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ESA's Space ENVironment Information System (SPENVIS): a Web-Based Tool for Assessing Radiation Doses and Effects in Spacecraft Systems

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Abstract – *Evaluations of the hazardous Earth environment and its effects on space systems are often hampered by the lack of comprehensive tools to access numerical models and data in an integrated environment. In order to help spacecraft engineers perform rapid analyses of environmental problems and to guarantee reliable results, ESA commissioned the development of the SPace ENVironment Information System (SPENVIS), a user-friendly WWW interface (available at* http://www.spenvis.oma.be/*) to models, tools and data describing the various aspects of the space environment and its hazardous effects. SPENVIS is conceived as a set of building blocks which are connected through a dynamic HTML interface. This design approach facilitates extensions and updates of the system with new models and tools, provides a flexible navigation through the many applications incorporated in the system and incorporates a protocol to interconnect with other services and tools, such as NASA's Space Ionizing Radiation Environments and Shielding Tools (SIREST). SPENVIS is based on internationally recognized standard models and methods in many domains. It uses an orbit generator to produce orbital point files necessary for many different types of problems. The radiation environment models in SPENVIS cover the Earth's radiation belts, cosmic rays and solar energetic particles. Fluxes and fluences derived from these models are used to calculate ionising and non-ionising dose, degradation of solar cells and single event effects for simple shielding configurations or in combination with a sectoring analysis. A Geant4-based Monte Carlo tool (Mulassis) for doses and pulse height analyses is available as well.*

I. INTRODUCTION

Evaluations of the hazardous Earth environment and its effects on space systems are often hampered by the lack of comprehensive tools to access numerical models and data in an integrated environment.

In order to help spacecraft engineers perform rapid analyses of environmental problems and to guarantee reliable results, ESA commissioned the development of the SPace ENVironment Information System (SPENVIS), a user-friendly WWW interface (available at http://www.spenvis.oma.be/) to models, tools and data describing the various aspects of the space environment and its hazardous effects.

SPENVIS is conceived as a set of building blocks, which are connected through a dynamic HTML interface. This design approach facilitates extensions and updates of the system with new models and tools, provides a flexible navigation through the many applications incorporated in the system and incorporates a protocol to interconnect with other services and tools, such as NASA's Space Ionizing Radiation Environments and Shielding Tools (SIREST).

SPENVIS is based on internationally recognized standard models and methods in many domains. It uses an orbit generator to produce orbital point files necessary for many different types of problems. The radiation environment models in SPENVIS cover the Earth's radiation belts, cosmic rays and solar energetic particles. Fluxes and fluences derived from these models are used to calculate ionising and non-ionising dose, degradation of solar cells and single event effects for simple shielding configurations or in combination with a sectoring analysis. A Geant4-based Monte Carlo tool (Mulassis) for doses and pulse height analyses is available as well.

SPENVIS is designed to help spacecraft engineers perform rapid analyses of environmental problems and, with extensive documentation and tutorial information, allows engineers with relatively little familiarity with the models to produce reliable results. It has various reporting and graphical utilities, and extensive help facilities. SPENVIS also contains an active, integrated version of the ECSS Space Environment Standard, and access to in-flight data. Apart from radiation and plasma environments, SPENVIS includes meteoroid and debris models, atmospheric models (including atomic oxygen), and magnetic field models.

All output files generated by SPENVIS are in a straightforward ASCII format, which can easily be read by other applications. In addition, several inputs can be provided as upload files, enhancing the flexibility of the system. These features also provide the opportunity to link SPENVIS with related tools, such as NASA's Space Ionizing Radiation Environments and Shielding Tools (SIREST); the SPENVIS and SIREST teams are currently investigating data exchange protocols.

The results of a SPENVIS model run are presented in the form of reports and data files that can be downloaded by the user, and as a variety of plot types (line plots, maps and 3-D plots) in different graphics formats (GIF, PS, JPG, VRML, etc.).

Extensive help facilities are provided in SPENVIS: context-sensitive help pages provide information on the model parameters and usage, background pages contain in-depth material on the space environment and models, and a user guide and links to other sites are available as well. The help pages are cross-referenced for fast navigation.

The European Cooperation on Space Standards (ECSS) is a system of harmonized standards for the management and engineering of space projects. One of the standards is on Space Environment (ECSS-E-10-04). SPENVIS implements an 'active' version of this standard, in the sense that links from an HTML version of the standard to SPENVIS utilities are provided when an engineer wishes to make use of a model or method referred to in the standard. In addition, on the SPENVIS help pages for the models links are provided to the relevant sections in the standard document. As further standards are prepared by ECSS in the areas of radiation effects and spacecraft charging, these will be similarly integrated.

II. MODELS IMPLEMENTED IN SPENVIS

Most of the models implemented in SPENVIS require as input a set of points on a spacecraft trajectory or a user-defined set of geographic points. Two tools produce these sets of points: the orbit generator and the coordinate grid generator.

The models in SPENVIS have been organised in the following packages:

- radiation sources and effects (see below for a detailed description);
- spacecraft charging: internal deep dielectric charging, surface charging, solar array potentials, and access to environment parameters
- atmosphere and ionosphere: world maps and profiles of atmospheric and ionospheric constituents and parameters, and estimation of atomic oxygen erosion effects on exposed surfaces on low altitude spacecraft;
- magnetic field: calculation of magnetic field strength and vector components and ancillary parameters such as (B,L) coordinates over spacecraft trajectories and coordinate grids, and visualisation of magnetic drift shells;
- meteoroid and debris fluxes;
- satellite solar and Earth albedo illumination;
- access to satellite data sets and geomagnetic and solar indices to produce combined panel plots;
- integrated access to ECSS standards on space environment and effects.

In this paper, we will concentrate on the radiation package.

II.A. Multi-Segment Spacecraft Trajectories

In order to perform a complete mission analysis, it is in general necessary to consider different stages in the spacecraft trajectory. This includes the consecutive trajectories to reach high altitude (typically geostationary) or interplanetary orbits, orbital decay, and changes in the radiation environment for long duration missions due to solar cycle variations.

The orbit generator in SPENVIS has been extended to allow users to define a number of consecutive mission segments with different orbital characteristics. Each segment is defined by a starting epoch and a duration. In addition, the concept of mission duration is introduced as the sum of all mission segment durations. For each segment, a representative orbital trajectory is generated in the form of a set of orbital points characterized by time and position in geographical coordinates. This ephemeris is then used by the radiation environment models to produce ion and energy spectra for each orbital point (see Fig. 1 for an illustration). Trapped particle spectra are then averaged over the respective mission segments and scaled to the mission segment length to obtain segment and total mission fluences and fluxes. Solar energetic proton (SEP) spectra can also be derived for the global mission duration. The environment spectra thus obtained for each mission segment are then fed into radiation effects models to derive segment and mission doses and single event upset (SEU) rates and numbers.

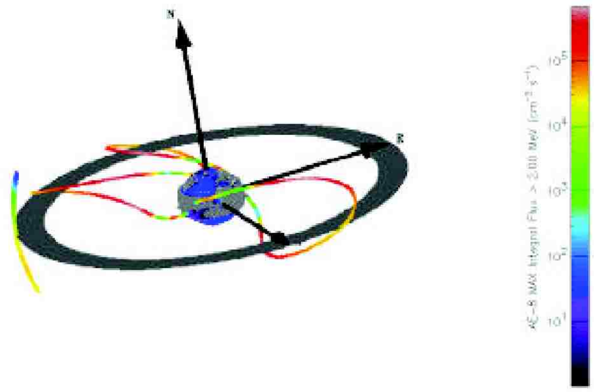

Fig. 1. Illustration of a composite mission trajectory consisting of a LEO, GTO and GEO segment. The colour scale represents the NASA AE-8 [1] electron flux >2 MeV.

Solar cycle effects and changes in the Earth's magnetic field are taken into account automatically and are reported in the various report files that are produced for each model run. The report files are generated in HTML format and are cross-linked. Each model also produces ASCII comma separated files of output parameters, which are used as inputs for other models and for producing graphical output. These output files can easily be downloaded and used in local applications.

II.B. Radiation Sources

The radiation sources currently included in SPENVIS are:

- trapped protons and electrons, implemented through several models: the NASA models AP-8 and AE-8 [1], the AFRL models CRRESPRO [2] and CRRESELE [3], the SAMPEX/PET model PSB97 [4], a model of the low-altitude trapped proton anisotropy [5], and flux maps of very high energy protons and electrons based on measurements from the AMS experiment [6].
- solar energetic protons: JPL-91 [7], the ESP total fluence and worst case event models [8-9], and the [10] model. Geomagnetic shielding is applied to attenuate the proton fluences.
- cosmic rays and solar energetic ions: particle spectra and LET conversion routines based on the CREME-86 code [11], more recent cosmic ray models are being added..

II.C. Radiation Effects

SPENVIS implements models and tools to estimate a number of radiation effects:

- ionizing dose: SHIELDOSE [12] and SHIELDOSE-2;
- the JPL EQFLUX code [13] for solar cell damage-equivalent fluences for Si and GaAs cells, augmented with multi-junction cell damage curves [14];
- non-ionizing energy loss (NIEL) for assessing displacement damage effects [15];
- SEU rates from cosmic and solar ions and trapped and solar protons, based on the CREME-86 code [11].

In computing all these parameters, spacecraft or solar cell coverglass shielding is taken into account. In addition, a geometric tool to calculate shielding distributions for simple spacecraft geometries is available (see Fig. 2 for a representation of the default geometry). The shielding distributions can be used as input for the ionizing dose and NIEL models to produce cumulative dose curves and total dose at the detector.

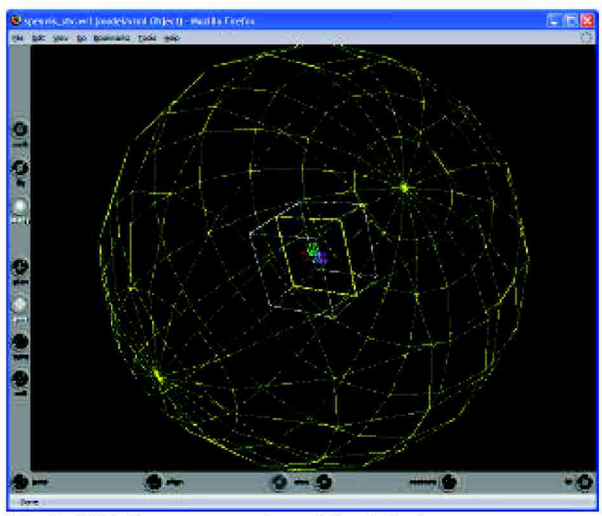

Fig. 2. VRML representation of the default geometry.

Figure 3 shows the dose curves obtained by folding the SHIELDOSE dose for trapped electrons, trapped protons and solar protons with the two-dimensional shielding distribution defined by the default geometry represented in Fig. 2. The sectoring analysis also produces a full 3D shielding distribution, which can be folded with environment spectra (see Fig. 4 for an illustration).

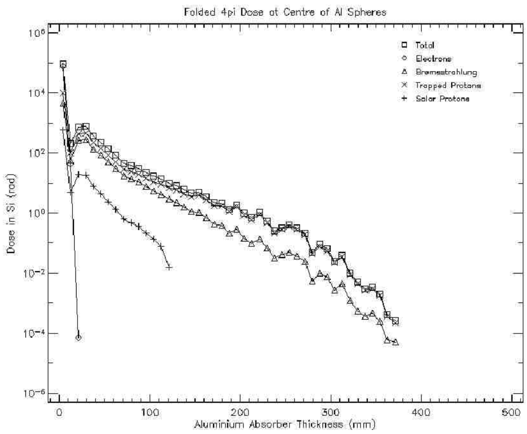

Fig. 3. SHIELDOSE dose curves folded with the 2D shielding distribution defined by the default geometry represented in Fig. 2.

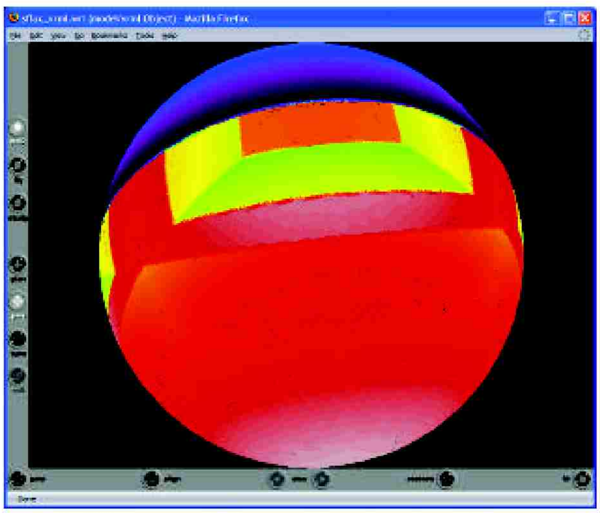

Fig. 4. 3D representation of the trapped proton flux >30 MeV after transportation through the 3D shielding distribution defined by the default geometry represented in Fig. 2.

II.D. Monte Carlo Shielding Simulation

Monte Carlo (MC) simulation of particle transport is complicated and computationally intensive. In space research it is only employed in specialised areas, with the use of super-computers in the past. Advances in computer technology have made it possible today for complicated simulations to be performed within a time-scale acceptable in the engineering world on low-cost personal computers. In addition to the participation in the Geant4 (http://wwwinfo.cern.ch/asd/geant4/geant4.html) toolkit development, ESA has also funded the development of a general space radiation shielding and effects analysis tool set based on the Geant4 toolkit. These are engineering tools and their executions are controlled by simple command line instructions or input parameter files. This hides the lower level inputs and post-simulation processing, and in the case of Geant4 C++ programming, which are generally required by an MC code. One of these tools is the Multi-Layered Shielding Simulation Software, Mulassis [16].

Mulassis is an MC simulation based tool for dose and particle fluence analysis associated with the use of radiation shields. Users can define the shielding and detector geometry as planar or spherical layers, with the material in each layer defined by its density and elemental/isotopic composition. Incident particles can be any Geant4 particles; these include protons, neutrons, electrons, gammas, alphas and light ions. There is a wide choice for their initial energy and angular distribution. In addition, radiation spectra produced by SPENVIS can be inputted.

Users can carry out fluence, total Ionising/Non-Ionising Energy Loss (NIEL) dose and Pulse Height Spectrum (PHS) analysis for any layer in the geometry. Fluence can be tallied into energy distribution histograms as a function of particle type and particle angular direction.

Remote access to Mulassis has been added to SPENVIS, thus making it one of the tools SPENVIS users can choose for their radiation analysis. The SPENVIS Mulassis web pages create a macro file using inputs from the user. Mulassis and the Geant4 toolkit operate on a separate PC/Linux server, which is linked to the SPENVIS server. The macro file is passed to the Mulassis server and the simulation starts. Upon completion the results are sent back to the SPENVIS server and made available to the user.

Most of the Mulassis functionality is available via the SPENVIS user interface. In addition, the radiation environment as evaluated by other SPENVIS models can be used as inputs for the MULASSIS simulation, thus making it very easy to obtain the modified radiation spectra behind a specific shield defined by the user.

III. CONCLUSIONS

SPENVIS provides a uniform framework for accessing models of the space environment and its effects on spacecraft systems, necessitating only a web browser from the user end. A comprehensive set of radiation tools has already been implemented, while new models and tools are being added when they become available.

Due to its modular approach, the system can easily be extended with new models or tools, either by the system developers or by users.

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