NEW FEATURES AND MODELS IN THE TRAPPED RADIATION SOFTWARE PACKAGE UNIRAD

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Abstract UNIRAD is a software package developed by BIRA-IASB for ESA to evaluate radiation-belt and solar particle event fluences and doses expected in a spacecraft from a definition of the mission characteristics. The UNIRAD suite of programs provides information about the radiation environment in an arbitrary Earth orbit, predicting satellite exposures to particle fluxes, the resulting radiation dose, and the resulting damage-equivalent fluences for solar cell degradation calculations. Recently, UNIRAD has been extended with two new programs that model the anisotropy of trapped particle flux distributions at low altitudes.

Various problems have been identified in the existing NASA radiation belt models AE-8 and AP-8. New models developed in the ESTEC/WMA-sponsored TREND study (Trapped Radiation ENvironment Development) are being added to UNIRAD. These models include: new trapped proton flux maps based on data from AZUR (proton telescopes), SAMPEX (PET) and UARS (PEM), and trapped electron models developed with data from CRRES (MEA) and ISEE (KED).

WWW-based access to UNIRAD is also being developed as part of the Space ENvironment Information System (SPENVIS).

Introduction

In the course of a series of contracts for ESA/ESTEC, the *Belgisch Instituut voor Ruimte-Aëronomie/Institut d'Aéronomie Spatiale de Belgique* (BIRA-IASB) has developed a software package, UNIRAD, for integrated analyses of the effects of the space environment on satellite missions.

The UNIRAD package consists of the following programs:

SAPRE is an orbit generator which produces a data file of orbit ephemeris information used by the next programs in the package.

BLXTRA calculates the geomagnetic coordinates (B, L) from the geographic coordinates generated by SAPRE, using a choice of all the common and current magnetic field models.

TREP determines the radiation flux for the geographic coordinates generated by SAPRE from the NASA trapped radiation models AP-8 and AE-8 [*Vette*, 1991] and determines the solar proton flux over the mission with the models of *King* [1974] and of *Feynman and Gabriel* [1990]. It produces a data file with the energy spectra of trapped protons and electrons and of solar protons.

TREPPOS calculates the trapped radiation flux for pairs of (B, L) or $(B/B_0, L)$ coordinates interactively input by the user. It produces a data file with the energy spectra of trapped protons and electrons.

TREPAVE averages the spectra generated by TREP for different orbits.

ANISO transforms the trapped proton omnidirectional integral flux produced by TREP into unidirectional integral and differential fluxes, taking into account pitch angle and azimuthal dependence [*Kruglanski*, 1996]. The user can define a set of look directions with respect to a satellite reference frame. The resulting fluxes are averaged over the orbit.

ANISOPOS provides the angular distribution (i.e. pitch angle and azimuthal dependence) of the unidirectional integral or differential flux at a given geographic location [*Kruglanski*, 1996].

SHIELDOSE reads the energy spectra resulting from TREP, TREPAVE or TREPPOS and converts them to radiation dose-depth curves for different detector materials and simple shielding geometries [*Seltzer*, 1979, 1980].

EQFRUX determines 1 MeV electron damage equivalent fluences from the TREP spectra to evaluate degradation of Si solar cells [*Tada*, 1982].

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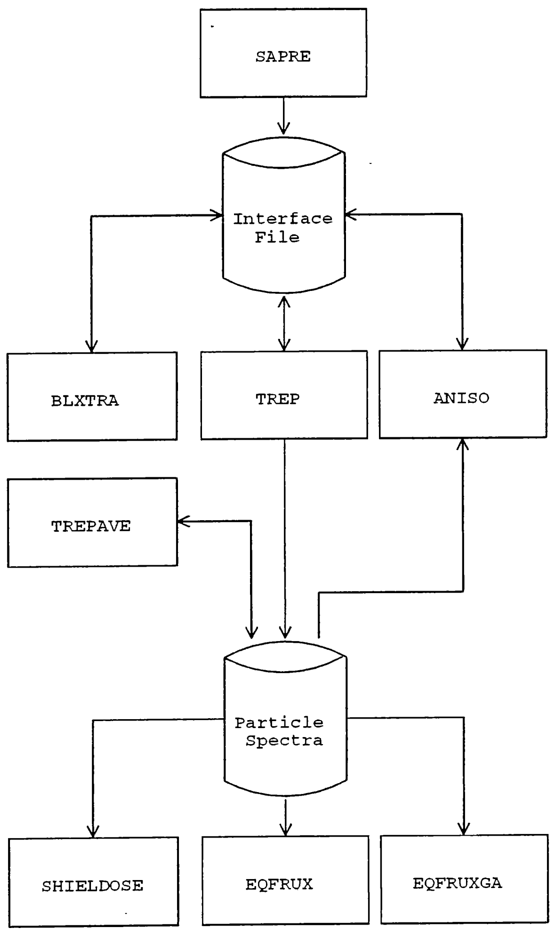

Figure 1. Flow diagram of UNIRAD

EQFRUXGA idem as EQFRUX, but for GaAs solar cells.

A set of IDL routines to produce graphical output is provided as well.

The flow diagram of the UNIRAD package is represented in Figure 1. This diagram illustrates the interdependence of the various programs making up UNIRAD. Except for the interface files, the output files are not shown in Figure 1.

Inputs and outputs

A complete UNIRAD radiation analysis requires only one user input file: the namelist file PROJECT.NML, where PROJECT represents the project name to be chosen by the user. The namelist file contains the orbit parameters, solar activity conditions, plotting and printing options, ... All parameters in the namelist file are assigned default values when not specified, and are reset for each project. NAMELISTs for more than one project may be put in the same file. The general syntax rules for NAMELIST input follow.

Namelist file input consists of a record delimited by the dollar sign $ (except on PC, where an ampersand & should be used) which starts in the second column (the first column must be blank).

Generally, namelist input has the form:

```
$NAME
 PARAMETER=VALUE [, PARAMETER=VALUE, ...]
$[END]
```

where

- $ (or & on PC) is the special dollar sign symbol that indicates the beginning and end of input and the start of a namelist section.
- NAME is the name of the namelist file section.
- PARAMETER is the name of one of the input parameters of the program for which the namelist file provides the data. The parameter list does not have to be exhaustive, i.e. not all parameters have to be given.
- VALUE is a constant or list of constants.
- END is an optional part of the last delimiter. On PCs, a namelist should be terminated with a slash /.

A sample namelist is given in Section 4.

For users not familiar with the namelist construction, the interface might seem a little tedious. However, as the example in Section 4 shows, the input required to run the models is kept to a minimum, especially through the use of default values for all parameters. On the other hand, the user has full control over the models by "activating" the additional parameters for which usually default values are sufficient. In all, setting up a run with UNIRAD requires the creation and editing of only one input file, and the typing of one command per model. Another powerful feature of the namelist interface is that multiple trajectories can be specified in one parameter file with the possibility of combining the trapped particle fluxes obtained with different models (e.g. for different phases of solar activity) prior to dose calculations.

From the orbit parameters, the system will generate a detailed trajectory, magnetic coordinates, integral and differential proton and electron fluences, doses for three shield geometries in four detector materials, and solar cell degradation information, in both printed and graphical form.

If the programmes are run in the proper order, all successively needed input files are generated by UNIRAD. Alternatively, the user may supply his own input files according to the specifications given in the user manual [*Heynderickx et al.*, 1996].

The output generated by UNIRAD consists of ASCII files with file names of the form PROJECT.XXX, where XXX identifies the program generating the file and the type of information in the file. PROJECT must be chosen so that PROJECT.XXX represents a valid file name.

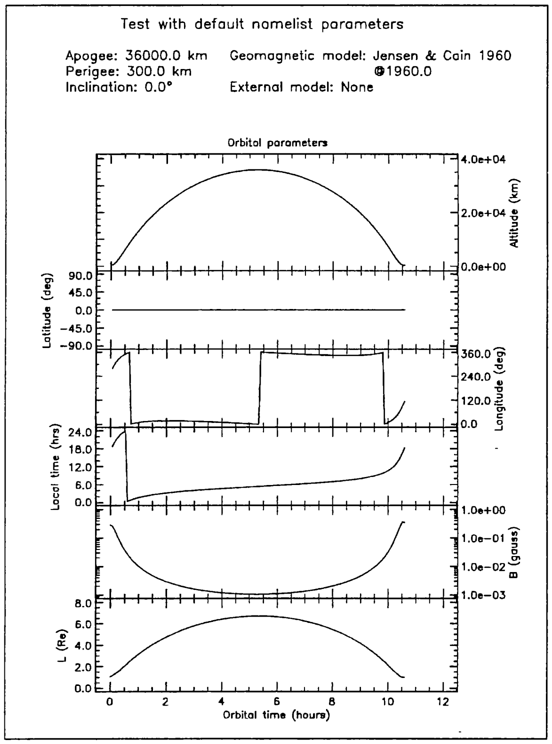

Figure 2. Geographic and magnetic coordinates for the sample orbit

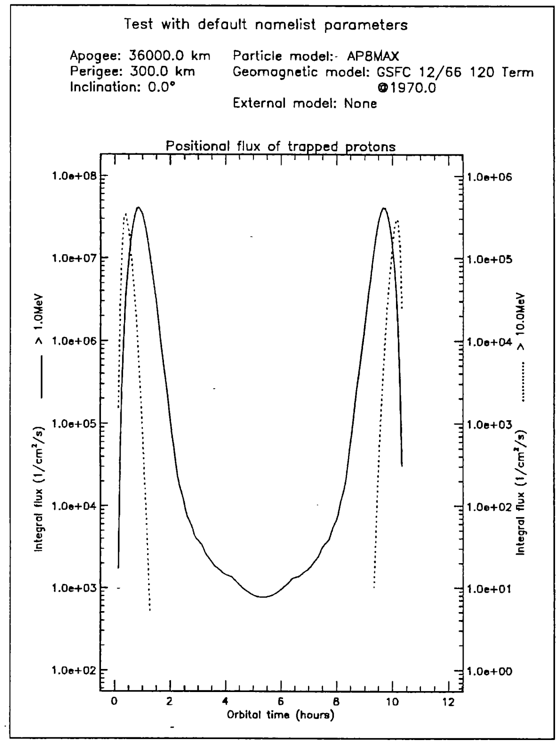

Figure 3. Integral trapped proton fluxes above 1 and 10 MeV for the sample orbit

The plotting program

The IDL routine UNIRAD.PRO is a menu driven plotting program that provides a graphical representation of the various output files produced by UNIRAD. The plots can be shown on the screen or sent to files in PostScript format.

UNIRAD.PRO will check which UNIRAD output files are available in the current directory, and present a menu with options. After making a selection from the main menu, other menus will appear depending on the UNIRAD output files available in the current directory. When a selection is made from the menu, UNIRAD.PRO produces a plot on the screen. The user then has the option to produce a PostScript version of this plot by making the appropriate menu selection. The program creates PostScript files in the current directory.

A sample run

In this section, we present the output of a sample run of UNIRAD with the default values for the namelist parameters. The default orbit is a geostationary transfer orbit during conditions of solar maximum. The plots presented in this section were produced with UNIRAD.PRO.

The following namelist file was used to generate the sample run:

```
$SAPRE
 TITLE = 'Sample run with default
          parameter values'
 IAE    = 0
 HAPO   = 36000.0D0
 HPER   = 300.0D0
 RINCL  = 0.0D0
 ORBITS = 1.0D0
$END
$TREP
 SOLACT = 'MAX'
$END
$SHIELDOSE
 IPLOT = 1
$END
$EQFRUX
 IPLOT = 2
$END
```

The parameters not in this list were assigned their default values. This illustrates that in general a UNIRAD radiation analysis requires setting only a small number of parameters. A detailed description of all namelist parameters is given in the manual [*Heynderickx et al.*, 1996].

Figure 2 represents the orbit generated for the sample project and the B and L values calculated at each orbital point. The positional trapped proton fluxes are plotted in

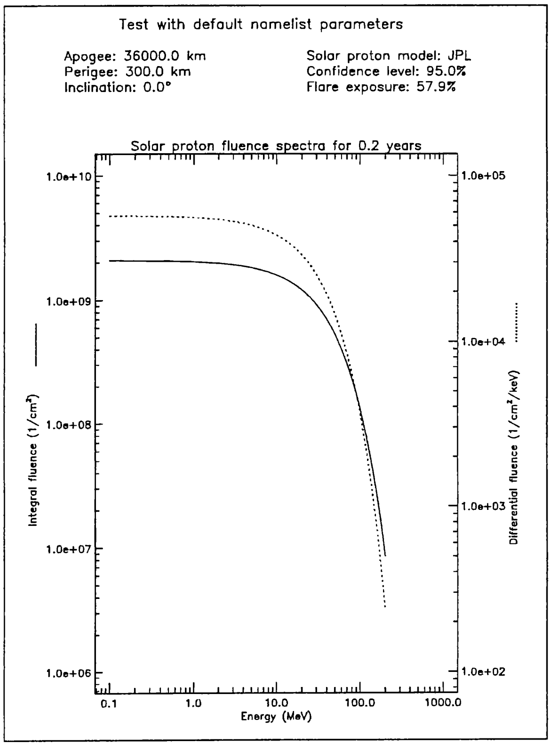

Figure 4. Integral and differential solar proton spectrum for the sample orbit

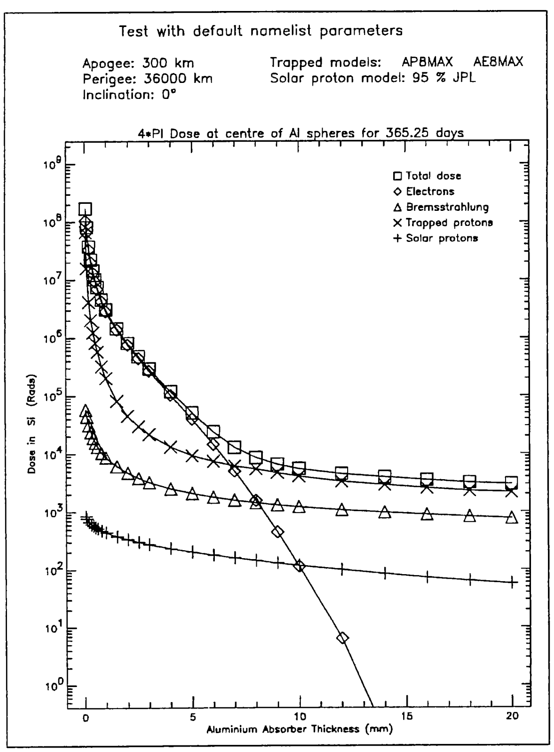

Figure 5. Dose in Si at the centre of Al spheres for the sample orbit.

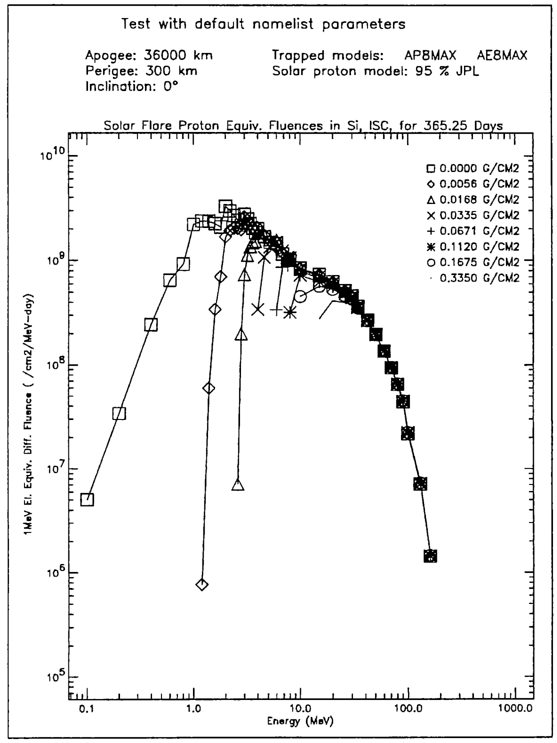

Figure 6. Solar flare proton equivalent fluences (ISC) for the sample orbit. The symbols correspond to the glass cover thicknesses listed in the graph.

Figure 3, and the orbit averaged proton fluence spectra are represented in Figure 4.

Figure 5 shows the doses in Si through a spherical Al shield resulting from the trapped proton and electron fluences and the solar proton fluence.

Figure 6 shows the energy dependence of the damage equivalent solar proton fluence in a Si solar panel in ISC mode, for different glass cover thicknesses.

The directional dependence of the trapped proton flux > 50 MeV, integrated over a 500 km, 28.5° orbit over one day, is illustrated in Figure 7, which was obtained with ANISO. The polar and azimuthal angles are defined in a three-axis stabilized reference frame parallel to the GEI coordinate system. The parameters used for this run are: `IAE=2` (circular orbit), `ALT=500`, `RINCL=28.5`, `EP-DUR=1` (one-day trajectory), `IATTI=3` (defines the satellite coordinate system) for SAPRE, `ISPEC=1` for TREP to generate a complete proton spectrum at every orbital point, and `JANIS=4` for ANISO to select the anistropy model developed by *Kruglanski and Lemaire* [1996].

Distribution

The distribution of UNIRAD is being handled by BIRA-IASB on a commercial basis. The software has already

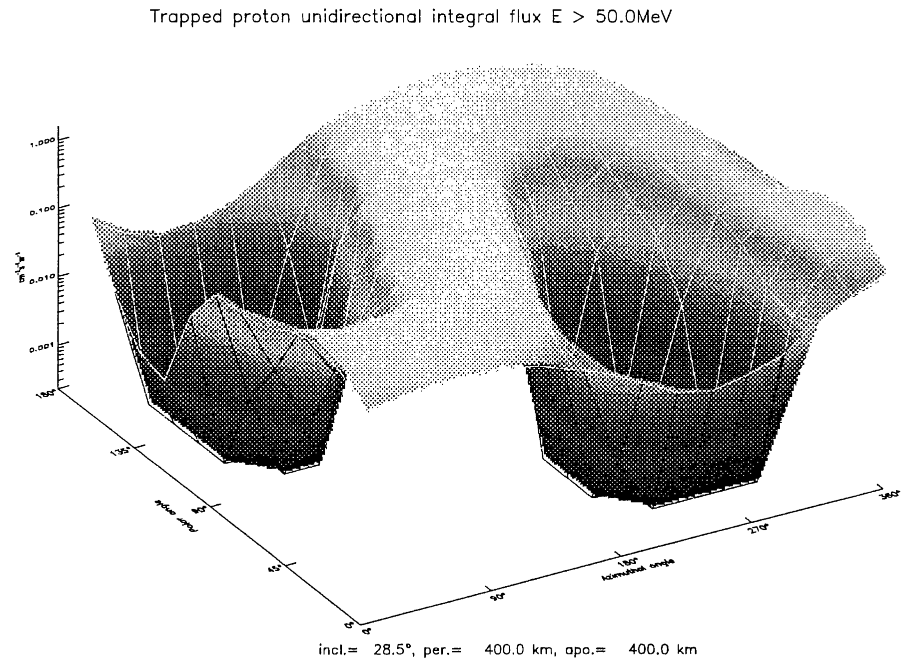

Figure 7. Directional dependence of the trapped proton flux > 50 MeV, integrated over a 500 km, 28.5° orbit over one day, in a three-axis stabilized reference frame parallel to the GEI coordinate system.

been installed on a variety of platforms and operating systems at different institutes.

The software package has been compiled and tested on the following operating systems: VMS, OSF, UNIX, SUN-OS, MS-DOS and MS-Windows.

Future developments

BIRA-IASB, in collaboration with Mullard Space Science Laboratory [*Rodgers et al.*, *Johnstone*, these proceedings] and Max Planck Institut für Aeronomie [*Friedel et al.*, these proceedings], is continuing the development of new trapped radiation belt models, and the updating of existing models, for ESA/ESTEC. The products coming out of this effort will be included in future releases of UNIRAD, as well as the output of the analysis of the Radiation Environment Monitor data [*Bühler et al.*, these proceedings].

BIRA-IASB is the main contractor for the ESTEC project SPENVIS (SPace ENVironment Information System) involving the installation on the World Wide Web of the main parts of UNIRAD and additional models of the near Earth environment (including spacecraft charging models and atmospheric and ionospheric models). The full system will be operational by September 1997, but subsystems will be made available as soon as their development allows. In particular, UNIRAD is scheduled for release on the BIRA-IASB server for September 1996.

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