SPENVIS Tutorial: Radiation models in SPENVIS and their accuracy

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Outline

• Radiation environments
• Sources of model uncertainties
• Running radiation models in SPENVIS
• Interplanetary radiation models
• Planetary radiation models
### Radiation environments

- **Interplanetary space**
  - Cosmic rays
  - Solar energetic particles
  - Shielding by planetary magnetospheres
  - Secondary radiation from back scattering

- **Planetary radiation belts**
  - Earth, Jupiter, Saturn

- **Mars environment model**

### Radiation sources and effects

#### Radiation sources
- Trapped proton and electron fluxes
- Trapped proton flux anisotropy
- Short-term solar particle fluxes (only for SEU)
- Long-term solar particle fluences
- Galactic cosmic ray fluences
- Shielded flux

#### Solar cell radiation damage
- Damage equivalent fluences for solar cells (EOFLUX)
- NIEL based damage equivalent fluences for solar cells (MC-SCREAM)

#### Long-term radiation doses
- Ionizing dose for simple geometries
- Non-ionizing energy loss for simple geometries
- Effective dose and ambient dose equivalent

#### Single event effects
- Short-term SEU rates and LET spectra
- Long-term SEUs and LET spectra

#### Spacecraft charging

#### Atmosphere and ionosphere

#### Magnetic field

#### Meteoroids and debris

#### Miscellaneous

#### Geant4 Tools

#### ECSS Space Environment Standard
Model uncertainties

• Difficult to quantify given the large number of contributing factors
• For most models at best a qualitative uncertainty is provided (e.g. “a factor 2”).
• Contributing factors:
  ▪ Errors in underlying data
  ▪ Undersampling of the environment
  ▪ Modelling assumptions
  ▪ Propagation of uncertainties
  ▪ The SPENVIS user!
Data error sources

• Instrument calibration and cross-calibration
• Instrument limitations:
  ▪ Resolution in time, energy, species, ...
  ▪ Saturation, dead time effects
  ▪ Channel contamination
  ▪ Systematic errors
  ▪ Unknown errors
• Data post-processing:
  ▪ Poor specification of coordinate systems
  ▪ Conversion to magnetic coordinates
  ▪ Inadequate or missing quality information
Environment undersampling

- Datasets are necessarily limited in time
  - For SEP modelling: less than 4 solar cycles of quality data. Are these cycles representative?
  - Earth radiation belts: 50 years of data, but of very variable quantity and not always easy to intercompare, and no continuous full spatial coverage.
- Spatial coverage is limited by orbit type
  - Oversampling of covered spatial regions
  - Undersampling of most of the environment space
  - Interpolation, extrapolation and weighting are needed
  - Radiation belts require multiple simultaneous missions (e.g. RBSP and PROBA V/EPT).
Modelling assumptions

• The physics of the radiation environments is not fully understood, necessitating simplifications and assumptions.

• Boundary conditions and driving parameters are not always known or agreed on. Even if they are, data to quantify them is not always available.

• Models need to be validated with independent quality datasets.
User responsibility

• SPENVIS aims at accurate and correct model implementation, and at easy interfacing between applications.
• Some users are very inventive and find ways to mis-use the models.
• Others don’t read the help pages...
• Don’t take anything for granted! For instance, if more than one model is available, compare them to appreciate the variations between them.
Running radiation models

- Define a set of coordinates
  - Spacecraft trajectory
    - Sampling of radiation belts
    - Magnetic shielding cut-off for CR and SEP models
  - Coordinate maps: single point, profile, 2D map
- Select the appropriate model, set parameters and run.
- Model outputs
  - Point by point spectra, transmission functions, ...
  - Trajectory and mission averages
  - CSV files (VOTable in SPENVIS-NG)
  - Plots of spectra, time series, maps, 3D views, ...
Spacecraft trajectories

• The *mission* concept: a series of consecutive trajectory segments, specified by start time and duration or stop time.
• For each segment a representative trajectory is defined and generated: the minimum number of orbits to cover the environment.
• Radiation model outputs are scaled up to segment lengths and summed to provide total mission quantities (except for the statistical SEP models).
• Outputs are provided for each segment and for the total mission.
Trajectory specification

- Selection of planetary body
- Mission definition: number of segments and duration
- Trajectory parameters:
  - Segment start epoch
  - Trajectory duration
  - Orbital parameters
    - Semi-major axis [km]
    - Eccentricity
    - Inclination [deg]
    - Argument of perigee [deg]
    - True anomaly [deg]

- Upload of trajectory files

Radiation models and their accuracy
Interplanetary radiation models

• Galactic and anomalous cosmic ray fluxes
• Solar Energetic Particle fluences
  ▪ Specified in terms of a confidence level
  ▪ Cumulative fluence
  ▪ Worst case event fluence
• Solar energetic particle fluxes
  ▪ Energy spectra for representative historic events
  ▪ Worst day or week, peak flux
• To be used in combination with magnetic shielding models
• SEP Fluxes and fluences are given at 1 AU. SPENVIS scales with $r^{-2}$ for distances < 1 AU.
Cosmic ray models

- Models available in SPENVIS
  - ISO 15390 (Nymmik MSU model): no ACR
  - Nymmik 1996: extension of ISO 15390 below 10 MeV/nuc (ACR?)
  - CREME86: GCR + ACR, sinusoidal solar cycle modulation
  - Badhwar-O’Neill model to be added in SPENVIS-NG

- Model parameters
  - Ion range (1-92)
  - Solar cycle phase
  - CREME86 model version
Cosmic ray model output

Radiation models and their accuracy
Short term SEP fluxes

- Used as input for SEU models (see tutorial)
- Models implemented in SPENVIS
  - CREME86: worst case and Aug 1972 spectra, cosmic ray component subtracted
  - CREME96: based on GOES and IMP8 data of Oct 1989 event: worst week, worst day, peak flux (worst 5 min)
  - Xapsos et al. (2000): Weibull spectra fitted to Oct 1989 event (19, 22, 24 Oct) proton spectra; ion fluxes obtained by applying abundance table
- Outputs are similar to CR models

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SEP fluence models in SPENVIS

- King (1974): data from cycle 20, Burrell statistics, solar max and min
- JPL: lognormal probability distribution, solar max only
- Rosenqvist et al.: extension of JPL model with GOES-8 data
- Emission of Solar Protons (ESP)
  - Event fluence distribution based on maximum entropy
  - Mission fluence and worst event fluence, solar max only
- PSYCHIC: extension of ESP with ion abundance tables
- SEPEM (http://dev.sepem.oma.be/) models to be implemented in SPENVIS-NG
- Model output: fluence spectrum for given confidence level

Radiation models and their accuracy
SEP fluence model runs

- Model parameters
  - Model selection
  - Prediction period: mission duration or duration specified by advanced users
  - Offset in solar cycle: calculated based on mission segment timing or specified by advanced users
- Confidence level
- Ion range for PSYCHIC

Model outputs
- Fluence: total mission and per solar cycle max (not for ESP/PSYCHIC)
- Magnetic shielding factor

Radiation models and their accuracy
Radiation belt models: Earth

- **AP8/AE8** for protons/electrons
  - Static models: rudimentary separation in solar min/max
  - Covers the complete radiation belts
  - Badhwar-Konradi model for low altitude directional flux
- **CRRESPRO, CRRESELE**
  - Dynamic models: quiet/active for protons, $A_{p15}$ levels for electrons
- **SAMPEX/PET** solar min model for LEO (<600 km)
- **IGE-2006/POLE** (International Geostationary Electron model, Particle ONERA-LANL Environment): statistical model for the GEO electron environment
- **AE8-MIN** update with CRRES/MEA data (Vampola)
- To be added in SPENVIS-NG: AP9/AE9, slot radiation environment model (SRREM project), Ganymede environment models (GREET project)
Earth RB model parameters

- AP-8/AE-8
  - Solar MIN/MAX
  - Local time variation for AE-8
  - Apply confidence levels for AE-8 (based on AE-4)
- CRRES
  - CRRESPRO: quiet or active model
  - CRRESELE: $A_{p15}$ range, average model or maximum model
- IGE-2006/POLE
  - Model version (IGE-2006, POLE-V2, POLE-V1)
  - Model type: lower, mean or upper flux
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- Report file: summary of spectra per mission segment and mission total
- Output files with point by point spectra, plus segment and mission integrated spectra
- Plots of spectra, time series, maps, 3D views
- Note: the models are run on each trajectory point and scaled to segment and mission durations.

Earth RB model outputs

Radiation models and their accuracy
Radiation belt models: Jupiter

• Trapped radiation models
  ▪ Divine & Garrett 83 (protons and electrons)
  ▪ D&G83 + Salammbo (protons and electrons)
  ▪ D&G83 + SalammboE (electrons)
  ▪ D&G83 + GIRE (electrons)

• Model sources
  ▪ D&G83: Voyager and Pioneer flybys
  ▪ GIRE: extension with Galileo data
  ▪ Salammbo: numerical transport code

• Models are run on spacecraft trajectories (only one mission segment), outputs are similar to Earth RB models.
JOREM models

- Jupiter Radiation Environment and Effects Models and Mitigation (JOREM): ESA project to develop radiation models and tools for Jovian missions
  - Jovian Specification Environment (JOSE) model
    - Based on re-processed data from the Pioneer, Voyager, and Galileo missions
    - Improved treatment of off-equatorial fluxes
    - Includes basic statistical information (mean model and percentile values)
    - Includes JPL ion models (JPL D-24813 and HIC Equatorial)
- Interplanetary electron background model (IEM, developed under ESA contract)
- Divine & Garrett 83 plasma model
- The models operate on uploaded OEM trajectory files in EME2000 coordinates.
- Planetocosmic-J simulations for the Galilean moons
Mars environment models

- **Mars Energetic Radiation Environment Models**
  - Developed under the ESA MarsREM project
  - Produces particle flux and fluence spectra (direct and back-scattered) for different particle species, absorbed dose, effective dose, ...
  - Applicable for Mars (sub-) surface and Phobos and Deimos
  - Primary environments: galactic cosmic rays and SEP event fluences
  - Two versions
    - Look-up tables generated with FLUKA for rapid analysis
    - Full Geant4 simulations for detailed studies

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