New radiation environment and effects models in the European Space Agency's Space Environment Information System (SPENVIS)

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Received 13 February 2004; revised 22 June 2004; accepted 8 September 2004; published 29 October 2004.

[1] The European Space Agency (ESA) Space Environment Information System (SPENVIS) provides standardized access to models of the hazardous space environment through a user-friendly Web interface, available at http://www.spenvis.oma.be/. 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. SPENVIS is based on internationally recognized standard models and methods in many domains. It uses an ESA-developed orbit generator to produce orbital point files necessary for many different types of problem. It has various reporting and graphical utilities and extensive help facilities. SPENVIS also contains an active, integrated version of the European Cooperation for Space Standardization 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. Recently, the radiation sources and effects module have been rewritten, providing enhanced mission analysis features, new radiation effects models, and streamlined navigation between various model pages. *INDEX TERMS:* 2732 Magnetospheric Physics: Magnetosphere interactions with satellites and rings; 2720 Magnetospheric Physics: Energetic particles, trapped; 2799 Magnetospheric Physics: General or miscellaneous; *KEYWORDS:* radiation environment, radiation effects, radiation models

Citation: Heynderickx, D., B. Quaghebeur, J. Wera, E. J. Daly, and H. D. R. Evans (2004), New radiation environment and effects models in the European Space Agency's Space Environment Information System (SPENVIS), *Space Weather*, *2*, S10S03, doi:10.1029/2004SW000073.

1. Introduction

[2] The Space Environment Information System (SPENVIS) developed for ESA/ESTEC provides easy access to most of the recent models of the hazardous space environment, in combination with an orbit generator, via an integrated user-friendly Web interface. The interface includes parameter input with extensive defaulting, definition of user environments, streamlined production of results (both in graphical and textual form), background information and online help. The tools are harmonized with European standard on the space environment and its effects, currently under parallel development. The URL for SPENVIS is http://www.spenvis.oma.be/.

[3] SPENVIS is based on internationally recognized standard models and methods in many domains. It uses an ESA-developed orbit generator to produce orbital point files necessary for many different aspects of mission analysis, and can also generate maps and profiles to study the geographical distribution of model parameters.

[4] 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.).

[5] 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.

[6] 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.

2. Models Implemented in SPENVIS

[7] 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. These sets of points are produced by two tools: the orbit generator and the coordinate grid generator. The models in SPENVIS have been organized in the following packages: (1) radiation sources and effects (see below for a detailed description); (2) spacecraft charging (internal deep dielectric charging, surface charging, solar array potentials, and access to environment parameters); (3) 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); (4) 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 visualization of magnetic drift shells); (5) meteoroid and debris fluxes; (6) satellite solar and Earth albedo illumination; (7) access to satellite data sets and geomagnetic and solar indices to produce combined panel plots; and (8) integrated access to ECSS standards on space environment and effects.

[8] In this paper, we will concentrate on the radiation package and the enhancements that have recently been made to it.

2.1. Multisegment Spacecraft Trajectories

[9] 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.

[10] 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 Figure 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.

[11] Solar cycle effects and changes in 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.

2.2. Radiation Sources

[12] The radiation sources currently included in SPENVIS are:

[13] 1. Trapped protons and electrons, implemented through several models: the NASA models AP-8 and AE-8 [*Vette*, 1991], the AFRL models CRRESPRO [*Meffert and Gussenhoven*, 1994] and CRRESELE [*Brautigam and Bell*, 1995], the SAMPEX/PET model PSB97 [*Heynderickx et al.*, 1999], a model of the low-altitude trapped proton anisotropy [*Kruglanski*, 1996], and flux maps of very high energy protons and electrons based on measurements from the AMS experiment [*Fiandrini et al.*, 2002].

[14] 2. Solar energetic protons: JPL-91 [*Feynman et al.*, 1993], the ESP total fluence and worst case event models [*Xapsos et al.*, 1999, 2000], and the *King* [1974] model. Geomagnetic shielding is applied to attenuate the proton fluences.

[15] 3. Cosmic rays and solar energetic ions: particle spectra and LET conversion routines based on the CREME-86 code [*Adams*, 1986]; more recent cosmic ray models are being added.

2.3. Radiation Effects

[16] SPENVIS implements models and tools to estimate a number of radiation effects: (1) ionizing dose, SHIELDOSE [*Seltzer*, 1980] and SHIELDOSE-2; (2) the JPL EQFLUX code [*Tada et al.*, 1982] for solar cell damage-equivalent fluences for Si and GaAs cells, augmented with multi-junction cell damage curves [*Marvin*, 2000]; (3) nonionizing energy loss (NIEL) for assessing displacement damage effects [*Dale et al.*, 1993]; (4) SEU rates from cosmic and solar ions and trapped and solar protons, based on the CREME-86 code [*Adams*, 1986]. 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 Figure 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.

2.4. Monte Carlo Shielding Simulation

[17] Monte Carlo (MC) simulation of particle transport is complicated and computationally intensive. In space research it is only employed in specialized areas, with the use of supercomputers in the past. Advances in computer

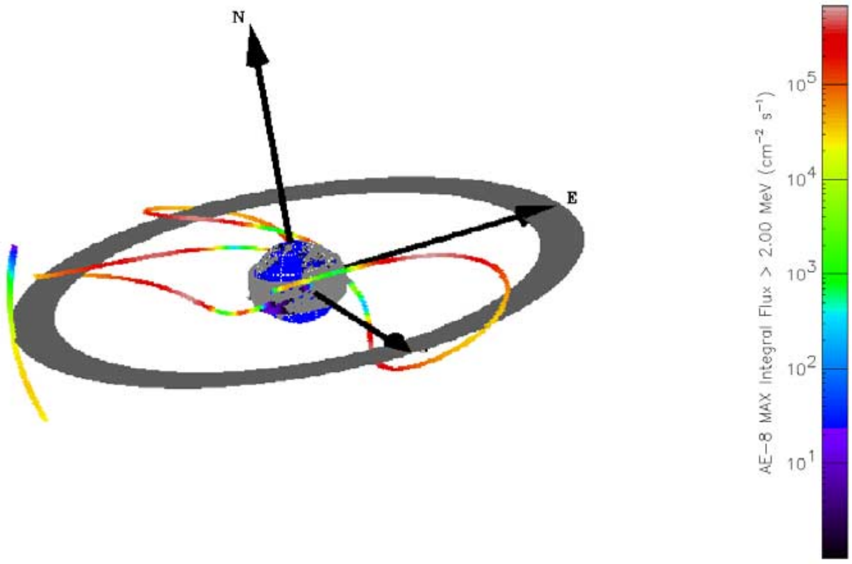

Figure 1. Illustration of a composite mission trajectory consisting of a LEO, GTO, and GEO segment. The color scale represents the NASA AE-8 [*Vette*, 1991] electron flux >2 MeV.

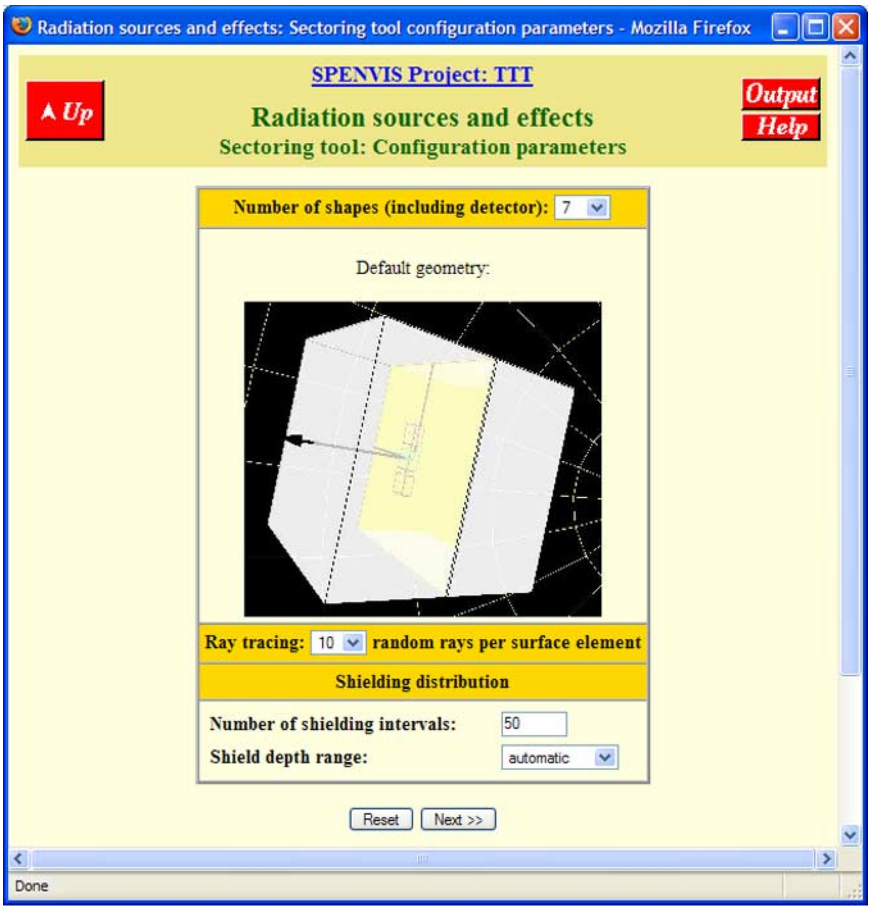

Figure 2. Representation of the default sectoring geometry.

technology have made it possible today for complicated simulations to be performed within a timescale 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 postsimulation 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 [*Lei et al.*, 2002].

[18] 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.

[19] Users can carry out fluence, total ionizing/nonionizing 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.

[20] 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 http 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.

[21] 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.

[22] **Acknowledgments.** SPENVIS is funded by General Support Technology Programme contract 11711. The continued support of J. Nijskens of the Belgian Federal Office for Scientific, Technical and Cultural Affairs is gratefully acknowledged.

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