

SPENVIS

SPace ENVironment Information System

Technical Note 1

Description of SPENVIS model inputs

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- chapter 9: creation of a separate chapter dedicated to the Geant4 tools in SPENVIS. Moving MULASSIS and SSAT sections from ch2 and adding GEMAT, SSAT, Magnetocosmics and Planetocosmics. MATERIAL program has become obsolete. Update of MULASSIS namelist

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- section 2.1.3: addition of separate section for GCR

- section 2.2.4: addition of NEWUPSETO = LETORB + UPSETO
- chapter 8: addition of View Factor and Contamination tools
- section 6.1: addition of KMASDEN in GRUN namelist

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- chapter 6: addition of section 6.3 for Particle/wall interaction
- chapter 9: update of GRAS namelists

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- chapter 7: addition of section 7.2 for MEREM (undocumented)
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- section 2.2.6: addition of Pelliccioni data implementation

Preface

This document describes the inputs needed by the models implemented in the World Wide Web (WWW) based SSpace ENVironment Information System (SPENVIS). Emphasis in this document is on the input/output streams of the models, and is not intended to be a description or manual for the models themselves. In this document, the models are presented in chapters corresponding to the SPENVIS model packages.

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 0.1 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.

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

Table 0.1. Record structure 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 1

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).

1.1 Orbit generator

The orbit generator `SAPRE` computes trajectory osculatory orbital elements using a numerical Runge-Kutta integration method. It was initially designed for having Earth as the central body. However, recent modifications allow also the computation of general orbits around Mars and Jupiter.

1.1.1 Earth

In the case of Earth, 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 CIRA 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 application 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)

PLANET Flag for definition of the central body: Earth (3), Mars (4) and Jupiter (5)

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 $IMISD=0, 3$

MISDUR Total mission duration (days or years); 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 (m^2kg^{-1}); only used if $IDRAG=1$

F107A 90 day average F_{107} solar radio flux ($10^{-22}\text{W m}^{-2}\text{Hz}^{-1}$); only used if $IDRAG=1$

F107 day value of F_{107} 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 (m^2kg^{-1}) at 1 A.U.; 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
PLANET = 3
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'), hyperbolic ('HYP'), heliosynchronous ('HEL'), geostationary ('GEO'), two-line elements ('TLE') or near Earth interplanetary¹ ('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 $TYPE='GEN'$ or ' HYP '; options 0 and 2 are not applicable for hyperbolic orbits

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 $IAE=1$ and $TYPE='GEN'$

E Eccentricity; only used if $IAE=1$ and $TYPE='GEN'$

HYP A Semi-major axis (km) of hyperbolic orbit; only used if $TYPE='HYP'$

HYP E Eccentricity of hyperbolic orbit; only used if $TYPE='HYP'$

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

RINCL Inclination (deg); only used if $TYPE='GEN'$ or ' HYP '

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

¹Near Earth interplanetary orbit is not a true interplanetary trajectory. It is defined as a circular orbit at 90,000 km altitude and inclination 0° that can be used as a good proxy.

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'` or `'HYP'`

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'` or `'HYP'` and `IAN=0`

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

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

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 only used when `TYPE='NEI'` to provide an input parameter or control variable to other models.

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

DH2 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
HYPA    = -70000.0
```

```

HYPE  = 1.2
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

```

1.1.2 Other planets

The original SAPRE orbit generator has been extended to calculate orbits around planets other than Earth. The calculation method is similar to the one described above for the Earth. Thus, it takes into account the non-spherical shape of the planet, the gravitational attraction of the Sun and possible moons, and solar radiation pressure. However, the user is not able to uploading a trajectory file or to provide two-line elements.

Table 1.1. Summary of the implementation of planets other than Earth in SAPRE

Planet	Grav. potential	Coord. system	Atm. drag	Moons
Mercury		not implemented		
Venus		not implemented		
Mars	Gapcynski et al (1977)	Airy-0	no	no moons
Jupiter	Campbell & Synnott (1985)	IAU2000	no	Io, Europa, Ganymede and Callisto
Saturn		not implemented		
Uranus		not implemented		
Neptune		not implemented		

The planetary coordinate systems used are compliant with IAU/IAG guidelines (Seidelmann et al, 2002). The orbital parameters are defined relative to a planetocentric coordinate system where the

- x-axis is given by the IAU-vector i.e. out along the intersection of the planet mean equator of “of date” and the Earth mean equator of epoch J2000,

- z-axis is parallel to the planet rotational axis (positive to the north) and
- xy-plane is the planet mean equator at a fixed epoch.

Note that this is an inertial reference frame. However, the resulting ephemerides are generated relative to planetographic (non-inertial) coordinates, defined specifically for each planet (figure 1.1). Some details of the SAPRE planetary implementation are summarised in Table 1.1.

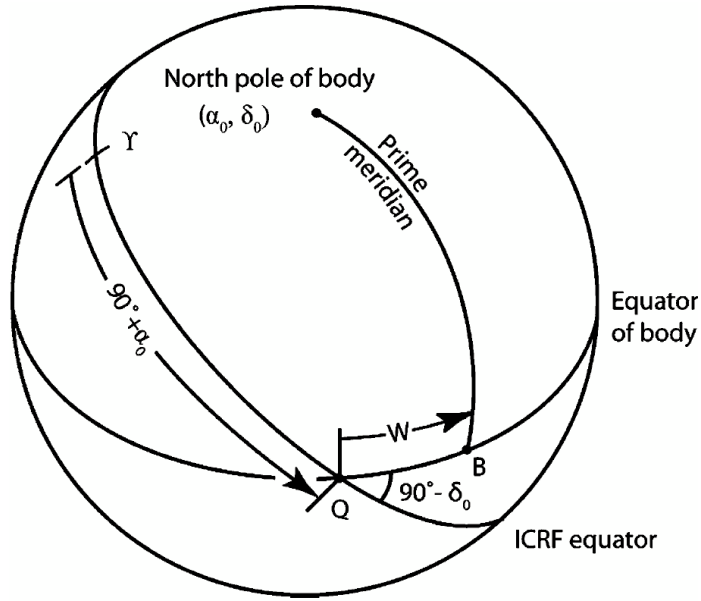


Figure 1.1. Reference system used by IAU/IAG to define planetographic coordinates (Seidelmann et al, 2002)

Despite the similarities with the implementation for Earth, there is a number of namelist parameters that are either not supported or not used by the orbit generator. An overview of the MISSION and SAPRE namelist for planetary orbits is presented in Table 1.2 and 1.3 respectively. Note that the parameter WISPR is scaled accordingly.

1.1.2.1 Mars

For the moment, only general and hyperbolic orbits are considered. Also, the gravitational effect of the Martian moons, Phobos and Deimos, have not been included in the calculation. Finally, the prime meridian of the Martian planetographic coordinate system is defined by the crater Airy-0.

Table 1.2. Default MISSION parameters for Mars and Jupiter

MISSION parameter	Mars	Jupiter
PRODEF	' '	' '
PROTIT	' '	' '
PLANET	4	5
NTRAJ	1	1
IMISD	3	3
JMISD	1	1
MISDUR	31.0	31.0
MEYEAR	2000	2000
MEMON	2	2
MEDAY	1	1
MEHRS	0	0
MEMIN	0	0
MESEC	0	0.0
EMJD	18293.0	18293.0
SEGDUR	31.0	31.0
ISRP	0	0
WIBSPR	0.0	0.0
ORBGEN	only 1 supported	
KATT	not supported	
IDRAG	not used	
WIBAIR	not used	
F107A	not used	
F107	not used	
AP	not used	
XB	not used	
XM	not used	
PB	not used	
PM	not used	

1.1.2.2 Jupiter

As in the case of Mars, one can only generate general or hyperbolic orbits around Jupiter. In addition, the gravitational effects of the four Galilean moons of Jupiter (Io, Europa, Ganymede and Callisto) have been taken into consideration. The planetographic coordinate system adopted for Jupiter is the IAU2000 as defined in Seidelmann et al, 2002.

Table 1.3. Default SAPRE parameters for Mars and Jupiter

SAPRE parameter	Mars	Jupiter
TITLE	' '	' '
OEYEAR	2005	2005
OEMON	1	1
OEDAY	1	1
OEHRS	0	0
OEMIN	0	0
OESEC	0.0	0.0
AMJD	-1.0	-1.0
IDUR	0	0
ORBITS	1.0	1.0
EPDUR	1.0	1.0
IAE	0	0
HPER	300.0	56602.0
HAPO	36000.0	1811302.0
A	3600.0	73000.0
E	0.0	0.0
HYP A	-30000.0	-300000.0
HYP E	1.2	1.4
RINCL	0.0	0.0
RAAN	0.0	0.0
ARGPER	0.0	0.0
TRANO	0.0	0.0
ISTART	1	1
STEP	0.5	0.5
DT1	60.0	60.0
DT2	240.0	240.0
DT3	3600.0	1200.0
DH2	20000.0	50000.0
DH3	80000.0	700000.0
PA	90.0	90.0
TYPE	only ' GEN' and ' HYP' supported	
IAN	not used, forced to 0	
IG50	not used, forced to 1	
TLE1	not used	
TLE2	not used	
ALT	not used	
SOLTIM	not used	
OELONG	not used	
RAU	not used	

1.2 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 2

Radiation sources and effects

2.1 Radiation sources

The TREP, SEP, SEPFLARE and GCR programs calculate orbital radiation environment fluxes for arbitrary spacecraft trajectories. They estimate fluxes of trapped particles in function of (B, L) coordinates, compute solar particle event probabilities to estimate solar particle fluences, short-term solar particle fluxes for Single Event Upset rates, and Galactic Cosmic Ray fluxes. 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.
4. solar flare flux spectra, taking into account geomagnetic shielding.
5. Galactic Cosmic Ray flux 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. 1.2), and TREPBL outputs trapped protons and electrons for a grid of magnetic coordinates.

To estimate SEU rates, the CREME (Cosmic Ray Effects on MicroElectronics) software package, developed by the Naval Research Laboratory (Adams 1986), was implemented in SPENVIS in the form of two programs: LETORB and UPSETO. LETORB calculated the attenuated cosmic ray and solar flare particle flux for each point of the generated orbit, and transformed the combined energy spectra together into LET spectra, which were then used by the UPSETO program to calculate SEU rates. However to implement new algorithm(s) for computing SEU rates (slowing down and stopping ion algorithm) both programs LETORB and UPSETO

have been merged into one program `NEWUPSETO` with the extraction of the environment models into `SEPFLARE` for solar particles and `GCR` for Galactic Cosmic Rays. The GCR model Nymmik et al. (1996) is similar to the ISO model but includes a rising flux at energies around 10 MeV/nucleon. Input particle spectra for computing SEU rates are the trapped particles, the short-term solar particles and the Galactic Cosmic Rays.

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)
 - IGE-2006/POLE (Boscher et al., 2003; Sicart-Piet et al., 2006 & 2008)
- long-term solar particle fluence models
 - JPL (Feynman et al. 1993)
 - Rosenqvist et al. (2005, 2007)
 - King (1974)
 - ESP worst case fluence (Xapsos et al. 1999) and cumulative fluence (Xapsos et al. 2000) both including PSYCHIC (Xapsos et al. 2007) for heavy ions
- short-term solar particle flux models
 - CREME-96 SEP ion models (peak 5min average fluxes, worst day and worst week fluxes)
 - CREME-86 SEP ion models (M=5-1, 6-1, 7-1, 8-1, 9-1, 10-1, 11-1, 12-1)
 - Xapsos et al. 2000 (October 1989 flare fluxes with mean or worst-case composition)
- Galactic Cosmic Ray particle flux models
 - ISO 15390
 - CREME-96 Solar Minimum (1977)
 - CREME-86 M=1, 2, 3, 4
 - Nymmik et al. (1996)

2.1.1 Trapped particle models

2.1.1.1 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), IGE-2006/POLE (4)¹

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, 4):

- AE-8: AE-8 MAX (1), AE-8 MIN (2)
- CRRESELE: 6 A_p ranges (1–6), average flux (7), maximum flux (8)
- IGE-2006/POLE: POLE-V1 (1), POLE-V2 (2), IGE-2006 (3)

CFLUX Flux case for the IGE-2006 electron model: lower (1), mean (2), upper (3)

ISIG Index for confidence level of AE-4 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:

¹This electron model only runs for geostationary orbits

```

TRPMOD = 1
TREMOT = 1
MINDP = 1
MINDE = 1
CFLUX = 2
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

```

2.1.1.2 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
```

2.1.1.3 Positional version: geographic coordinates

TREPPPOS reads the coordinates of the points in the `spenvis_pos.txt` file produced by GRID (see Sect. 1.2). 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'

TREMOD 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, 4):

- 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. 1.2). 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
TREMOT = 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
```

2.1.1.4 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) or 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
```

2.1.2 Solar particle models

SEP predicts solar energetic particle 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 particle 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), Rosenqvist et al. (2005, 2007) (6)

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

HIFLUENCE Inclusion of heavy ion fluences from PSYCHIC: yes (1) or no (0)

ION1 atomic number of the lightest ion (2–92)

ION2 atomic number of the heaviest ion (2–92)

The defaults for the SEP namelist are defined as:

```
FLAMOD = 5
NAL = 0
NOR = 0
NENERS = 30
ENEREFL = 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
HIFLUENCE = 0
ION1 = 2
ION2 = 92
```

SEPFLARE predicts solar energetic particle fluxes. For trajectories inside the magnetosphere, geomagnetic shielding is evaluated at each spacecraft location in the orbit file `spenvis_sao.txt` and for each particle energy. The model parameters are defined in the SEPFLARE namelist:

FLAREMOD Index of the solar energetic particle models (0: CREME-86, 1: CREME-96, 3: Xapsos et al. (2000))

ION1 atomic number of the lightest ion (1–92)

ION2 atomic number of the heaviest ion (2–92)

MQNEW index of CREME-86 flare model (5: M=5-1, 6: M=6-1, 7: M=7-1, 8: M=8-1, 9: M=9-1, 10: M=10-1, 11: M=11-1, 12: M=12-1, 13: M=13-1) or index of Xapsos et al. (2000) model (13: October 1989 flare flux and mean composition, 14: October 1989 flare flux and worst-case composition)

CREME96 index of CREME-96 flare model (1: worst week, 2: worst day, 3: peak 5 min average)

EVENT89 October 1989 flare flux day (19: Oct. 19, 22: Oct. 22, 24: Oct. 24)

IGC Flag for magnetic shielding: off (0) or on (1)

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

The defaults for the SEPFLARE namelist are defined as:

```
FLAREMOD = 1
ION1 = 1
ION2 = 28
CREME96 = 1
NENERS = 75
ENERFL = 0.10,0.11,0.12,0.14,0.16,0.18,0.20,0.22,0.25,0.28,0.32,0.35,0.40,0.45,0.5,
0.55,0.63,0.71,0.80,0.90,1.0,1.1,1.2,1.4,1.6,1.8,2.0,2.2,2.5,2.8,3.2,3.5,4.0,
4.5,5.0,5.5,6.3,7.1,8.0,9.0,10.0,11.0,12.0,14.0,16.0,18.0,20.0,22.0,25.0,28.0,
32.0,35.0,40.0, 45.0,50.0,55.0,63.0,71.0,80.0,90.0,100.0,110.0,120.0,140.0,
160.0,180.0,200.0,220.0,250.0,280.0,320.0,350.0,400.0,450.0,500.0
IGC = 0
ISTORM = 0
```

2.1.3 Galactic Cosmic Ray particle models

GCR predicts Galactic Cosmic Ray particle fluxes. For trajectories inside the magnetosphere, geomagnetic shielding is evaluated at each spacecraft location in the orbit file `spenvis_sao.txt` and for each particle energy. The model parameters are defined in the GCR namelist:

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

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

GCRMOD GCR model (0: CREME-86, 1: ISO 15390, 2: Nymmik et al.(1996), 3: CREME-96)

MQ Interplanetary space weather index (1–4: CREME-86, 30–32: ISO-15390, 38–40: Nymmik et al.(1996), 9677: CREME-96)

UISCD Solar activity data: mission epoch (0), Solar Minimum (May 1996) (1), user defined (2)

SCN Solar cycle number: odd (1) or even (2)

MINSa Yearly averaged SSN at minimum

MAXSA Yearly averaged SSN at maximum

REVMOM Moment of polarity reversal of solar magnetic field

ASSN Yearly averaged SSN at epoch

SSN_LAG Yearly averaged SSN at epoch - lag

PROP Scaling with r : no scaling(1) or force field approximation (2)

VSUN average solar wind velocity (km/s)

KAPPA radial diffusion coefficient : constant (1) or power law (2)

K0 value of radial diffusion coefficient if KAPPA constant, value of proportionality if constant KAPPA power law

POWERI power of radial diffusion coefficient in inner heliosphere

RIN boundary of inner heliosphere (AU)

POWERO power of radial diffusion coefficient in outer heliosphere

ROU boundary of outer heliosphere (AU)

IGC Flag for magnetic shielding: off (0) or on (1)

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

We remark that **UISCD** is an option that comes along with the MSU model and that **UISCD=2** is only available for the advanced user. In this case the user can enter his own solar cycle data (=SCN, MINSa, MAXSA, REVMOM, ASSN and SSN_LAG).

The defaults for the GCR namelist are defined as:

```

IELM = 1
JELM = 92
GCRM0D = 1
MQ = 30
UISCD = 1
SCN = 1
MINSA = 9.6
MAXSA = 110.6
REVMOM = 1968.87
ASSN = 110.0
SSN_LAG = 95.0
PROP = 1
VSUN = 400
KAPPA = 1
K0 = 4.38
POWERI = 1.1
RIN = 10.0
POWERO = 1.4
ROUT = 100.0
IGC = 1
ISTORM = 0

```

2.1.4 Shielded flux

MFLUX calculates proton, electron and neutron fluxes behind a given spacecraft shielding (defined in terms of the total thickness of the shielding and the Tantalum to Aluminium ratio) by using the MULASSIS look-up tables included in SPENVIS. The incident particles are assumed to be trapped protons and electrons and solar energetic protons.

The model parameters are defined in the MFLUX namelist:

ENVTP Flag for selecting trapped protons as incident source

ENVTE Flag for selecting trapped e- as incident source

ENVSP Flag for selecting solar protons as incident source

UTSHIELD Total thickness in $[g/cm^2]$

UTA2AL Tantalum to Aluminium ratio in [%]

PDATA Electron MULASSIS look-up data path

EDATA Proton MULASSIS look-up data path

TRAJ Mission segments

The defaults for the MFLUX namelist are defined as:

```

ENVTP = 1
ENVTE = 0
ENVSP = 0
UTSHIELD = 1
UTA2AL = 0
PDATA = ' '
EDATA = ' '
TRAJ = 1

```

2.2 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:

- SHIELDOSE and SHIELDOSE-2 for ionizing dose;
- non-ionizing dose curves;
- EQFLUX for solar cell damage equivalent fluences;
- MC-SCREAM for NIEL based damage equivalent fluences for solar cells;
- NEWUPSETO for LET spectra and Single Event Upset rates;
- Effective dose and ambient dose equivalent;
- MULASSIS, a Geant4 based Monte Carlo tool for analysing the radiation effects in simple shielding geometries.
- GEMAT, a Geant4 based Monte Carlo tool for studying microdosimetry effects of space radiation on microelectronics/micro-sensors.
- GRAS, a Geant4 based Monte Carlo tool for analysing the radiation effects in generic 3D geometry models.

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

Note that all Geant4 tools implemented in SPENVIS along with the sectoring analysis tool are described later on in a separate Geant4 tools section (Ch. 9).

2.2.1 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 $\text{JSHLD}=2$

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 $\text{JSHLD}=1$

DOSMOD Control variable for use with SPENVIS only to check that the namelist was generated for SD. For applications outside SPENVIS, set $\text{DOSMOD}=0$ 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 $\text{JSHLD}=2$

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 $\text{JSHLD}=1$

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 $\text{DOSMOD}=0$ 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
```

2.2.2 Non-ionizing energy loss

NIEL calculates equivalent proton fluences deposited in devices, using non-ionizing 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
```

2.2.3 Damage equivalent fluence

EQFLUX calculates 1 MeV damage equivalent electron fluences for exposure to trapped particle and SEP fluences. The model parameters for EQFLUX 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 Isc

PEDRV Damage ratio between protons and electrons for Voc

PEDRP Damage ratio between protons and electrons for Pmax

CGTHICK Cover glass thickness

CGUNIT Unit cover glass thickness: mils (1), g/cm² (2), μm (3)

The defaults for the EQFLUX namelist are defined as:

```
ICELL = 1
JCELL = 1
CGTHICK = 25.4
CGUNIT = 3
```

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

2.2.4 MC-SCREAM (Undocumented)

The MC-SCREAM application in SPENVIS (Messenger et al. 2008) implements the displacement damage dose (DDD) methodology in a format complementary to that of SAVANT, using MULASSIS simulations and fluences predicted by the trapped radiation models for Earth or Jupiter and the solar proton flux models. The model parameters are defined in the SCREAM namelist.

2.2.5 LET spectra and Single Event Upset rates

NEWUPSETO calculates SEU rates and LET spectra from the energy spectra produced by TREP, SEPFLARE and GCR. Currently, LET curves are computed for Si and GaAs. The advanced user has the option to make the calculations for each orbital point by setting SFULL=1.

The LET and SEU rates for each orbital point are written respectively to the files `spenvis_nloo.txt` and `spenvis_nuoo.txt`. The particle energy and the LET spectra corrected for spacecraft shielding are written to the file `spenvis_nlol.txt`. In case the variable LET method is used for heavy ion upset rates, the averaged (over all ions in the spectra) LET values are given in the file `spenvis_nlof.txt` for mission averages and in

`spenvis_nloq.txt` for each orbital point. The record format of the `spenvis_nloo.txt` file is given in Table 2.1.

If experimental data are used in `NEWUPSETO`, the data and fit parameters are written to the file `spenvis_nuof.txt`. In case of an imported path length distribution, the normalised differential and cumulative probability density distribution is written to the file `spenvis_nuol.txt`. The model parameters for `NEWUPSETO` are defined in the `NEWUPSETO` namelist which is splitted in two, one for the environment and one for the devices:

for the environment (`MAINUPSETO`):

ITP include (1) or not (0) trapped particles if spectra exists

ISETP include (1) or not (0) solar particles if spectra exists

IGCR include (1) or not (0) gcr particles if spectra exists

SFULL output resolution: mission segment averages (0) or spectra for each orbital point (1)

THICK Shielding thickness (cm)

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

NDEVICES Number of devices (max. 15)

The defaults for the environment namelist are defined as:

```
ITP = 1
ISEP = 1
IGCR = 1
SFULL = 0
THICK = 1.0
IUNT = 1
NDEVICES = 2
```

for the devices (`PARUPSETO`):

IDEDX device material: Si (SRIM2008) (0), Si(CREME-86) (1), GaAs(SRIM2008) (2), GaAs(Geant4.9) (3)

DEVICE user defined device (0) or a device selected from a list of predefined devices (1)

DNAME device name; only when `DEVICE` = 0

PLDISTR shape of sensitive volume: rectangular parallelepiped (0) or arbitrary (1)

X First device dimension (μm); only when `PLDISTR` = 0

Y Second device dimension (μm); only when `PLDISTR` = 0

Z Third device dimension (μm); only when $\text{PLDISTR} = 0$

SIGMA LIM cross section; only when $\text{PLDISTR} = 0$

TOPA topsurface of sensitive volume; only when $\text{PLDISTR} = 1$

TOTA total surface of sensitive volume; only when $\text{PLDISTR} = 1$

VOL volume of sensitive volume; only when $\text{SHAPE} = 1$

IPLD(500,2) input path length (μm) and corresponding probability density values ($1/\mu\text{m}$); only when $\text{SHAPE} = 1$

IB Flag for proton induced upsets: experimental data (0), Bendel function (1), Weibull function (2), PROFIT (3), ignore (5)

A First parameter of Bendel function; only when $\text{IB}=1$

B or $[\sigma_{lim}]$ Second parameter of Bendel function; only when $\text{IB}=1$

PLS First parameter of Weibull function; only when $\text{IB}=2$

PLTH Second parameter of Weibull function; only when $\text{IB}=2$

PLW Third parameter of Weibull function; only when $\text{IB}=2$

PLCSLIM Fourth parameter of Weibull function; only when $\text{IB}=2$

ANGLE Average diffusion angle of protons; only when $\text{IB}=3$

PROF_S First parameter of Weibull function; only when $\text{IB}=3$

PROF_L0 Second parameter of Weibull function; only when $\text{IB}=3$

PROF_W Third parameter of Weibull function; only when $\text{IB}=3$

PROF_CSLIM Fourth parameter of Weibull function; only when $\text{IB}=3$

PIUR(100, 2) Experimental proton induced upset data: energy (MeV), cross section ($\text{cm}^2 \text{ bit}^{-1}$); only when $\text{IB}=0$

IIB fitting method (-1 : Bendel fit, -2 : Weibull fit, -3 : Lin. int.); only when $\text{IB}=0$

IU Flag for direct ionization upsets: critical charge (1), experimental data (0), Weibull function (-1) or ignore (2)

QCRIT Critical charge (pC); only when $\text{IU}=1$

DLS First parameter of Weibull function; only when $\text{IU}=-1$

DLTH Second parameter of Weibull function; only when $\text{IU}=-1$

DI_W Third parameter of Weibull function; only when $IU=-1$

DI CSLIM Fourth parameter of Weibull function; only when $IU=-1$

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

LETFLAG Flag for algorithm direct ionization upsets: constant LET (CREME-86) (0), variable LET (1), slowing and stopping ions (2)

The defaults for the NEWUPSETO namelist are defined as:

```
IDEDX = 0
DEVICE = 0
DNAME = 'DEFAULT'
PLDISTR = 0
X = 38.7
Y = 38.7
Z = 2.0
SIGMA LIM = 1450
TOPA = 1.5e3
TOTA = 3.3e3
VOL = 3.0e3
IPLD = 1000*-1.0
IB = 1
A = 4.88 (Si) and 28.44 (GaAs) if IB=1
B = 7.09 (Si) and 42.02 (GaAs) if IB=1
PI_S = 2.51 (Si) and 1.60 (GaAs) if IB=2
PI_TH = 4.0 (Si) and 17.6 (GaAs) if IB=2
PI_W = 21.8 (Si) and 90 (GaAs) if IB=2
PI CSLIM = 1.19e-10 (Si) and 0.5e-10 (GaAs) if IB=2
ANGLE = 90
PROF S = 0.66
PROF L0 = 0.55
PROF W = 5.49
PROF CSLIM = 1.5e-5
PIUR = 200*-1.0 if IB= 0
IIB = -2
IU = 1
QCRIT = 1.13e-2 (Si) and 3.02e-2 (GaAs) if IU=1
DI S = 0.66 (Si) and 0.48 (GaAs) if IU=-1
DI TH= 0.547 (Si) and 0.85 (GaAs) if IU=-1
DI W = 5.49 (Si) and 0.70 (GaAs) if IU=-1
DI CSLIM = 1.5e-5 (Si) and 3.2e-6 (GaAs) if IU=-1
DIUR = 200*-1.0 if IU=0
LETFLAG = 0
```

Table 2.1. Record structure of the `spenvis_nlooo.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

2.2.6 Effective dose and ambient dose equivalent

This particular SPENVIS application consists of two FORTRAN programs `SMUL_MACRO` and `SMUL_POST`. The first one allows the user to create a specific Geant4 macro file for input by the stand-alone binary implementation of MULASSIS. The user can define the geometry, the incident particle source and the physics scenario. However, the analysis type is fixed and only fluences behind the total shielding are considered. Then, the second program processes the MULASSIS output and utilises the appropriate conversion coefficients (Pelliccioni, 2000) in order to calculate the effective dose or the ambient dose equivalent.

The shielding materials can be selected from a separate namelist called `USERMAT` generated

by the material definition tool (see Sect. 9.3.3). The model parameters for `SMUL_MACRO` are defined in the `MULMAC` namelist. In addition to the parameters defined in the definition of physical models sections the following parameters are also part of the `MULMAC` namelist:

ENVTP Flag for selecting trapped protons as incident source

ENVTE Flag for selecting trapped e- as incident source

ENVSP Flag for selecting solar protons as incident source

TRAJ Mission segments

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`

NEVENTS Number of primary events to simulate

ARBINT Interpolation type for energy spectra: linear (`Lin`), power law (`Log`), exponential (`Exp`), cubic spline (`Spline`)

USE_EBIAS Flag for energy biasing: if `USE_EBIAS=0` then no energy biasing

NREGION Number of regions for region dependent cuts

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

DEFCUTREGUNIT Region cut units: μm (um), mm (mm), cm (cm), m (m)

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

The defaults for the SMUL namelist are defined as:

```
ENVTP = 0
ENVTE = 0
ENVSP = 0
USER = 0
SHAPE = 'slab'
NLAYER = 1
MATERIALNAME = 42*' '
THICKNESS = 42*0.0d0
TUNIT = 42*' mm'
COLOURINDEX = layer index
VIS = 0
TRACK = 0
FILE = 0
NEVENTS = 10
TRAJ = 1
ARBINT = 'Lin'
GLOBCUTV = 1.0d0
DEFCUTUNIT = 'um'
DEFCUTREGUNIT = 'um'
PARCUT = 0
GAMCUTV = 1.0d0
ELECUTV = 1.0d0
POSCUTV = 1.0d0
NREGION = 0
CUTLAYER = 1764*0
RGLOCUTV = 42*1.0
RGAMCUT = 42*0.0
RELECUT = 42*0.0
RPOSCUT = 42*0.0
RGAMCUTV = 42*1.0
RELECUTV = 42*1.0
RPOSCUTV = 42*1.0
```

The SMUL_POST parameters are defined in the SMULPOST namelist:

ANALYSIS Analysis type: Antero-posterior irradiation (eap), isotropic irradiation (eis), lateral irradiation (ela), postero-anterior irradiation (epa), from top irradiation (etp), or ambient dose equivalent (ade).

INFN_PATH Pelliccioni INFN data path

ENVTP Flag for selecting trapped protons as incident source

ENVTE Flag for selecting trapped e- as incident source

ENVSP Flag for selecting solar protons as incident source

TRAJ Mission segments

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`

NEVENTS Number of primary events to simulate

ARBINT Interpolation type for energy spectra: linear (`Lin`), power law (`Log`), exponential (`Exp`), cubic spline (`Spline`)

USE_EBIAS Flag for energy biasing: if `USE_EBIAS=0` then no energy biasing

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

```
USER = 0
ENVTP = 0
ENVTE = 0
ENVSP = 0
SHAPE = 'slab'
ANALYSIS = ' '
INFN_PATH = ' '
```

```

NLAYER = 1
MATERIALNAME = 42*' '
THICKNESS = 42*0.0d0
TUNIT = 42*' mm'
COLOURINDEX = layer index
VIS = 0
TRACK = 0
FILE = 0
NEVENTS = 10
TRAJ = 1
ARBINT = 'Lin '
USE_EBIAS = 0

```

2.3 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.

2.3.1 Material data base

The `MATERIAL` programme is now obsolete.

2.3.2 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 3

Spacecraft charging models

3.1 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
```

3.2 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
```

3.3 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), cold single Maxwellian and Fontheim electrons (7). 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(30,20) Predefined patch material parameters

UPNAME Name of user defined patch material

UPPROPS(20) 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 20 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 resistivity (ohm sq^{-1}), not used
13. flag for selecting the SEE formula: 1 for Katz, 0 for Sims, -1 for Whipple and -2 for Burke
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
19. the number of valence electrons in a monomeric unit (for Burke SEE formula)
20. the molecular weight (in gram) of monomeric unit

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 = 90.0
ICHO = 0
VSTART = 0.0
DV0 = 100.0
IRAM = 0
WSAT = 500.0
AATT = 90.0
VS0 = 0.0
THICKI = 0.001
BCONDI = 1.0D-15
DIELCI = 3.0
VBEGIN = 0.0
VEND = 50.0
DV = 5.0
TPATCH = 273.0
IMATS = 7
IMATP = 1
IFELD(1) = 0
IFELD(2) = 0
ENVTyp = 1
IENV = 1

```

3.4 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);
- 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 3.1) 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 3.1)

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)

Table 3.1. 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			

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 3.1)

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 3.1 or 'Kp' for Kapton)

UMATS Materials for spacecraft structure (two two-character strings from the list in Table 3.1 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 4

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);
- NeQuick v2.0 (Nava, Coisson & Radicella 2008).

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.

4.1 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 and the attitude files (`spenvis_sao.txt` and `spenvis_att.txt` respectively) 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), NeQuick v2.0 (6)

F107 F_{107} solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$); not used when MODEL=6

F107A Average F_{107} 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 and for the NeQuik model corresponds to the monthly average solar radio flux

AP Daily A_p index (2 nT); not used when MODEL=5 or MODEL=6

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; not used when MODEL=6

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 = 60.0
AP = 20.0
NPART = 2
IRATE = 0
EROSION = 1.0
ERLIST = 1.0
THERM_MOT = 0
DIR = 1
THETA = 0.0
PHI = 0.0
```

4.2 Positional version

The ATMOPUS program calculates densities and temperatures for the geographic positions in the grid file `spenvvis_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), NeQuick v2.0 (6)

DAY Day of year

F107 F_{107} solar radio flux ($10^{-22} \text{W m}^{-2} \text{Hz}^{-1}$); not used when `MODEL=6`

F107A Average F_{107} 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 and for the NeQuik model corresponds to the monthly average solar radio flux

AP Daily A_p index (2 nT); not used when `MODEL=5` or `MODEL=6`

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_{107} (2), average F_{107} 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_{107} range; only used if `IRANGE=2`

F107A2 Last value of the average F_{107} 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. 1.2). 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 = 60.0
F107A2 = 60.0
AP = 20.0
AP2 = 20.0
IRANGE = 0
ISEL = 0
STEP = 10.0
NVAL = 1
ILOG = 0
IMAP = -1
```

Chapter 5

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. 1.2. 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)

5.1 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
```

5.2 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. 1.2). 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

```

5.3 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 = 0.0
    IMFY = 0.0
    IMFZ = 0.0
    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 6

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.

6.1 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 square meters 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)

KMASDEN Flag for selecting density model: constant value (0) or step function mass (1)

DENSITY Particle density (g cm^{-3}); used if KMASDEN=0

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 GRUN namelist are defined as:

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

6.2 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_{107} 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
```

6.3 Particle/wall interaction

The tool implemented in SPENVIS evaluates the ballistic limit equations for micro-particle environment risk analysis, based on the Micrometeoroid and Orbital Debris (MMOD) Shield Ballistic Limit Analysis Program. Once the user has input all shield properties and impact conditions, a ballistic limit curve is generated. The ballistic limit curve defines the failure (e.g. perforation) limits of the structure in terms of projectile diameter and impact velocity. This means that for impact conditions that are below the curve the shield is predicted to successfully defeat the impactor. The model parameters are entered using the `impact_mmod` namelist:

ANG_P Impact angle (deg)

RHO_P Density of impactor (g/cm^3)

WALLTYPE Shielding configuration (1: metallic monolithic shield, 2: carbon fiber reinforced plastic, 3: fiberglass wall, 4: thick glass window, 5: polycarbonate window, 6: metallic Whipple shield, 7: honeycomb sandwich panel, 8: metallic triple wall)

MLI_FRONT Presence/absence (1/0) of thermal blanket in case **WALLTYPE** = 1, 6, 7, 8

MLI_AD Areal density of thermal blanket (g/cm²)

FAILMODE Failure type that must be prevented (1: internal fracturing, 2: spallation, 3: perforation), only available for WALLTYPE = 1 - 5

OBUMP_MAT Material of outer bumper in case WALLTYPE = 8 (materials 1-36 listed in table 6.1)

OBUMP_THICK Thickness of outer bumper (cm)

BUMP_MAT Material of bumper in case WALLTYPE = 6, 7, 8 (materials 1-37 listed in table 6.1)

BUMP_THICK Thickness of bumper (cm)

WALL_MAT Material of target wall (all materials listed in table 6.1)

WALL_THICK Thickness of target wall (cm)

SPACE_OB_B Distance between outer bumper and bumper (cm)

SPACE_B_RW Distance between bumper and target wall (cm)

PRODEF Character string containing the project name

TITLE Character string containing the project title

All available materials with their index are given in table 6.1. The defaults for the `impact_mmod` namelist are defined as:

```
ANG_P = 0.0
RHO_P = 2.7
WALLTYPE = 1
MLI_FRONT = 1
MLI_AD = 0.1
FAILMODE = 1
OBUMP_MAT = 1
OBUMP_THICK = 1.5
BUMP_MAT = 1
BUMP_THICK = 1.5
WALL_MAT = 1
WALL_THICK = 1.5
SPACE_OB_B = 5.0
SPACE_B_RW = 10.0
PRODEF = ' '
TITLE = ' '
```

Table 6.1. List of materials available for shielding configurations.

Index	Material
Annealed Aluminium alloys	
1	Al 99.0 Cu
2	Al Cu4SiMg
3	Al Cu4Mg1
4	Al Mn1Cu
5	Al Mg2.5
6	Al Mg3.5
7	Al Mg3Mn
8	Al Mg1SiCu
9	Al Zn6MgCu
Strain-hardened Aluminium alloys	
10	Al 99.0 Cu (H14)
11	Al 99.0 Cu (H18)
12	Al Mn1Cu (H14)
13	Al Mn1Cu (H18)
14	Al Mg2.5 (H34)
15	Al Mg2.5 (H38)
16	Al Mg3.5 (H34)
17	Al Mg3.5 (H38)
18	Al Mg3Mn (H34)
Solution heat-treated Aluminium alloys	
19	Al Cu4SiMg (T4)
20	Al Cu4SiMg (T6)
21	Al Cu4Mg1 (T4)
22	Al Mg1SiCu (T4)
23	Al Mg1SiCu (T6)
24	Al Zn6MgCu (T6)
Stainless steel (SST)	
25	Austenitic X5CrNi18-10
26	Austenitic X5CrNiMo17-12-2
27	Austenitic X3NiCrMoN-24-20-6
28	Duplex X2CrNiN23-4
29	Duplex X2CrNiMoN25-7-4
30	Duplex X2CrNiMoCuN25-6-3
Precipitation-hardening SST	
31	X5CrNiCuNb16-4
32	X7CrNiAl17-7
33	15-5 (*)
Other metallic alloys	
34	β -Titanium 15-3-3-3
35	α/β Titanium 6-2-2
36	β -Titanium 15-3-3-3 (*)
37	Carbon fiber reinforced plastic
38	Fiberglass
39	Fused silica glass
40	Fused quartz glass
41	Polycarbonate

Chapter 7

Planetary models and tools

As we have mentioned in Chapter 1, `SAPRE` orbit generator has been modified in order to be able to calculate orbits around Mars and Jupiter. Thus, this chapter contains the descriptions of a number of models and tools that are related to planets other than Earth.

7.1 Jovian radiation sources

The `TREP_JUP` program calculates orbital radiation environment fluxes for spacecraft trajectories around Jupiter. Its output consists of:

1. the integral and differential fluxes of trapped protons and trapped electrons;
2. trajectory-averaged spectra for trapped protons and electrons;

The following trapped particle radiation models have been implemented in `SPENVIS`:

- trapped proton models
 - D&G83 (Divine & Garrett 1983)
 - Salammbô (Bourdarie & Sicard 2006)
- trapped electron models
 - D&G83 (Divine & Garrett 1983)
 - GIRE (Garrett et al. 2003)
 - Salammbô (Bourdarie & Sicard 2006)

7.1.1 Trapped particle models for Jupiter

7.1.1.1 Orbital version

TREP_JUP accesses Jovian 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_JUP namelist:

TRPMOD Index of the trapped proton models: D&G83 (1), D&G83 + Salammbô (2)

TREMOD Index of the trapped electron models: D&G83 (1), D&G83 + Salammbô (2), D&G83 + GIRE (3), D&G83 + Salammbô + GIRE (4)

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

The defaults for the TREP_JUP namelist are defined as:

```
TRPMOD = 1
TREMOD = 1
NENERP = 30
NENERE = 30
PROEN  = 0.6, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0,
          20.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0, 100.0, 200.0,
          300.0, 400.0, 500.0, 600.0, 700.0, 800.0, 900.0, 1000.0, 2000.0
ELEEN  = 0.06, 0.1, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0,
          20.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0, 100.0, 200.0,
          300.0, 400.0, 500.0, 600.0, 800.50, 1000.0, 2000.0
```

7.2 MEREM (Undocumented)

The Mars Energetic Radiation Environment Model (MEREM) framework that has been integrated into SPENVIS has been developed as part of the MarsREM study (Keating and Valente 2007). MEREM allows the user to input mission-related information such as mission epoch (defining solar cycle and Martian season), duration, Mars orbit, coordinates of lander/habitat and local soil conditions. MEREM produces a variety of output quantities: particle flux or fluence spectra as a function of species, absorbed dose, effective dose, etc. Two MEREM applications were developed:

- eMEREM, an engineering model, to provide rapid assessment of different mission options;
- dMEREM, a detailed radiation simulation model to provide more accurate analysis of a few sites.

There are also four types of coordinate input available:

1. single location (both eMEREM and dMEREM);
2. elevation profile (10 pre-set elevations for both eMEREM and dMEREM);
3. Mars orbit calculated using `SAPRE` (eMEREM only);
4. moon surface (dMEREM only).

Note that dMEREM runs a full Geant4 Monte Carlo simulation for each specified location, taking into account the detailed soil and atmosphere composition. In contrast, eMEREM uses a set of response matrices for energetic radiation incidence at the top of the Martian atmosphere, pre-calculated with FLUKA using a simple fixed layered atmosphere model and a selection of four ground materials (global average, equatorial composition, water ice and dry ice) (Lei, 2008).

The model parameters are defined in the MEREM namelist.

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.
- a tool for converting unidirectional radiation damage coefficients into omnidirectional ones.
- a tool for computing view factors between the surfaces of given geometry
- a tool for computing the contamination of surfaces

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_att.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. 1.2). 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 RDC converter

The RDC converter tool computes omnidirectional radiation damage coefficients for a range of thickness values of cover glass, using the JPL procedure (Tada et al., 1982; Anspaugh et al., 1996). The main required input are the unidirectional RDC values for naked cells. The input data are specified in the **RDCCONV** namelist:

PRODEF Character string containing the project name

TITLE Character string containing the project title

CELLN The name of the cell

CELLM The material of the cell: silicon (2) or gallium-arsenide (3)

CELLT Thickness of the cell in micrometer

PEDRI Damage ratio between protons and electrons for Isc

PEDRV Damage ratio between protons and electrons for Voc

PEDRP Damage ratio between protons and electrons for Pmax

ERDC0(100,2) Input table: unidirectional RDCs vs. electron energies

PRDC0(100,4) Input table: unidirectional RDCs vs. proton energies for Isc, Voc and Pmax

The defaults for the RDCCONV namelist are defined as:

```
PRODEF = ' '
TITLE = ' '
CELLN = ' '
CELLM = 2
ERDC0 = 200*-1.0
PRDC0 = 400*-1.0
```

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

8.5 View Factor

The View Factor tool computes the view factor between each pair of surfaces in a given geometry. The main required input is a geometry file and some precision parameters. The input data are specified in the VIEWF namelist:

CHOICE Geometry definition: sample geometry file (1), existing uploaded geometry file (2), upload new geometry file (3)

GEOSAMP Name of the sample geometry file

GEONAME Name of the uploaded geometry file

DELAU Limiting area of the Delaunay triangle: relative (1) or absolute (2)

RALIM Value of limit in % if DELAU = 1

AALIM Value of limit in m² if DELAU = 2

ITOL Integration tolerance

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

```
CHOICE = 1
GEOSAMP = Shapiro(1983)
GEONAME = ' '
DELAU = 1
RALIM = 10
AALIM = 1E-4
ITOL = 1E-4
```

8.6 Contamination

The Contamination tool computes the deposited masses and surface densities for a given geometry due to one contaminant emitting surface. It uses the view factors from the View Factor tool computed for the same geometry file. The input data are specified in the `CONTAM` namelist:

ESURFACE The contaminant emitting surface

EVOLUME The object containing the contaminant emitting surface

ORATE Outgassing type: constant (0) or proportional to available mass (1)

MOLMASS Molecular mass in a.m.u. if `ORATE` = 0

VPRESS Vapour pressure in hPa if `ORATE` = 0

MASS0 Initial available mass in g/cm² if `ORATE` = 1

REFTEMP Reference temperature in K

TEMPLEVEL Temperature run of the surface: low (1) or high (2)

INVTAU0 Inverse of the oscillation constant τ_0 in s⁻¹

TDC Residence time on the surface in s

STICK Sticking coefficient on the surface

T_LOW Temperature of surface in K when run is low

T_HIGH Temperature of surface in K when run is high

DURATION Duration of the outgassing process in s

TSTEP Integration time step

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

```
ESURFACE = ' '  
EVOLUME = ' '  
ORATE = 0  
MOLMASS = 18.0  
VPRESS = 13.3  
MASS0 = 10.0  
REFTEMP = 298  
TEMPLEVEL = low  
INVTAU0 = 25.0  
TDC = 0.07  
STICK = 1  
T_LOW = 10  
T_HIGH = 150  
DURATION = 100.0  
TSTEP = 1.0
```


Chapter 9

Geant4 tools

Geant4 (<http://geant4.web.cern.ch/geant4/>) is a Monte Carlo toolkit that simulates the passage of particles through matter. Its application areas include high-energy physics and nuclear experiments, medical, accelerator and space physics studies.

A number of Geant4 tools specific for space applications have been developed as part of the European Space Agency (ESA) activities in the Geant4 collaboration and have been subsequently integrated into SPENVIS. Table (9.1) gives an overview of the various Geant4 tools available in SPENVIS.

Table 9.1. Different Geant4 tools implemented in SPENVIS

Model name	Model version	Geant4 version
MULASSIS	1.19	4.9.2
GEMAT	2.4	4.9.0
SSAT	2.1	4.9.0
MAGNETOCOSMICS	2.0	4.7.1
PLANETOCOSMICS	2.0	4.8.1
GRAS	2.3	4.9.2

9.1 General models

In this section we present the Geant4 tools that are available for all the possible planet choices.

9.1.1 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 by

considering electromagnetic and nuclear interactions.

The SPENVIS program MULASSIS creates the Geant4 macro file `spenvis_mul.g4mac` for input by the stand-alone binary implementation of MULASSIS. The shielding materials can be selected from a separate namelist called USERMAT generated by the material definition tool (see Sect. 9.3.3).

The model parameters for MULASSIS are defined in the MULASSIS namelist. In addition to the parameters defined in the definition of source particles and physical models sections the following parameters are also part of 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 (`um`), 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`

NREGION Number of regions for region dependent cuts

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

DEFCUTREGUNIT Region cut units: μm (`um`), mm (`mm`), cm (`cm`), m (`m`)

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)

PARTICLENAME 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'`

FEOUT 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'

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

PHSEEDGEUNIT 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
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
TRAJ = 1
USE_EBIAS = 0
ENERGYDIS = 'Mono'
ENERGY = 1.00
IEUNIT = 'MeV'
MONOFLUX = 1.0
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 = 0.0
MAXTHETA = 90.0
ANGMINUNIT = 'deg'
ANGMAXUNIT = 'deg'
FLUNIT = ' '
LEEM = 0
SHOW\_ALL = 0
HADRON = 0
LN = 0
GEM = 0
DEFCUTUNIT = 'um'
DEFCUTREGUNIT = 'um'
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'

```

9.1.2 GEMAT

The Geant4-based Microdosimetry Analysis Tool (GEMAT) is used for the study microdosimetry effects of space radiation on microelectronics and micro-sensors.

The SPENVIS program GEMAT creates the Geant4 macro file `spenvis-gem.g4mac` for input by the stand-alone binary implementation of GEMAT. The shielding materials can be selected from a separate namelist called `USERMAT` generated by the material definition tool (see Sect. 9.3.3).

The model parameters for GEMAT are defined in the `GEMAT` namelist. In addition to the parameters defined in the definition of source particles and physical models sections the following

parameters are also part of the GEMAT namelist:

LSD Flag for defining the layer surface dimensions: default (0) or user defined (1)

XYSIZE Square side length; only used if LSD =1

XYUNITS Square side length units; only used if LSD =1

NLAYER Number of layers (maximum 100)

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

LMATNAME Names for the layer material: one pre-defined material (Vacuum) or a material from the USERMAT namelist

THICKNESS Layer thicknesses

TUNIT Units for the layer thicknesses: μm (μm), mm (mm), cm (cm), m (m), km (km)

LCOL Colour index for the visualisation of the layers: 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

NCV Number of contact volumes

CSHAPE Shape of a contact volume: cylinder(cylinder), box(box), L-shape(lshape) or U-shape(ushape)

CMATNAME Material of a contact volume

CLAYER Layer where the contact volume is situated

XCV X-coordinate of the axis (CSHAPE=cylinder) or the centre (CSHAPE= box, lshape or ushape) of a contact volume

YCV Y-coordinate of the axis (CSHAPE=cylinder) or the centre (CSHAPE= box, lshape or ushape) of a contact volume

RCV Radius of cylindrical contact volume; only used if CSHAPE=cylinder

HXCV Dimensions of a contact volume in X-axis; not used when CSHAPE=cylinder

HYCV Dimensions of a contact volume in Y-axis; not used when CSHAPE=cylinder

VHXCV Denotes the X-size of the void to create the L or U-shape of contact volume (orientation of the shape is denoted by its sign; only used if CSHAPE= lshape or ushape)

VHYCV Denotes the Y-size of the void to create the L or U-shape of contact volume (orientation of the shape is denoted by its sign; only used if CSHAPE= lshape or ushape)

CUNIT Length units associated with a contact volume

CCOL Colour for the visualisation of a contact volume

NDV Number of depletion volumes

DSHAPE Shape of a depletion volume: cylinder (cylinder), box (box), L-shape (lshape) or U-shape (ushape)

DMATNAME Material of a depletion volume

DLAYER Layer where the depletion volume is situated

XDV X-coordinate of the axis (DSHAPE=cylinder) or the centre (DSHAPE= box, lshape or ushape) of a depletion volume

YDV Y-coordinate of the axis (DSHAPE=cylinder) or the centre (DSHAPE= box, lshape or ushape) of a depletion volume

RDV Radius of cylindrical depletion volume; only used if DSHAPE=cylinder

HXDV Dimensions of a depletion volume in X-axis; not used when DSHAPE=cylinder

HYDV Dimensions of a depletion volume in Y-axis; not used when DSHAPE=cylinder

VHXdV Denotes the X-size of the void to create the L or U-shape of depletion volume (orientation of the shape is denoted by its sign; only used if DSHAPE= lshape or ushape)

VHYdV Denotes the Y-size of the void to create the L or U-shape of depletion volume (orientation of the shape is denoted by its sign; only used if DSHAPE= lshape or ushape)

DELTA Defines an increase in the dimensions of the bottom of the depletion volume by two times DELTA

DUNIT Length units associated with a depletion volume

DCOL Colour for the visualisation of a depletion volume

DVDEFCUTUNIT Default depletion volume region dependent cut units: μm (μm), mm (mm), cm (cm), m (m)

DVGLOBCUTV Default depletion volume region dependent cut

DVPARCUT Flag for particle dependent depletion volume region dependent cut (0 or 1)

DVGAMCUTUNIT Depletion volume region dependent cut units for γ particles: μm (μm), mm (mm), cm (cm), m (m); only used if DVPARCUT=1

DVELECUTUNIT Depletion volume region dependent cut units for electrons: μm (μm), mm (mm), cm (cm), m (m); only used if DVPARCUT=1

DVPOSCUTUNIT Depletion volume region dependent cut units for positrons: μm (μm), mm (mm), cm (cm), m (m); only used if PDVPARCUT=1

DVGAMCUTV Depletion volume region dependent cut for γ particles; only used if DVPARCUT=1

DVELECUTV Depletion volume region dependent cut for electrons; only used if DVPARCUT =1

DVPOSCUTV Depletion volume region dependent cut for positrons; only used if DVPARCUT=1

PARTICLENAME 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

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'

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'

CATE Threshold energy for coincidence analysis; only when NDV > 1 and PARTICLETYPE $\neq$ 'geantino'

CAEU Threshold energy units; only when NDV > 1

The defaults for the GEMAT namelist are defined as:

```
LSD = 0
XYSIZE = 100.0
XYUNITS = 'um'
NLAYER = 1
LMATNAME = 100*' '
THICKNESS = 100*0.0
TUNIT = 100*'um'
LCOL(100) = I (layer index)
CSHAPE = 100*' '
CMATNAME = 100*' '
CLAYER = 100*0
XCV = 100*0.0
YCV = 100*0.0
RCV = 100*0.0
HXCV = 100*0.0
HYCV = 100*0.0
VHXCV = 100*0.0
VHYCV = 100*0.0
```

```

CUNIT = 100*'um      '
CCOL(100) = I (layer index)
DSHAPE = 100*'      '
DMATNAME = 100*'  ' )
DLAYER = 100*0
XDV = 100*0.0
YDV = 100*0.0
RDV = 100*0.0
HXDV = 100*0.0
HYDV = 100*0.0
VHXDV = 100*0.0
VHYDV = 100*0.0
DELTA = 100*0.0
DUNIT = 100*'um      '
DCOL(100) = I (layer index)
VIS = 0
TRACK = 0
FILE = 5
PARTICLETYPE='e-      '
TRAJ = 1
USE_EBIAS = 0
Z = 1
A = 1
Q = 0
E = 0.0
NEVENTS = 10
ENERGYDIS = 'Mono      '
ENERGY = 100.0
IEUNIT = 'MeV'
MONOFLUX = 1.0
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 = 0.0
MAXTHETA = 90.0
ANGMINUNIT = 'deg'
ANGMAXUNIT = 'deg'
FLUNIT = '      '
SHOW_ALL = 0
HADRON = 0
LN = 0
GEM = 2
LEEM = 0
GLOB CUTV = 1.0
DEFCUTUNIT = 'um      '
PARCUT = 0
GAMCUTV = 1.0
ELECUTV = 1.0
POSCUTV = 1.0
GAMCUTUNIT = 'um      '
ELECUTUNIT = 'um      '
POSCUTUNIT = 'um      '
DVGLOB CUTV = 1.0
DVDEFCUTUNIT = 'um      '
DVPARCUT = 0
DVGAMCUTV = 1.0
DVELECUTV = 1.0

```

```

DVPOSCUTV = 1.0
DVGAMCUTUNIT = 'um '
DVELECUTUNIT = 'um '
DVPOSCUTUNIT = 'um '
PARTICLENAME = 8* ' '
EMODE = ' '
NBIN = 1
EOMIN = 0.0
EOMINUNIT = 'MeV'
EOMAX = 0.0
EOMAXUNIT = 'MeV'
EDGE = 30*0.0
EDGEUNIT = 'MeV'
PHSMODE = 'default'
PHSNBIN = 1
PHSEOMIN = 0.0
PHSEOMINUNIT = 'MeV'
PHSEOMAX = 0.0
PHSEOMAXUNIT = 'MeV'
PHSEEDGE = 30*0.0
PHSEEDGEUNIT = 'MeV'
CATE = 100*0.0
CAEU = 100*'keV'

```

9.1.3 Sector Shielding Analysis Tool (SSAT)

The Sector Shielding Analysis Tool (SSAT) performs ray tracing from a user defined point within the geometry to determine shielding levels and shielding distributions.

The SPENVIS program SSAT creates the Geant4 macro file `spenvis_ssa.g4mac` for input by the stand-alone binary implementation of SSAT. The model parameters for SSAT are defined in the SSAT namelist:

BINNINGScheme Binning scheme for the shielding histograms: linear (`lin`), logarithmic (`log`), default (`default`) or arbitrary (`arb`)

BINNINGUNIT Units by which the shielding will be measured: `cm`(`cm`), `g/cm2` (`g/cm2`) or radiation lengths (`radlen`); not used when `BINNINGScheme = 'arb'`

SMIN Lower edge of the lowest shield bin in `g/cm2`; not used when `BINNINGScheme = 'arb'`

SMAx Upper edge of the highest shield bin in `g/cm2`; not used when `BINNINGScheme = 'arb'`

NSINTV Number of bins for a linear or logarithmic binning scheme; only used when `BINNINGScheme = 'lin', 'log'`

SEDGES Defining bin edges for the arbitrary binning scheme; only used when `BINNINGScheme = 'arb'`

REFDIR Flag for setting reference direction (0 or 1)

X X Cartesian coordinate for setting the position of the geantino source; only used if `GEOMETRY == -1` and `REFDIR = 1`

Y Y Cartesian coordinate for setting the position of the geantino source; only used if `GEOMETRY == -1` and `REFDIR = 1`

Z Z Cartesian coordinate for setting the position of the geantino source; only used if `GEOMETRY == -1` and `REFDIR = 1`

TUNIT Geantino source position units (`micron`, `mm`, `cm`, `m` or `km`); only used if `GEOMETRY == -1` and `REFDIR = 1`

TMIN Minimum θ for setting the direction window in spherical polar coordinates

TMAX Maximum θ for setting the direction window in spherical polar coordinates

PMIN Minimum ϕ for setting the direction window in spherical polar coordinates

PMAX Maximum ϕ for setting the direction window in spherical polar coordinates

AUNIT Units for setting the direction window in spherical polar coordinates: degrees (`deg`) or radians (`rad`)

U1 Direction cosines in Cartesian coordinates for setting the first reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

V1 Direction cosines in Cartesian coordinates for setting the first reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

W1 Direction cosines in Cartesian coordinates for setting the first reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

U2 Direction cosines in Cartesian coordinates for setting the second reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

V2 Direction cosines in Cartesian coordinates for setting the second reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

W2 Direction cosines in Cartesian coordinates for setting the second reference direction for the local spherical coordinate system ($\theta = 90^\circ$, $\phi = 0^\circ$)

PATHLENGTH Defines the path length calculation method (`slant`, `normal` or `weighted`)

COSINELAW Flag for angular sampling distribution: cosine law (`COSINELAW='true'`) or isotropic (`COSINELAW='false'`)

NTINTV Sets the number of θ bins between `TMIN` and `TMIN`

NPINTV Sets the number of ϕ bins between `PMIN` and `PMIN`

TINTV Specifies the binning interval in polar angle θ : linear (`lin`), sine (`sin`) and sine-cosine (`sincos`)

NRAYS Number of rays per angular bin (1, 10 or 100)

GEOMETRY Flag for selecting the GDML file: use SPENVIS generated sectoring GDML file (1) or new GDML file upload (-1)

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

TRACK Flag for inclusion of rays 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`

CALC Flag for including (1) or not (0) calculation in the visualisation

STEPMIN Minimum step size in [g/cm²]; only used when `PATHLENGTH = 'normal'`

DOSECURVE Flag for selecting dose curve: none (0), new dose curve upload (-1)

DUNIT Dose units (rad); only used if `DOSECURVE = -1`

DINTERPOL Dose curve interpolation: linear (`lin`) or logarithmic (`log`); only used if `DOSECURVE = -1`

The defaults for the SSAT namelist are defined as:

```

BINNINGSCHEME='linear'
BINNINGUNIT='g/cm2'
SMIN=0.0
SMAX=100.0
NSINTV=10
SEDGES =1000*(-1.0)
X=0.0
Y=0.0
Z=0.0
TUNIT='cm'
TMIN=0.0
TMAX=180.0
PMIN=0.0
PMAx=360.0
AUNIT='deg'
U1=1.0
V1=0.0
W1=0.0
U2=0.0
V2=1.0
W2=0.0
PATHLENGTH='slant'
COSINELAW='false'
NTINTV=1
NPINTV=1
TINTV='sin'
NRAYS=1
GEOMETRY=1

```

```

VIS = 0
TRACK = 0
FILE = 0
CALC = 0
STEPMIN = 0.1
DOSECURVE = 0
DUNIT = 'rad'
DINTERPOL = 'lin'

```

9.1.4 GRAS

The GRAS tool provides a general space radiation analysis for 3D geometry models (Santin et al. 2005). More specifically, GRAS allows the definition of a multi-volume 3D (MULASSIS-like geometry can also be defined) and incident particle source. Then, using the Geant4 toolkit it simulates radiation transport through the geometry, treating electromagnetic and nuclear interactions.

The SPENVIS program G4_GRAS_MACRO creates the Geant4 macro file `spenvis_gras.g4mac` for input by the stand-alone binary implementation of GRAS. The shielding materials for the MULASSIS-like geometry can be selected from a separate namelist called USERMAT generated by the material definition tool (see Sect. 9.3.3).

The model parameters for G4_GRAS_MACRO are defined in the GRAS namelist. In addition to the parameters defined in the definition of source particles and physical models sections the following parameters are also part of the GRAS namelist:

USER Defines the GRAS execution mode: Mulassis (0) or GDML (2)

SHAPE Selects shielding geometry: planar slab (`slab`) or sphere (`sphere`); only used if `USER=0`

NLAYER Number of layers (maximum 42); only used if `USER=0`

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

MATERIALNAME Names (`CHARACTER*30`) for the layer material: one pre-defined material (`Vacuum`) or a material from the the material definition tool; only used if `USER=0`

THICKNESS Layer thicknesses; only used if `USER=0`

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`); only used if `USER=0`

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`; only used if `USER=0`

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

SOURCE_TYPE Source type (Point or Sphere); only used if USER=2

REF_VOLUME GDML volume where the initial position of the source centre is situated; only used if USER=2

XSOURCE X-coordinate defining the initial position of the source centre; only used if USER=2

YSOURCE Y-coordinate defining the initial position of the source centre; only used if USER=2

ZSOURCE Z-coordinate defining the initial position of the source centre; only used if USER=2

SOURCE_LUNIT Length units for the coordinates of the initial position and radius of the source (cm, m or km); only used if USER=2

SOURCE_RADIUS Source radius; only used if USER=2 and SOURCE_TYPE = 'Sphere'

TRG_VOLUME GDML volume where the source is initially pointing to; only used if USER=2

XTARGET X-coordinate defining the targeting position of the source; only used if USER=2

YTARGET Y-coordinate defining the targeting position of the source; only used if USER=2

ZTARGET Z-coordinate defining the targeting position of the source; only used if USER=2

GDML_GEO_STAMP Time stamp associated with the definition of the GDML geometry; only used if USER=2

NREGION Number of regions for region dependent cuts

CUT_LAYER Flags for selecting cut-in-range regions in 1D geometry (0 or 1); only used if NREGION>0 and USER=0

CUT_VOLUME Flags for selecting cut-in-range regions in 3D geometry: use global default (-2) or use region I cut-in-range ($I = 1, \dots, NREGION$); only used if NREGION>0 and USER=2

DEFCUTREGUNIT Region cut-in-range units: μm (μm), mm (mm), cm (cm), m (m)

RGLOCUTV Default region cut-in-range; only used if NREGION>0

RGAMCUT Flags for region cut-in-range for γ particles (0 or 1); only used if NREGION>0

RGAMCUTV Region cut-in-range for γ particles; only used if `RGAMCUT=1`

RELECUT Flags for region cut-in-range for electrons (0 or 1); only used if `NREGION>0`

RELECUTV Region cut-in-range for electrons; only used if `RELECUT=1`

RPOSCUT Flags for region cut-in-range for positrons (0 or 1); only used if `NREGION>0`

RPOSCUTV Region cut-in-range for positrons; only used if `RPOSCUT=1`

GDML_CUT_STAMP Time stamp associated with the definition of region cuts-in-range; only used if `USER=2`

ANALYSIS Analysis type: fluence (`fluence`), non-ionizing dose (`niel`), total ionizing dose (`tid`), dose equivalent analysis (`dea`) and equivalent dose (`eqdose`)

PARTICLENAME 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

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

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'`

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

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

FUNCTIONNAME NIEL function identifier for NID analysis: JPL/NRL/NASA 2003 Silicon (`JPL_NRL_NASA_Si`), JPL/NRL/NASA 2003 Gallium Arsenide (`JPL_NRL_NASA_GaAs`), JPL/NRL/NASA 2003 Indium Phosphide (`JPL_NRL_NASA_InP`), ROSE (`ROSE`) or CREME-86 (`SPENVIS`); 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'`

NIELLAYER Flags for selection of boundary layers for NID analysis (0 or 1); only used if `ANALYSIS='niel'` and `USER=0`

TIDUNIT Output units for TID analysis: MeV (MeV), 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' and USER=0

DEAUNIT Output units for dose equivalent analysis: MeV (MeV), rad (rad), Gy (Gy); only used if ANALYSIS='dea'

DEALAYER Flags for selection of boundary layers for dose equivalent analysis (0 or 1); only used if ANALYSIS='dea' and USER=0

EQDOSEUNIT Output units for equivalent dose analysis: MeV (MeV), rad (rad), Gy (Gy); only used if ANALYSIS='eqdose'

EQDOSELAYER Flags for selection of boundary layers for equivalent dose analysis (0; only used if ANALYSIS='eqdose' and USER=0

WRAD Radiation weighting factor, W_R (ICRP60 or ICRP92); only used if ANALYSIS='eqdose'

NVOLUMES Number of volumes considered for analysis; only used if USER=2 and ANALYSIS='tid', ANALYSIS='dea' or ANALYSIS='eqdose'

NINTERFACES Number of interfaces considered for analysis; only used if USER=2 and ANALYSIS='fluence' or ANALYSIS='niel'

I_VOLUME Index of volume selected for analysis; only used if USER=2 and ANALYSIS='tid', 'dea' or 'eqdose'

I0_VOLUME Index of first volume specifying an interface for analysis; only used if USER=2 and ANALYSIS='fluence' or 'niel'

I1_VOLUME Index of second volume specifying an interface for analysis; only used if USER=2 and ANALYSIS='fluence' or 'niel'

GDML_ANA_STAMP Time stamp associated with the definition of analysis for the GDML GRAS execution mode; only used if USER=2

FUOUT Output units for fluence analysis; only used if ANALYSIS='fluence' and USER=0

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

AMODE Angle binning mode for fluence analysis: default (default), linear (lin), user defined (arb); only used if ANALYSIS='fluence' and USER=0

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' and USER=0

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' and USER=0

EEDGE Energy bin edges for fluence analysis; only used if EMODE='arb' and USER=0

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' and USER=0

ANINTV Number of angle bins for fluence analysis; only used if AMODE='lin' and USER=0

AOMIN Lower edge of lowest angle bin for fluence analysis; only used if AMODE='lin' and USER=0

AOMINUNIT Units of lowest angle bin edge for fluence analysis: degrees (deg), radians (rad); only used if AMODE='lin' and USER=0

AOMAX Upper edge of highest angle bin for fluence analysis; only used if AMODE='lin' and USER=0

AOMAXUNIT Units of highest angle bin edge for fluence analysis: degrees (deg), radians (rad); only used if AMODE='lin' and USER=0

AEDGE Angle bin edges for fluence analysis; only used if AMODE='arb' and USER=0

AEDGEUNIT Units of angle bin edges for fluence analysis: degrees (deg), radians (rad); only used if AMODE='arb' and USER=0

The defaults for the GRAS namelist are defined as:

```
DEFCUTUNIT = 'um'
SCENARIO = 1
SHOW\_ALL = 0
LN = 0
GEM = 0
LEEM = 0
HADRON = 0
PARCUT = 0
GLOBCUTV = 1.0
GAMCUTV = 1.0
ELECUTV = 1.0
POSCUTV = 1.0
IEUNIT = 'MeV'
EMINUNIT = 'MeV'
EMAXUNIT = 'MeV'
ANGDIS3D = 'cos'
ANGMAXUNIT3D = 'deg'
ANGDIS = 'cos'
```

```

ANGMINUNIT = 'deg'
ANGMAXUNIT = 'deg'
FLUNIT = 'cm2'
ARBINT = 'Lin'
ENERGYDIS = 'Mono'
PARTICLETYPE = 'e-'
SOURCE_GEOMETRY_TYPE = 1
Z = 1
A = 1
Q = 0
NEVENTS = 10
TRAJ = 1
USE_EBIAS = 0
E = 0.0
ENERGY = 100.00
GRADIENT = 0.0
INTERCEPT = 0.0
ALPHA = 0.0
HISTPOINT = 200*0.0
EMIN = 0.0
EMAX = 0.0
MAXTHETA3D = 90.0
MINTHETA = 0.0
MAXTHETA = 90.0
MONOFLUX = 1.0
E0 = 0.0
SHAPE = 'slab'
MATERIALNAME = 42*' '
TUNIT = 42*' mm'
THICKNESS = 42*1.0
COLOURINDEX = 42*1
USER = 2
NLAYER = 26
VIS = 0
FILE = 1
TRACK = 0
REF_VOLUME = 0
XSOURCE = 0
YSOURCE = 0
ZSOURCE = 0
SOURCE_RADIUS = 0
SOURCE_LUNIT = 'm'
SOURCE_TYPE = 'Point'
ALAYER = 43*0
NIELLAYER = 43*0
TIDLAYER = 42*0
DEALAYER = 42*0
EQDOSELAYER = 42*0
FUNCTIONNAME = 43*'ROSE'
PARTICLENAME = 6*' '
EMODE = ' '
NBIN = 1
EOMIN = 0.0
EOUNIT = 'MeV'
EOMAX = 0.0
NIELUNIT = 'MeVcm2/g'
TIDUNIT = 'MeV'
ANALYSIS = ' '
DEAUNIT = 'rad'
EQDOSEUNIT = 'rad'
WRAD = 'ICRP60'
NVOLUMES = 0
NINTERFACES = 0
I0_VOLUME = 50*0
I1_VOLUME = 50*0

```

```

I_VOLUME = 50*0
DEFCUTREGUNIT = 'um'
NREGION = 0
CUTLAYER = 1764*0
CUT_VOLUME = 42*(-2)
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
EOMINUNIT = 'MeV'
EOMAXUNIT = 'MeV'
EDGEUNIT = 'MeV'
AEDGEUNIT = 'deg'
AMODE = 'default'
FUOUT = ' '
AOMINUNIT = 'deg'
AOMAXUNIT = 'deg'
ANINTV = 1
FUDENS = -1
AOMIN = 0.0
AOMAX = 180.0
EEDGE = 42*0.0
AEDGE = 30*0.0

```

When the geometry is defined using a GDML file, the information about the GDML geometry is provided in two separate namelists, GDML and VOLUME.

The GDML namelist includes the following parameters:

N_MATERIALS Number of materials defined in the GDML file

N_VOLUMES Number of volumes defined in the GDML file

GDML_WORLD Name of the world volume as defined in the GDML file

GDML_VACUUM Name of the vacuum element as defined in the GDML file

GDML_FILE GDML file generated by SPENVIS after the GDML file is processed

GDML_TITLE Name of the GDML title provided by the user

GDML_REPORT HTML report file generated by SPENVIS after the GDML file is processed

GDML_VOLUME Name of the volumes included in the GDML file

GDML_SETUP Setup name included in the GDML file

GDML_ERROR Number of errors included in the GDML file

The defaults for the GDML namelist are defined as:

```

GDML_FILE = 'spenvis_gdm.gdml'
GDML_TITLE = ' '
GDML_REPORT = 'spenvis_gdm.html'
GDML_WORLD = 'World'
GDML_VACUUM = 'Vacuum'
GDML_SETUP = ' '
GDML_VOLUME = 100* ' '
VOL_NAME = ' '
VOL_MATERIAL = ' '
GDML_ERROR = -1
N_MATERIALS = 0
N_VOLUMES = 0

```

Finally, the VOLUME namelist includes the following parameters:

VOL_NAME Name of the GDML volume

VOL_MATERIAL Name of the GDML volume material

VOL_TRANS Transformation matrix of the GDML volume

with

```

VOL_NAME = ' '
VOL_MATERIAL = ' '
VOL_TRANS(1,1) = 0
VOL_TRANS(1,2) = 0
VOL_TRANS(1,3) = 0
VOL_TRANS(1,4) = 0
VOL_TRANS(2,1) = 0
VOL_TRANS(2,2) = 0
VOL_TRANS(2,3) = 0
VOL_TRANS(2,4) = 0
VOL_TRANS(3,1) = 0
VOL_TRANS(3,2) = 0
VOL_TRANS(3,3) = 0
VOL_TRANS(3,4) = 0
VOL_TRANS(4,1) = 0
VOL_TRANS(4,2) = 0
VOL_TRANS(4,3) = 0
VOL_TRANS(4,4) = 0

```

as default. Note that a VOLUME namelist is generated for every volume included in the GDML file.

9.2 Planet specific models

The Geant4 tools presented here are only available for specific planet choices.

9.2.1 Magnetocosmics

Magnetocosmics allows the computation and visualisation of charged particle trajectories and magnetic field lines, as well as the computation of cut-off rigidities as a function of position, for different types of magnetic field models. The use of Magnetocosmics applies only for Earth.

The SPENVIS program `G4_MAGCOS_MACRO` creates the Geant4 macro file `spenvis_mco.g4mac` for input by the stand-alone binary implementation of Magnetocosmics. The model parameters for MAGCOS are defined in the MAGCOS namelist:

SCENARIO_SEL Flag for selecting a scenario: Rigidity cut-off (0), Particle trajectory (1), Magnetic field lines (2)

DRAWINGTYPE Flag specifying the drawing scenario; not used when `SCENARIO_SEL=0`

SOURCETYPE Flag specifying the type of the source: Single position (`ONEPOSITION`), Orbit (`ORBIT`) or Grid (`GRID`)

PARTICLETYPE Type of particle: Electron (`e-`), Positron (`e+`), Proton (`proton`), Anti proton(`anti_proton`), Alpha(`alpha`), He3(`He3`), Deuteron(`deuteron`), Triton(`triton`) or Ion (`ion`); only used if `SCENARIO_SEL=1`

CHARGETYPE Type of charge; only used if `SCENARIO_SEL=0`

ENERGY_OR_RIGIDITY Flag for choosing between energy and rigidity; only used if `SCENARIO_SEL=1`

ENERGY_UNIT Energy unit; only used if `SCENARIO_SEL=1`

RIGIDITY_UNIT Rigidity unit; only used if `SCENARIO_SEL=1`

DRAWING_COORSYS Coordinate system for visualisation; not used when `SCENARIO_SEL=0`

DRAWINGTYPE Flag for choosing between forward and backward particle trajectories; only used if `SCENARIO_SEL=1`

IONZ Atomic number of ion; only used if `PARTICLETYPE='ion'`

IONA Atomic mass number of ion; only used if `PARTICLETYPE='ion'`

NB_TRAJECTORIES Number of particle trajectories; only used if `SCENARIO_SEL=1`

ENERGIES(10) Energy values; only used if `SCENARIO_SEL=1`

RIGIDITIES(10) Rigidity values; only used if `SCENARIO_SEL=1`

DRAW_COLOR(3) Drawing colour; not used when `SCENARIO_SEL=0`

LON Initial longitude of the source; used only when `SOURCETYPE=ONEPOSITION`

LAT Initial latitude of the source; used only when `SOURCETYPE=ONEPOSITION`

ALT Initial altitude of the source; used only when `SOURCETYPE=ONEPOSITION`

POSITION_COORSYS Coordinate system for specifying the position; used only when `SOURCETYPE=ONEPOSITION`

DIRECTION_COORSYS Coordinate system for specifying the direction; not used when `SCENARIO_SEL=2`

DIRECTION_SEL Flag for selecting the direction; not used when `SCENARIO_SEL=2`

LENGTH_UNIT Length unit; used only when `SOURCETYPE=ONEPOSITION`

PREDEFINED_DIR Flag for selecting between predefined directions: Zenith (0), Magnetic north pole axis (1), Geographic north pole axis (2), Sun (3), Local magnetic east (4), Local magnetic west (5)

PITCHANGLE Pitch angle; only used if `DIRECTION_SEL= 1`

GYRATIONANGLE Gyration angle; only used if `DIRECTION_SEL= 1`

DIRX X component of initial direction; only used if `PREDEFINED_DIR=1-5`

DIRY Y component of initial direction; only used if `PREDEFINED_DIR=1-5`

DIRZ Z component of initial direction; only used if `PREDEFINED_DIR=1-5`

ZENITH Zenith angle specifying initial source direction; only used if `DIRECTION_SEL=2` or `PREDEFINED_DIR=0` or `SOURCETYPE≠ONEPOSITION`

AZIMUTH Azimuth angle specifying initial source direction; only used if `DIRECTION_SEL=2` or `PREDEFINED_DIR=0` or `SOURCETYPE≠ONEPOSITION`

BINTERN Internal magnetic field of Earth: IGRF (IGRF), IGRF Tilted centered dipole (IGRFTiltedDipole), IGRF Tilted excentric dipole (IGRFEccentricTiltedDipole) or Dipole (DIPOLE)

DAY Reference day for Earth internal magnetic field model

MONTH Reference month for Earth internal magnetic field model

YEAR Reference year for Earth internal magnetic field model

HOURL Reference hour for Earth internal magnetic field model

MINUTE Reference minute for Earth internal magnetic field model

SEC Reference second for Earth internal magnetic field model

DIPOLEB0_UNIT Dipole B0 units; only used if `BINTERN=DIPOLE`

DIPOLECENTER_UNIT Dipole centre units; only used if `BINTERN=DIPOLE`

DIPOLECENTER(3) Dipole centre; only used if BINTERN=DIPOLE

DIPOLEAXIS(2) Dipole axis; only used if BINTERN=DIPOLE

DIPOLEB0 Dipole B0 value; only used if BINTERN=DIPOLE

BEXTERN External magnetic field: None (NOFIELD), Tsyganenko 89 C (TSY89), Tsyganenko 96 (TSY96) or Tsyganenko 2001 (TSY2001)

KPINDEX Kp index; only used if BEXTERN=TSY89

DSTINDEX Dst index; only used if BEXTERN=TSY96

IMFBY IMF By component; only used if BEXTERN=TSY96

IMFBZ IMF Bz component; only used if BEXTERN=TSY96

PDYN Solar wind dynamic pressure in nPa; only used if BEXTERN=TSY96

G1 G1 parameter; only used if BEXTERN=TSY2001

G2 G2 parameter; only used if BEXTERN=TSY2001

PROJECT_NAME Project name

MAX_RUN_TIME_UNIT Maximum run time unit

MAX_RUN_TIME Maximum run time

The defaults for the MAGOS namelist are defined as:

```
DRAWINGTYPE = 'BLINE'
SOURCETYPE = 'ONEPOSITION'
PARTICLETYPE = 'e-'
CHARGEType = 'NEGATIVE'
ENERGY_OR_RIGIDITY = 'ENERGY'
ENERGY_UNIT = 'GeV'
RIGIDITY_UNIT = 'GV'
DRAWING_COORSYS = 'GEO'
DRAWINGTYPE = 'FORWARD_TRAJECTORY'
IONZ = 6
IONA = 12
NB_TRAJECTORIES = 1
SCENARIO_SEL = 0
ENERGIES(10) = 1.0
RIGIDITIES(10) = 1.0
DRAW_COLOR(3) = 1.0
LON = 0.0
LAT = 0.0
ALT = 20
POSITION_COORSYS = 'GEOID'
DIRECTION_COORSYS = 'GEO'
DIRECTION_SEL = 0
LENGTH_UNIT = 'km'
PREDEFINED_DIR = 0
PITCHANGLE = 0.0
GYRATIONANGLE = 0.0
```

```

DIRX = 1.0
DIRY = 0.0
DIRZ = 0.0
ZENITH = 0.0
AZIMUTH = 0.0
BINTERN = 'IGRF'
KPINDEX = 0
DSTINDEX = 0
IMFBY = 0
IMFBZ = 0
PDYN = 2.4
G1 = 1
G2 = 0
DAY = 1
MONTH = 1
YEAR = 2005
HOUR = 0
MINUTE = 0
SEC = 0
DIPOLEB0_UNIT = 'nT'
DIPOLECENTER_UNIT = 'km'
DIPOLECENTER(3) = 0.0
DIPOLEAXIS(2) = 0.0
DIPOLEB0 = 30000
BEXTERN = 'NOFIELD'
PROJECT_NAME = 'spenvis'
MAX_RUN_TIME_UNIT = 'minute'
MAX_RUN_TIME = 5.00

```

9.2.2 Planetocosmics

Planetocosmics allows the definition of a planetary magnetic field, atmosphere and soil and is using the Geant4 toolkit to simulate the hadronic and electromagnetic interactions of cosmic rays with the planetary environment. Currently, Planetocosmics concerns the planets Mercury, Earth and Mars

The SPENVIS program `G4_PLACOS_MACRO` creates the Geant4 macro file `spenvis_pco.g4mac` for input by the stand-alone binary implementation of Planetocosmics. The model parameters are defined in the `PLACOS` namelist. The soil materials can be selected from a separate namelist called `USERMAT` generated by the material definition tool (see Sect. 9.3.3).

In addition to the parameters defined in the definition of source particles section the following parameters are also part of the `PLACOS` namelist:

ATMODEL Earth atmospheric model: none (`NONE`), `MSISE90` (`MSISE90`) or `NRLMSISE00` (`NRLMSISE00`)

REFLON Reference longitude for Earth atmospheric model

REFLAT Reference latitude for Earth atmospheric model

F107 F10.7 (previous day)

F107A F10.7 (81 day average)

AP Daily Ap

ATMODEL_MERC Mercury atmospheric model: none (NONE)

ATMODEL_MARS Mars atmospheric model: none (NONE),
Mars-GRAM2001 0N180E (marsgram_atmo_table_0N180E.txt),
Mars-GRAM2001 45N180E (marsgram_atmo_table_45N180E.txt) or
Mars-GRAM2001 45S180E (marsgram_atmo_table_45S180E.txt)

HEIGHT Height above atmosphere/surface

HEIGHTUNIT Height unit

NLAYER Number of soil layers

THICKNESS Thickness of soil layer; not used when NLAYER=-1 or NLAYER=0

TUNIT Thickness unit; not used when NLAYER=-1 or NLAYER=0

MATERIALNAME Name of the soil material; not used when NLAYER=-1 or
NLAYER=0

BINTERN Internal magnetic field of Earth: IGRF (IGRF), IGRF Tilted centered dipole
(IGRFTiltedDipole), IGRF Tilted excentric dipole
(IGRFEccentricTiltedDipole) or Dipole (DIPOLE)

BINTERN_MERC Internal magnetic field of Mercury: Dipole (DIPOLE)

BINTERN_MARS Internal magnetic field of Mars: CAIN90 (CAIN90), CAIN50
(CAIN50) or PURUCKER (PURUCKER)

DAY Reference day for Earth internal magnetic field model and/or atmospheric model

MONTH Reference month for Earth internal magnetic field model and/or atmospheric
model

YEAR Reference year for Earth internal magnetic field model and/or atmospheric model

HOURL Reference hour for Earth internal magnetic field model and/or atmospheric model

MINUTE Reference minute for Earth internal magnetic field model and/or atmospheric
model

SEC Reference second for Earth internal magnetic field model and/or atmospheric model

DIPOLEB0_UNIT Dipole B0 units; only used if BINTERN=DIPOLE

DIPOLECENTER_UNIT Dipole centre units; only used if BINTERN=DIPOLE

DIPOLECENTER(3) Dipole centre; only used if BINTERN=DIPOLE

DIPOLEAXIS(2) Dipole axis; only used if `BINTERN=DIPOLE`

DIPOLEB0 Dipole B0 value; only used if `BINTERN=DIPOLE`

BEXTERN External magnetic field: None (`NOFIELD`), Tsyganenko 89 C (`TSY89`), Tsyganenko 96 (`TSY96`) or Tsyganenko 2001 (`TSY2001`)

KPINDEX Kp index; only used if `BEXTERN=TSY89`

DSTINDEX Dst index; only used if `BEXTERN=TSY96`

IMFBY IMF By component; only used if `BEXTERN=TSY96`

IMFBZ IMF Bz component; only used if `BEXTERN=TSY96`

PDYN Solar wind dynamic pressure in nPa; only used if `BEXTERN=TSY96`

G1 G1 parameter; only used if `BEXTERN=TSY2001`

G2 G2 parameter; only used if `BEXTERN=TSY2001`

GTYPE Geometry type (`'flat'` or `'spherical'`)

POSCOORSYS Coordinate system for defining positions

LON Longitude of the centre of the world box or the central initial position of the source in the case of flat and spherical geometry respectively

LAT Latitude of the centre of the world box or the central initial position of the source in the case of flat and spherical geometry respectively

ALT Altitude of the central initial position of the source

X Cartesian X-coordinates of the central initial position of the source; only used if `GTYPE='flat'`

Y Cartesian Y-coordinates of the central initial position of the source; only used if `GTYPE='spherical'`

LENGTH_UNIT Length unit

DIRCOORSYS Coordinate system for defining directions

ZENITH Zenith angle of the initial direction of the source

AZIMUTH Azimuth angle of the initial direction of the source

PARTVIS Flag for visualising particle trajectories (0 or 1)

ATMCUTV Cut-in-range for the atmosphere

SOILCUTV Cut-in-range for a specific soil layer

ATMGAMCUT Flag for considering atmosphere cut-in-range for gamma

ATMELECUT Flag for considering atmosphere cut-in-range for electrons

ATMPROCUT Flag for considering atmosphere cut-in-range for protons

SOILGAMCUT Flag for considering cut-in-range for gamma in a specific soil layer

SOILELECUT Flag for considering cut-in-range for electrons in a specific soil layer

SOILPROCUT Flag for considering cut-in-range for protons in a specific soil layer

ATMOCUTUNIT Unit for atmosphere cut-in-range

SOILCUTUNIT Unit for soil cut-in-range

SOIL_LAYER_NAME Name of the soil layer

SCENARIO_SEL Flag for the selection of analysis scenario: Particle fluxes (0) or Energy deposition (1)

PR_ENERGY_MODE Type of scale for energy axis of primary particles; only used if SCENARIO_SEL=0

PR_ENERGY_UNIT Energy unit for primary particles; only used if SCENARIO_SEL=0

SEC_PARTICLETYPE Name of secondary particles; only used if SCENARIO_SEL=0

SEC_ENERGY_MODE Type of scale for energy axis of secondary particles; only used if SCENARIO_SEL=0

SEC_ENERGY_UNIT Energy unit for secondary particles; only used if SCENARIO_SEL=0

N_PR_ENERGY_BIN Number of energy bins for primary particles; only used if SCENARIO_SEL=0

N_SEC_ENERGY_BIN Number of energy bins for secondary particles; only used if SCENARIO_SEL=0

PR_ENERGY_MIN Minimum energy for primary particles respectively; only used if SCENARIO_SEL=0

PR_ENERGY_MAX Maximum energy for primary particles respectively; only used if SCENARIO_SEL=0

SEC_ENERGY_MIN Minimum energy for secondary particles respectively; only used if SCENARIO_SEL=0

SEC_ENERGY_MAX Maximum energy for secondary particles respectively; only used if SCENARIO_SEL=0

NDETECT Number of detectors; only used if SCENARIO_SEL=0

DETECTALT Altitude of detector; only used if SCENARIO_SEL=0

DETECTUNIT Unit of detector altitude; only used if SCENARIO_SEL=0

ATMEDEPBINS Number of bins dividing the atmosphere; only used if SCENARIO_SEL=1 and an atmospheric model defined

SOILEDEPBINS Number of bins dividing the soil; only used if SCENARIO_SEL=1 and NLAYER $\neq$ 0

The defaults for the PLACOS namelist are defined as:

```

ATMODEL = 'NONE'
REFLON = 45.0
REFLAT = 45.0
F107 = 70.0
F107A = 70.0
AP = 15.0
ATMODEL_MERC = 'NONE'
ATMODEL_MARS = 'NONE'
HEIGHT = 10.0
HEIGHTUNIT = 'km'
NLAYER = -1
THICKNESS = 1.0
TUNIT = 'cm'
MATERIALNAME = 'C'
BINTERN = 'IGRF'
BINTERN_MERC = 'DIPOLE'
BINTERN_MARS = 'CAIN90'
BEXTERN = 'NOFIELD'
DIPOLEB0_UNIT = 'nT'
DIPOLECENTER_UNIT = 'km'
DAY = 1
MONTH = 1
YEAR = 2005
HOUR = 0
MINUTE = 0
SEC = 0
KPINDEX = 0
DSTINDEX = 0
IMFBY = 0.0
IMFBZ = 0.0
PDYN = 2.4
G1 = 1.0
G2 = 0.0
DIPOLEB0 = 30000
DIPOLEAXIS(2) = 0.0
DIPOLECENTER(3) = 0.0
GTYPE = Flat
POSCOORSYS = 'PLAG'
LON = 0.0

```

```

LAT = 0.0
ALT = 20.0
X = 0.0
Y = 0.0
LENGTH_UNIT = 'km'
DIRCOORSYS = 'PLA'
ZENITH = 0.0
AZIMUTH = 0.0
PARTVIS = 0
ATMCUTV = 0.0
SOILCUTV(3) = 0.0
ATMGAMCUT = 0
ATMELECUT = 0
ATMPROCUT = 0
SOILGAMCUT(3) = 0
SOILELECUT(3) = 0
SOILPROCUT(3) = 0
ATMOCUTUNIT = 'g/cm2'
SOILCUTUNIT = 'g/cm2'
SOIL_LAYER_NAME(3) 'soil1', 'soil2', 'soil3'
SCENARIO_SEL = 0
PR_ENERGY_MODE = 'log'
PR_ENERGY_UNIT = 'GeV'
SEC_PARTICLETYPE = ' '
SEC_ENERGY_MODE = 'log'
SEC_ENERGY_UNIT = 'GeV'
N_PR_ENERGY_BIN = 15
N_SEC_ENERGY_BIN = 20
PR_ENERGY_MIN = 0.01
PR_ENERGY_MAX = 10.0
SEC_ENERGY_MIN = 0.01
SEC_ENERGY_MAX = 10.0
NDETECT = 1
DETECTALT = 10.0
DETECTUNIT = 'm'
ATMEDEPBINS = 30
SOILEDEPBINS = 30

```

9.3 Common settings

The common settings refer to various parameters that can also be defined independently (i.e. outside the main page of a particular tool) and shared by more than one Geant4 tools.

9.3.1 Definition of source particles

The parameters defined here are included in the MULASSIS, GEMAT, PLACOS and GRAS namelists:

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

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

ENVIRSOURCE Environment specification for the source: mission based (0) or user defined (1)

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'`

MONOFLUX 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'`

TRAJ Mission segments; only used if `ENERGYDIS='Trep'`

USE_EBIAS Flag for energy biasing: if `USE_EBIAS=0` then no energy biasing; only used if `ENERGYDIS='Trep'`

SOURCE_GEOMETRY_TYPE Flag for the definition of angular distribution geometry: 1-dim (1) or 3-dim (3)

ANGDIS Angular distribution from 1-dim geometry point of view: omnidirectional (`cos`), point source (`iso`) and parallel beam (`planar`); only option `cos` is applicable for trapped or solar particles

MINTHETA Minimum angle for omnidirectional 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'`

ANGDIS3D Angular distribution from 3-dim geometry point of view: none (`none`), isotropic (`iso`) and cosine law (`cos`); only option `cos` is applicable for trapped or solar particles

MAXTHETA3D Half opening angle (`ANGDIS='iso'`) or maximum angle (`ANGDIS='cos'`) for angular distribution from 3-dim geometry point of view

ANGMAXUNIT3D Units of `MAXTHETA3D`; only used if `ANGDIS='iso', 'cos'`

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

9.3.2 Definition of physical models

The parameters defined here are part of the `MULASSIS`, `GEMAT` and `GRAS` namelists:

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

SHOW_ALL Flag for displaying all physics scenarios (0 or 1); only used if `PARTICLETYPE='e-', 'gamma'`

HADRON Flag for inclusion of hadron nuclear interactions (0 or 1); not used if `SHOW_ALL=0`

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 Global cut units: μm (μm), mm (mm), cm (cm), m (m)

GLOBCUTV Default global cut-in-range

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

GAMCUTV Global cut-in-range for γ particles; only used if PARCUT=1

ELECUTV Global cut-in-range for electrons; only used if PARCUT=1

POSCUTV Global cut-in-range for positrons; only used if PARCUT=1

9.3.3 User defined material

Users can select materials from a list of pre-defined materials or define their own using the material definition utility. The parameters defined here are included in the USERMAT namelist used by MULASSIS, GEMAT, G4_PLACOS_MACRO and G4_GRAS_MACRO :

NUSERMAT Number of user defined materials

MNAME Material name

MATERIAL Material chemical formula

DENSITY Material density

9.3.4 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 `spenvismat.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
```

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Appendix A

Output files produced by the models in SPENVIS

A.1 Output data files produced by the models in SPENVIS

<code>spenvis_ano.txt</code>	Look directions and directional proton fluxes (ANISO)
<code>spenvis_apo.txt</code>	Atmospheric densities and temperatures (ATMOPOS)
<code>spenvis_ato.txt</code>	Atmospheric densities, fluxes and fluences (ATOMOX)
<code>spenvis_att.txt</code>	Attitude vectors (SAPRE)
<code>spenvis_blo.txt</code>	Magnetic field parameters (BLXTRA)
<code>spenvis_bpo.txt</code>	Magnetic field parameters (BLPOS)
<code>spenvis_cmo.txt</code>	Contaminant masses and surface densities (CONTAM)
<code>spenvis_coo.txt</code>	Transmission factors (CUTOFF)
<code>spenvis_cto.txt</code>	Coordinate transformation vectors (COORDTRANS)
<code>spenvis_dbf.txt</code>	Fluence for the selected period (QUERY)
<code>spenvis_dbo.txt</code>	Data base values (QUERY)
<code>spenvis_dbp.txt</code>	Report file (QUERY)
<code>spenvis_dia.txt</code>	Diagnostics file (DICTAT)
<code>spenvis_dio.txt</code>	Maximum electric field, surface voltage and electron spectra (DICTAT)
<code>spenvis_dmo.txt</code>	dMEREM output file (RUN_DMEREM)

spenvis_dso.txt Drift shell coordinates (SHELL)

spenvis_dss.txt Footpoint and mirror point coordinates (SHELL)

spenvis_efo.txt Damage equivalent fluences (EQFLUX)

spenvis_emd.txt eMEREM single position dose and total flux/fluence (EMEREMML)

spenvis_eme.hbook eMEREM hbook file (EMEREMML)

emerem.nml Namelist file for eMEREM (RUN_MEREM_MACRO)

spenvis_emo.txt eMEREM orbital output (EMEREMO)

spenvis_emp.txt eMEREM profile output (EMEREMP)

spenvis_ems.txt eMEREM single position spectra (EMEREMML)

spenvis_epo.txt Emission yields, currents and fluxes (EQUIPOT)

spenvis_gcf.txt proton and ion fluxes (GCR)

spenvis_gdml.nml List of volumes (NML) (GDML_UPLOAD)

spenvis_gem.g4mac Macro file for GEMAT (GEMAT_MACRO)

spenvis_geo.txt Output file for GEMAT (RUN_GEMAT)

spenvis_gep.txt Log file for GEMAT (RUN_GEMAT)

spenvis_ger.txt Report file for GEMAT (RUN_GEMAT)

spenvis_gras.csv Output file for the Geant4 analysis for space tool (RUN_GRAS)

spenvis_gras.g4log Log file for the Geant4 analysis for space tool (RUN_GRAS)

spenvis_gras.g4mac Macro file for the GRAS (UPLOADS)

spenvis_gras.g4mac Macro file for the Geant4 analysis for space tool (GRAS_MACRO)

spenvis_gro.txt Grun meteoroid fluxes (GRUN)

spenvis_ilo.txt Illumination, radiation fluxes and shadowing (ILLUM)

spenvis_leo.txt LEO environment parameters (LEOPOLD)

spenvis_mco.g4log Log file for Magnetocosmics (RUN_MAGCOS)

spenvis_mco.g4mac Macro file for Magnetocosmics (G4_MAGCOS_MACRO)

spenvis_mco.txt Result file for Magnetocosmics (RUN_MAGCOS)

`spenvis_mer.g4log` Log file for dMEREM (RUN_DMEREM)
`spenvis_mer.g4mac` Macro file for dMEREM (RUN_MEREM_MACRO)
`merem_atmo.txt` MEREM atmosphere file (MEREM_PRE)
`merem_soil.txt` MEREM soil file (MEREM_PRE)
`spenvis_mes.txt` Incident radiation spectrum for MEREM (RUN_MEREM_MACRO)
`spenvis_mlo.txt` Output file for the multilayered analysis tool (RUN_MULASSIS)
`spenvis_mlp.txt` Log file for the multilayered analysis tool (RUN_MULASSIS)
`spenvis_mlr.txt` Report file for the multilayered analysis tool (RUN_MULASSIS)
`spenvis_mpc.txt` Command file for MEREM pre-processor (RUN_MEREM_MACRO)
`spenvis_mpl.txt` Log file for MEREM pre-processor (MEREM_PRE)
`spenvis_mul.g4mac` Macro file for the multilayered analysis tool (MULASSIS_MACRO)
`spenvis_nao.txt` NASA90 debris fluxes (NASA90)
`spenvis_nio.txt` Shielded proton spectra and NIEL parameters (NIEL)
`spenvis_nlof.txt` Average LET, proton and ion fluxes (NEWUPSETO)
`spenvis_nlol.txt` LET averaged over all particle species (NEWUPSETO)
`spenvis_nloo.txt` LET and proton fluxes along the orbit (NEWUPSETO)
`spenvis_nloq.txt` particle averaged LET along the orbit (NEWUPSETO)
`spenvis_nuof.txt` Experimental cross sections (NEWUPSETO)
`spenvis_nuol.txt` Path length distribution (NEWUPSETO)
`spenvis_nuoo.txt` SEU rates along the orbit (NEWUPSETO)
`spenvis_pco.g4log` Log file for Planetocosmics (RUN_PLACOS)
`spenvis_pco.g4mac` Macro file for Planetocosmics (UPLOADS)
`spenvis_pco.g4mac` Macro file for Planetocosmics (G4_PLACOS_MACRO)
`spenvis_pco.txt` Result file for Planetocosmics (RUN_PLACOS)
`spenvis_pos.txt` Coordinate grid (GRID)
`spenvis_rco.txt` Generated RDC file (RDCCONVERT)

spenvis_s2o.txt SHIELDOSE-2 Doses (SD2)

spenvis_sao.txt Spacecraft coordinates (SAPRE)

spenvis_sec.gdml Geometry definition GDML file (SECTOR)

spenvis_sec.nml List of volumes (SECTOR)

spenvis_sef.txt Solar particle fluence spectra (SEP)

spenvis_seo.txt Attenuation factor along the orbit (SEP)

spenvis_sefflare.txt Solar particle flux spectra (SEPFLARE)

spenvis_seoflare.txt Attenuation factor along the orbit (SEPFLARE)

spenvis_sho.txt SHIELDOSE Doses (SD)

spenvis_soo.txt Erosion rates and current collection (SOLARC)

spenvis_spe.txt Trapped electron spectra along the orbit (TREP)

spenvis_spe.txt Trapped electron spectra along the orbit (TREP_JUP)

spenvis_spp.txt Trapped proton spectra along the orbit (TREP)

spenvis_spp.txt Trapped proton spectra along the orbit (TREP_JUP)

spenvis_ssa.g4mac Macro file for the sector shielding analysis tool (SSAT_MACRO)

spenvis_ssa.gdml GDML file for the sector shielding analysis tool (SSAT_MACRO)

spenvis_sso.txt Output file for the sector shielding analysis tool (RUN_SSAT)

spenvis_ssp.txt Log file for the sector shielding analysis tool (RUN_SSAT)

spenvis_sxa.txt Angular distribution of proton spectra at detector (SFLUX)

spenvis_sxo.txt Attenuated cumulative proton spectra at detector (SFLUX)

spenvis_tbo.txt Trapped particle fluxes (TREPBL)

spenvis_tpo.txt Trapped particle fluxes (TREPPOS)

spenvis_tri.txt Averaged proton and electron fluxes (TREP)

spenvis_tri.txt Averaged proton and electron fluxes (TREP_JUP)

spenvis_upl.gdml Uploaded GDML file (GDML_UPLOAD)

spenvis_vfo.txt View factor matrix (VIEWF)

A.2 Graphical output generated by SPENVIS models

`aniso_flux.*` Trapped proton unidirectional flux (ANISO)
`atmopos_map.*` World map of atmospheric parameters (ATMOPOS)
`atmopos_spheres.*` Spherical projections of atmospheric parameters (ATMOPOS)
`atmopos_vrml.*` VRML visualisation of atmospheric parameters (ATMOPOS)
`atmopos_xy.*` Two-dimensional plot of atmospheric parameters (ATMOPOS)
`atomox_globe.*` 3D-View of atmospheric parameters (ATOMOX)
`atomox_map.*` World map of atmospheric parameters (ATOMOX)
`atomox_time.*` Atmospheric parameters as a function of orbital time (ATOMOX)
`atomox_vrml.*` VRML Representation of atmospheric parameters (ATOMOX)
`bl_globe.*` 3D-View of the field line traces (BLPOS)
`bl_proj.*` 2D-View of the field line traces (BLPOS)
`bl_vrml.*` VRML representation of the field line traces (BLPOS)
`blpos_map.*` World map of magnetic field parameters (BLPOS)
`blpos_spheres.*` Spherical projections of magnetic field parameters (BLPOS)
`blpos_vrml.*` VRML visualisation of magnetic field parameters (BLPOS)
`blpos_xy.*` Two-dimensional plot of the magnetic field parameters (BLPOS)
`blxtra_globe.*` 3D-View of magnetic field parameters (BLXTRA)
`blxtra_map.*` World map of magnetic field parameters (BLXTRA)
`blxtra_time.*` Magnetic field parameters as a function of orbital time (BLXTRA)
`blxtra_vrml.*` VRML Representation of magnetic field parameters (BLXTRA)
`coortrans.*` 3D-View of the coordinate transformations (COORTRANS)
`cutoff_map.*` World map of transmission factors (CUTOFF)
`cutoff_spheres.*` Spherical projections of transmission factors (CUTOFF)
`cutoff_vrml.*` VRML visualisation of transmission factors (CUTOFF)
`cutoff_xy.*` Two-dimensional plot of transmission factors (CUTOFF)

contam_xy.* Two-dimensional plot of contaminant mass and surface densities (CONTAM)

dbplot.* Stacked plot of the data base query (QUERY)

dbscat.* Scatter plot of the data base query (QUERY)

dictat_spec.* DICTAT Electron spectrum (DICTAT)

dictat_xy.* DICTAT Output parameter as a function of time (DICTAT)

dmereml.* dMEREM single position spec (RUN_DMEREM)

dmeremp.* dMEREM profile (RUN_DMEREM)

earth_mco.jpg Ancillary image (RUN_MAGCOS)

emereml.* eMEREM single position spec (EMEREMML)

emeremo.* eMEREM orbital (EMEREMO)

emeremp.* eMEREM profile (EMEREMP)

eqflux_si.* Summary of equivalent fluences for Isc (EQFLUX)

eqflux_sp.* Summary of equivalent fluences for Pmax (EQFLUX)

eqflux_spi.* Solar Proton Equivalent Fluences for Isc (EQFLUX)

eqflux_spp.* Solar Proton Equivalent Fluences for Pmax (EQFLUX)

eqflux_spv.* Solar Proton Equivalent Fluences for Voc (EQFLUX)

eqflux_sv.* Summary of equivalent fluences for Voc (EQFLUX)

eqflux_te.* Trapped Electron Equivalent Fluences (EQFLUX)

eqflux_tpi.* Trapped Proton Equivalent Fluences for Isc (EQFLUX)

eqflux_tpp.* Trapped Proton Equivalent Fluences for Pmax (EQFLUX)

eqflux_tpv.* Trapped Proton Equivalent Fluences for Voc (EQFLUX)

equipot_cc.* EQUIPOT current as a function of time (EQUIPOT)

equipot_see.* EQUIPOT Electron emission yields (EQUIPOT)

equipot_spec.* EQUIPOT Environment parameter as a function of energy (EQUIPOT)

flare_spec.* Solar proton flux spectra (SEPFLARE)

flarei_spec.* Solar heavy ion flux spectra (SEPFLARE)

`fluxe_evo.*` Evolution of trapped electron flux (TREP)
`fluxe_evo.*` Evolution of trapped electron flux (TREP_JUP)
`fluxe_globe.*` 3D-View of the trapped electron flux (TREP)
`fluxe_globe.*` 3D-View of the trapped electron flux (TREP_JUP)
`fluxe_map.*` World map of the trapped electron flux (TREP)
`fluxe_map.*` World map of the trapped electron flux (TREP_JUP)
`fluxe_spec.*` Averaged spectra of trapped electrons (TREP)
`fluxe_spec.*` Averaged spectra of trapped electrons (TREP_JUP)
`fluxe_time.*` Trapped electron flux as a function of orbital time (TREP)
`fluxe_time.*` Trapped electron flux as a function of orbital time (TREP_JUP)
`fluxe_vrml.*` VRML Representation of the trapped electron flux (TREP)
`fluxe_vrml.*` VRML Representation of the trapped electron flux (TREP_JUP)
`fluxi_spec.*` Solar heavy ion fluence spectra (SEP)
`fluxp_evo.*` Evolution of trapped proton flux (TREP)
`fluxp_evo.*` Evolution of trapped proton flux (TREP_JUP)
`fluxp_globe.*` 3D-View of the trapped proton flux (TREP)
`fluxp_globe.*` 3D-View of the trapped proton flux (TREP_JUP)
`fluxp_map.*` World map of the trapped proton flux (TREP)
`fluxp_map.*` World map of the trapped proton flux (TREP_JUP)
`fluxp_spec.*` Averaged spectra of trapped protons (TREP)
`fluxp_spec.*` Averaged spectra of trapped protons (TREP_JUP)
`fluxp_time.*` Trapped proton flux as a function of orbital time (TREP)
`fluxp_time.*` Trapped proton flux as a function of orbital time (TREP_JUP)
`fluxp_vrml.*` VRML Representation of the trapped proton flux (TREP)
`fluxp_vrml.*` VRML Representation of the trapped proton flux (TREP_JUP)
`fluxs_spec.*` Solar proton fluence spectra (SEP)

gcr_a.* ACR ion spectra (GCR)
gcr_i.* GCR ion spectra (GCR)
gcr_p.* GCR proton spectrum (GCR)
spenvis_gem.wrl VRML representation of the GEMAT geometry (RUN_GEMAT)
gemat_flu.* Fluence/ (RUN_GEMAT)
gemat_phs.* Pulse height spec (RUN_GEMAT)
spenvis_gras.eps EPS representation of the geometry (RUN_GRAS)
spenvis_gras.jpg JPEG representation of the geometry (RUN_GRAS)
spenvis_gras.wrl VRML representation of the geometry (RUN_GRAS)
gras_dose.* Total ionizing (RUN_GRAS)
gras_flu.* Fluence/ (RUN_GRAS)
gras_niel.* Non ionizing energy (RUN_GRAS)
gras_phs.* Pulse height spec (RUN_GRAS)
grun_xy.* Grun meteoroid flux (GRUN)
illum_globe.* 3D-View of illumination (ILLUM)
illum_map.* World map of illumination (ILLUM)
illum_time.* Illumination as a function of orbital time (ILLUM)
illum_vrml.* VRML Representation of illumination (ILLUM)
leopold_xy.* LEOPOLD Parameter as a function of altitude (LEOPOLD)
magcos_cutoff_xy.* Plot of Rigidity cut (RUN_MAGCOS)
spenvis_mco.wrl VRML representation (RUN_MAGCOS)
spenvis_mul.eps EPS representation of the geometry (RUN_MULASSIS)
spenvis_mul.jpg JPEG representation of the geometry (RUN_MULASSIS)
spenvis_mul.wrl VRML representation of the geometry (RUN_MULASSIS)
mulassis_dose.* Total ionizing (RUN_MULASSIS)
mulassis_flu.* Fluence/ (RUN_MULASSIS)

mulassis_niel.* Non ionizing energy (RUN_MULASSIS)
mulassis_phs.* Pulse height spec (RUN_MULASSIS)
nasa90_xy.* NASA90 Debris flux (NASA90)
newupseto_ac.* Spacecraft shielded ion (ACR) spectra (NEWUPSETO)
newupseto_d.* Experimental direct ionisation cross sections (NEWUPSETO)
newupseto_globe.* 3D-View of SEU rates (NEWUPSETO)
newupseto_io.* Spacecraft shielded ion (GCR+SEP) spectra (NEWUPSETO)
newupseto_l.* Path length distribution (NEWUPSETO)
newupseto_le.* Spacecraft shielded LET spectra (NEWUPSETO)
newupseto_map.* World map of SEU rates (NEWUPSETO)
newupseto_p.* Experimental proton cross sections (NEWUPSETO)
newupseto_pr.* Spacecraft shielded proton spectra (NEWUPSETO)
newupseto_time.* SEU rates as a function of orbital time (NEWUPSETO)
newupseto_vrml.* VRML Representation of SEU rates (NEWUPSETO)
niel_ef.* Equivalent proton fluence (NIEL)
niel_nl.* Non-ionising energy loss (NIEL)
niel_rd.* Relative degradation (NIEL)
niel_sp.* Shielded solar proton fluence spectrum (NIEL)
niel_tp.* Shielded trapped proton fluence spectrum (NIEL)
orbit_globe.* 3D-View of the orbit (SAPRE)
orbit_map.* World map of the orbit (SAPRE)
orbit_par.* Orbit parameters as a function of time (SAPRE)
orbit_time.* Time plot of the orbit (SAPRE)
orbit_vrml.* VRML Representation of the orbit (SAPRE)
spenvis_pco.vrml VRML representation (RUN_PLACOS)
sd_cumu.* Cumulative dose as a function of shielding thickness (SD)

sd_dose.* Dose as a function of shielding thickness (SD)

sd_fold.* Folded dose as a function of shielding thickness (SD)

sd2_cumu.* Cumulative dose as a function of shielding thickness (SD2)

sd2_dose.* Dose as a function of shielding thickness (SD2)

sd2_fold.* Folded dose as a function of shielding thickness (SD2)

sep_globe.* 3D-View of the attenuation factor (SEP)

sep_map.* World map of the attenuation factor (SEP)

sep_time.* Attenuation factor as a function of orbital time (SEP)

sep_vrml.* VRML Representation of the attenuation factor (SEP)

sepa.* Attenuation factor as a function of energy (SEP)

sept.* Exposure time as a function of energy (SEP)

sepflare_globe.* 3D-View of the attenuation factor (SEPFLARE)

sepflare_map.* World map of the attenuation factor (SEPFLARE)

sepflare_time.* Attenuation factor as a function of orbital time (SEPFLARE)

sepflare_vrml.* VRML Representation of the attenuation factor (SEPFLARE)

sepflarea.* Attenuation factor as a function of energy (SEPFLARE)

sepflaret.* Exposure time as a function of energy (SEPFLARE)

sflux_globe.* 3D-View of proton flux at detector (SFLUX)

sflux_map.* Azimuthal-polar map of proton flux at detector (SFLUX)

sflux_spec.* Cumulative proton spectra at detector (SFLUX)

sflux_vrml.* VRML Representation of proton flux at detector (SFLUX)

shell_1.* 3D-View of the shell (SHELL)

shell_2.* Cylindrical projection of the shell (SHELL)

shell_3.* Altitude of the mirror points as a function of the longitude (SHELL)

shell_4.* Polar projection of the foot points in the Northern hemisphere (SHELL)

shell_5.* Polar projection of the foot points in the Southern hemisphere (SHELL)

`solarc_cce.*` Electron current collection models (SOLARC)
`solarc_cci.*` Ion current collection models (SOLARC)
`solarc_er.*` Solar array erosion rates (SOLARC)
`solarc_gc.*` Solar array/structure grounding configuration (SOLARC)
`solarc_vi.*` Solar array V/I characteristics (SOLARC)
`spenvis_ssa.wrl` VRML representation of the GDML geometry (RUN_SSAT)
`ssat_dist.*` Shielding distribution as a function of shielding thickness (RUN_SSAT)
`ssat_dose.*` Dose distribution as a function of shielding thickness (RUN_SSAT)
`ssat_globe.*` 3D-View of the shielding distribution (RUN_SSAT)
`ssat_map.*` Azimuthal-polar map of the shielding distribution (RUN_SSAT)
`ssat_surface.*` Surface representation of the shielding distribution (RUN_SSAT)
`ssat_vrml.*` VRML representation of the shielding distribution (RUN_SSAT)
`spenvis_stv.wrl` VRML Visualisation of the geometry definition (SECTOR)
`trepbl_map.*` Two-dimensional map of trapped particle flux (TREPBL)
`trepbl_prof.*` Trapped particle flux profile (TREPBL)
`trepbl_spec.*` Trapped particle spectrum (TREPBL)
`treppos_map.*` World map of trapped particle fluxes (TREPPPOS)
`treppos_spheres.*` Spherical projections of trapped particle fluxes (TREPPPOS)
`treppos_vrml.*` VRML visualisation of trapped particle fluxes (TREPPPOS)
`treppos_xy.*` Two-dimensional plot of trapped particle fluxes (TREPPPOS)
`viewf_vfv.x3d` VRML visualisation of the view factor geometry (VIEWF)

A.3 Report files produced by the models in SPENVIS

spenvis_anp.html Report file (ANISO)
spenvis_app.html Report file (ATMOPOS)
spenvis_atp.html Report file (ATOMOX)
spenvis_blp.html Report file (BLXTRA)
spenvis_bpp.html Report file (BLPOS)
spenvis_cmp.html Report file (CONTAM)
spenvis_cop.html Report file (CUTOFF)
spenvis_ctp.html Report file (COORDTRANS)
spenvis_dip.html Report file (DICTAT)
spenvis_dsp.html Report file (SHELL)
spenvis_efp.html Report file (EQFLUX)
spenvis_emr.html Report file for eMEREM (EMEREMML)
spenvis_emr.html Report file for eMEREM (EMEREMP)
spenvis_emr.html Report file for eMEREM (EMEREMO)
spenvis_epeakfl.html Electron peak fluxes (TREP)
spenvis_epp.html Report file (EQUIPOT)
spenvis_gcr.html Report file (GCR)
spenvis_gdp.html Report file (GDML_UPLOAD)
spenvis_grp.html Report file (GRUN)
spenvis_ilp.html Report file (ILLUM)
spenvis_lep.html Report file (LEOPOLD)
spenvis_nap.html Report file (NASA90)
spenvis_nip.html Report file (NIEL)
spenvis_nuop.html Report file (NEWUPSETO)
spenvis_pos.html Report file (GRID)

spenvis_ppeakfl.html Proton peak fluxes (TREP)
spenvis_rcp.html Report file (RDCCONVERT)
spenvis_s2p.html Report file (SD2)
spenvis_sap.html Report file (SAPRE)
spenvis_sep.html Report file (SEP)
spenvis_sepflare.html Report file (SEPFLARE)
spenvis_shp.html Report file (SD)
spenvis_sop.html Report file (SOLARC)
spenvis_stp.html Report file (SECTOR)
spenvis_stp+.html Complementary report file (SECTOR)
spenvis_sxp.html Report file (SFLUX)
spenvis_tbp.html Report file (TREPBL)
spenvis_tpp.html Report file (TREPPOS)
spenvis_trj.html Report file (TREP_JUP)
spenvis_trp.html Report file (TREP)
spenvis_vfp.html Report file (VIEWF)

Appendix B

Upload files used by the models in SPENVIS

`spenvis_dos.upl` Uploaded dose curve (SSAT_MACRO)

`spenvis_gdm.upl` Uploaded GDML file (SSAT, GRAS)

`spenvis_nie.upl` Uploaded NIEL file (NIEL)

`spenvis_orb.upl` Uploaded trajectory file (SAPRE)

`spenvis_rdc.upl` Uploaded RDC file (EQFLUX)

`spenvis_vfg.upl` Uploaded geometry file (VIEWF)

Appendix C

Data used by Geant4 tools in SPENVIS

The following table gives an overview of the various data used by the Geant4 tools implemented in SPENVIS.

Table C.1. Geant4 data tools used by Geant4 tools implemented in SPENVIS

Process	Folder name	Geant4 version
Photon evaporation	PhotonEvaporation2.0	4.7.0 and higher
Radio-active decay hadronic	RadioactiveDecay3.2	4.9.0 and higher
Low energy electromagnetic	G4EMLOW6.9	4.9.3 and higher
	G4EMLOW6.2	4.9.2
	G4EMLOW5.1	4.9.1
	G4EMLOW4.3	4.9.0
	G4EMLOW4.0	4.8.1
High-energy elastic scattering	G4ELASTIC1.1	4.7.1 - 4.8.1
High-precision neutron with thermal cross sections	G4NDL3.13	4.9.2 and higher
	G4NDL3.12	4.9.1
	G4NDL3.11	4.9.0
	G4NDL3.9	4.8.1
Nuclear shell effects in INCL/ABLA hadronic mode	G4ABLA3.0	4.9.1 and higher
High-energy hadron using dual parton model DPMJET-II.5 (QinetiQ module developed for MarsREM project)	GlauberData	available for 4.8.3 - 4.9.1

Appendix D

SPENVIS model-model data exchange

In SPENVIS the data exchange between two models is done through the output data files (see Appendix A). Figures D.2, D.3 and D.4 show which models are using as input an output file from another model. The ellipses denote the various SPENVIS models, the green rectangles correspond to model output files and yellow rectangles correspond to uploaded data files. Finally, the arrows show the flow of the data exchange. Note that the output files used for exchanging data between two models follow the format describe in the preface of this document (Table 0.1).

In addition to the result data files, some meta-variables are also used to pass information between different models. Table D.1 describes the set of meta-variables that have to be included in the output file generated by a specific model.

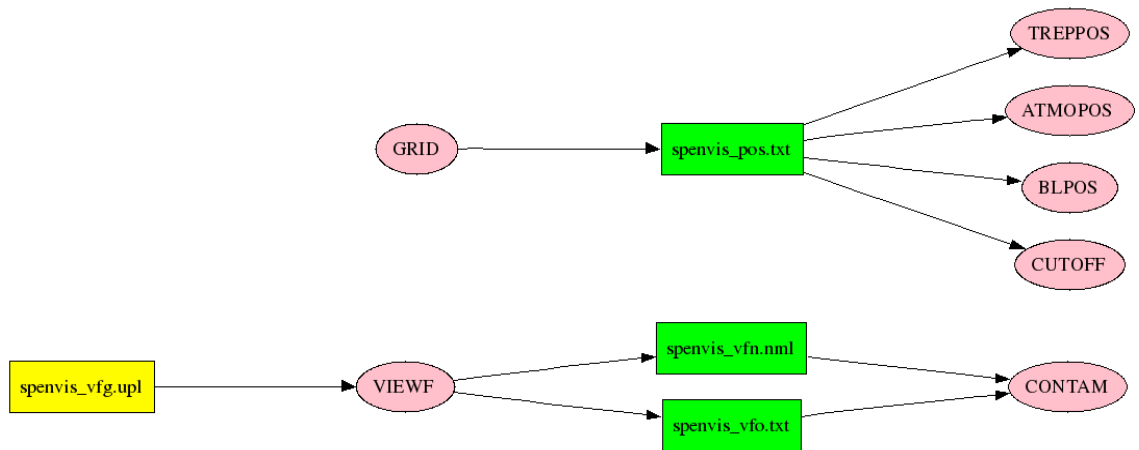


Figure D.1. Model-model data exchange related to GRID and VIEWF models (common for all planets)

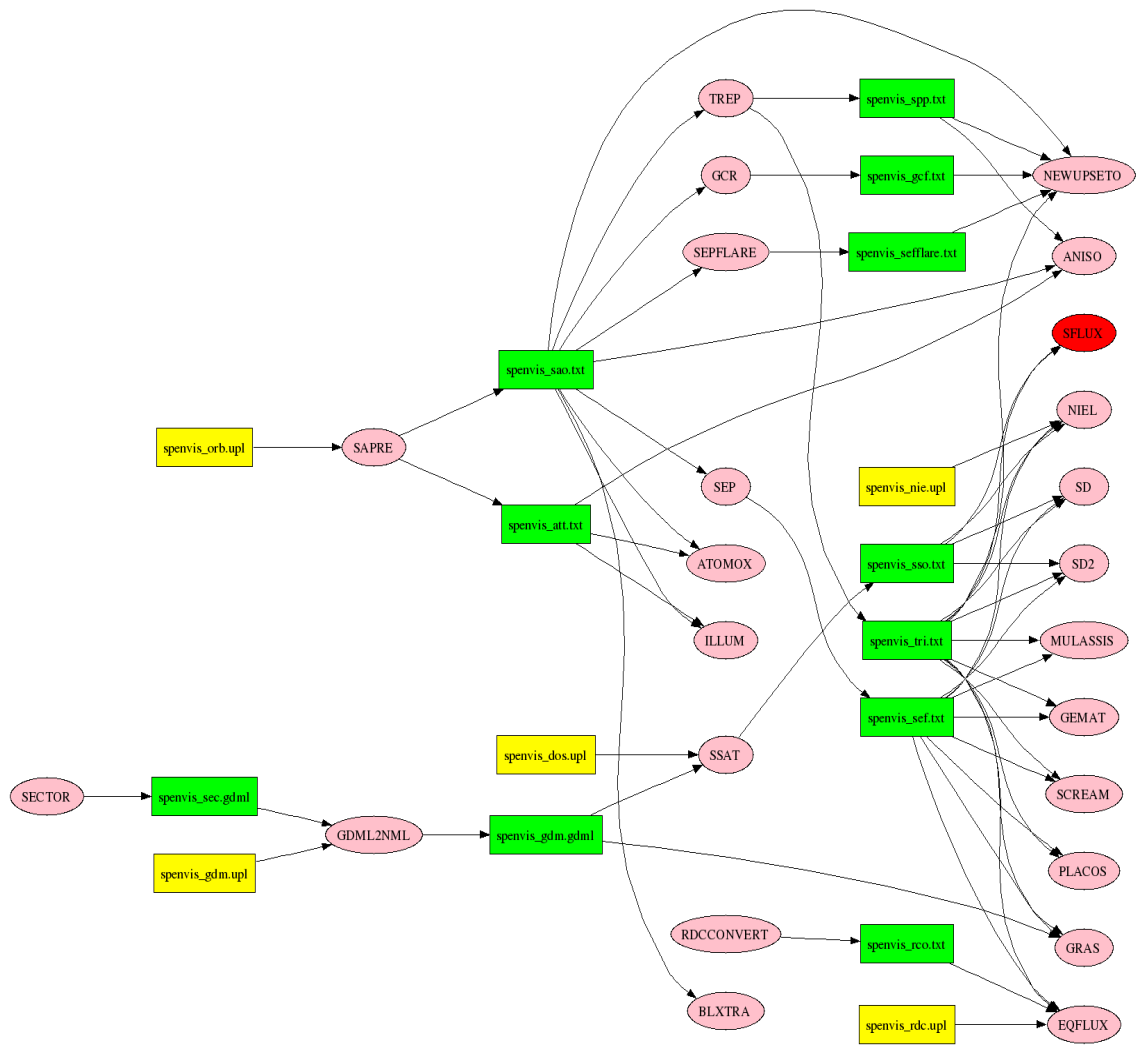


Figure D.2. Model-model data exchange when planet is Earth

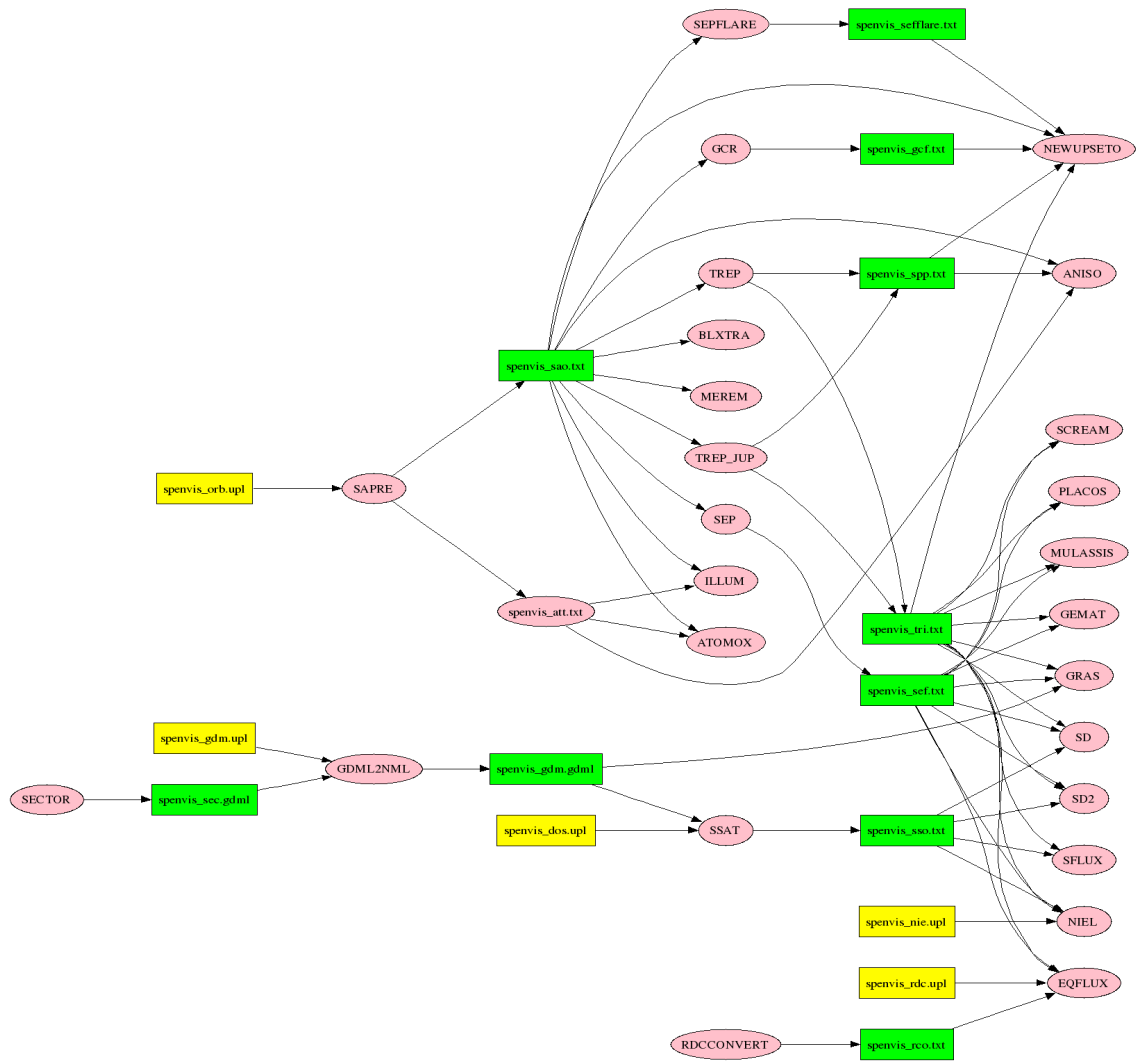


Figure D.3. Model-model data exchange when planet is Mars

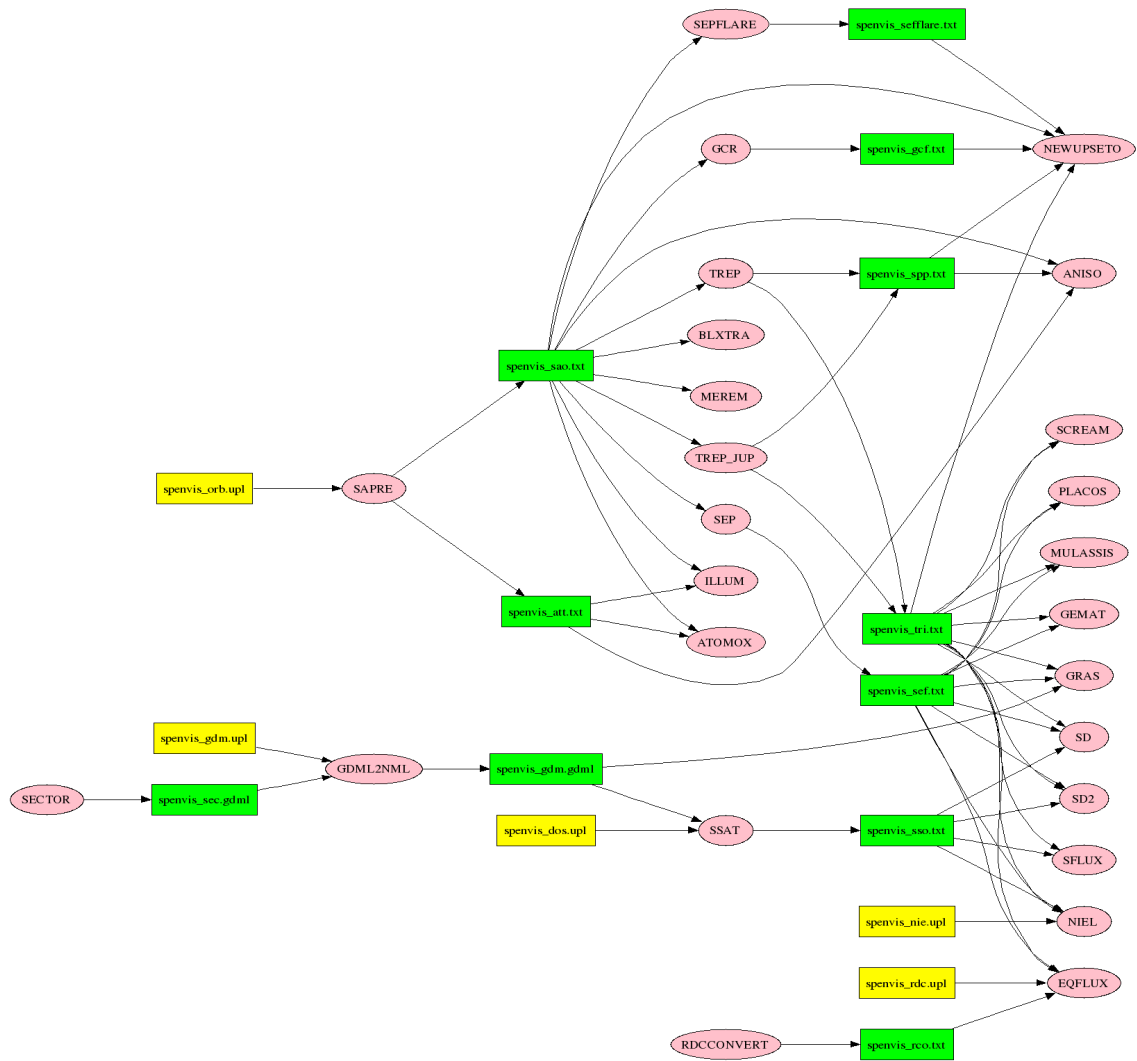


Figure D.4. Model-model data exchange when planet is Jupiter

Table D.1: List of meta-variables included in the SPENVIS model output files

Name	Type	Description	Output file using it
PRJ_DEF	token	Project name	All files
PRJ_HDR	string	Project title	All files
MOD_ABB	token	Model ID (generally three letter code)	All files
MIS_NTR	integer	Number of mission segments	spenvis_sao.txt spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt spenvis_gcf.txt spenvis_sefflare.txt
MIS_PLA	integer	Planet index (e.g. Earth=3)	spenvis_sao.txt spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt spenvis_gcf.txt spenvis_sefflare.txt
MIS_STA	double	Mission start time (MJD)	spenvis_sao.txt
MIS_END	double	Mission end time (MJD)	spenvis_sao.txt
MIS_DUR	double	Mission duration (MJD)	spenvis_sao.txt spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt spenvis_gcf.txt spenvis_sefflare.txt
ORB_HDR	string	Orbit title	spenvis_sao.txt
ORB_MJD	double	Orbit start time (MJD)	spenvis_sao.txt spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt
ORB_TSE	double	Orbit end time (MJD)	spenvis_sao.txt spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt
ORB_YEA	integer	Orbit start time: year	spenvis_sao.txt
ORB_MON	integer	Orbit start time: month	spenvis_sao.txt
ORB_DAY	integer	Orbit start time: day	spenvis_sao.txt
ORB_HOU	integer	Orbit start time: hours	spenvis_sao.txt

ORB_MIN	integer	Orbit start time: minutes	spenvis_sao.txt
ORB_SEC	float	Orbit start time: seconds	spenvis_sao.txt
ORB_AMX	integer	Orbit attitude index (KAT)	spenvis_sao.txt
ORB_TYP	integer	Type of orbit	spenvis_sao.txt
PLA_RAD	float	Planet radius in km	spenvis_sao.txt
PLA_DIS	float	Distance to Sun in AU	spenvis_sao.txt
GRD_LBL	string	Grid title	spenvis_pos.txt
GRD_TYP	integer	Grid type index (MAP)	spenvis_pos.txt
???_MOD^(†)	string	Model title	spenvis_spp.txt
???_ABS^(†)	token	Variable name for LET spectrum abscissa	spenvis_lof.txt
???_OMN^(†)	integer	Omnidirectional spectrum flag	spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt spenvis_gcf.txt spenvis_sefflare.txt
PLT_HDR	string	Spectrum title (when plotting)	spenvis_tri.txt spenvis_sef.txt spenvis_lof.txt spenvis_gcf.txt spenvis_sefflare.txt
SPECIES	array of tokens	List of species (e.g. H, He etc)	spenvis_gcf.txt spenvis_sefflare.txt
???_IEL^(†)	integer	Index of the first element in SPECIES	spenvis_gcf.txt spenvis_sefflare.txt
???_JEL^(†)	integer	Index of the last element in SPECIES	spenvis_gcf.txt spenvis_sefflare.txt
???_IWI^(†)	integer	Space weather index	spenvis_gcf.txt
???_IAC^(†)	integer	Inclusion (1) or not (0) of ACR spectra	spenvis_gcf.txt
???_IGC^(†)	integer	Geomagnetic cut-off on (1) or off (0)	spenvis_gcf.txt spenvis_sefflare.txt
???_IST^(†)	integer	Quiet (1) or stormy (0) magnetosphere	spenvis_gcf.txt spenvis_sefflare.txt
VOL_NAM	array of strings	Volume name	spenvis_vfo.txt
SRF_NAM	array of strings	Surface name	spenvis_vfo.txt
VWF_GRP	integer	Number of groups	spenvis_vfo.txt
VWF_FCS	integer	Number of faces	spenvis_vfo.txt

† Note that **???** corresponds to the content of MOD_ABB (model ID) e.g. TRP, SEP, GCR, LET etc.

