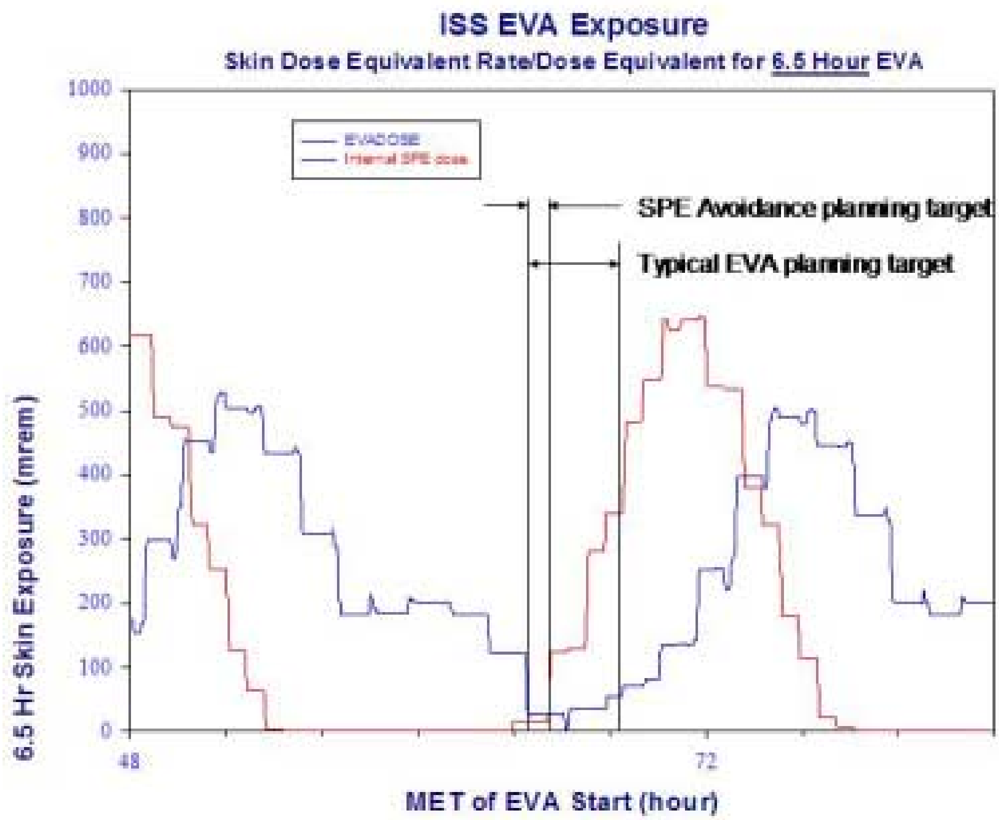

Figure 6 – comparison of EVA exposure timing vs. SPE exposure timing.

OTHER LIMITATIONS

EVADOSE is limited by the accuracy of the AP8 and AE8 models, the basis for estimating the exposure levels from the trapped radiation. While the accuracy of the trapped models introduces errors in the absolute exposure magnitudes, the temporal location of the exposure minima which results from spatial avoidance is fairly well defined and useful for ALARA planning. Another limitation resulting from the use of the AP8/AE8 models is that they represent long term static averages. In reality, changes in the geomagnetic field during storm conditions can cause dramatic change in the low altitude spatial extent and intensity of the electron belts, but generally, the optimal exposure trajectories will remain unchanged because the regions will broaden. Other methods can be used to adjust the dose projections during enhanced electron belt conditions.

SUMMARY

EVADOSE provides an easy method to assess potential EVA exposures. This tool provides an effective preflight assessment for EVA scheduling and may be used to guide EVA scheduling to minimize crew exposures and meet ALARA guidelines. Although the impacts of SPEs are not included in EVADOSE's capabilities and must be analyzed on a case basis, the results of EVADOSE can be used in conjunction with other tools to evaluate these enhanced radiation conditions.

REFERENCES

1 **Radiation and the International Space Station: Recommendations to Reduce Risk**, National Research Council, Board on Atmospheric Science and Climate, National Academy Press, Washington D.C., 2000.

2 Golightly, Michael J., E. Neal Zapp, A. Steve Johnson, and Tom Lin, **Manned Space Flight Operational Radiological Support: Tools (Models) of the Trade**, American Geophysical Union (AGU) Spring 2002 conference, May 28-31, 2002.