

SPENVIS-3

SPace ENVironment Information System III

Final Report

ESTEC Contract No. 11711/95/NL/JG(SC) WO 1, CCN 3 to 6¹

Belgian Institute for Space Aeronomy (BIRA-IASB)

Issue 1, November 2008²

¹ESA Technical Management: E.J. Daly (WMA)

²This report was compiled by M. Kruglanski on behalve of the SPENVIS team

Executive summary

Since 1996, BIRA/IASB has been developing the ESA S_Pace ENVironment Information System (SPENVIS), a World Wide Web based interface to a comprehensive set of models of the space environment. SPENVIS Has a large international user community who use the system for various purposes, i.e. educational support, mission analysis and planning, and running models for scientific applications. The system includes extensive background information on the space environment and the environment models, which is consulted very frequently.

The emphasis of the development in this study has been on:

- implement new models and methods;
- take advantage of new software technologies to make the system more responsive and maintainable;
- guarantee the maintenance of the system at BIRA/IASB.

The study was extending from November 2001 to October 2005

Implemented models

SAPRE Orbit generator

GRID Coordinate grid generator

LEOPOLD Earth Low-altitude polar-orbit environment

TREP, TREPPPOS, TREPBL Earth radiation belts trapped proton and electron fluxes: AP-8/AE-8, CRRESPRO/CRRESELE, PSB97, ESA-SEE1

ANISO Low-altitude trapped proton anisotropy: Watts, Badhwar&Konradi

SEP Solar proton fluences in Earth neighborhood: JPL, King, Xapsos

MULASSIS Radiation transport through a multi-layer one-dimensional shield

SECTOR Shield distribution analysis for simple geometries

SFLUX Attenuation of (trapped and solar) proton fluxes

LETORB Cosmic ray fluences in Earth neighborhood: CREME 86

LETORB Linear-energy-transfer behind an Aluminium shield

SHIELDOSE, SD2 Ionizing dose in detector behind an Aluminium shield

NIEL Non-ionizing energy loss in detector behind an Aluminium shield

EQFLUX Damage equivalent 1-MeV electron fluence

UPSETO Single event upset rates in Silicon device

DICTAT Internal deep dielectric charging

EQUIPOT Surface equilibrium charging potential

SOLARC Solar array power loss in Eart plasma environment

ATOMOX, ATMOPOS Earth atmospheric and ionospheric profiles: NRLMSISE-00, MET, DTMB78, HWM93, IRI2001

ATOMOX Erosion by atomic oxygen

BLXTRA, BLPOS, SHELL Earth's internal and magnetospheric magnetic field: Mead&Fairfield, Tsyganenko, Olson&Pfitzer, Ostapenko

SHELL Earth magnetic drift shell visualization

GRUN Meteoroid flux in Earth neighborhood

NASA90 Debris flux in Earth neighborhood

COORDTRANS Earth-centric coordinate transformations

ILLUM Satellite illumination in Earth orbit

CUTOFF Geomagnetic Størmer cutoff

Implemented data sets

INDICES Geomagnetic indices, solar wind parameters and some derived parameters

GOES GOES 5–12 Space Environment Monitor (SEM) data

METEOSAT3 Meteosat-3 Space Environment Monitor (SEM) data provided by MSSL

ISEE International Sun-Earth Explorer mother/daughter WIM and KED data

STRV STRV-1b Radiation Environment Monitor data

MIR MIR station Radiation Environment Monitor data

CRRES Medium Electrons A spectrometer data

AZUR GRS-A German spacecraft EI-88 experiment data

UARS UARS Particle Environment Monitor data

ADIPE Ion and electron fluxes related to charging events for the Gorizont 91/2 satellite

LEPA Ion and electron fluxes related to charging events for the CRRES satellite

Contractor and team

- Belgium Institute for Space Aeronomy (BIRA-IASB)
Ringlaan 3, 1180 Ukkel, Belgium
 - Project manager: Daniel Heynderickx
 - Application engineer: Bart Quaghebeur
 - IT Developer: Eric Speelman (2001–2002), Jan Wera (2002–2005)

Contents

Introduction	1
1 Model interface	3
2 Orbit and coordinate grid generator	5
2.1 Orbit generator	5
2.2 Coordinate grid generator	10
3 Radiation sources and effects	13
3.1 Radiation sources	13
3.1.1 Trapped particle models	14
3.1.1.1 Orbital version	14
3.1.1.2 Proton anisotropy models	15
3.1.1.3 Positional version: geographic coordinates	16
3.1.1.4 Positional version: magnetic coordinates	18
3.1.2 Solar proton models	19
3.1.3 Ion flux and LET spectra	21
3.2 Radiation effects	21
3.2.1 Ionizing dose	23
3.2.2 Non-ionizing energy loss	24
3.2.3 Damage equivalent fluence	25
3.2.4 Single event upset rates	25
3.2.5 Mulassis	26
3.3 Sector analysis tool and related utilities	33
3.3.1 Material data base	33
3.3.2 Sectoring tool	36
3.3.3 Attenuation of trapped and solar protons	38

4	Spacecraft charging models	39
4.1	Internal deep dielectric charging: the DICTAT model	39
4.2	Environment parameters: the LEOPOLD code	42
4.3	Surface charging: the EQUIPOT code	42
4.4	SOLARC	46
5	Atmosphere and ionosphere models	51
5.1	Orbital version	51
5.2	Positional version	53
6	Magnetic field models	55
6.1	Orbital version	56
6.2	Positional version	56
6.3	Drift shell tool	58
7	Meteoroid and debris models	61
7.1	The Grün meteoroid model	61
7.2	The NASA90 debris model	62
8	Miscellaneous models and tools	65
8.1	Coordinate transformations	65
8.2	Satellite illumination	66
8.3	Geomagnetic cut-off maps	67
8.4	Database query tool	68
9	SPENVIS statistics	71
	References	75
A	Output files produced by the models in SPENVIS	79

List of Tables

1.1	Record structure of the SPENVIS output files.	4
3.1	Record structure of the <code>spenvis_loo.txt</code> spectrum file	22
3.2	Predefined materials for MATERIAL	34
4.1	Ion types (elements) available for SOLARC	47
8.1	Available data sets in SPENVIS.	69

List of Figures

9.1	Number of users of registered users on April 2004 since January 1998	72
9.2	Number of users still active since their first usage on April 2004	72
9.3	Geographical distribution of SPENVIS accesses on April 2004	73
9.4	Active user access on April 2004 illustrated by the number of file downloads per week per active user since first usage (black and purple lines, left axis) and the cumulative number of downloads (red and green curves, right axis)	73
9.5	Distribution of the model runs on April 2004	74
9.6	Distribution of the plot runs on April 2004	74

Introduction

The planning of space missions requires an analysis of the space environment and its impact on space systems. The space environment includes the following hazardous environments:

- radiation environment due to the radiation belts, solar particles and cosmic rays;
- the plasma environments of the ionosphere and geomagnetic substorms;
- neutral gaseous environments, including upper-atmospheric atomic oxygen;
- micro-meteoroids and space debris;
- magnetic fields;
- solar emissions.

Empirical or quasi-empirical models of these hazardous environments have been developed by different organizations, often independent of one another. As a consequence, the availability of existing models is not always known to potential users. In addition, the issue of updating models and acquiring up-to-date versions is not straightforward.

The SPENVIS system provides easy access to most of the recent models of the hazardous space environment via integrated user-friendly interface based on the HTML protocol and streamlined production of results (both in graphical and textual form), background information and on-line help.

The authors of the models included in SPENVIS are identified in the respective sections of this document. The SPENVIS team acknowledges their support in granting permission to include the models in the system, providing the model source code and documentation, and assisting with the implementation.

Structure of this document

The first chapter provides a general description of the model interface, i.e. how the input/output streams are managed. The eight next chapters describes the different models implemented in the SPENVIS system. Note that these chapters are not intended to be a description or manual

for the models themselves. Each chapters corresponds to a SPENVIS model package. The packages are:

1. Orbit and coordinate grid generator;
2. Radiation sources and effects;
3. Spacecraft charging models;
4. Atmosphere and ionosphere models;
5. Magnetic field models;
6. Meteoroid and debris models;
7. Miscellaneous models and tools.

Some statistics on the SPENVIS user community and its usage of SPENVIS are provides in Chapter 10.

Acknowledgements

The SPENVIS teams thanks the following persons for supplying models and/or assisting with their implementation: J.H. Adams (CREME), B.E. Anspaugh (EQFRUX, EQFRUXGA), F. Barlier (DTM), D. Bilitza (IRI, MSIS, MET, HWM), R.A. Bond (SOLARC, LEOPOLD), S. Chabrillat (MSISE-90), G. Drolshagen (meteoroid-debris models), H. Evans (orbit generator, NIEL), M.A. Hapgood (coordinate transformations), A.D. Johnstone (CRRES/LEPA charging data sets), G. Kockarts (MSISE-90), M. Kruglanski (UNILIB magnetic field software library), Y.P. Maltsev (Ostapenko-Maltsev magnetic field model), K.A. Pfitzer (Olson-Pfitzer magnetic field models), M. Ratliff (JPL solar proton models), D.J. Rodgers (GORIZONT/ADIPE charging data sets, DICTAT, SOLARC, LEOPOLD), S.M. Seltzer (SHIELDOSE), J. Sorensen (ATOMOX), G. Spitale (JPL solar proton models), C. Tranquille (solar proton models), N. Tsyganenko (magnetic field models), G. Wrenn (EQUIPOT).

The SPENVIS team also thanks the following persons for supplying data sets and/or assisting with their implementation: J.B. Blake (SAMPEX/PET), P. Bühler (REM on MIR and STRV 1b), A.J. Coates (Meteosat-3/SEM2), H.A. Garcia (GOES/SEM), D.K. Hovestadt (AZUR/EI-88), E. Keppler (ISEE 2/KED), A. Lazarus (Indices-WIND/SWE), H. Leinbach (GOES/SEM), M.D. Looper (SAMPEX/PET), G.M. Mason (SAMPEX/PET), K. Ogilvie (Indices-WIND/SWE), B.E. Rowland (Indices-WIND/MFI), J.T. Steinberg (Indices-WIND/SWE), A.L. Vampola (CRRES/MEA), D.J. Williams (ISEE 1/WIM), D. Wilkinson (GOES/SEM), J.D. Winningham (UARS/PEM), A. Zehnder (REM on MIR and STRV 1b).

Chapter 1

Model interface

Models implemented within SPENVIS are access through a web interface. For each models, the system provides the user with one or several HTML form to enter the model inputs to each model. The model proposes default values and ensures that the user input is syntactically correct and within allowable ranges. Besides the traditional functionalities of HTML forms, error checking, automatic resetting of input values and hierarchical form management are provided. Two types of input to the models are foreseen:

1. model parameters: in SPENVIS, these are input by the user in HTML forms and written to FORTRAN namelist files, which are then read by the models;
2. data files produced by other models, e.g. an ephemeris file written by the orbit generator.

The output produced by the models can be divided into two categories:

1. results of model calculations in the form of report files (in HTML format) and ASCII data files to be used for plotting or as input to other models or applications (see Table 1.1 for a description of the file format).
2. warning and error messages to the user.

Each model produces a report file `spenvis_xxp.html` (where `xx` identifies the model) in HTML format, which summarizes the model inputs and in general provides a summary of the model results. Report files may contain hyperlinks to report files produced by other models in order to reduce the length of each report. Each model also produces one or more output file(s) with file name `spenvis_xxx.txt`. A list of all output files produced by the models in SPENVIS is given in Appendix A.

Table 1.1. Record structure of the SPENVIS output files.

Record	Format	Description
Header Records		
1	'*', 8(, I)	Total number of header lines, number of comment lines (N_c), number of second level comments (N_s , set to 0 for the time being), number of metavariables (N_m), number of variable definition lines (N_v), total number of column variables (N_c), number of data lines (N_d , set to -1 if unknown), number of blocks remaining in the file (N_b)
2—($N_c + 1$)	'text'	Comment lines
($N_c + 2$)—($N_c + N_s + 1$)	'text'	Second level comments
($N_c + N_s + 2$)—($N_c + N_s + N_m + 1$)	comma separated	Variable name, units, dimensions (-1 for strings), label
($N_c + N_s + N_m + 2$)—($N_c + N_s + N_m + N_v + 1$)	comma separated	Variable name, units, dimensions (-1 for strings), label
Data Records		
1— N_d	comma separated	Values
$N_d + 1$	'text'	Terminator string: 'End of Block' or 'End of File'

Chapter 2

Orbit and coordinate grid generator

Almost all the models in SPENVIS are applied to either a spacecraft trajectory (orbital version) or to a grid of geographical points (positional version).

2.1 Orbit generator

The orbit generator `SAPRE` computes trajectory osculatory orbital elements using a numerical Runge-Kutta integration method. The numerical Runge-Kutta orbit generator can be used for low altitude orbits, geostationary orbits, and highly eccentric orbits. It takes into account the oblateness of the Earth, the gravitational attraction of Sun and Moon, air drag (by means of the `NRLMSISE-00` atmospheric model) and solar radiation pressure. The independent variable is the eccentric anomaly. Osculatory elements are computed at constant equidistant eccentric anomaly steps.

The current version of `SAPRE` allows the definition of multiple orbit segments that are combined into a spacecraft mission. To this effect, the mission segment start and stop times or segment lengths have to be defined. These times and lengths are then used by other applications to scale fluxes to segment and mission fluences, for instance. The start of the mission is defined by the start date of the first trajectory.

As an alternative to generating a trajectory, a trajectory file can be uploaded. In this case, there is only one mission segment, and the only parameter to be set is the mission duration or the date of the end of the mission.

The mission parameters are defined in the `MISSION` namelist:

PRODEF Character string containing the project name

PROTIT Character string containing the project title

ORBGEN Generate a trajectory (1) or upload a trajectory file (0)

NTRAJ Number of mission segments

IMISD Flag for definition of the mission end date: by specifying a mission duration (0), by directly entering the mission end date as a calendar date (1), by directly entering the mission end date as a modified Julian date since 1950.0 (2), or by specifying the duration of the last mission segment (3)

JMISD Flag for specifying the mission or last segment duration: in years (0) or days (1); only used if $IMISD=0 \mid 3$

MISDUR Total mission duration; only used if $IMISD=0$

MEYEAR Mission end year; only used if $IMISD=1$

MEMON Mission end month; only used if $IMISD=1$

MEDAY Mission end day; only used if $IMISD=1$

MEHRS Mission end hour; only used if $IMISD=1$

MEMIN Mission end minute; only used if $IMISD=1$

MESEC Mission end second; only used if $IMISD=1$

EMJD Modified Julian day since 1950.0 of the mission end; only used if $IMISD=2$

SEGDUR Duration of the last mission segment; only used if $IMISD=3$

KATT Flag for satellite orientation: one axis points to the zenith (1), one axis parallel to the velocity vector (2), axes parallel to GEI axes (3), one axis points to the Sun (4)

IDRAG Air drag flag: use NRLMSISE-00 neutral atmosphere model to take into account air drag (1)

WIBAIR Air drag parameter ($\text{m}^2 \text{kg}^{-1}$); only used if $IDRAG=1$

F107A 90 day average $F_{10.7}$ solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$); only used if $IDRAG=1$

F107 day value of $F_{10.7}$ solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$); only used if $IDRAG=1$

AP daily average of A_P index (2 nT); only used if $IDRAG=1$

ISRP solar radiation pressure flag: 0 or 1

WIBSPR Solar radiation pressure ($\text{m}^2 \text{kg}^{-1}$); only used if $ISRP=1$

XB Bow shock distance (R_E)

XM Magnetopause distance (R_E)

PB Bow shock curvature (R_E)

PM Magnetopause curvature (R_E)

The defaults for the `MISSION` namelist are defined as:

```

PRODEF = ' '
PROTIT = ' '
ORBGEN = 1
NTRAJ = 1
IMISD = 3
JMISD = 1
MISDUR = 31.0
MEYEAR = 2000
MEMON = 2
MEDAY = 1
MEHRS = 0
MEMIN = 0
MESEC = 0.0
EMJD = 18293.0
SEGDUR = 31.0
KATT = 2
IDRAG = 0
WIBAIR = 0.0
F107A = 50.0
F107 = 70.0
AP = 20.0
ISRP = 0
WIBSPR = 0.0
XB = 15.25
XM = 10.0
PB = 22.164
PM = 15.0

```

For each mission segment, a description of the trajectory, i.e. a set of ephemeris elements, has to be provided in a `SAPRE` namelist segment.

TITLE Character string containing the segment title

OEYEAR Orbit start year

OEMON Orbit start month

OEDAY Orbit start day

OEHRS Orbit start hour

OEMIN Orbit start minute

OESEC Orbit start second

AMJD Orbit epoch in Modified Julian Day from 1950.0; Used instead of `OEYEAR` ... when ≥ 0

TYPE Character string to define the orbit type: general ('`GEN`'), heliosynchronous ('`HEL`'), geostationary ('`GEO`'), two-line elements ('`TLE`') or near Earth interplanetary ('`NEI`')

IDUR Flag to define the representative trajectory: number of orbits (0) or trajectory duration(1); only used if `TYPE` $\neq$ 'NEI'

ORBITS Number of orbits; only used if `IDUR`=0

EPDUR Trajectory duration (days); only used if `IDUR`=1

ISTART Flag to define the orbit start: calendar date (1) or end of previous segment (−1, only if previous segment is not 'NEI')

TLE1 First line of two-line elements; only used if `TYPE`='TLE'

TLE2 Second line of two-line elements; only used if `TYPE`='TLE'

IAE Flag for altitude specification for general orbit: perigee and apogee altitudes (0), semi-major axis and eccentricity (1) or altitude for a circular orbit (2); only used if `TYPE`='GEN'

HPER Perigee altitude (km); only used if `IAE`=0

HAPO Apogee altitude (km); only used if `IAE`=0

A Semi-major axis (km); only used if `IAE`=1

E Eccentricity; only used if `IAE`=1

ALT Altitude for circular orbit (km); only used if `TYPE`='GEN' and `IAE`=2 or for heliosynchronous orbits

RINCL Inclination (deg); only used if `TYPE`='GEN'

IAN Flag for specifying right ascension of ascending node (0), longitude of apogee (1) or longitude of perigee (2); only used if `TYPE`='GEN'; options 1 and 2 are not applicable for circular orbits

RAAN Generic input parameter (deg) for right ascension of ascending node, longitude of apogee or longitude of perigee, depending on the value of `IAN`; only used if `TYPE`='GEN'

IG50 Flag for the reference point of the right ascension of the ascending node: γ_{50} (1) or Greenwich longitude (0); only used if `TYPE`='GEN' and `IAN`=0

ARGPER Argument of perigee (deg); only used if `TYPE`='GEN'

TRANO True anomaly (deg); only used if `TYPE`='GEN'

SOLTIM Local time of ascending node (deg); only used if `TYPE`='HEO'

OELONG Longitude (deg); only used if `TYPE`='GEO'

RAU Distance from the Sun (AU); this parameter is not used by SAPRE but serves as a control variable for SPENVIS when `TYPE='NEI'`

STEP Eccentric anomaly step (deg)

DT1 Output resolution (s) for altitudes below DH2

DT2 Output resolution (s) for altitudes between DH2 and DH3

DT3 Output resolution (s) for altitudes above DH3

DH2 Altitude separation (km) between regions of high and intermediate output resolution

DH3 Altitude separation (km) between regions of intermediate and low output resolution

PA Pitch angle (deg) for use with magnetic field models

The defaults for the SAPRE namelist are defined as:

```

TITLE = ' '
OEYEAR = 2005
OEMON = 1
OEDAY = 1
OEHRS = 0
OEMIN = 0
OESEC = 0.0
AMJD = -1.0
TYPE = 'GEN'
TLE1 = ' '
TLE2 = ' '
IDUR = 0
ORBITS = 1.0
EPDUR = 1.0
IAE = 0
HPER = 300.0
HAPO = 36000.0
A = 6671.0
E = 0.0
ALT = 300.0
RINCL = 0.0
IAN = 0
RAAN = 0.0
IG50 = 1
ARGPER = 0.0
TRANO = 0.0
SOLTIM = 0.0
OELONG = 0.0
ISTART = 1
RAU = 1.0
STEP = 2.0
DT1 = 60.0
DT2 = 240.0
DT3 = 3600.0
DH2 = 20000.0
DH3 = 80000.0
PA = 90.0

```

2.2 Coordinate grid generator

This tool generates three types of coordinate grids:

1. one single geographical point: this is used when the dependence of a model on a model parameter other than geographic coordinates or local and universal time is studied;
2. one-dimensional profile: a range of one geographical coordinate, local time, or universal time, to be used with non-varying parameters of a model;
3. two-dimensional world map: a grid of fixed, equidistant geographic longitudes and latitudes, for fixed altitude and local or universal time.

The coordinate ranges and options are defined in the GRID namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

MAP Flag for defining the grid type: single point (0), profile (1) or world map (2)

ALT Altitude (km)

LAT Latitude (deg); only used if MAP<2

LON Longitude (deg); only used if MAP<2

IHOUR Flag for the definition of time: local (0) or universal (1)

DHOUR Time (hr)

IRANGE Index of the variable coordinate: altitude (1), latitude (2), longitude (3) or time (4); only used if MAP=1

ALT2 Last value of the altitude range (km); only used if IRANGE=1

LAT2 Last value of the latitude range (deg); only used if IRANGE=2

LON2 Last value of the longitude range (deg); only used if IRANGE=3

DHOUR2 Last value of the time range (hr); only used if IRANGE=4

ISEL Flag for defining variable range: by number of values (0) or by step size (1); only used if MAP=1

STEP Step size for variable range (units depend on variable); only used if ISEL=1

NVAL Number of values in variable range (the maximum number is 1001); only used if ISEL=0

ILOG Flag for linear (0) or logarithmic (1) increments in the variable range; only used if ISEL=0

The defaults for the GRID namelist are defined as:

```
PRODEF = ' '  
TITLE = ' '  
MAP = 0  
ISEL = 0  
IRANGE = 1  
ALT = 100.0  
ALT2 = 100.0  
LAT = 0.0  
LAT2 = 0.0  
LON = 0.0  
LON2 = 0.0  
DHOURL = 0.0  
DHOURL2 = 0.0  
IHOURL = 0  
STEP = 10.0  
NVAL = 1  
ILOG = 0
```


Chapter 3

Radiation sources and effects

3.1 Radiation sources

The TREP and SEP programs calculate orbital radiation environment fluxes for arbitrary spacecraft trajectories. They estimate fluxes of trapped particles in function of (B, L) coordinates, and compute solar proton event probabilities to estimate solar proton fluences. Their outputs consists of:

1. the integral and differential fluxes of trapped protons and trapped electrons, for solar minimum and solar maximum conditions;
2. trajectory-averaged spectra for trapped protons and electrons;
3. solar flare fluence spectra, taking into account geomagnetic shielding.

In addition, two positional versions of TREP are available: TREPPPOS calculates fluxes of trapped protons and electrons for the geographic points in the coordinate files produced by GRID (see Sect. 2.2), and TREPBL outputs trapped protons and electrons for a grid of magnetic coordinates.

The Naval Research Laboratory (Adams, 1986) has developed a software package called Cosmic Ray Effects on MicroElectronics (CREME) to estimate SEU rates. CREME Has been implemented in SPENVIS in the form of two programs: LETORB and UPSETO. LETORB Reads in the coordinate file generated by the orbit generator and uses the CREME environment models to calculate the attenuated cosmic ray and solar flare particle flux for each point of the orbit. If trapped proton fluxes have been calculated by TREP, these are read in as well. The combined energy spectra are transformed into LET spectra, which are then used by the UPSETO program to calculate SEU rates.

The following particle models have been implemented in SPENVIS:

- trapped proton models

- AP-8 (Sawyer & Vette 1976)
- CRRESPRO (Meffert and Gussenhoven 1994)
- SAMPEX/PET PSB97 (Heynderickx et al. 1999)
- trapped electron models
 - AE-8 (Vette 1991)
 - AE-8 MIN update ESA-SEE1 (Vampola 1996)
 - CRRESELE (Brautigam and Bell 1995)
- solar proton models
 - JPL (Feynman et al. 1993)
 - King (1974)
 - ESP worst case fluence (Xapsos et al. 1999) and cumulative fluence (Xapsos et al. 2000)
- CREME cosmic ray and SEP ion models (Adams 1986)

3.1.1 Trapped particle models

3.1.1.1 Orbital version

TREP accesses trapped proton and electron models at each orbital point contained in the orbit file `spenvis_sao.txt`. The model parameters are defined in the TREP namelist:

TRPMOD Index of the trapped proton models: AP-8 (1), SAMPEX/PET PSB97 (2), CRRESPRO (3)

TREMOD Index of the trapped electron models: AE-8 (1), AE-8 MIN update ESA-SEE1 (2), CRRESELE (3)

MINDP Sub-index of the trapped proton models (only applicable for TRPMOD=1 | 3):

- AP-8: AP-8 MAX (1), AP-8 MIN (2), AP-8 MAX unidirectional(3), AP-8 MIN unidirectional (4)
- CRRESPRO: quiet (1), active (2)

MINDE Sub-index of the trapped electron models (only applicable for TREMOD=1 | 3):

- AE-8: AE-8 MAX (1), AE-8 MIN (2)
- CRRESELE: 6 A_p ranges (1—6), average flux (7), maximum flux (8)

ISIG Index for confidence level of AE-8 statistical model: -2 , -1 , 0 , 1 , or 2 ; only used if TREMOD=1

ILTV Flag for local time variation: include (1) or exclude (0) variation; only used if TREMOD=1

NENERP Number of proton energies (maximum 30)

NENERE Number of electron energies (maximum 30)

PROEN Proton energies (MeV) in ascending order

ELEEN Electron energies (MeV) in ascending order

FLUXTH(2) Flux thresholds for protons and electrons

The defaults for the TREP namelist are defined as:

```
TRPMOD = 1
TREMOD = 1
MINDP = 1
MINDE = 1
ISIG = 0
ILTV = 0
NENERP = 30
NENERE = 30
PROEN = 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7,
        1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0,
        10.0, 15.0, 20.0, 30.0, 40.0, 50.0, 60.0, 70.0,
        100.0, 150.0, 200.0, 300.0, 400.0, 500.0
ELEEN = 0.04, 0.1, 0.20, 0.3, 0.40, 0.5, 0.60, 0.7, 0.80, 1.0,
        1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75, 3.0, 3.25, 3.5,
        3.75, 4.0, 4.25, 4.5, 4.75, 5.0, 5.50, 6.0, 6.50, 7.0
FLUXTH = 1.0, 1.0
```

3.1.1.2 Proton anisotropy models

At low altitude, the high-energy trapped proton fluxes are strongly anisotropic and may induce anisotropies in the radiation exposure of a spacecraft with stabilized attitude. The flux anisotropy is understood theoretically by the interaction of the trapped protons with the Earth's atmosphere and by the finite length of the proton gyroradius. The main purpose of modelling this flux anisotropy is to deduce angular-dependent proton flux spectra from standard omnidirectional flux databases. Such a model has been developed analytically by Watts et al. (1989) and has been applied to the evaluation of radiation shielding for manned spacecraft. A new model based on the Badhwar & Konradi (1990) pitch angle distribution has been developed by Kruglanski (1996).

The ANISO program transforms trapped proton omnidirectional integral fluxes produced by TREP into orbit-averaged unidirectional integral and differential fluences. The program also provides the unidirectional integral and differential fluxes along the orbit of the satellite.

ANISO reads the orbit and attitude files `spenvis_sao.txt` and `spenvis_att.txt` and the proton spectrum file `spenvis_spp.txt`. The model parameters are defined in the ANISO namelist:

JANIS Index of the anisotropy models: VF1MIN (1), VF1MAX (2), BK-MIN model (3), BK-MAX model (4). Note that the trapped proton anisotropy models have to be used with the appropriate omnidirectional spectra. VF1MIN and BK-MIN are defined with the NASA model AP-8 MIN for solar minimum, while VF1MAX and BK-MAX are defined for the solar maximum model AP-8 MAX. ANISO produces a warning when the omnidirectional model and the anisotropy model are not consistent.

NDIR Number of look directions (maximum 400)

DALPH(400) Polar angle for each look direction (deg)

DBETA(400) Azimuthal angle for each look direction (deg)

XOMEGA(400) Solid angle (sr) for each look direction. When XOMEGA is set to zero, XALPH and XBETA are used as polar and azimuthal opening angles to compute the solid angle.

XALPH(400) Polar opening angle (deg) for each look direction; only used if XOMEGA=0

XBETA(400) Azimuthal opening angle (deg) for each look direction; only used when XOMEGA=0

IFULL Flag for producing (1) the full resolution file `spenvis_and.txt`

The defaults for the ANISO namelist are defined as:

```
JANIS = 1
NDIR = 180
DALPH(j+15*i+1) = 7.5 + 15*i      0<=i<=11, 0<=j<=14
DBETA(12*j+i+1) = 12.0 + 12*j     0<=i<=11, 0<=j<=14
XOMEGA(i) = 0.0      1<=i<=180
XALPH(i) = 13.42     1<=i<=180
XBETA(i) = 13.42     1<=i<=180
IFULL = 0
```

3.1.1.3 Positional version: geographic coordinates

TREPPPOS reads the coordinates of the points in the `spenvis_pos.txt` file produced by GRID (see Sect. 2.2). The model parameters are defined in the TREPPPOS namelist:

SPECIES Single character identifying the trapped particle: proton ('P') or electron ('E')

TRPMOD Index of the trapped proton models: AP-8 (1), SAMPEX/PET PSB97 (2), CRRESPRO (3); only used if SPECIES='P'

TREMOT Index of the trapped electron models: AE-8 (1), AE-8 MIN update ESA-SEE1 (2), CRRESELE (3); only used if SPECIES='E'

MINDP Sub-index of the trapped proton models (only applicable for TRPMOD=1 | 3):

- AP-8: AP-8 MAX (1), AP-8 MIN (2), AP-8 MAX unidirectional(3), AP-8 MIN unidirectional (4)
- CRRESPRO: quiet (1), active (2)

MINDE Sub-index of the trapped electron models (only applicable for TREMOD=1 | 3):

- AE-8: AE-8 MAX (1), AE-8 MIN (2)
- CRRESELE: 6 A_p ranges (1—6), average flux (7), maximum flux (8)

ENP Proton energy (MeV); only used if SPECIES='P'

ENE Electron energy (MeV); only used if SPECIES='E'

ALPHA Pitch angle (deg)

IRANGE Index of the variable parameter (this option can only be used with a coordinate grid consisting of one point); the only variable is pitch angle (1)

ALPHA2 Last value of the pitch angle range (deg); only used if IRANGE=1

ISEL Flag for defining variable range: by number of values (0) or by step size (1); only used with a coordinate grid consisting of one point

STEP Step size for variable range (units depend on variable); only used when ISEL=1

NVAL Number of values in variable range (the maximum number is 1001); only used when ISEL=0

ILOG Flag for linear (0) or logarithmic (1) increments in the variable range; only used when ISEL=0

IMAP Control variable for use with SPENVIS only to check the coordinate grid type: its value should be equal to the MAP parameter in the GRID namelist (see Sect. 2.2). For applications outside SPENVIS, set IMAP=-1 or do not specify it in the namelist.

The defaults for the TREPPPOS namelist are defined as:

```
SPECIES = 'P'
TRPMOD = 1
TREMOD = 1
MINDP = 1
MINDE = 1
ENP = 50.0
ENE = 1.0
ALPHA = 90.0
IRANGE = 0
ALPHA2 = 170.0
ISEL = 0
STEP = 10.0
NVAL = 1
ILOG = 0
IMAP = -1
```

3.1.1.4 Positional version: magnetic coordinates

TREPBL uses a range of (B, L) , $(B/B_0, L)$ or (B, α_0) pairs as input for the trapped particle models. The model parameters are defined in the TREPBL namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

SPECIES Single character identifying the trapped particle: proton ('P') or electron ('E')

TRPMOD Index of the trapped proton models: AP-8 (1), SAMPEX/PET PSB97 (2), CRRESPRO (3); only used if SPECIES='P'

TREMOD Index of the trapped electron models: AE-8 (1), AE-8 MIN update ESA-SEE1 (2), CRRESELE (3); only used if SPECIES='E'

MIND Sub-index of the trapped particle models:

- AP-8: AP-8 MAX (1), AP-8 MIN (2), AP-8 MAX unidirectional(3), AP-8 MIN unidirectional (4)
- CRRESPRO: quiet (1), active (2)
- AE-8: AE-8 MAX (1), AE-8 MIN (2)
- CRRESELE: 6 A_p ranges (1—6), average flux (7), maximum flux (8)

MAP Flag for selecting the coordinate range: energy (0), magnetic coordinate profile (1), magnetic coordinate grid (2)

IRANGE Selection of the magnetic coordinate profile: L (0) or another coordinate (1) to be selected with ICOR; only used if MAP=1

ICOR Flag for selecting the magnetic coordinate profile (if IRANGE=1) of the second coordinate of the magnetic coordinate grid (first coordinate is L): B (1), B/B_0 (2) or α_0 (3); only used if MAP=1 | 2

ENERGY Particle energy (MeV)

FL L value (R_E); only used if MAP=0 | 1

VAL1 First value of the variable coordinate range (units depend on the coordinate selection)

VAL2 Last value of the variable coordinate range (units depend on the coordinate selection)

ISEL Flag for defining variable range: by number of values (0) or by step size (1)

STEP Step size for variable range (units depend on variable)

NVAL Number of values in variable range (the maximum number is 1001)

ILOG Flag for linear (0) or logarithmic (1) increments in the variable range

FLL First L value (R_E) for the magnetic coordinate grid; only used if MAP=2

FLU Last L value (R_E) for the magnetic coordinate grid; only used if MAP=2

ISELF Flag for defining the L range: by number of values (0) or by step size (1); only used if MAP=2

STEPF Step size for the L range (R_E); only used if MAP=2

NFL Number of values in the L range (the maximum number is 101) ; only used if MAP=2

ILOGF Flag for linear (0) or logarithmic (1) increments in the L range; only used if MAP=2

The defaults for the TREPBL namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
SPECIES = 'P'
TRPMOD = 1
TREMOT = 1
MIND = 1
MAP = 0
ENERGY = 50.0
ICOR = 1
IRANGE = 0
VAL1 = 1.0
VAL2 = 6.0
ISEL = 0
STEP = 1.0
NVAL = 1
ILOG = 0
FL = 2.0
FLL = 1.0
FLU = 6.0
NFL = 51
ISELF = 0
ILOGF = 0
STEPF = 0.1
```

3.1.2 Solar proton models

SEP predicts solar energetic proton fluences for the whole mission duration defined for the orbit generator. For trajectories inside the magnetosphere, geomagnetic shielding is evaluated at each spacecraft location in the orbit file `spenvis_sao.txt` and for each proton energy. The model parameters are defined in the SEP namelist:

FLAMOD Index of the solar energetic proton models: JPL-91 (1), JPL-85 (2), King (3), ESP total fluence (4), ESP worst case event (5)

NAL Number of anomalously large events; only used if FLAMOD=3 to override the number of events generated by Burrell statistics

NOR Number of ordinary events; only used if FLAMOD=3 to override the number of events generated by Burrell statistics

NENERS Number of proton energies (maximum 30)

ENERFL Proton energies (MeV)

IFORM Flag for spectrum extrapolation: exponential in energy (0) or exponential in rigidity (1); only used if FLAMOD=1, 2

RAU Distance from the Sun (AU)

FLPROB Probability (%) of not exceeding the solar proton fluence

IFLATT Flag for taking into account (1) or ignoring (0) geomagnetic shielding; shielding is automatically ignored for NEI type orbits

ISTORM Flag for selecting the state of the magnetosphere in the calculation of geomagnetic shielding: quiet (0) or stormy (1)

ITFLARE Flag for setting the prediction period: use the mission duration defined by the orbit generator (0), or use TFLARE (1)

TFLARE Prediction period (years); only used if ITFLARE=1

ISTART Flag for setting the offset in the solar cycle: use the mission start date defined by the orbit generator (0), or use FLSTART (1)

FLSTART Offset (years) in solar activity cycle (counted from solar maximum - 2.5 years); only used if ISTART=1

The defaults for the SEP namelist are defined as:

```
FLAMOD = 1
NAL = 0
NOR = 0
NENERS = 30
ENERFL = 0.1, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0,
          8.0, 10.0, 12.0, 15.0, 17.0, 20.0, 25.0, 30.0,
          35.0, 40.0, 45.0, 50.0, 60.0, 70.0, 80.0, 90.0,
          100.0, 120.0, 140.0, 160.0, 180.0, 200.0
IFORM = 1
RAU = 1.0
FLPROB = 95.0
IFLATT = 1
ISTORM = 0
ITFLARE = 0
TFLARE = 1.0
ISTART = 0
FLSTART = -1.0
```

3.1.3 Ion flux and LET spectra

CREME Has been implemented in SPENVIS in the form of two programs: LETORB and UPSETO. LETORB Reads in the coordinate file generated by the orbit generator and uses the CREME environment models to calculate the attenuated cosmic ray and solar flare particle flux for each point of the orbit. If trapped proton fluxes have been calculated by TREP, these are read in as well. The model parameters are defined in the LETORB namelist:

THICK Shielding thickness (cm)

IUNT Units for the shielding thickness: mils (1), g cm^{-2} (2), cm (3)

MQ Interplanetary medium weather index (1–14)

IELM Atomic number of the lightest element (1–92)

JELM Atomic number of the heaviest element (1–92)

ITP Flag for inclusion of trapped proton fluxes (0 or 1)

IGC Flag for calculation of geomagnetic shielding (0 or 1)

ISTORM Flag for magnetosphere condition: quiet (0) or stormy (1)

SFULL Flag for creation of full resolution spectrum file (0 or 1)

The defaults for the LETORB namelist are defined as:

```
IELM = 1
JELM = 92
MQ = 5
ISTORM = 0
IGC = 1
ITP = 1
IUNT = 3
THICK = 1.0D0
SFULL = 1
```

LETORB creates the `spenvis_lof.txt` file with the orbit averaged energy spectrum of the protons in the environment (if `IELM=1`), and the combined LET spectrum of all the requested ions. When `SFULL=1`, the spacecraft shielded proton (if `IELM=1`) and ion spectra are written to the `spenvis_loo.txt` file. The record format of the `spenvis_loo.txt` file is given in Table 3.1.

3.2 Radiation effects

The radiation effects models implemented in SPENVIS use the fluxes and fluences obtained with the radiation source models to estimate doses and other parameters in materials and electronic components. The following effects models are available:

Table 3.1. Record structure of the `spenvis_100.txt` spectrum file. The data records are repeated for each point on the orbit (N points). The whole structure is repeated for additional orbits. Header records 3–5 and the first of each set of three data records are not written if the proton spectrum is not required.

Record	Format	Description
Header Records		
1	1X, A80	Project descriptor
2	2I6	Number of points in proton and LET spectra
3	free format	Header for proton energy record
4	free format	Header for differential proton flux records
5	E13.5	Proton energies
6	free format	Header for LET record
7	free format	Header for differential LET records
8	free format	Header for integral LET records
9	E13.5	LET values
10	1X, A80	Orbit segment descriptor
Data Records		
	E13.5	Differential proton flux spectrum
	E13.5	Differential LET spectrum
	E13.5	Integral LET spectrum
⋮		
3N+1– 3N+3	E13.5	Records containing –1.0 for each energy or LET to signal end of orbit segment

- SHIELDOSE and SHIELDOSE-2 for ionizing dose;
- non-ionizing dose curves;
- EQFLUX for solar cell damage equivalent fluences;
- the CREME86 model suite for galactic cosmic ray fluxes, LET spectra and single event upset rates;
- Mulassis, a Geant4 based tool for Monte Carlo analyses of radiation effects in simple shielding geometries.

All these models use simple shielding geometries. A separate sectoring analysis tool is available as well: it allows the definition of more complex geometries and produces shielding distribu-

tions which can be used as input for the ionizing and non-ionizing dose models.

3.2.1 Ionizing dose

SD and SD2 are implementations of Seltzer's (1979, 1980) SHIELDOSE programme and its undocumented SHIELDOSE-2 upgrade. Both programmes make use of pre-calculated, mono-energetic depth-dose data for an isotropic fluence of radiation incident on uniform aluminium plane media and integrate these mono-energetic data over the incident flux spectrum. Their outputs consist of doses in four, respectively eleven, different detector materials as a function of shield depth for three different shielding geometries: finite slab, semi-infinite, spherical.

The model parameters for SHIELDOSE are defined in the SD namelist:

IDET Selects detector material: aluminium (1), water (2), silicon (3), silicon dioxide (4)

IUNT Selects units for shield depths: mils (1), g cm^{-2} (2), mm (3)

ISHLD Shielding configuration: finite slab (1), semi-infinite medium (2), centre of spheres (3); set to 3 when JSHLD=2

JSHLD Input selection for shield depth values: default SHIELDOSE values (0), Z values (1), shielding distribution from sectoring tool (2)

Z(201) Shield depth values (terminate with zero value); only used when JSHLD=1

DOSMOD Control variable for use with SPENVIS only to check that the namelist was generated for SD. For applications outside SPENVIS, set DOSMOD=0 or do not specify it in the namelist.

The defaults for the SD namelist are defined as:

```
IDET = 3
IUNT = 3
ISHLD = 3
JSHLD = 0
Z = 201*0.0
DOSMOD = 0
```

The model parameters for SHIELDOSE-2 are defined in the SD2 namelist:

IDET Selects detector material: aluminium (1), graphite (2), silicon (3), air (4), bone (5), calcium fluoride (6), gallium arsenide (7), lithium fluoride (8), silicon dioxide (9), tissue (10), water (11)

IUNT Selects units for shield depths: mils (1), g cm^{-2} (2), mm (3)

ISHLD Shielding configuration: finite slab (1), semi-infinite medium (2), centre of spheres (3); set to 3 when JSHLD=2

JSHLD Input selection for shield depth values: default SHIELDOSE values (0), Z values (1), shielding distribution from sectoring tool (2)

Z(201) Shield depth values (terminate with zero value); only used when JSHLD=1

INUC Control flag for nuclear attenuation for protons in Al: no attenuation (1), attenuation with local charged-secondary energy deposition (2), attenuation with local charged-secondary energy deposition and approximate exponential distribution of neutron dose (3)

RADIUS Conversion of results to off-centre dose in spheres or to dose at surface of spherical shells

DOSMOD Control variable for use with SPENVIS only to check that the namelist was generated for SD2. For applications outside SPENVIS, set DOSMOD=0 or do not specify it in the namelist.

The defaults for the SD2 namelist are defined as:

```
IDET = 3
IUNT = 3
ISHLD = 3
JSHLD = 0
Z = 201*0.0
INUC = 1
RADIUS = 0.0
DOSMOD = 0
```

3.2.2 Non-ionizing energy loss

NIEL calculates equivalent proton fluences deposited in devices, using non-ionising energy loss rates from different sources. The model parameters for NIEL are defined in the NIEL namelist:

IUNT Selects units for shield depths: mils (1), g cm^{-2} (2), mm (3)

JSHLD Input selection for shield depth values: default SHIELDOSE values (0), Z values (1), shielding distribution from sectoring tool (2)

Z(201) Shield depth values (terminate with zero value); only used when JSHLD=1

C Relative degradation (g MeV^{-1})

PEQEN Equivalent proton energy (MeV)

ICURVE NIEL curve selection: JPL Si (1), Dale Si (2), Akkerman Si (3), Huhtinen Si (4), Summers Si, 21 eV (5), Summers Si, 12.9 eV (6), Summers GaAs (7), Summers InP (8), Messenger Si (9), Messenger GaAs (10), Messenger InP (11), user input (0), read file `spenvis_nie.upl` (< 0)

UCURVE(201,2) : User defined NIEL curve: energy (MeV), NIEL values ($\text{MeV cm}^2 \text{g}^{-1}$); terminate with zero value; only used if **ICURVE**=0

DOSMOD Control variable for use with SPENVIS only to check that the namelist was generated for NIEL. For applications outside SPENVIS, set **DOSMOD**=0 or do not specify it in the namelist.

The defaults for the NIEL namelist are defined as:

```
IUNT = 3
JSHLD = 0
Z = 201*0.0
C = 3.9D-11
PEQEN = 10.0
ICURVE = 1
UCURVE = 402*0.0
DOSMOD = 0
```

3.2.3 Damage equivalent fluence

EQFLUX calculates 1 MeV damage equivalent electron fluences for exposure to trapped particle and SEP fluences. The model parameters for EQFULX are defined in the EQFLUX namelist:

ICELL Selects solar cell type: Si (1), GaAs (2), multi-junction (3)

JCELL Selects solar cell subtype; only used when **ICELL**=3

PEDRI Damage ratio between protons and electrons for I_{sc}

PEDRV Damage ratio between protons and electrons for V_{oc}

PEDRP Damage ratio between protons and electrons for P_{max}

The defaults for the EQFLUX namelist are defined as:

```
ICELL = 1
JCELL = 1
```

The default values for **PEDRI**, **PEDRV** and **PEDRP** depend on the cell type.

3.2.4 Single event upset rates

UPSETO calculates SEU rates from the energy and LET spectra produced by LETORB. If the option **SFULL**=1 was set for LETORB, SEU rates for each orbital point are written to the file `spenvis_uoo.txt`. If experimental data are used in UPSETO, the data and fit parameters are written to the file `spenvis_uof.txt`. The model parameters for UPSETO are defined in the UPSETO namelist:

IB Flag for Bendel function: fit to experimental data (−1) or use function parameters A and B (1)

IBD Dimension of Bendel function (1 or 2)

A First parameter of Bendel function; only used when $IB=1$

B Second parameter of Bendel function; only used when $IB=1$ and $IBD=2$

IU Flag for direct ionization upsets: use critical charge (1) or experimental data (0)

QCRIT Critical charge (pC); only used when $IU=1$

X First device dimension (μm)

Y Second device dimension (μm)

Z Third device dimension (μm)

PIUR(100,2) Experimental proton induced upset data: energy (MeV), cross section ($\text{cm}^2 \text{bit}^{-1}$); only used when $IB=-1$

DIUR(100,2) Experimental direct ionization upset data: LET ($\text{MeV cm}^2 \text{mg}^{-1}$), cross section (cm^2); only used when $IU=0$

The defaults for the UPSETO namelist are defined as:

```
IB = 1
IBD = 2
IU = 1
A = 10.0
B = 24.0
QCRIT = 0.1
X = 5.0
Y = 5.0
Z = 5.0
PIUR = 200*-1.0
DIUR = 200*-1.0
```

3.2.5 Mulassis

The Mulassis tool (Lei et al. 2002) allows the definition of a multi-layered, one-dimensional shield and incident particle source, and simulates radiation transport through the geometry using the Geant4 toolkit (<http://wwwinfo.cern.ch/asd/geant4/geant4.html>) treating electromagnetic and nuclear interactions.

The SPENVIS program MULASSIS creates the Geant4 macro file `spenvis.g4mac` for input by the stand-alone binary implementations of Mulassis. The shielding materials can be selected from a list of pre-defined materials or can be defined using the MATERIAL utility (see Sect. 3.3.1).

The model parameters for MULASSIS are defined in the MULASSIS namelist:

USER Selects geometry definition: default (0) or user defined (1)

SHAPE Selects shielding geometry: planar slab (`slab`) or sphere (`sphere`)

NLAYER Number of layers (maximum 42)

VIS Flag for producing graphical output of the geometry (0 or 1)

MATERIALNAME Names (`CHARACTER*30`) for the layer material: four pre-defined materials (`Vacuum`, `Air`, `Aluminium`, `Silicon`) or a material from the materials file `spenvis.mat.dat`

THICKNESS Layer thicknesses

TUNIT Units for the layer thicknesses: μm (`mum`), mm (`mm`), cm (`cm`), m (`m`), km (`km`), mg cm^{-2} (`mg/cm2`), g cm^{-2} (`g/cm2`), kg m^{-2} (`kg/m2`)

COLOURINDEX Colour index for the graphical output: white (1), grey (2), dark grey (3), red (4), blue (5), cyan (6), magenta (7), yellow (8), dark blue (9), green (10), dark green (11), dark red (12); only used if `VIS=1`

TRACK Flag for inclusion of particle tracks in the graphical output of the geometry (0 or 1); only used if `VIS=1`

FILE Format of the graphical output of the geometry: EPS (1), JPEG (3), VRML (5); only used if `VIS=1`

PARTICLETYPE Incident particle type: electron (`e-`), positron (`e+`), γ (gamma), neutron (`neutron`), proton (`proton`), α (alpha), ion (`ion`)

Z Atomic number for ions; only used if `PARTICLETYPE='ion'`

A Nucleon number for ions; only used if `PARTICLETYPE='ion'`

Q Charge for ions; only used if `PARTICLETYPE='ion'`

E Nuclear excitation for ions; only used if `PARTICLETYPE='ion'`

NEVENTS Number of primary events to simulate

ENERGYDIS Incident energy spectrum type: mono-energetic (`Mono`), trapped particles (`Trep`), solar particles (`Sep`), linear (`Lin`), power law (`Pow`), exponential (`Exp`), user defined (`Arb`)

ENERGY Energy for mono-energetic spectrum; only used if `ENERGYDIS='Mono'`

IEUNIT Energy units for mono-energetic spectrum; only used if `ENERGYDIS='Mono'`

MONOTYPE Spectrum type for mono-energetic spectrum: flux (0) or fluence (1); only used if `ENERGYDIS='Mono'`

GRADIENT Gradient or amplitude for linear, power law and exponential energy spectra ($\text{MeV}^{-2}\text{cm}^{-2}$ for beam, $\text{MeV}^{-2}\text{cm}^{-2}\text{sr}^{-1}$ for other angular distributions); only used if `ENERGYDIS='Lin', 'Pow', 'Exp'`

INTERCEPT Intercept for linear energy spectrum ($\text{MeV}^{-2}\text{cm}^{-2}$ for beam, $\text{MeV}^{-2}\text{cm}^{-2}\text{sr}^{-1}$ for other angular distributions); only used if `ENERGYDIS='Lin'`

ALPHA Power index for power law energy spectrum; only used if `ENERGYDIS='Pow'`

E0 Energy exponent for exponential energy spectrum (MeV); only used if `ENERGYDIS='Exp'`

HISTPOINT User defined energy spectrum: energy (MeV) and weight: only used if `ENERGYDIS='Arb'`

EMIN Minimum energy for linear, power law and exponential energy spectra; only used if `ENERGYDIS='Lin', 'Pow', 'Exp'`

EMINUNIT Units of minimum energy for linear, power law and exponential energy spectra; only used if `ENERGYDIS='Lin', 'Pow', 'Exp'`

EMAX Maximum energy for linear, power law and exponential energy spectra; only used if `ENERGYDIS='Lin', 'Pow', 'Exp'`

EMAXUNIT Units of maximum energy for linear, power law and exponential energy spectra; only used if `ENERGYDIS='Lin', 'Pow', 'Exp'`

ARBINT Interpolation type for energy spectra: linear (Lin), power law (Log), exponential (Exp), cubic spline (Spline); only used if `ENERGYDIS='Trep', 'Sep', 'Arb'`

ANGDIS Angular distribution: cosine law (cos), point source (iso), parallel beam (bea); option `iso` is not applicable for trapped or solar particles

MINTHETA Minimum angle for cosine law and point source angular distribution, or angle of incidence for beam

ANGMINUNIT Units of MINTHETA

MAXTHETA Maximum angle for angular distribution; only used if `ANGDIS='cos', 'iso'`

ANGMAXUNIT Units of MAXTHETA; only used if `ANGDIS='cos', 'iso'`

FLUNIT Units for flux or fluence; not used when `ENERGYDIS='Trep', 'Sep'`

LEEM Selects EM processes: standard (0) or low energy (4)

HADRON Flag for inclusion of hadron nuclear interactions (0 or 1); not used if `PARTICLETYPE='e-', 'gamma'`

LN Flag inclusion of low energy neutrons (0 or 1); not used if `HADRON=0`

GEM Flag for inclusion of lepton-gamma transport (0 or 2)

DEFCUTUNIT Default cut units: μm (mum), mm (mm), cm (cm), m (m)

GLOBCUTV Default global cut

PARCUT Flag for particle dependent global cut (0 or 1)

GAMCUTV Global cut for γ particles; only used if `PARCUT=1`

ELECUTV Global cut for electrons; only used if `PARCUT=1`

POSCUTV Global cut for positrons; only used if `PARCUT=1`

NREGION Number of regions for region dependent cuts

CUTLAYER Flags for selecting cut regions (0 or 1); only used if `NREGION>0`

RGLOCUTV Default region cuts; only used if `NREGION>0`

RGAMCUT Flags for region cuts for γ particles (0 or 1); only used if `NREGION>0`

RGAMCUTV Region cuts for γ particles; only used if `RGAMCUT=1`

RELECUT Flags for region cuts for electrons (0 or 1); only used if `NREGION>0`

RELECUTV Region cuts for electrons; only used if `RELECUT=1`

RPOSCUT Flags for region cuts for positrons (0 or 1); only used if `NREGION>0`

RPOSCUTV Region cuts for positrons; only used if `RPOSCUT=1`

ANALYSIS Analysis type: fluence (fluence), non-ionizing energy loss (niel), total ionizing dose (tid), pulse height spectrum (phs)

PARTICLETYPE Particle types for fluence analysis output: incident particle (nil), proton (proton), neutron (neutron), electron (e-), gamma (gamma), pion (pion), muon (muon); only used if `ANALYSIS='fluence'`; multiple selections are allowed

FUOUT Output units for fluence analysis; only used if `ANALYSIS='fluence'`

FUDENS Fluence density type for fluence analysis: omnidirectional (0) or planar (1); only used if `ANALYSIS='fluence'`

ALAYER Flags for selection of boundary layers for fluence analysis (0 or 1); only used if `ANALYSIS='fluence'`

EMODE Energy binning mode for fluence analysis: default (default), linear (lin), logarithmic (log), user defined (arb); only used if ANALYSIS='fluence'

NBIN Number of energy bins for fluence analysis; only used if EMODE='lin', 'log'

EOMIN Lower edge of lowest energy bin for fluence analysis; only used if EMODE='lin', 'log'

EOMINUNIT Units of lowest energy bin edge for fluence analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if EMODE='lin', 'log'

EOMAX Upper edge of highest energy bin for fluence analysis; only used if EMODE='lin', 'log'

EOMAXUNIT Units of highest energy bin edge for fluence analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if EMODE='lin', 'log'

EEDGE Energy bin edges for fluence analysis; only used if EMODE='arb'

EDGEUNIT Units of energy bin edges for fluence analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if EMODE='arb'

AMODE Angle binning mode for fluence analysis: default (default), linear (lin), user defined (arb); only used if ANALYSIS='fluence'

ANINTV Number of angle bins for fluence analysis; only used if AMODE='lin'

AOMIN Lower edge of lowest angle bin for fluence analysis; only used if AMODE='lin'

AOMINUNIT Units of lowest angle bin edge for fluence analysis: degrees (deg), radians (rad); only used if AMODE='lin'

AOMAX Upper edge of highest angle bin for fluence analysis; only used if AMODE='lin'

AOMAXUNIT Units of highest angle bin edge for fluence analysis: degrees (deg), radians (rad); only used if AMODE='lin'

AEDGE Angle bin edges for fluence analysis; only used if AMODE='arb'

AEDGEUNIT Units of angle bin edges for fluence analysis: degrees (deg), radians (rad); only used if AMODE='arb'

FUNCTIONNAME NIEL function identifier for NIEL analysis: CERN (cern), JPL (jpl); only used if ANALYSIS='niel'

NIELUNIT Output units for NIEL analysis: rad(Si) (rad), Gy(Si) (Gy), MeV g⁻¹(Si) (MeV/g); only used if ANALYSIS='niel'

NIELayer Flags for selection of boundary layers for NIEL analysis (0 or 1); only used if ANALYSIS='niel'

FEOU Output units for TID analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV), rad (rad), Gy (Gy); only used if ANALYSIS='tid'

TIDLayer Flags for selection of boundary layers for TID analysis (0 or 1); only used if ANALYSIS='tid'

PHSLayer Flags for selection of boundary layers for pulse height analysis (0 or 1); only used if ANALYSIS='phs'

PHSMODE Energy binning mode for pulse height analysis: default (default), linear (lin), logarithmic (log), user defined (arb); only used if ANALYSIS='phs'

PHSNBIN Number of energy bins for pulse height analysis; only used if PHSMODE='lin', 'log'

PHSEOMIN Lower edge of lowest energy bin for pulse height analysis; only used if PHSMODE = 'lin', 'log'

PHSEOMINUNIT Units of lowest energy bin edge for pulse height analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if PHSMODE='lin', 'log'

PHSEOMAX Upper edge of highest energy bin for pulse height analysis; only used if PHSMODE = 'lin', 'log'

PHSEOMAXUNIT Units of highest energy bin edge for pulse height analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if PHSMODE='lin', 'log'

PHSEGE Energy bin edges for pulse height analysis; only used if PHSMODE='arb'

PHSEGEUNIT Units of energy bin edges for pulse height analysis: eV (eV), keV (keV), MeV (MeV), GeV (GeV), TeV (TeV), PeV (PeV); only used if PHSMODE='arb'

The defaults for the MULASSIS namelist are defined as:

```
USER = 0
SHAPE = 'slab '
NLAYER = 1
DO I=1,MLAYER
MATERIALNAME = 42*' '
THICKNESS = 42*0.0
TUNIT = 42*' mm'
COLOURINDEX = layer index
```

```

VIS = 0
TRACK = 0
FILE = 0
PARTICLETYPE = 'e-      '
Z = 1
A = 1
Q = 0
E = 0.0
NEVENTS = 10
ENERGYDIS = 'Mono      '
ENERGY = 1.00
IEUNIT = 'MeV'
MONOFLUX = 1.0
MONOTYPE = 0
GRADIENT = 0.0
INTERCEPT = 0.0
ALPHA = 0.0
E0 = 0.0
HISTPOINT = 200*0.0
EMIN = 0.0
EMINUNIT = 'MeV'
EMAX = 0.0
EMAXUNIT = 'MeV'
ARBINT = 'Lin      '
ANGDIS = 'cos'
MINTHETA = 0.0d0
MAXTHETA = 90.0d0
ANGMINUNIT = 'deg'
ANGMAXUNIT = 'deg'
FLUNIT = '      '
LEEM = 0
HADRON = 0
LN = 0
GEM = 0
DEFCUTUNIT = 'mum'
GLOBCUTV = 1.0
PARCUT = 0
GAMCUTV = 1.0
ELECUTV = 1.0
POSCUTV = 1.0
NREGION = 0
CUTLAYER = 1764*0
RGLOCUTV = 42*1.0
RGAMCUT = 42*0
RELECUT = 42*0
RPOSCUT = 42*0
RGAMCUTV = 42*1.0
RELECUTV = 42*1.0
RPOSCUTV = 42*1.0
ANALYSIS = ' '
PARTICLENAME = 6*' '
FUOUT = ' '
FUDENS = 0
ALAYER = 43*0
EMODE = ' '
NBIN = 1
EOMIN = 0.0
EOMINUNIT = 'MeV'
EOMAX = 0.0
EOMAXUNIT = 'MeV'
EEDGE(42) = 0.0
EDGEUNIT = 'MeV'
AMODE = ' '
ANINTV = 1
AOMIN = 0.0

```

```

AOMINUNIT = 'deg'
AOMAX = 180.0
AOMAXUNIT = 'deg'
AEDGE = 30*0.0
AEDGEUNIT = 'deg'
FUNCTIONNAME = 'cern'
NIELUNIT = 'rad'
NIELLAYER = 42*0
FEOUT = 'MeV'
TIDLAYER = 42*0
PHSLAYER = 42*0
PHSMODE = 'default'
PHSNBIN = 1
PHSEOMIN = 0.0
PHSEOMINUNIT = 'MeV'
PHSEOMAX = 0.0
PHSEOMAXUNIT = 'MeV'
PHSEEDGE = 30*0.0
PHSEEDGEUNIT = 'MeV'

```

3.3 Sector analysis tool and related utilities

The dose models `SHIELDOSE` and `NIEL` are based on simple spherical or planar geometries. More realistic shielding distributions can be obtained with the technique of ray tracing in a geometry defined by a number of basic building blocks that can be positioned and oriented with respect to each other and to a fixed reference frame.

In `SPENVIS`, this technique is implemented in a sector analysis tool. The shielding distributions produced by this tool can be imported into the `SHIELDOSE` and `NIEL` programmes, and can also be used to obtain the trapped and solar proton spectra at the detector location inside the geometry (`SFLUX` tool).

In contrast to the simple shielding configurations for the dose models which only allow for aluminium shielding material, the sectoring tool accepts any material that can be converted to Al equivalent. Material properties are defined and stored in a data base by a separate tool (`MATERIAL`). The data base is also used by `MULASSIS`.

3.3.1 Material data base

The `MATERIAL` programme constructs a data base of material properties (currently material name, chemical formula and density) in the file `spenvis_mat.dat`. This file is formatted in such a way as to make it readable by the `SPENVIS` script (see below), and as such has no direct application outside the frame of the `SPENVIS` environment. The material data base is used by `SECTOR` and `MULASSIS`.

The parameters for `MATERIAL` are defined in the `MATERIAL` namelist:

REMOVE Flag for removing a material from the `spenvis_mat.dat` file (0 or 1)

REMMAT Name of the material to be removed (CHARACTER*30); only used when REMOVE=1

DEFINED Flag for adding a predefined material to the `spenvis.mat.dat` file (0 or 1)

MATINDEX Index (see Table 3.2) of the pre-defined material to be added; only used when `DEFINED=1`

ADD Flag for adding a user defined material to the `spenvis.mat.dat` file (0 or 1)

NAME Name of the user defined material to be added (`CHARACTER*30`); only used when `ADD=1`

FORM Chemical formula of the user defined material to be added (`CHARACTER*80`); only used when `ADD=1`

DENS Material density of the user defined material to be added (g cm^{-3}); only used when `ADD=1`

The defaults for the `MATERIAL` namelist are defined as:

```
REMOVE = 0
DEFINED = 0
MATINDEX = 0
ADD = 0
DENS = 0.0
```

The pre-defined materials are listed in Table 3.2.

Table 3.2: Predefined materials for `MATERIAL`

Name	Formula	Density
antimony	Sb	6.62
arsenic	As	5.73
beryllium	Be	1.85
boron	B	2.54
cadmium	Cd	8.64
cadmium_sulfide	Cd-S	4.83
cadmium_telluride	Cd-Te	5.85
calcium_fluoride	Ca-F2	3.18
carbon_(graphite)	C	2.25
chromium	Cr	7.20
cobalt	Co	8.71
copper	Cu	8.93
gallium	Ga	5.93
gallium_arsenide	Ga-As	5.31
germanium	Ge	5.35
gold	Au	19.3

Table 3.2: Predefined materials for MATERIAL (continued)

Name	Formula	Density
indium	In	7.30
indium_antimonide	In-Sb	5.76
iridium	Ir	22.4
iron	Fe	7.86
lead	Pb	11.3
lead_sulfide	Pb-S	11.3
lithium_fluoride	Li-F	2.64
magnesium	Mg	1.74
magnesium_oxide	Mg-O	3.58
manganese	Mn	7.20
molybdenum	Mo	10.2
nickel	Ni	8.91
niobium	Nb	8.57
palladium	Pd	12.0
platinum	Pt	21.4
potassium_chloride	K-Cl	1.98
selenium	Se	4.82
silicon_dioxide_(fused_quartz)	Si-O2	2.20
silver	Ag	10.5
silver_bromide	Ag-Br	6.47
silver_chloride	Ag-Cl	5.56
sodium_chloride	Na-Cl	5.56
tantalum	Ta	16.6
tellurium	Te	6.25
tin	Sn	7.30
titanium	Ti	4.50
titanium_oxide	Ti-O	4.9
titanium_dioxide	Ti-O2	4.3
tungsten	W	19.3
tungsten_carbide	W-C	15.6
uranium	U	18.7
vanadium	V	5.96
yttrium	Y	4.34
zinc	Zn	7.04
zinc_oxide	Zn-O	5.61
zinc_selenide	Zn-Se	5.26
zinc_sulfide	Zn-S	4.09

Material parameters are written to the `spenvis_mat.dat` file, in the format illustrated below:

```
$define (NUSERMAT ["TEMPLATE"] = 1);
$define (MNAME (01) ["TEMPLATE"] = Silicon_dioxide_ (fused_quartz));
$define (MATERIAL (01) ["TEMPLATE"] = Si-O2);
$define (DENSITY (01) ["TEMPLATE"] = 2.200E+00);
```

The NUSERMAT parameter is the number of materials in the file, and should be updated when materials are added or deleted. This is handled automatically by the MATERIAL programme.

3.3.2 Sectoring tool

The sectoring tool constructs a simple representation of a spacecraft using simple geometrical objects as building blocks. A ray tracing is performed from a detector location (the location where the sensitive device to be modelled is situated) yielding a three dimensional shielding distribution, which is then integrated to a two dimensional distribution. The latter can be used as input for the dose models in SPENVIS.

The model parameters for SECTOR are defined in two namelists: BLUEPRINT for setting up the ray tracing and shielding distribution, and a SECTOR namelist section for each geometry element. The BLUEPRINT namelist parameters are:

PRODEF Character string containing the project name

TITLE Character string containing the project title

DEFAULT Flag to set the default geometric configuration (1); this should only be used by the SPENVIS interface

SECTORN Dummy parameter used by the SPENVIS interface

NSEC Number of shapes (including detector); maximum value is 42

RANDOM Flag to select non-random (0) or random rays (1); the number of non-random rays is fixed at 3

RANDOMN Number of random rays to be added to the 3 non-random rays; only used if RANDOM=1

NSTEP Number of shielding intervals

DIST Flag for definition of two-dimensional shielding distribution interval: minimum and maximum shielding value encountered (0), or user defined (1)

MIND Lower shielding limit (mm); only used if DIST=1

MAXD Upper shielding limit (mm); only used if DIST=1

The defaults for the BLUEPRINT namelist are defined as:

```

DEFAULT = 1
SECTORN = 0
NSEC = 6
RANDOM = 1
RANDOMN = 10
NSTEP = 50
DIST = 0
MIND = 0.0
MAXD = 1.0

```

The SECTOR namelist parameters are:

NGEO Selects geometric shape: detector (0), sphere (1), cylinder (2), box (3)

NMATERIAL Material name: 4 pre-defined materials (Vacuum, Air, Aluminium, Silicon) or a material from the materials file `spenvis.mat.dat`

NR Radius for sphere or cylinder or length for box (m)

NH Height for cylinder or box (m); only used if `NGEO=2, 3`

NW Width for box (m); only used if `NGEO=3`

NT Wall thickness (mm); only used if `NGEO=1, 2, 3`

NVIS Flag for wire frame (0) or solid (1) rendering

NMOT Selects reference shape for the position and orientation parameters: world reference frame (0) or the index number of a shape defined in another namelist segment

NTRANSX Translation vector *X* component (m)

NTRANSY Translation vector *Y* component (m)

NTRANSZ Translation vector *Z* component (m)

NROTX Rotation axis vector *X* component

NROTY Rotation axis vector *Y* component

NROTZ Rotation axis vector *Z* component

NTHETA Rotation angle (deg)

RAY Flag for inclusion of rays in VRML rendering (0 or 1)

LAST_GEO Index of the last element to be included in the VRML rendering

SECTORN Dummy parameter used by the SPENVIS interface

The defaults for the SECTOR namelist are defined as:

```

NGEO = 1
NMATERIAL = 'Aluminium'
NR = 0.0
NH = 0.0
NW = 0.0
NT = 0.0
NVIS = 1
NMOT = -1
NTRANSX = 0.0
NTRANSY = 0.0
NTRANSZ = 0.0
NROTX = 0.0
NROTY = 0.0
NROTZ = 0.0
NTHETA = 0.0
RAY = 0

```

3.3.3 Attenuation of trapped and solar protons

The `SFLUX` program folds trapped and solar proton fluxes and fluences with the 2D and 3D shielding distributions produced by `SECTOR`. For each direction in the shielding distribution, it transports the proton spectrum through the amount of Al equivalent material encountered in that direction and then sums the attenuated spectra over all directions to obtain the attenuated spectrum at the detector location. In addition, one full 3D attenuated spectrum distribution is written to the file `spenvis_sxa.txt`.

The `SFLUX` namelist parameters are:

IFLUX Flag for selection of 3D shielded spectrum output: trapped (0) or solar (1) protons

JFLUX Selects orbit segment for trapped proton spectrum; only used if `IFLUX=0`

FTYPE Flag for integral (0) or differential (1) 3D spectrum output

The defaults for the `SFLUX` namelist are defined as:

```

IFLUX = 0
JFLUX = 0
FTYPE = 0

```

Chapter 4

Spacecraft charging models

4.1 Internal deep dielectric charging: the DICTAT model

Electrical charging of dielectric materials in the magnetosphere is a major cause of satellite anomalies. DICTAT was developed to provide a practical engineering tool to address problems of internal dielectric charging.

DICTAT Calculates the electron current that passes through a conductive shield and becomes deposited inside a dielectric. From the deposited current, the maximum electric field within the dielectric is found. This field is compared with the breakdown field for that dielectric to see if the material is at risk of an electrostatic discharge.

The user inputs details of the structure to be simulated. The tool allows both planar and cylindrical structures, made up of a single dielectric and a shield. An absent or negligibly thin shield may be simulated by defining a shield of zero thickness. The dielectric may be grounded on both surfaces or on either the outer surface (nearest the environment) or on the inner surface.

The user can select whether the simulation should use a constant spectrum (as in a laboratory test), or a changing environment experienced over an orbit. In the latter case the user must supply details of the orbit but does not need to know the environment experienced by spacecraft in that orbit. The tool has, in-built, a position-dependent worst-case model of electron fluxes in the outer radiation belt. The model is named FLUMIC (Fluence Model for Internal Charging) and gives electron spectra as a function of L , B/B_0 and solar cycle phase (Wrenn et al. 1999). If the structure does not discharge in this environment, then it should be safe.

If the structure is predicted to exceed the breakdown threshold, then the tool will suggest changes to the shield and dielectric thicknesses that would bring the structure safely below the threshold.

For SPENVIS, the DICTAT parameters have been collected in a single namelist. When DICTAT is to be run over a spacecraft orbit, a SAPRE namelist section should be added to the namelist file. The DICTAT namelist consists of the following parameters:

PRODEF Character string containing the project name

TITLE Character string containing the project title

SPECTRUM Type of input spectrum: run FLUMIC over the spacecraft orbit defined in the SAPRE namelist ('S'), run FLUMIC for a pair of (B/B_0 , L) values ('L'), use a user defined spectrum ('U')

BB0 Value of B/B_0 ; used when SPECTRUM='L'

LSHELL Value of L (R_E); used when SPECTRUM='L'

FSC Fraction of solar cycle; used when SPECTRUM='L'

FYR Fraction of year; used when SPECTRUM='L'

SPECNAM User spectrum label; used when SPECTRUM='U'

TDUR Exposure duration (hr); used when SPECTRUM='U'

DIRECTION User spectrum directionality flag: 'O' for omnidirectional, 'U' for unidirectional; used when SPECTRUM='U'

NSPEC Number of energies in the user spectrum; used when SPECTRUM='U'

ENERGIES Energies for the user spectrum (MeV); used when SPECTRUM='U'

FLUXES Fluxes for the user spectrum ($\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$); used when SPECTRUM='U'

GEOM Geometry flag: 'P' for planar, 'C' for cylindrical

FOV Field of view (deg)

NGROUNDS Number of grounds (1 or 2)

GROUND Flag to select grounded surface: 'I' for inner, 'O' for outer; used when NGROUNDS=1

NDIEL Dielectric material name: 'PLEXIGLAS', 'KAPTON', 'MYLAR', 'EPOXY', 'POLYTHENE', 'TEFLON', 'ETFE', 'CMXGLASS', 'BOROSILGLASS' or 'USER' (for user defined material)

TDIEL Dielectric thickness (cm)

TK Dielectric temperature (K)

NSHIELD Shield material name: 'ALUMINIUM', 'SILVER', 'COPPER', 'GOLD' or 'USER' (for user defined material)

TSHIELD Shield thickness (cm)

NCORE Core material name (see NSHIELD; only used when GEOM='C')

RCORE Core radius (cm)

The dielectric material is defined by seven parameters, plus a label. The index *i* in the namelist parameters below refers to the available materials: 'PLEXIGLAS' (2), 'KAPTON' (3), 'MYLAR' (5), 'EPOXY' (6), 'POLYTHENE' (7), 'TEFLON' (8), 'ETFE' (9), 'CMXGLASS' (11), 'BOROSILGLASS' (12), 'USER' (19).

NAME(i) Material name

DENS(i) Density (g cm^{-3})

COND(i) Conductivity ($\text{ohm}^{-1}\text{m}^{-1}$)

PERM(i) Dielectric constant

BREAK(i) Breakdown electric field (V m^{-1})

KP(i) RIC dose rate factor

DELTA(i) Delta

EA(i) Activation energy (eV)

For the shield and core materials, only the material name and density have to be specified, with the following indices: 'ALUMINIUM' (1), 'SILVER' (4), 'COPPER' (10), 'GOLD' (13) or 'USER' (18 for shield, 20 for core).

The defaults for the DICTAT namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
SPECTRUM = 'L'
BBO = 1.0
L = 4.5
SPECNAM = 'UNNAMED SPECTRUM'
TDUR = 48.0
DIRECTION = 'O'
NSPEC = 1
ENERGIES(1) = 1.0
FLUXES(1) = 0.0
GEOM = 'P'
FOV = 90.0
NGROUNDS = 1
GROUND = 'I'
NDIEL = 'POLYTHENE'
TDIEL = 0.1
TK = 298.0
NSHIELD = 'ALUMINIUM'
TSHIELD = 0.1
NCORE = 'COPPER'
RCORE = 0.1
```

4.2 Environment parameters: the LEOPOLD code

LEOPOLD is a simple menu driven code that allows the rapid determination of the principal parameters that characterise the low Earth and polar orbital environments (Martin 1991).

The basic inputs to the code are the orbital altitude and inclination, and a mission start and end date. Using empirical and theoretical relationships and in-built data bases the code will then evaluate and output seventeen space environment parameters.

For SPENVIS, the LEOPOLD.DAT file has been converted to a Fortran BLOCK DATA file which is linked to the code. Currently, only the orbital altitude is used to evaluate the parameters. The interactive menu input has been replaced by a set of namelist parameters, defined as follows:

PRODEF Character string containing the project name

TITLE Character string containing the project title

UORALT Vector with the orbital altitude range (upper and lower limits in km)

UORINC Orbit inclination (deg)

ISEL Flag for generation of altitude range. ISEL=0: use NVAL and calculate STEP; ISEL=1: use STEP and calculate NVAL.

NVAL Number of altitudes; only used if ISEL=0

STEP Altitude step (km); only used if ISEL=1

The defaults for the LEOPOLD namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
UORALT(1) = 500.0
UORALT(2) = 500.0
UORINC = 28.5
ISEL = 1
STEP = 100.0
NVAL = 1
```

4.3 Surface charging: the EQUIPOT code

EQUIPOT (Wrenn & Simms 1990) computes the equilibrium potential of a surface using a simple model of differential material charging. A spacecraft material and an isolated conductor or dielectric are selected. The materials can be in sunlight or in eclipse. Standard particle spectra are used as the input environment for the case where the materials are subject to bombardment by energetic electrons in the auroral zones. The program then uses a technique to step the material potential until the net current is zero. This represents the equilibrium charging potential attained.

The EQUIPOT program is driven by means of four menus: main menu, run parameters menu, materials input menu and environment input menu. The material and environment description files (*.mat and *.env) provided with EQUIPOT have been transformed into BLOCK DATA files and linked with the main programme. The interactive menu input has been replaced by a set of namelist parameters, grouped in one EQUIPOT namelist. A first group of parameters defines the program run environment:

PRODEF Character string containing the project name

TITLE Character string containing the project title

NSIM Number of integration steps

VSTART Start potential (V)

DV0 First potential step (V)

VBEGIN First potential for I-V table (V)

VEND Last potential for I-V table (V)

DV Potential step for I-V table (V)

ICHO Flag to switch field induced conductivity on (ICHO=1) or off (0)

IECL Sunlight status flag: 0 for spacecraft in eclipse, 1 for spacecraft in sunlight

SUNANG Sun angle on isolated patch (deg); only used if IECL=1

ITYPE Incident distribution flag: 1 for isotropic distribution, -1 for normal distribution

ENVTYP Environment type: 1 for high altitude, 0 for low altitude

IDEB Debye sheath flag: 1 for thin sheath, 2 for thick sheath

For low altitude environments, additional parameters have to be defined:

IRAM Ram/wake effects: 0 for ram off, 1 for ram on, 2 for wake on

WSAT Satellite altitude (km); not used if IRAM=0

AATT Angle of attack (deg); not used if IRAM=0

The ambient environment is selected from a number of predefined environments by means of the IENV parameter. The available low altitude environments are: IRI solar min (IENV=1), IRI solar max (4), Maxwellians at 1,000 km (2), DMSP auroral spectra (3), cold Maxwellians for ram test (5), test spectra and Maxwellians (6). For high altitudes, the selection is: ECSS SCATHA worst case (IENV=14), NASA guidelines worst case (15), NASA guidelines average GEO (16), Meteosat very disturbed (13), Meteosat very quiet (12), Meteosat test environment (11). In addition, by setting IENV=0, a user defined environment of up to ten components can be specified:

1. Three thermal electron and one thermal ion component cater for a bi-Maxwellian fit to high energies plus a cold plasma (using a mean mass for the ions).
2. One electron and three ion flux spectra (to cover different masses). Flux spectra have to be entered in order of increasing energy.

The user defined environments are specified with the following parameters:

IETH(3) Flags for inclusion (positive value) of a thermal electron component

IITH(3) Flags for inclusion (positive value) of a thermal ion component

UETHRM(2,3) Densities (cm^{-3}) and temperatures (eV) for the thermal electron components

UITHRM(3,3) Densities (cm^{-3}), temperatures (eV) and mean masses (amu) for the thermal ion components

ISPEC(4) Flags for inclusion (positive value) of electron and ion flux spectra

UMASS(4) Electron and ion masses; **UMASS (1)** is not used

USPEC1(100,2) – USPEC4(100,2) Electron and ion energies (eV) and differential fluxes ($\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{eV}^{-1}$)

The final set of parameters defines the structure (conductor) and patch (conductor or insulator) materials. A number of predefined materials are available, both for structure and patch. In addition, user defined materials can be specified, or individual values of predefined parameters can be modified.

IMATS Index of predefined structure material: Al (**IMATS**=7), Au (9), Ar (12), steel (17), Electrodag 501 (5), PCB-Z (6), PSG 120 FD (15), ITOX coating (10), carbon fibre (11), user defined material (−1), fixed structure potential (0), in which case all other structure material parameters are ignored.

VS0 Structure potential (V); used when **IMATS**=0

IMATP Index of predefined patch material: in addition to the structure materials: Kapton (**IMATS**=1), Teflon (16), solar cell with MgF_2 coating (2), MARECS/ECS glass (3), epoxy resin on conducting carbon fibre ((8), non-conductive black paint (4), Herberts 1002-E black paint (14), generic dielectric after 5 years at GEO (13), SiO_2 (19), user defined insulator (−2), user defined conductor (−1)

SNAME(30) Names of predefined structure materials

SPROPS(30,18) Predefined structure material parameters

USNAME Name of user defined structure material

USPROPS(18) User defined structure material parameters

PNAME(30) Names of predefined patch materials

PPROPS(30,18) Predefined patch material parameters

UPNAME Name of user defined patch material

UPPROPS(18) User defined patch material parameters

IFELD(2) Flag for stopping power fit for surface and patch

TPATCH Patch temperature (K) material: 0 for Katz fit, 1 for Feldman fit

A material is defined by 18 parameters:

1. relative permittivity
2. thickness (m)
3. conductivity ($\text{ohm}^{-1}\text{m}^{-1}$)
4. atomic number
5. maximum SEE yield for electrons
6. electron energy for maximum SEE yield (keV)
7. energy loss power (for Sims SEE formula)
8. density (g cm^{-3}), used with Feldman stopping power fit
9. SEE yield for 1 keV protons
10. proton energy for maximum SEE yield (keV)
11. photo-electric current (A m^{-2})
12. surface resistance (ohm sq^{-1}), not used
13. flag for selecting the SEE formula: 1 for Katz, 0 for Sims, -1 for Whipple
14. R_1 ($\text{\AA}$), used with Katz SEE formula
15. n_1 , used with Katz SEE formula
16. R_2 ($\text{\AA}$), used with Katz SEE formula
17. n_2 , used with Katz SEE formula
18. atomic weight, used with Feldman stopping power fit

When the patch material is conductive, three parameters for an intermediate insulator have to be defined:

DIELCI Relative permittivity

THICKI Thickness (m)

BCONDI Conductivity ($\text{ohm}^{-1}\text{m}^{-1}$)

The defaults for the EQUIPOT namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
ITYPE = 1
IDEB = 2
NSIM = 100
IECL = 1
SUNANG = 90.0D0
ICHO = 0
VSTART = 0.0D0
DV0 = 100.0D0
IRAM = 0
WSAT = 500.0D0
AATT = 90.0D0
VS0 = 0.0D0
THICKI = 0.001D0
BCONDI = 1.0D-15
DIELCI = 3.0D0
VBEGIN = 0.0D0
VEND = 50.0D0
DV = 5.0D0
TPATCH = 273.0D0
IMATS = 7
IMATP = 1
IFELD(1) = 0
IFELD(2) = 0
ENVTyp = 1
IENV = 1
```

4.4 SOLARC

SOLARC Provides an estimate of the current collection and power loss that would be experienced by a solar array in the low Earth orbit plasma environment (Bond 1993). For a given set of conditions the code creates current-voltage characteristics derived from two sets of empirical formulae. The first set is based upon the results of ground based solar array experiments, while the second set is derived from data obtained by tests in space.

The following characteristics of the solar array and spacecraft are determined:

- current collected by the specified solar array and spacecraft surfaces;
- array and structure voltages relative to the ambient plasma potential (i.e. floating voltages);

Table 4.1. Ion types (elements) available for SOLARC

Number	Element	Symbol	Number	Element	Symbol
1	hydrogen	H	41	niobium	Nb
2	helium	He	42	molybdenum	Mo
4	beryllium	Be	44	ruthenium	Ru
5	boron	B	45	rhodium	Rh
6	carbon	C	46	palladium	Pd
8	oxygen	O	47	silver	Ag
10	neon	Ne	50	tin	Sn
13	aluminium	Al	54	xenon	Xe
14	silicon	Si	72	hafnium	Hf
18	argon	Ar	73	tantalum	Ta
22	titanium	Ti	74	tungsten	W
23	vanadium	V	75	rhenium	Re
24	chromium	Cr	76	osmium	Os
25	manganese	Mn	77	iridium	Ir
26	iron	Fe	78	platinum	Pt
27	cobalt	Co	79	gold	Au
28	nickel	Ni	80	mercury	Hg
29	copper	Cu	90	thorium	Th
32	germanium	Ge	92	uranium	U
40	zirconium	Zr			

- plasma current and power loss;
- erosion or sputtering of surfaces caused by energetic ion impingement.

In performing an analysis the user has considerable control over the specification of the plasma environment as well as the configuration of the solar array and associated spacecraft. This flexibility in the input to a simulation includes the following features:

- specification of a variety of solar array and spacecraft configurations;
- availability of a number of different current collection models (including user defined);
- the ability to specify up to 10 thermal distributions and up to 5 energetic distributions of ions and electrons (in SPENVIS, the number of distributions has been limited to 1 electron distribution and 1 ion distribution). A variety of ion types (listed in Table 4.1) may also be selected.

The SOLARC program is driven by means of five menus: main menu, environment data menu, solar array and structure menu, material data menu and program control menu. The

other menu options control the program flow or permit the user to create or modify input and output files. In SPENVIS, all SOLARC input has been converted to a single namelist. The data files *.DTn are no longer needed nor created, since all the necessary parameters are contained in the namelist file. The SOLARC namelist is defined as follows:

PRODEF Character string containing the project name

TITLE Character string containing the project title

NITHD Number of thermal ion distributions (0 or 1)

PTI Thermal ion temperature (K)

PRHOI Thermal ion number density (m^{-3})

YI Thermal ion type (two-character string from the list in Table 4.1)

NETHD Number of thermal electron distributions (0 or 1)

PTE Thermal electron temperature (K)

PRHOE Thermal electron number density (m^{-3})

NIEND Number of energetic ion spectra (0 or 1)

PEI Energetic ion energy (eV)

PFLIEN Energetic ion flux ($\text{m}^{-2}\text{s}^{-1}$)

YIEN Energetic ion type (two-character string from the list in Table 4.1)

NEEND Number of energetic electron spectra (0 or 1)

PEE Energetic electron energy (eV)

PFLEEN Energetic electron flux ($\text{m}^{-2}\text{s}^{-1}$)

VARR Solar array voltage (V)

NC Number of blocks in array

AC Area of each block (m^2)

AF Fractional area of interconnects

ASP Spacecraft structure surface area (m^2)

CF Structure/array attachment fraction: fractional distance of the structure attachment point from the lower (i.e. negative) end of the solar array; values must lie between 0 (at the negative end) and 1 (at the positive end).

ILSTRC Flag for inclusion of structure in analysis (0 or 1)

IMODA Array current collection model number (1–4)

IMODS Structure current collection model number (1–4)

ILCENI Energetic ion current collection flag: include (1) or exclude (0) the influence of the current collection models on the energetic particle distributions.

ILCENE Energetic electron current collection flag (see `ILCENI`)

UMATA Materials for solar array (two two-character strings from the list in Table 4.1 or 'Kp' for Kapton)

UMATS Materials for spacecraft structure (two two-character strings from the list in Table 4.1 or 'Kp' for Kapton)

The defaults for the SOLARC namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
NITHD = 1
PTI = 1400.0
PRHOI = 6.0E11
YI = 'O '
NETHD = 1
PTE = 2600.0
PRHOE = 6.0E11
NIEND = 0
PEI = 4.82
PFLIEN = 4.56E15
YIEN = 'O '
NEEND = 0
PEE = 0.2
PFLEEN = 4.75E16
VARR = 160.0
NC = 100
AC = 4.0
AF = 0.05
ASP = 100.0
CF = 0.0
ILSTRC = 1
IMODA = 1
IMODS = 4
ILCENI = 1
ILCENE = 1
UMATA(1) = 'Cu'
UMATA(2) = 'Kp'
UMATS(1) = 'Al'
UMATS(2) = 'Ag'
```


Chapter 5

Atmosphere and ionosphere models

The following atmosphere and ionosphere models have been implemented:

- NRLMSISE-00 (Hedin et al. 1988, Hedin 1991);
- MET-V 2.0 (Owens 2002);
- DTMB78 (Barlier et al. 1979);
- HWM93 (Hedin et al. 1988, 1991);
- IRI2001 (Bilitza 2001).

The models are implemented in two ways:

1. linked to the orbit generator so that atmospheric and ionospheric fluxes are integrated over an orbit and atomic oxygen erosion can be evaluated;
2. using the geographic positions generated by the GRID program to produce density and temperature profiles and world maps.

5.1 Orbital version

The atmosphere and ionosphere models are linked to the orbit generator through the ATOMOX tool (Borde & de Sabbathier 1994). ATOMOX reads in the orbit file `spenvis_sao.txt` and the attitude file `spenvis_att.txt` and calculates the flux and fluence of one atmospheric or ionospheric constituent on an oriented surface. The orientation of the normal to this surface corresponds to the attitude vectors in the `spenvis_att.txt` file. For atomic oxygen, the erosion rate is calculated as well. The model parameters are defined in the ATOMOX namelist:

MODEL Model index: NRLMSISE-00 (1), MET-V 2.0 (2), DTMB78 (3), IRI2001 (5)

F107 $F_{10.7}$ solar radio flux ($10^{-22}\text{W m}^{-2}\text{Hz}^{-1}$)

F107A Average $F_{10.7}$ solar radio flux ($10^{-22}\text{W m}^{-2}\text{Hz}^{-1}$); for the IRI2001 model, this parameter is the 12 month average sunspot number R_Z

AP Daily A_p index (2 nT); not used when MODEL=5

NPART Atmospheric/ionospheric constituent: He (1), O (2), N_2 (3), O_2 (4), Ar (5, only for MODEL=1, 2), H (6, only for MODEL=1, 2), N (7, only for MODEL=1) or anomalous O (8, only for MODEL=1) for the neutral atmosphere models; electrons (15), O^+ (16), H^+ (17), He^+ (18), O_2^+ (19), NO^+ (20), cluster ions (21) or N^+ (22) for the ionosphere model; when NPART=11, the average mass density of all particles available for each model is calculated.

IRATE Flag for O erosion yield input: predefined (0) or user defined (1); only used if NPART=2, 8

EROSION User defined O erosion yield (10^{-24}cm^3); only used if NPART=2, 8 and IRATE=1

ERLIST Predefined O erosion yield (10^{-24}cm^3) from a list of values compiled by Banks & Rutledge (1988); only used if NPART=2, 8 and IRATE=0

THERM_MOT Flag to include (1) or exclude (0) the contribution of thermal motion to the fluxes

DIR Flag for orientation of the surface normal: parallel to the satellite polar axis (1), as defined by the orbit generator, or user defined (0)

THETA Polar angle (deg); used if DIR=0

PHI Azimuthal angle (deg); used if DIR=0

The defaults for the ATOMOX namelist are defined as:

```
MODEL = 1
F107 = 70.0
F107A = 50.0
AP = 20.0
NPART = 2
IRATE = 0
EROSION = 1.0
ERLIST = 1.0
THERM_MOT = 0
DIR = 1
THETA = 0.0
PHI = 0.0
```

5.2 Positional version

The ATMOPUS program calculates densities and temperatures for the geographic positions in the grid file `spenvis_pos.txt`. The model parameters are defined in the ATMOPUS namelist:

MODEL Model index: NRLMSISE-00 (1), MET-V 2.0 (2), DTMB78 (3), HWM93 (4), IRI2001 (5)

DAY Day of year

F107 $F_{10.7}$ solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$)

F107A Average $F_{10.7}$ solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$); for the IRI2001 model, this parameter is the 12 month average sunspot number R_Z

AP Daily A_p index (2 nT); not used when `MODEL=5`

YEAR Epoch year; only used when `MODEL=2, 5`

IRANGE Index of the variable parameter (this option can only be used with a coordinate grid consisting of one point): day of year (1), $F_{10.7}$ (2), average $F_{10.7}$ or R_Z (3), A_p (4, not applicable for the ionosphere model)

DAY2 Last value of the day of year range; only used if `IRANGE=1`

F1072 Last value of the $F_{10.7}$ range; only used if `IRANGE=2`

F107A2 Last value of the average $F_{10.7}$ or R_Z range; only used if `IRANGE=3`

AP2 Last value of the day of year range; only used if `IRANGE=4`

ISEL Flag for defining variable range: by number of values (0) or by step size (1); only used with a coordinate grid consisting of one point

STEP Step size for variable range (units depend on variable); only used when `ISEL=1`

NVAL Number of values in variable range (the maximum number is 1001); only used when `ISEL=0`

ILOG Flag for linear (0) or logarithmic (1) increments in the variable range; only used when `ISEL=0`

IMAP Control variable for use with SPENVIS only to check the coordinate grid type: its value should be equal to the `MAP` parameter in the `GRID` namelist (see Sect. 2.2). For applications outside SPENVIS, set `IMAP=-1` or do not specify it in the namelist.

The defaults for the ATMOPUS namelist are defined as:

```
MODEL = 1
YEAR = 2003
DAY = 1
DAY2 = 1
F107 = 70.0
F1072 = 70.0
F107A = 50.0
F107A2 = 50.0
AP = 20.0
AP2 = 20.0
IRANGE = 0
ISEL = 0
STEP = 10.0
NVAL = 1
ILOG = 0
IMAP = -1
```

Chapter 6

Magnetic field models

Three tools have been developed to implement models of the Earth's internal and magnetospheric magnetic field:

1. BLXTRA converts geographical positions generated by the orbit generator into the (B, L) coordinate system (McIlwain 1961).
2. BLPOS calculates (B, L) for the grid of points generated with the GRID tool described in Sect. 2.2. This tool outputs the complete field line and its footprints, or a colour map of the output parameters on a world map.
3. SHELL traces magnetic drift shells: it outputs a number of field lines that make up the drift shell, plus the locations of the mirror points, the foot points, and the point where the magnetic field strength is minimal, for each field line.

SPENVIS uses the DGRF/IGRF model series (1900–2005) for the internal magnetic field. In addition, the following external magnetic field models have been implemented:

1. Mead & Fairfield (1975)
2. Tsyganenko (1987) short
3. Tsyganenko (1987) long
4. Tsyganenko (1989)
5. Olson & Pfitzer (1977) quiet
6. Olson & Pfitzer dynamic (Pfitzer et al. 1988)
7. Tsyganenko & Stern (1996)
8. Ostapenko & Maltsev (1996)
9. T01 (Tsyganenko 2002ab)

10. T04 (Tsyganenko & Sitnov 2005)
11. Paraboloid model (Alexeev & Feldstein 2001)

6.1 Orbital version

BLXTRA reads geodetic coordinates, modified Julian day, and pitch angle from the orbit file `spenvis_sao.txt`. The magnetic field model parameters are specified in the BLXTRA namelist:

OUTER Index of the external magnetic field model: none (0), Mead & Fairfield (1), Tsyganenko 87s (2), Tsyganenko 87l (3), Tsyganenko 89c (4), Olson & Pfitzer quiet (5), Olson & Pfitzer dynamic (6), Tsyganenko 96 (7), Ostapenko & Maltsev (8)

FKP K_p index; only used when OUTER=1, 2, 3, 4, 8

DST D_{st} index (nT); only used when OUTER=6, 7, 8

SWD Solar wind density (cm^{-3}); only used when OUTER=6

SWV Solar wind velocity (km s^{-1}); only used when OUTER=6

SWP Solar wind pressure (nP); only used when OUTER=7, 8

IMFX $B_{\text{IMF},X}$ (nT); currently not used

IMFY $B_{\text{IMF},Y}$ (nT); only used when OUTER=7

IMFZ $B_{\text{IMF},Z}$ (nT); only used when OUTER=7, 8

The defaults for the BLXTRA namelist are defined as:

```
OUTER = 0
FKP   = 0.0
DST   = -30.0
SWD   = 25.0
SWV   = 300.0
SWP   = 3.0
IMFX  = 6.0
IMFY  = 0.0
IMFZ  = 0.0
```

6.2 Positional version

The positional version BLPOS reads in the map file `spenvis_pos.txt` produced by the coordinate grid generator. The model parameters are specified in the BLPOS namelist:

OUTER Index of the external magnetic field model: none (0), Mead & Fairfield (1), Tsyganenko 87s (2), Tsyganenko 87l (3), Tsyganenko 89c (4), Olson & Pfitzer quiet (5), Olson & Pfitzer dynamic (6)

FKP K_p index; only used when OUTER=1, 2, 3, 4

DST D_{st} index (nT); only used when OUTER=6

DEN Solar wind density (cm^{-3}); only used when OUTER=6

VEL Solar wind velocity (km s^{-1}); only used when OUTER=6

SWP Solar wind pressure (nP); currently not used

IMFX $B_{\text{IMF},X}$ (nT); currently not used

IMFY $B_{\text{IMF},Y}$ (nT); currently not used

IMFZ $B_{\text{IMF},Z}$ (nT); currently not used

YEAR Epoch year

DAY Epoch day

ALPHA Pitch angle (deg)

IRANGE Index of the variable parameter (this option can only be used with a coordinate grid consisting of one point): IGRF epoch (1), pitch angle (2), day of year (3, only applicable when using an external magnetic field)

YEAR2 Last value of the epoch year range; only used if IRANGE=1

ALPHA2 Last value of the pitch angle range (deg); only used if IRANGE=2

DAY2 Last value of the day of year range; only used if IRANGE=3

ISEL Flag for defining variable range: by number of values (0) or by step size (1); only used with a coordinate grid consisting of one point

STEP Step size for variable range (units depend on variable); only used when ISEL=1

NVAL Number of values in variable range (the maximum number is 1001); only used when ISEL=0

ILOG Flag for linear (0) or logarithmic (1) increments in the variable range; only used when ISEL=0

IFLAG(8) Flags to control field line tracing options. Currently, only two values are used: IFLAG (1) to exclude (1) or include (0) points close to the magnetic pole; IFLAG (2) to allow (0) or disallow (1) magnetopause crossing.

IMAP Control variable for use with SPENVIS only to check the coordinate grid type: its value should be equal to the MAP parameter in the GRID namelist (see Sect. 2.2). For applications outside SPENVIS, set IMAP=-1 or do not specify it in the namelist.

The defaults for the BLPOS namelist are defined as:

```

OUTER = 0
FKP = 0.0
DST = -30.0
SWD = 25.0
SWV = 300.0
SWP = 3.0
IMFX = 6.0
IMFY = 0.0
IMFZ = 0.0
YEAR = 2003
YEAR2 = 2003
DAY = 1
DAY2 = 1
ALPHA = 90.0
ALPHA2 = 90.0
IRANGE = 0
ISEL = 0
STEP = 10.0
NVAL = 1
ILOG = 0
IFLAG = 1,1,1,1,1,1,1,1
IMAP = -1

```

6.3 Drift shell tool

A third implementation of the magnetic field models consists of the SHELL tool which generates magnetic drift shells. The model parameters are defined in the SHELL namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

KINT Index of the internal magnetic field model: DGRF/IGRF (0), Jensen & Cain (1962) (1), GSFC 12/66 (Cain et al. 1967) (1)

EPOCH Epoch for the internal magnetic field model; only used when KINT=0, 2

KEXT Index of the external magnetic field model: none (0), Mead & Fairfield (1), Tsyganenko 87s (2), Tsyganenko 87l (3), Tsyganenko 89c (4), Olson & Pfitzer quiet (5), Olson & Pfitzer dynamic (6), Tsyganenko 96 (7), Ostapenko & Maltsev (8)

YEAR Calendar year; only used when KEXT>0

MONTH Calendar month; only used when KEXT>0

DAY Calendar day; only used when KEXT>0

- HOUR** Calendar hour; only used when $KEXT > 0$
- MIN** Calendar minute; only used when $KEXT > 0$
- SEC** Calendar second; only used when $KEXT > 0$
- FKP** K_p index; only used when $OUTER = 1, 2, 3, 4, 8$
- DST** D_{st} index (nT); only used when $OUTER = 6, 7, 8$
- SWD** Solar wind density (cm^{-3}); only used when $OUTER = 6$
- SWV** Solar wind velocity (km s^{-1}); only used when $OUTER = 6$
- SWP** Solar wind pressure (nP); only used when $OUTER = 7, 8$
- IMFX** $B_{IMF,X}$ (nT); currently not used
- IMFY** $B_{IMF,Y}$ (nT); only used when $OUTER = 7$
- IMFZ** $B_{IMF,Z}$ (nT); only used when $OUTER = 7, 8$
- CHOICE1** Flag for defining the drift shell: magnetic (0) or geodetic (1) coordinates
- FLM0** L value for the drift shell (R_E); only used when $CHOICE1 = 0$
- CHOICE** Flag for selecting the second magnetic coordinate: B_m (0), B_m/B_0 (1), α_0 (2); only used when $CHOICE1 = 0$
- BMAX** B_m value for the drift shell (Gauss); only used when $CHOICE2 = 0$
- BB0** B_m/B_0 value for the drift shell; only used when $CHOICE2 = 1$
- ALPHA0** α_0 value for the drift shell (deg); only used when $CHOICE2 = 2$
- ALTGEOD** Altitude for the drift shell (km); only used when $CHOICE1 = 1$
- LATGEOD** Latitude for the drift shell (deg); only used when $CHOICE1 = 1$
- ELONGGEOD** Longitude for the drift shell (deg); only used when $CHOICE1 = 1$
- ALPHA** Local pitch angle (deg); only used when $CHOICE1 = 1$

The defaults for the SHELL namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
KINT = 0
EPOCH = 1995.0
KEXT = 0
YEAR = 1995
MONTH = 1
DAY = 1
```

```

    HOUR = 0
    MIN = 0
    SEC = 0.0
    FKP = 0.0
    DST = -30.0
    SWD = 25.0
    SWV = 300.0
    SWP = 3.0
    IMFX = 0.0D0
    IMFY = 0.0D0
    IMFZ = 0.0D0
    CHOICE1 = 0
    CHOICE2 = 0
    FLMO = 4.0
    BMAX = 0.3
    BB0 = 50.0
    ALPHA0 = 90.0
    ALTGEOD = 0.0
    LATGEOD = 0.0
    ELONGGEOD = 0.0
    ALPHA = 90.0

```

Chapter 7

Meteoroid and debris models

Both natural meteoroids and man-made space debris particles represent a serious hazard to space vehicles in orbit around the Earth. Nearly all meteoroids originate from comets or asteroids, and are generally distributed isotropically (termed “sporadic” meteoroids), except those that retain their parent body orbit, which are termed “meteoroid streams”. The total meteoroid environment is thus comprised of the average of the sporadic meteoroids together with the yearly average of meteoroid streams. Also co-existent with the natural particle flux are space debris particles, most of which are in high-inclination orbits, and consist of spent rocket stages, inactive payloads, debris from exploded satellites, etc.

7.1 The Grün meteoroid model

The flux-mass model for meteoroids at 1 AU of Grün et al. (1985) gives the total average meteoroid flux in terms of the integral flux, i.e. the number of particles per m² per year of mass larger than or equal to a given mass, impacting a randomly-oriented flat plate under a viewing angle of 2π . Except for Earth shielding and gravitational effects, this flux is omnidirectional.

The Grün model consists of a set of equations. In SPENVIS, these equations are used to generate mass or diameter profiles of meteoroid fluxes. The model parameters are entered using the GRUN namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

ALT Altitude (km)

DENSITY Particle density (g cm⁻³)

IVAR Flag for selecting mass (0) or diameter (1) as the independent variable

MASS1 log₁₀ of the lower limit of the mass range (g); used if IVAR=0

MASS2 $\log_{10}$ of the upper limit of the mass range (g); used if `IVAR=0`

DIAM1 $\log_{10}$ of the lower limit of the diameter range (cm); used if `IVAR=1`

DIAM2 $\log_{10}$ of the upper limit of the diameter range (cm); used if `IVAR=1`

The defaults for the `GRUN` namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
ALT = 400.0
DENSITY = 2.0
IVAR = 0
MASS1 = -18
MASS2 = 0
DIAM1 = -6
DIAM2 = 0
```

7.2 The NASA90 debris model

The NASA90 debris model (Anderson 1991) is an analytical formulation of the debris flux vs. particle diameter. The orbit altitude, epoch and inclination are used in the formulation. The main input parameter is the particle diameter. The increase of space debris is accounted for by user defined growth rates. The flux formulation computes the impact flux on a random tumbling plate.

The NASA90 model consists of a set of equations. In `SPENVIS`, these equations are used to generate mass or diameter profiles of meteoroid fluxes. The model parameters are entered using the `NASA90` namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

ALT Altitude (km)

INC Inclination (deg)

EPOCH Calendar year

F107 $F_{10.7}$ solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$) averaged over the previous year

P Mass growth rate

Q Fragment growth rate

DENSITY Particle density (g cm^{-3})

IVAR Flag for selecting mass (0) or diameter (1) as the independent variable

MASS1 $\log_{10}$ of the lower limit of the mass range (g); used if `IVAR=0`

MASS2 $\log_{10}$ of the upper limit of the mass range (g); used if `IVAR=0`

DIAM1 $\log_{10}$ of the lower limit of the diameter range (cm); used if `IVAR=1`

DIAM2 $\log_{10}$ of the upper limit of the diameter range (cm); used if `IVAR=1`

The defaults for the NASA90 namelist are defined as:

```
PRODEF = ' '  
TITLE = ' '  
ALT = 400.0  
INC = 0.0  
YEAR = 2000  
F107 = 140.0  
P = 0.05  
Q = 0.02  
DENSITY = 2.8  
IVAR = 1  
MASS1 = -9  
MASS2 = 6  
DIAM1 = -3  
DIAM2 = 2
```


Chapter 8

Miscellaneous models and tools

This chapter contains the descriptions of a number of models and tools that are not easily classified under the SPENVIS model packages:

- a tool for visualising coordinate transformations.
- a tool for evaluating the electromagnetic radiation on a satellite surface.

8.1 Coordinate transformations

Many different coordinate systems are in common use in space physics. The coordinate transformation tool illustrates the relationship between the various coordinate systems.

For a given position in space, specified in one of the available coordinate systems, the tool converts the coordinates to all of the other coordinate systems, and produces a three dimensional view of the respective coordinate vectors.

The input coordinates are specified in the `COORDTRANS` namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

SYS Index of the input coordinate system: geodetic (0), GEO (1), GEI (2), MAG (3), SM (4), GSM (5), GSE (6), GEI-2000 (7)

ALL Flag for selecting between geographical (0), spherical (1) or Cartesian coordinates for the input coordinate system

ALTGEOD Altitude (km); used if `ALL=0`

LATGEOD Latitude (deg); used if `ALL=0`

ELONGGEOD Longitude (deg); used if `ALL=0`

RAD Radius (km); used if `ALL=1`

COLAT Colatitude (deg); used if `ALL=1`

ELONG Longitude (deg); used if `ALL=1`

X *X* (km); used if `ALL=2`

Y *Y* (km); used if `ALL=2`

Z *Z* (km); used if `ALL=2`

YEAR Epoch year

MONTH Epoch month

DAY Epoch day

HOURL Epoch hour

MIN Epoch minute

SEC Epoch second

The defaults for the `COORTRANS` namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
SYS = 1
ALL = 0
ALTGEOD = 0.0
LATGEOD = 0.0
ELONGGEOD = 0.0
RAD = 6371.2
COLAT = 90.0
ELONG = 0.0
X = 0.0
Y = 0.0
Z = 0.0
YEAR = 1995
MONTH = 1
DAY = 1
HOURL = 0
MIN = 0
SEC = 0.0
```

8.2 Satellite illumination

This application is intended to determine the exposure of a surface to direct sunlight and to sunlight reflected off a planetary surface (albedo contribution). The tool reads in the orbit file `spenvis_sao.txt` and the attitude file `spenvis_sao.txt` generated by `SAPRE`. The model parameters for `ILLUM` are specified in the `ILLUM` namelist:

SC Solar constant (W m^{-2})

DTEMP Temperature at sub-solar point (K)

NTEMP Nightside temperature (K)

ALB Planetary albedo

DIR Flag for orientation of the surface normal: parallel to the satellite polar axis (1), as defined by the orbit generator, or user defined (0)

POLD Polar angle (deg); used if `DIR=0`

AZID Azimuthal angle (deg); used if `DIR=0`

DATM Atmosphere thickness (km)

AU Distance from the Sun (km)

UGRID Number of grid points for the planetary surface ($\leq 65,500$)

The defaults for the `ILLUM` namelist are defined as:

```
SC = 1371.0
DTEMP = 306.0
NTEMP = 248.0
ALB = 0.3
DIR = 1
POLD = 0.0
AZID = 0.0
AU = 149.5988D6
DATM = 0.0
UGRID = 65000
```

8.3 Geomagnetic cut-off maps

The `CUTOFF` program reads in the map file `spenvis_pos.txt` produced by the coordinate grid generator, and calculates the geomagnetic cutoff (transmission function) for each point in the grid for a user specified particle coming from outside the magnetosphere, using the Størmer formula.

The model parameters for `CUTOFF` are specified in the `CUTOFF` namelist:

YEAR Epoch for the IGRF field model

IELM Atomic number of the particle

ICH Charge state of the particle $1 \leq \text{ICH} \leq \text{IELM}$

ENERGY Energy of the particle (MeV)

ISTORM Flag for quiet (0) or stormy (1) magnetosphere

IRANGE Index of the variable parameter (this option can only be used with a coordinate grid consisting of one point): IGRF epoch (1), or no variable parameter (0)

YEAR2 Last value of the epoch year range; only used if `IRANGE=1`

ISEL Flag for defining variable range: by number of values (0) or by step size (1); only used with a coordinate grid consisting of one point

STEP Step size for variable range; only used when `ISEL=1`

NVAL Number of values in variable range (the maximum number is 1001); only used when `ISEL=0`

IMAP Control variable for use with SPENVIS only to check the coordinate grid type: its value should be equal to the `MAP` parameter in the `GRID` namelist (see Sect. 2.2). For applications outside SPENVIS, set `IMAP=-1` or do not specify it in the namelist.

The defaults for the `CUTOFF` namelist are defined as:

```
YEAR = 2005
YEAR2 = 2005
IELM = 1
ICH = 1
ENERGY = 100.0
ISTORM = 0
IRANGE = 0
ISEL = 0
STEP = 1.0
NVAL = 1
IMAP = -1
```

8.4 Database query tool

The database query tool provides access to a number of mission databases and indices (geomagnetic and solar wind parameters). The original data sets have been rewritten to the CDF-format using ISTP/IACG and Cluster guidelines, and when possible, have been modified to include physical quantities such as fluxes. Magnetic coordinates have in most cases been (re)-calculated using the UNILIB library.

Table 8.1. Available data sets in SPENVIS.

Mission	Instrument	Orbit	PI	Period	
Goes 12	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Apr 2003	
Goes 11	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	14 Jun 2003	
Goes 10	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Jul 1998	
Goes 9	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Dec 1995	31 Jul 1998
Goes 8	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Mar 1995	08 Apr 2003
Goes 7	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Mar 1987	31 Aug 1996
Goes 6	SEM	GEO	Terry Onsager (NOAA) Dan Wilkinson (NGDC)	01 Jan 1986	30 Nov 1994
Goes 5	SEM	GEO	Harold Leinbach Howard A. Garcia	01 Jan 1986	31 Mar 1987
Meteosat 3	SEM-2	GEO	Andrew J. Coates	01 Nov 1988	23 Nov 1995
ISEE 1	WIM	highly elliptical	Donald J. Williams	09 Nov 1977	07 Sep 1979
ISEE 2	KED	highly elliptical	Erhard Keppler	03 Nov 1977	02 Mar 1987
STRV 1b	REM	GTO	A. Zehnder	30 Jun 1994	31 Dec 1997
MIR	REM	LEO	A. Zehnder	01 Nov 1994	29 Nov 1996
CRRES	MEA	GTO	Alfred L. Vampola	15 Aug 1990	12 Oct 1991
AZUR	EI-88	near polar	Dieter K. Hovestadt	08 Nov 1969	05 Mar 1970
UARS	PEM/HEPS	LEO	J. David Winningham	07 Oct 1991	01 Sep 1992
Indices				01 Jan 1949	

Chapter 9

SPENVIS statistics

The different plots presented in this Chapter provides an overview of the SPENVIS user population and their usage of the system. They cover the period from January 1998 till April 2004. During this period, about 1700 people registered on the system with a frequency of about 5 users per week. The last two years (Figure 9.1), the user growth rate has increased to a mean of 7 users per week. Most of the users are still active one year after their registration. About one hundred of them are active since four years. In average, active users access SPENVIS between 20 and 40 times per week almost independently of their experience with the system (Figure 9.4). The users are mainly located in the U.S. and the ESA member states (Figure 9.3).

Figures 9.5 and 9.6 provide an overview of the usage of the users active on April 2004. Most of the runs are related to the radiative environment and its effects along an orbital trajectory. Consequently the most popular models are the orbit generator (SAPRE), the radiation belts trapped proton and electron fluxes (TREP) and the solar proton fluences (SEP). The results of these models are used to asset e.g. the ionizing dose in detector behind an Aluminium shield (SD2), single event upset rates in Silicon device (UPSETO), or damage equivalent 1-MeV electron fluence (EQFLUX).

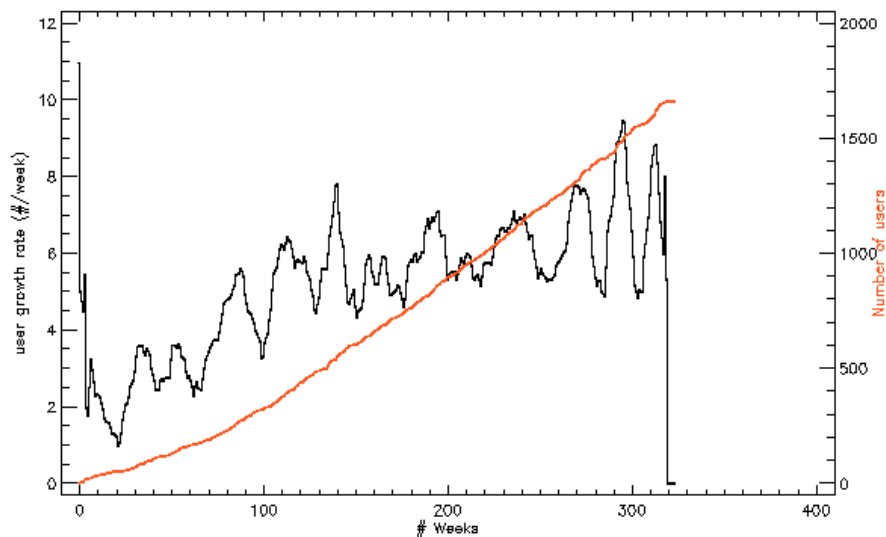


Figure 9.1. Number of users of registered users on April 2004 since January 1998

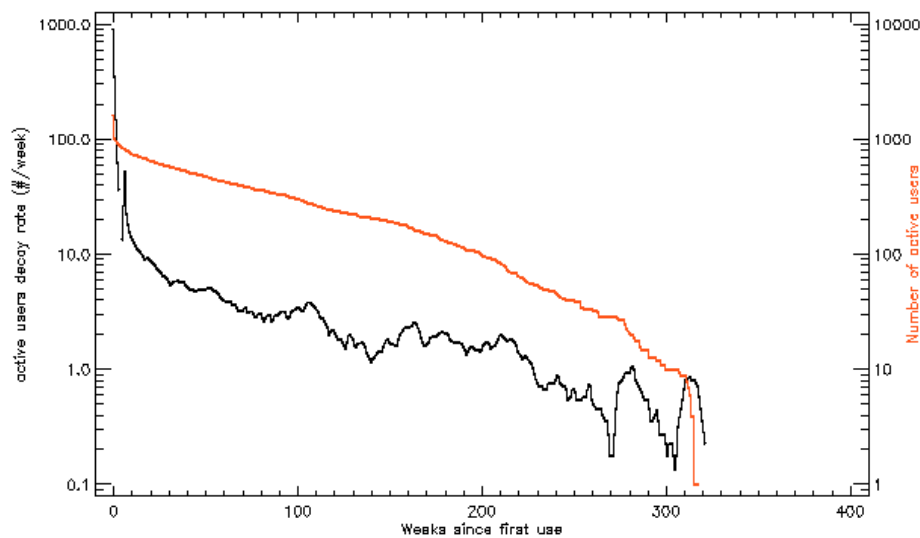


Figure 9.2. Number of users still active since their first usage on April 2004

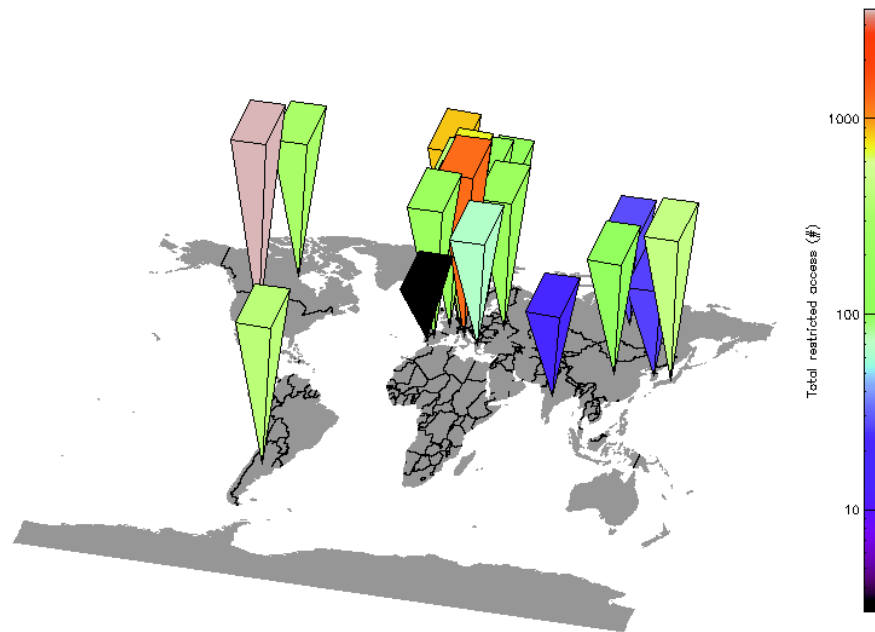


Figure 9.3. Geographical distribution of SPENVIS accesses on April 2004

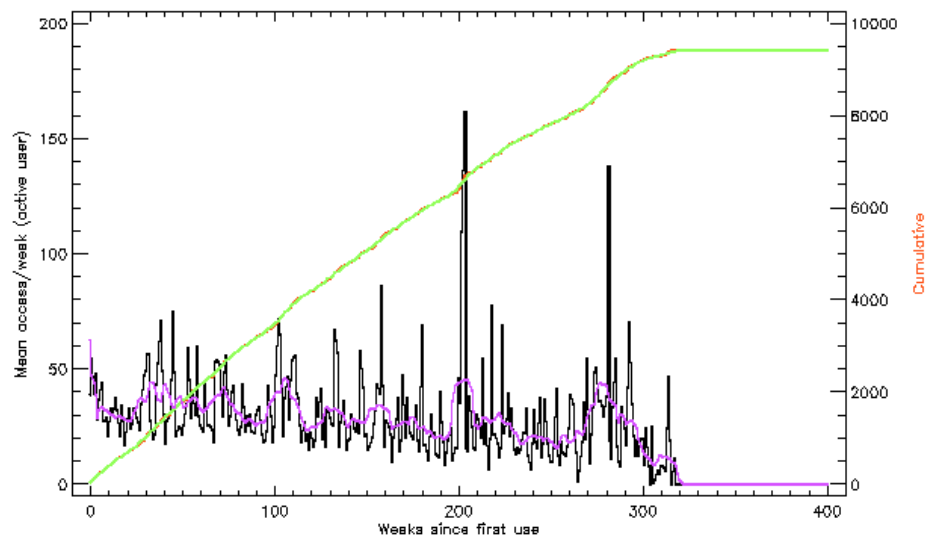


Figure 9.4. Active user access on April 2004 illustrated by the number of file downloads per week per active user since first usage (black and purple lines, left axis) and the cumulative number of downloads (red and green curves, right axis)

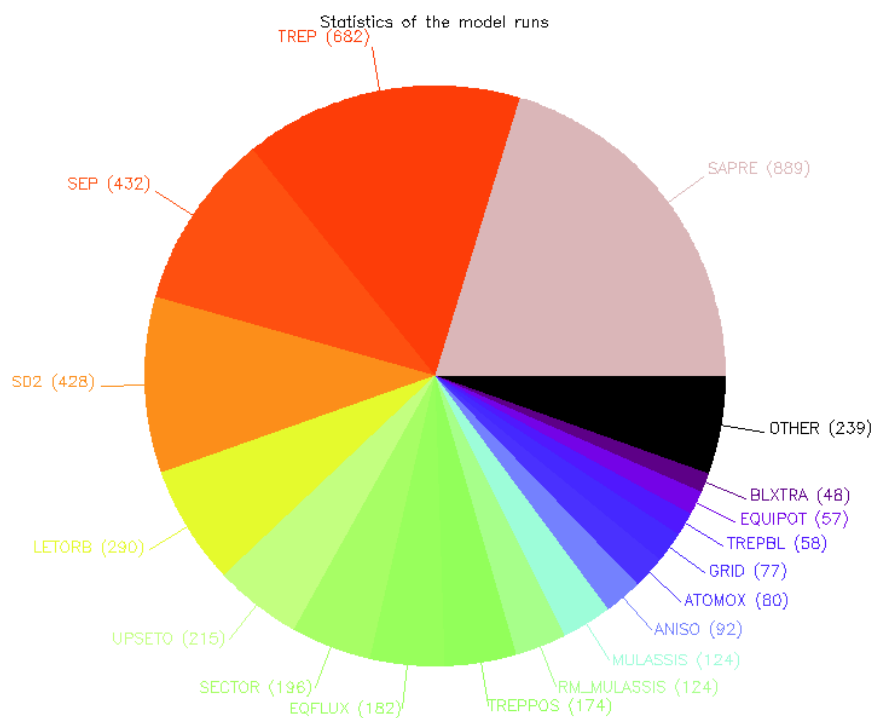


Figure 9.5. Distribution of the model runs on April 2004

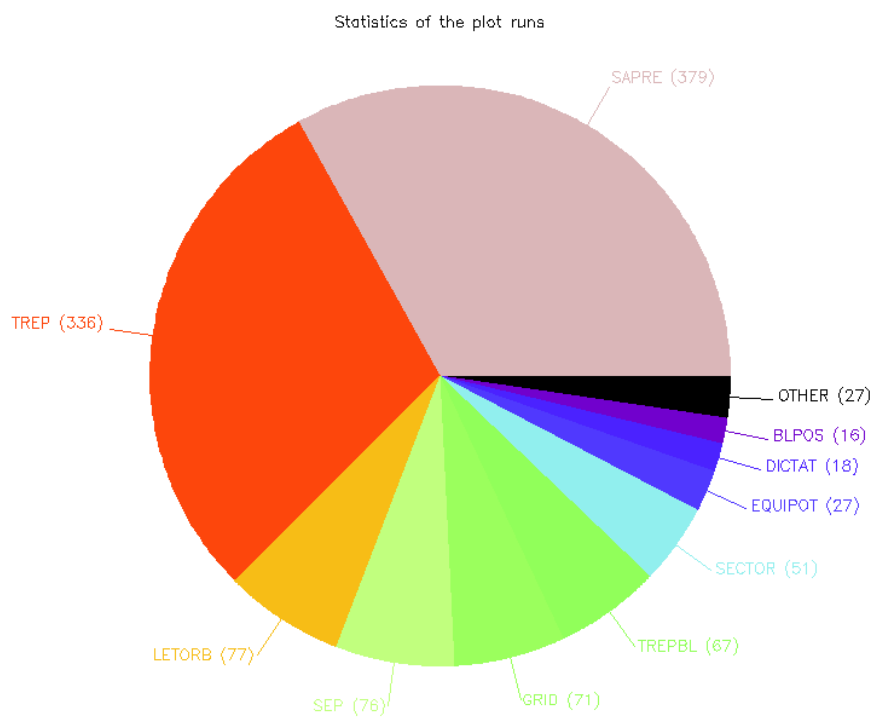


Figure 9.6. Distribution of the plot runs on April 2004

References

- Adams, J.H.: 1986, *Cosmic Ray Effects on MicroElectronics, Part IV*, NRL Memorandum Report **5901**
- Alexeev, I.I., Feldstein, Y.I., 2001, *J. Atmos. Sol. Terr. Phys.* **65**, 331
- Anderson, B.J.: 1991, *Review of Meteoroids/Orbital Debris Environment*, NASA SSP 30425, Revision A
- Badhwar, G.D., Konradi, A.: 1990, *Conversion of Omnidirectional Proton Fluxes Into a Pitch Angle Distribution*, *J. Spacecraft Rockets* **27**, 350
- Banks, B.A., Rutledge, S.K.: 1988, *Low Earth Orbital Atomic Oxygen Simulation for Materials Durability Evaluation*, Proc. Fourth European Symposium on Spacecraft Materials in Space Environment, CERT, Toulouse, 6–9 Sept. 1988
- Barlier, F., Berger, C., Falin, J.L., Kockarts, G., Thuillier, G.: 1979, *J. Atmosph. Terr. Phys.* **41**, 527–541
- Bilitza, D.: 2001, *International Reference Ionosphere 2000*, *Radio Science* **36**, 261–275
- Bond, R.: 1991, *ESPIRE Software Users Manual*
- Bond, R.A.: 1993, *SOLARC Version 2.0 Software Reference Manual*
- Borde, J., de Sabbathier, G.: 1994, *Development of Improved Atomic Oxygen Analysis Tool*, Final Report of ESA/ESTEC Contract Nr. 9558/91/NL/JG
- Brautigam, D.H., Bell, J.T.: 1995, *CRRESELE Documentation*, PL-TR-95-2128, Environmental Research Papers **1178**, Phillips Laboratory.
- Cain, J.C., Hendricks, S.J., Langel, R.A., Hudson, W.V.: 1967, *A Proposed Model for the International Geomagnetic Reference Field-1965*, *J. Geomag. Geoelectr.* **19**, 335–355
- Dale, C., Marshall, P., Cummings, B., Shamey, L., Holland, A.: 1993, *Displacement Damage Effects in Mixed Particle Environments for Shielded Spacecraft CCDs*, *IEEE Trans. Nucl. Sci.* **40**, 1628–1637
- Feynman, J., Spitale, G., Wang, J., Gabriel, S.: 1993, *Interplanetary Proton Fluence Model: JPL 1991*, *J. Geophys. Res.* **98**, 13,281–13,294
- Grün, E., H.A. Zook, H. Fechtig, R.H. Giese: 1985, *Collisional Balance of the Meteoritic Complex*, *Icarus* **62**, 244–272
- Hedin, A.E.: 1991, *Extension of the MSIS thermosphere model into the middle and lower atmosphere*, *J. Geophys. Res.* **96**, 1159–1172

- Hedin, A.E., Spencer, N.W., Killeen, T.L.: 1988, *Empirical Global Model of Upper Thermosphere Winds Based on Atmosphere and Dynamics Explorer Satellite Data*, J. Geophys. Res. **93**, 9959–9978
- Hedin, A.E., et al.: 1991, *Revised Global Model of Thermosphere Winds Using Satellite and Ground-Based Observations*, J. Geophys. Res. **96**, 7657–7688
- Heynderickx, D., Kruglanski, M., Pierrard, V., Lemaire, L. Looper, M.D. Blake, J.B.: 1999, *A Low Altitude Trapped Proton Model for Solar Minimum Conditions Based on SAM-PEX/PET Data*, IEEE Trans. Nucl. Sci. **46**, 1475.
- Jensen, D.C., Cain, J.C.: 1962, *An Interim Geomagnetic Field*, J. Geophys. Res. **67**, 3568
- King, J.H.: 1974, *Solar proton fluences for 1977–1983 space missions*, J. Spacecr. Rockets **11**, 401
- Kruglanski, M., : 1996, *Trapped Proton Anisotropy at Low Altitudes*, Technical Note 6 for ESA/ESTEC/WMA TRP Contract No. 10725/94/JG(SC)
- Lei, F., Truscott, P.R., Dyer, C.S., Quaghebeur, B., Heynderickx, D., Nieminen, P., Evans, H., Daly, E.: 2002, *MULASSIS: A Geant4 Based Multi-Layered Shielding Simulation Tool*, IEEE Trans. Nucl. Sci. **49**, 2788
- Martin, A.R.: 1991, *Spacecraft/Plasma Interactions and Electromagnetic Effects in LEO and Polar Orbits*, Final Report of ESA/ESTEC Contract No. 7989/88/NL/PB(SC), Volume 3, Executive Summary
- McIlwain, C.E.: 1961, *Coordinates for Mapping the Distribution of Magnetically Trapped Particles*, J. Geophys. Res. **66**, 3681–3691
- Mead, G.D., Fairfield, D.H.: 1975, *A Quantitative Magnetospheric Model Derived From Spacecraft Magnetometer Data*, J. Geophys. Res. **80**, 523–534
- Meffert, J.D., Gussenhoven, M.S.: 1994, *CRRES PRO Documentation*, PL-TR-94-2218, Environmental Research Papers **1158**, Phillips Laboratory,
- Olson, W.P., Pfizter, K.A.: 1974, *A Quantitative Model of the Magnetospheric Magnetic Field*, J. Geophys. Res. **79**, 3739–3748
- Ostapenko, Maltsev: 1996,
- Owens, J.K.: 2002, *NASA Marshall Engineering Thermosphere Model Version 2.0*, NASA TM2002211786
- Pfizer, K.A., Olson, W.P., Mogstad, T.: 1988, *A Time Dependent, Source Driven Magnetospheric Magnetic Field Model*, EOS **69**, 426
- Rodgers, D.J.R.: 2003, *DICTAT Software: Users Manual*, QinetiQ
- Sawyer, D.M., Vette, J.I.: 1976, *AP-8 Trapped Proton Environment for Solar Maximum and Solar Minimum*, NSSDC/WDC-A-R&S 76-06
- Seltzer, S.M.: 1979, *Electron, Electron-Bremsstrahlung and Proton Depth-Dose Data for Space Shielding Applications*, IEEE Trans. Nucl. Sci. NS-26, 4896
- Seltzer, S.M.: 1980, *A Computer Code for Space Radiation Shielding Methods*, NBS Technical Note 116

- Tada, H.Y., Carter, J.R., Anspaugh, B.E., Downing, R.G.: 1982, *Solar Cell Radiation Handbook*, 3rd edition, NASA JPL 82-69
- Tsyganenko, N.A.: 1987, *Global Quantitative Models of the Geomagnetic Field in the Cislunar Magnetosphere for Different Disturbance Levels*, Planet. Space Sci. **35**, 1347–1358
- Tsyganenko, N.A.: 1989, *A Magnetospheric Magnetic Field Model with a Warped Tail Current Sheet*, Planet. Space Sci. **37**, 5–20
- Tsyganenko, N.A.: 2002a, *A model of the near magnetosphere with a dawn-dusk asymmetry. 1. Mathematical structure*, J. Geophys. Res. **107**, 1179
- Tsyganenko, N.A.: 2002b, *A model of the near magnetosphere with a dawn-dusk asymmetry. 2. Parametrization and fitting to observations*, J. Geophys. Res. **107**, 1176
- Tsyganenko, N.A., Sitnov, M.I.: 2005, *Modeling the dynamics of the inner magnetosphere during strong magnetic storms*, J. Geophys. Res., in press
- Tsyganenko, N.A., Stern, D.P.: 1996, *Modeling the global magnetic field the large-scale Birke-land current systems*, J. Geophys. Res. **101**, 21,187–21,198
- Vampola, A.L.: 1996, *Outer Zone Energetic Electron Environment Update*, <http://www.estec.esa.nl/wmwww/wma/vampola/frame1.html>
- Vette, J.I.: 1991, *The AE-8 Trapped Electron Model Environment*, NSSDC/WDC-A-R&S 91-24
- Watts, J.W., Parnell, T.A., Heckman, H.H.: 1989, *Approximate Angular Distribution and Spectra for Geomagnetically Trapped Protons in Low-Earth Orbit*, Conf. on High-Energy Radiation in Background Space, A.C. Rester Jr. and J.I. Trombka (Eds.), Santibel Island, FL, 1987, Am. Inst. Phys. Conf. Proc., New York, 75–85
- Wrenn, G.L., Sims, A.J.: 1990, *The EQUIPOT Charging Code*, Working Paper SP-90-WP-37, Royal Aerospace Establishment; updated by D.J. Rodgers, 2002
- Wrenn, G.L., Rodgers, D.J., Bühler, P.: 1999, *Modelling the outer belt enhancements of MeV electrons*, J. Spacecr. Rockets
- Xapsos, M.A., G.P. Summers, J.L. Barth, E.G. Stassinopoulos, E.A. Burke: 1999, *Probability Model for Worst Case Solar Proton Event Fluences*, IEEE Trans. Nucl. Sci. **46**, 1481–1485.
- Xapsos, M.A., G.P. Summers, J.L. Barth, E.G. Stassinopoulos, E.A. Burke, *Probability Model for Cumulative Solar Proton Event Fluences*, IEEE Trans. Nucl. Sci. **47**, 486–490.

Appendix A

Output files produced by the models in SPENVIS

`and.txt` ANISO directional fluxes along a spacecraft orbit

`ano.txt` ANISO average fluences

`anp.html` ANISO report file

`apo.txt` ATMOPOS fluxes

`app.html` ATMOPOS report file

`ato.txt` ATOMOX fluxes and fluences

`atp.html` ATOMOX report file

`att.txt` Spacecraft attitude vectors

`blo.txt` BLXTRA magnetic field parameters

`blp.html` BLXTRA report file

`bpl.txt` BLPOS magnetic field lines

`bpo.txt` BLPOS magnetic field parameters

`bpp.html` BLPOS report file

`coo.txt` Geomagnetic transmission factor values

`cop.html` CUTOFF report file

`cto.txt` Coordinate transformation components

`ctp.html` Coordinate transformation report file

dia.txt DICTAT diagnostics file

dio.txt DICTAT maximum electric field, surface voltage and electron spectra

dip.html DICTAT report file

dso.txt SHELL drift shell coordinates

dsp.html SHELL report file

dss.txt SHELL footpoints and mirror points

efo.txt EQFLUX damage equivalent fluences

efp.html EQFLUX report file

epeakfl.txt TREP peak electron fluxes

epo.txt EQUIPOT environment spectra, SEE tables and I-V characteristics

epp.html EQUIPOT report file

gro.txt GRUN meteoroid fluxes

grp.html GRUN report file

ilo.txt Satellite illumination fluxes

ilp.html Satellite illumination report file

leo.txt LEOPOLD environment parameters

lep.html LEOPOLD report file

lof.txt LETORB orbit averaged proton and LET spectra

loo.txt LETORB proton and ion spectra for each orbit point

lop.html LETORB report file

mat.dat Material definition file

mlo.txt Mulassis output file

mlp.txt Mulassis log file

mlp.txt Mulassis report file

nao.txt NASA90 debris fluxes

nap.html NASA90 report file

nio.txt NIEL tables
nip.html NIEL report file
pos.html GRID report file
pos.txt GRID coordinate file
ppeakfl.txt TREP peak proton fluxes
s2o.txt SHIELDOSE-2 dose tables
s2p.html SHIELDOSE-2 report file
sao.txt Spacecraft trajectory (time and location)
sap.html Orbit generator report file
sdo.txt SHIELDOSE dose tables
sdp.html SHIELDOSE report file
sef.txt SEP proton fluence spectra
seo.txt SEP attenuation factors along a spacecraft orbit
sep.html SEP report file
soo.txt SOLARC Erosion rates and current collection
sop.html SOLARC report file
spe.txt TREP electron fluxes along a spacecraft orbit
spp.txt TREP proton fluxes along a spacecraft orbit
std.txt 2D shielding distribution
stg.txt Angular grid for the 3D shielding distribution
sto.txt 3D shielding distribution
stp.html Sectoring tool report file
stv.wrl VRML rendering of the sectoring tool geometry
sxa.txt 3D shielded proton fluences
sxo.txt 2D shielded proton fluences
sxp.html SFLUX report file

tbo.txt TREPBL fluxes

tbp.html TREPBL report file

tpo.txt TREPPPOS fluxes

tpp.html TREPPPOS report file

tri.txt TREP average fluxes and fluences

trp.html TREP report file

uof.txt Experimental SEU data and fit parameters

uoo.txt SEU rates for each orbital point

uop.html UPSETO report file