Luleå University of Technology
Department of Space Science

Space Environment Laboratory Work with SPENVIS
Radiation Environment and Effects

V2.2
March 2016

Prepared by: Hugh Evans

Largely Based on previous versions by:
Johnny Ejemalm
J. Kero
J. Forest
P. Johansson
L. Andersson

Purpose
To improve understanding of the space environment, become familiar with a specific program tool as means of studying that environment and describing it. To study the effect of space environment on the satellite, especially the radiation environment effects on electronics and solar panels.

Computer program
The program **SPENVIS** (SPace ENVironment Information System) to be used is described in a separate document "SPENVIS – Brief Guideline".
The software package can be found at:
http://www.spenvis.oma.be/spenvis/
The teacher will be provide you with login information.

Overview of the task
Characterize the space radiation environment of the mission!
Estimate the worst possible cases and identify the critical phases of the mission!
Study in detail the radiation environment effects on an electronic device of the satellite!
Study the performance degradation of solar arrays!

You can work alone or, preferably, in a group of maximum two students.
You shall present your results with a full report, including appendix.
The total work shall correspond to 1.5 ECTS credits (40h work).
Your report shall be in the style of being an analysis done by expert/experts for submission to a formal Preliminary Design Review (PDR).

Mission Definition, Orbitography

Mission definition
Having chosen a mission, which ideally should be different for each group of students, briefly introduce your mission and its aim. You can find two-line elements, which can be used to derive the orbital elements needed in SPENVIS at e.g. http://www.celestrak.com. The orbital parameters needed may also be found in other places, as on the information web-pages of the real mission themselves. Figure 1 in Appendix B of the instruction shows a definition of four of the orbital elements.

Orbitography
Using SPENVIS, make an illustrative plot of the orbit of the spacecraft during the mission.

General
Overview of the space environment
Comment on the above results. Where is the spacecraft during its mission (e.g. inside or outside the Earth magnetosphere, what regions are passed)? In order to provide a background of the numerical results of the next part, give a brief description of the various environments passed and describe briefly the possible mechanisms of the

interactions (atmospheric drag, spacecraft charging, radiation, micrometeroid and debris, etc.). If parts of, or the whole, orbit altitude of the mission is between 200 and 2000 km, characteristic values of many physical parameters for these mechanisms can be found by running the **LEO Environmental parameters** model of the **Space Charging** module. According to this theoretical approach, which interactions in general do you think will be the most significant for your mission?

Radiation Environment

Where do you expect the radiation environment should be strongest? Or, in other terms, which are the critical phases in the mission? During these phases, try to describe the composition of different particles in the particle flux?

Numerical simulations

Environmental flux

Using the possibilities of SPENVIS, compute the different environmental fluxes of particles and discuss their significances. When analyzing the results, compare with and verify the critical phases expected initially.

Life time and Performance Degradation

The performance of many electronic devices decreases during the mission due to the received dose. In particular, two elements might be critical, a memory device, mounted in a shielded box, and the solar arrays whose output power decreases in time.

Total Dose and Shielding

If the solar array is dimensioned to deliver enough power to the payload as long as the Pmax at end of mission remains above 95%, how thick must the cover glass be? Is the estimated thickness reasonable to be used in a space mission?
The memory device, made of silicon (Si), can take 25 krad(Si) before it is out of specfication. Currently it is mounted on the front face of the spacecraft in a shielded box. Assume a shielding of 1.0 mm, for how long do you predict the device will work?
How thick do you recommend the walls of the box to be to make sure the device will work throughout the whole mission?
For a mission in Low Earth Orbit you can include the satellite orientation to take into account how the anisotropy of fluxes affects the results for different positions of the box. To do this, use the Sectoring Analyses for More Complex Geometries module (optional).

Single Event Upsets

After the last progress meeting and your first results, the project manager thinks that some problems can appear due to Single Event Upsets (SEU). He asks you to investigate different chices of on-board RAM (volatile memory). One unit to investigate proposed to you by an elderly, but distinguished, colleague of yours is a chip based on CMOS technology, which has been used successfully in modern designs, in applications such as cars and personal computers. The TTL chip is much faster, much lighter and has much higher capacity then the CMOS chip.

Linear Energy transfer (LET) Spectrum
Estimating the LET spectrum is the first step in calculating the SEU rate. Using SPENVIS and taking into account an effective shielding of 1 g/cm^2, find the flux of particles as a function of LET. The integral representation of the SEU rate dU/dt is given by

$$\frac{dU}{dt} = \int_0^{2\pi}\int_0^{\pi} \sin\theta \int_0^{\infty} \sigma(LET,\theta,\phi)\cdot \sum_{Z=1}^{92} h(LET)d(LET)d\theta d\phi \quad , \qquad (1)$$

where σ is the experimentally determined cross section of a device as a function of LET and angles (θ,ϕ) and h(LET) is the differential fluxes of ions as functions of LET, summed over all relevant ion species (also called the LET spectrum). Compare with the method used in SPENVIS/CREME - rectangular parallelipiped. What are the differences?

Cross Section and Components Characteristics
Several components of the various technologies were tested in a laboratory by exposing them to a normally incident monoenergetic beam of a cyclotron. In Appendix A a summary of the experimental results are presented. For some of them, the cross section σ was obtained by fitting the results with a Weibull function. However, only direct experimental results are available for the SMJ329C50GFAM66 chip. Find the cross section for the SMJ329C50GFAM66 chip by fitting a Weibull function to the data with help of, e.g. MATLAB. If you do not have any previous experience with MATLAB, talk to the instructor who (on agreement only) will approve a solution in which you estimate all cross sections in Appendix A with Heaviside functions and calculate the number of single events by hand.
(Guideline: Estimate the stopping power (LET) for the various ions as precice as possible with help of Figure 3, Appendix B. Calculate the cross section σ and plot these data points as a function of LET to find reasonable estimates for the critical threshold L_0 and saturated cross section C_s. With MATLAB it is possible to fit a Weibull function to the data points using lsqcurvefit(). You have to decrease the tolerance of lsqcurvefit() to something like e^{-60} by: options = optimset('TolFun',1e-60). If you get imaginary results, make sure your function evaluation give real output by using abs() on all parameters and the function output as a whole in your Weibull function definition. W and s should be of the same order of magnitude as corresponding parameters of the nmos 2164 and the Bipolar chip.)

SEU Estimation
Using the above results, compute the SEU rate for each device in the worst case of environmental conditions using both MATLAB and SPENVIS.
When do you think the SEU rate is highest (i.e. may be critical) during the flight?
Which of the devices do you recommend to use?
Are proton induced upsets expected to be significant? If so, estimate the proton induced upsets using the SPENVIS PROFIT module (optional).
(Guideline: Calculate the product of the differential flux and the cross section (evaluated at the same LET values with help of the Weibull functions) of each chip using MATLAB. Integrate the result over the LET range numerically using trapz().)

Conclusions

What do you conclude? Is there a danger for the satellite and/or the experiment? What are your recommendations? Is the performance degradation of studied components compatible with the mission duration and requirements?

Describe all details of your work including assumptions, MATLAB calculations, and simulation results in your report. Motivate your conclusions!

Please send an e-mail to the instructor with subject title 'LET spectrum', in which you have attached your simulation results of the LET Spectra module. These results are found in the 'Tables and Plots' page on your SPENVIS account.
(Output
→ Tables and Plots
→ Radiation sources and effects
→ Short-term SEU rates and LET spectra
→ Average LET (Si, SRIM), proton and ion fluxes)

When you download the report file it is originally called 'spenvis_nlof_srimsi.txt'. Please rename it according to your mission before sending it. Also, write the names of all participating students and which SPENVIS account you have used in the e-mail.

Appendix A
Experimental cross section data for SMJ329C50GFAM66, nmos 2164, CMOS R160-25 and bipolar 93L422 1K SRAM

Many experimental measurements of the sensitivity (cross section) of various types of components have been done. For a better estimation of the cross section than the classic step function, the cross section is fitted using a Weibull curve, defined below. The cross section σ is then described as a function of linear energy transfer L with the formulas below

$$\sigma(L) = 0 \quad , \quad L < L_0$$

$$\sigma(L) = C_s\left(1 - e^{-\left(\frac{L-L_0}{W}\right)^s}\right), \quad L \geq L_0 \quad ,$$

where

L_0 = the threshold in LET $[MeV \cdot cm^2/mg]$,
C_s = the saturated cross section,
W = the weight of the distribution, and
s = an experimentally determined shape parameter.

Table A1 nmos 2164

L_0	0.487 $MeV \cdot cm^2/mg$
C_s	$1.71 \cdot 10^{-5}\, cm^2$
W	4.95 $MeV \cdot cm^2/mg$
s	1.422

Table A2 CMOS R160-25

L_0	136.8 $MeV \cdot cm^2/mg$
C_s	$1.2 \cdot 10^{-5}\, cm^2$
W	350 $MeV \cdot cm^2/mg$
s	3.0

Table A3 Bipolar 93L422 1K SRAM

L_0	0.6 $MeV \cdot cm^2/mg$
C_s	$2.6 \cdot 10^{-5}\, cm^2$
W	4.4 $MeV \cdot cm^2/mg$
s	0.7

The mono-beam experimental results of the SMJ329C50GFAM66 component are summarized in Table A4.

Table A4 SMJ329C50GFAM66

Ion	Energy of Beam [MeV]	Flux of particles [$cm^{-2}s^{-1}$]	Exposure Time [minutes]	Number of Flips
^{12}C	0.60	$25\cdot10^6$	5	8
^{12}C	0.72	$25\cdot10^6$	5	7497
^{12}C	9.6	$25\cdot10^6$	5	22514
^{16}O	4.8	$17\cdot10^6$	5	23986
^{40}Ar	20	$23\cdot10^6$	5	33810
^{56}Fe	56	$10\cdot10^6$	10	29991
^{84}Kr	84	$7\cdot10^6$	10	21022
^{131}Xe	786	$4\cdot10^6$	15	18043

Appendix B

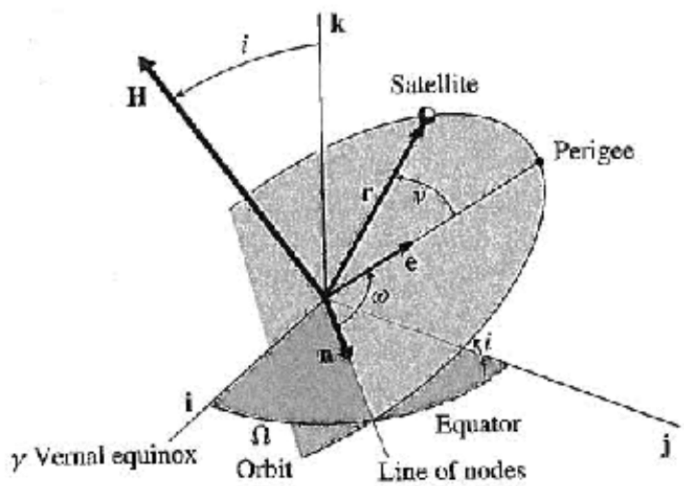
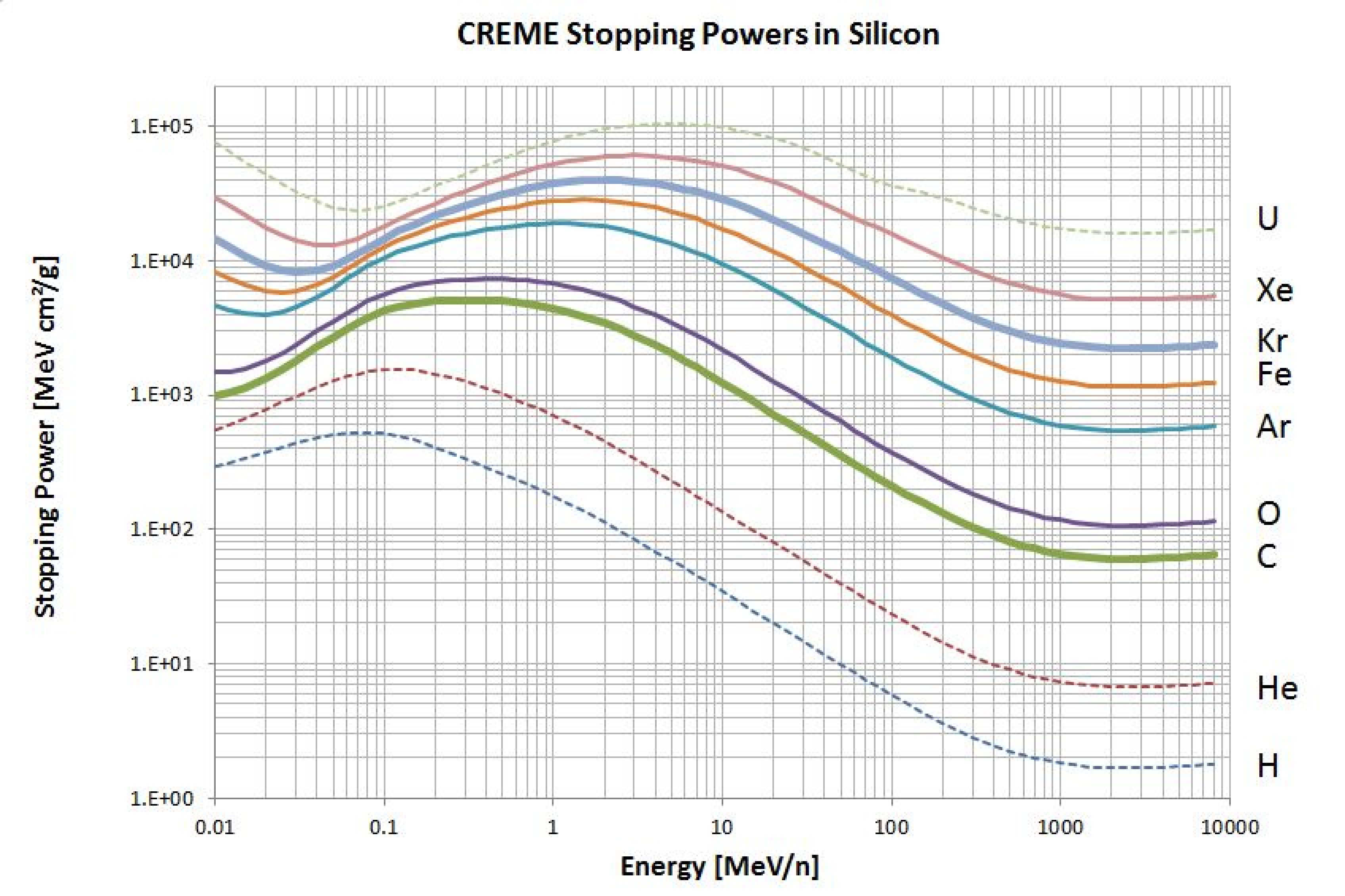


Figure 1. Classical orbital elements. Inclination i; right ascension of the ascending node Ω; argument of perigee ω; and true anomaly ν.



CREME Stopping Powers in Silicon
Stopping Power [MeV cm²/g]
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0.01
0.1
1
10
100
1000
10000
Energy [MeV/n]
U
Xe
Kr
Fe
Ar
O
C
He
H