The SPENVIS SEE Tool

E. De Donder

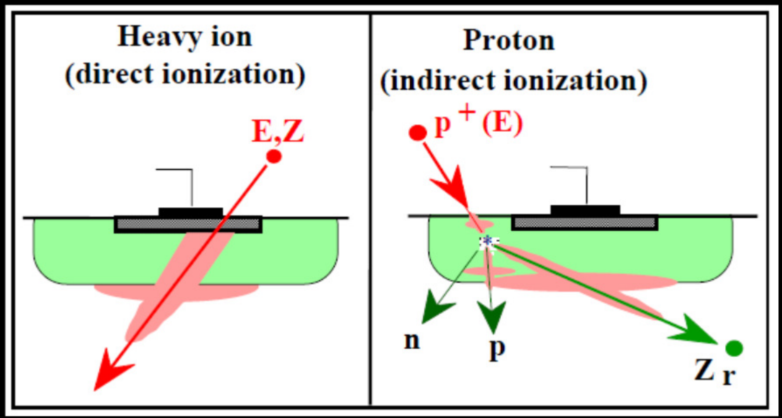
Belgian Institute for Space Aeronomy
(BIRA-IASB)

Outline

- Introduction
- How to access the SPENVIS SEE tool?
- Input and output
- SEE tool in the Next Generation SPENVIS

Introduction

Single Event Effect (SEE): perturbation of the behavior of electronic (optoelectronic) devices, circuits and/or systems produced by a single ionizing particle



Parameters to model SEE response of a device:

- Linear Energy Transfer (LET in MeV·cm²/mg) : rate of energy deposit per unit path length ≈ $\rho^{-1} \cdot dE(x)/dx$
- Cross section (σ in cm²/bit) : probability for SEE = #events/fluence
- Sensitive Volume (SV in μm³) : charge collection region
- Critical Charge (Q_c in pC) : min. required charge for SEE

Access to SEE package

INPUT

① Coordinate generators — S/C trajectory definition

Radiation sources and effects

Radiation sources

② Environment Definition

- 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 fluxes

Shielded flux

Solar cell radiation damage

- Damage equivalent fluences for solar cells (EQFLUX)
- 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

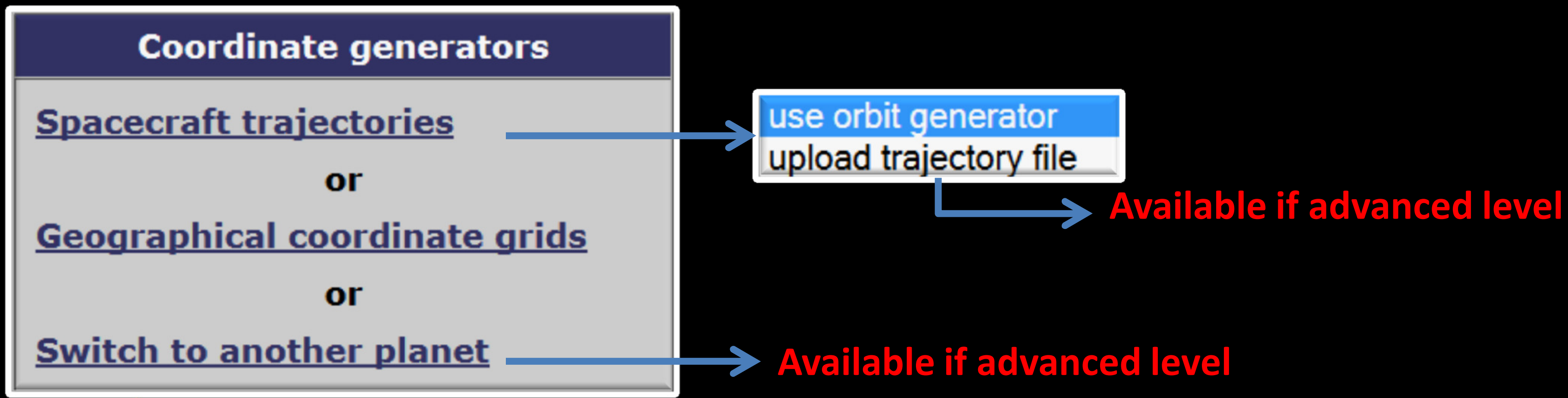
③ LET spec and Upset calculation

- Short-term SEU rates and LET spectra
- Long-term SEUs and LET spectra

Input 1: Planet/orbit selection

- planet selection: Earth, Mars or Jupiter
- 2 ways to specify the trajectory:
  1. Orbit generator
  2. Upload trajectory file in SPENVIS format

→ http://www.spenvis.oma.be/help/models/sapre_upl.html



Input 2: Environment specification

(see ECSS-E-ST-10-04C for required models)

- Trapped protons in radiation belts
- Solar particles (long, short term; Z=1-92)
- GCR particles (Z=1-92)

→ Inclusion of magnetic shielding

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 fluxes

Magnetic shielding: on (quiet magn.) edit

SEE tool

Select particle source(s)

PARTICLE ENVIRONMENT

- [ ] solar particles
- [ ] trapped protons
- [x] GCR particles

f(E') : differential energy spectra at skin S/C

If advanced level

output resolution: mission segment averages / spectra for each orbital point

Shielding

shielding thickness (Al equivalent): 1 cm / g/cm2 / mils

→ differential energy spectra inside S/C

If advanced level

number of devices: 1 max. 15

Device 1: defined | DEFAULT (Si) | edit

Input 3: Device characteristics

- **Device Material:** **Si:** CREME86 or SRIM2008

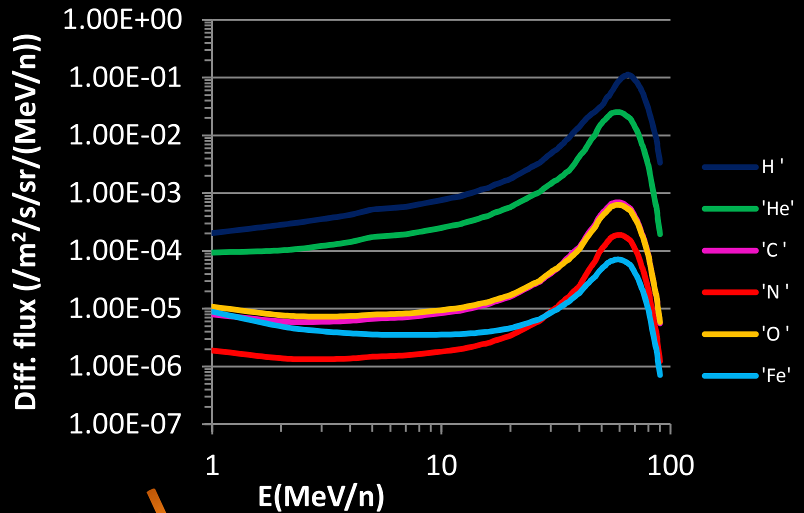
  GaAs: SRIM2008 or Geant4.9

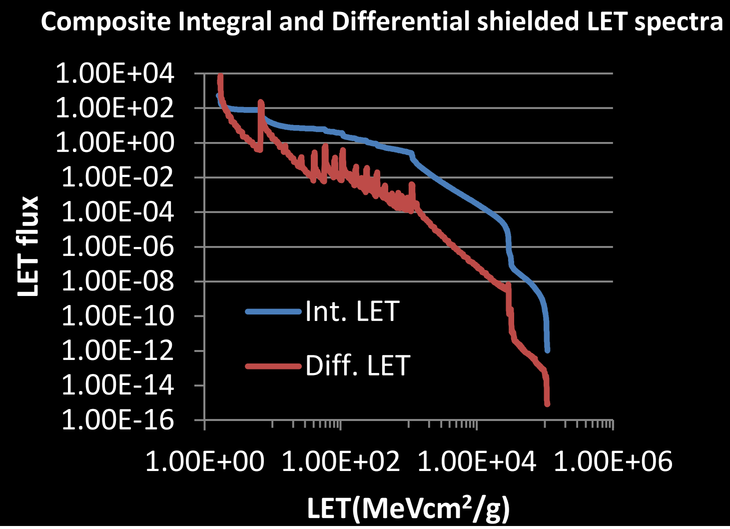
→ diff. LET spectrum : f(S) = f(E)[dS/dE]

→ int. LET spectrum with E_{min} = 0.1 MeV/n (before 1 MeV/n)

→ sum over all species: **composite integral spectrum**

→to be used for SEU rate calculation





- **SV parameters:**
  - Library (selection from literature)
  - User defined:
    - Shape of SV
    - Cross section data

Device source: library

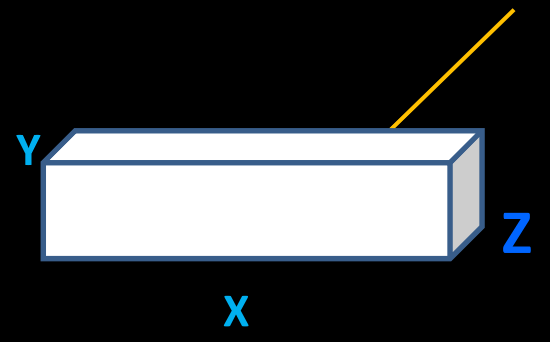
- (•) 93L422 (BIPOLAR)(51x51x2)
- ( ) 93L422AM (BIPOLAR)(38.7298x38.7298x2)
- ( ) 2164 (MOS)(13x13x2)
- ( ) D424100V (4M DRAM)(5.96x5.96x1)

Device material:	Si (SRIM2008)
Device source:	user defined
Device name:	R2D2

Device name	Heavy ion method	Proton method
#01: 93L422 Mat.: Si Manu.: Fairchild Ref.: Petersen, 1998 (IEEE Trans. Nuc. Sci. 45) RPP: 51.00 x 51.00 x 2.00 (μm^3)	$S = 0.70$ $L_0 = 0.60$ MeV·cm²/mg $W = 4.40$ MeV·cm²/mg $\sigma_{lim} = 2.60E\text{-}05$ cm²/bit SEU algorithm: CREME	A = 6.50 MeV B = 9.26 MeV

(given in report file)

Shape SV: (only for direct ionisation rates)



- **RPP (X x Y x Z):**

  Input: X, Y and Z or XY and Z

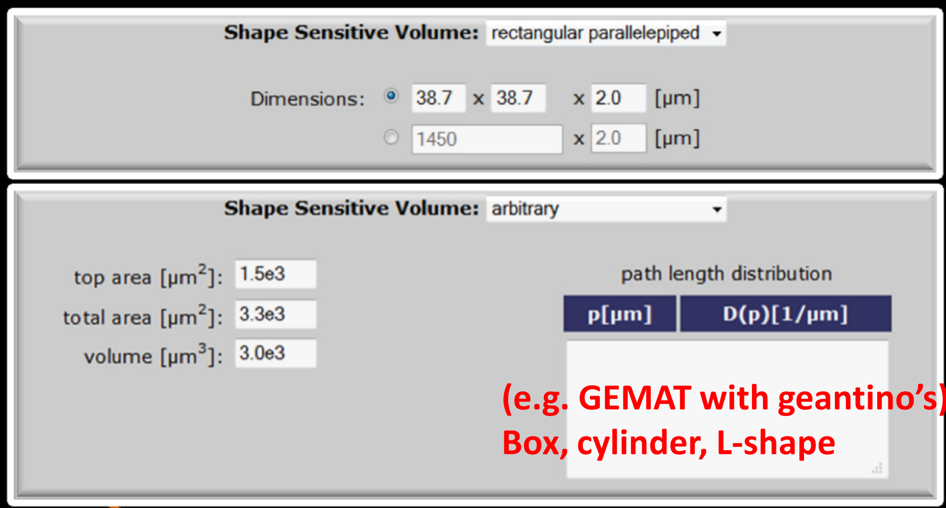
  →from manufacturer or from cs data i.e. $X=Y=\sqrt{\sigma_{sat}}$

  →Z = 2µm (historical) or 1 µm (wc)

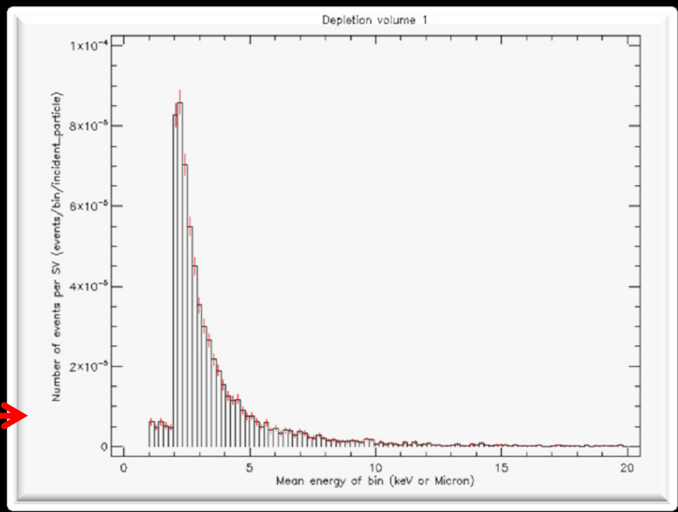
- **Arbitrary:**

  µm units!!

  Input: Top area (A), Total area (S), Volume (V) and Differential pathlength distribution D(p)



(e.g. GEMAT with geantino's)
Box, cylinder, L-shape



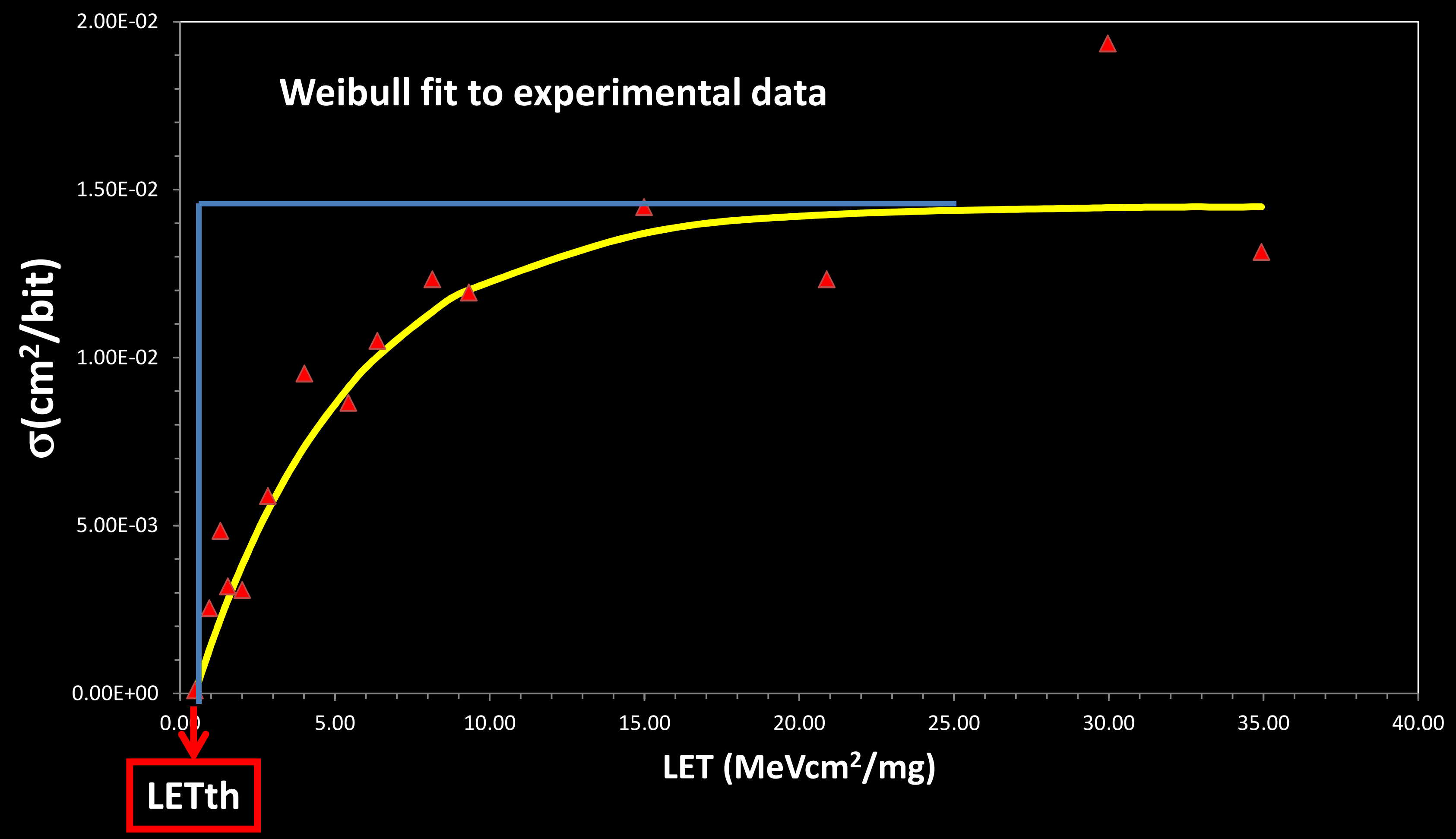
Cross section data:

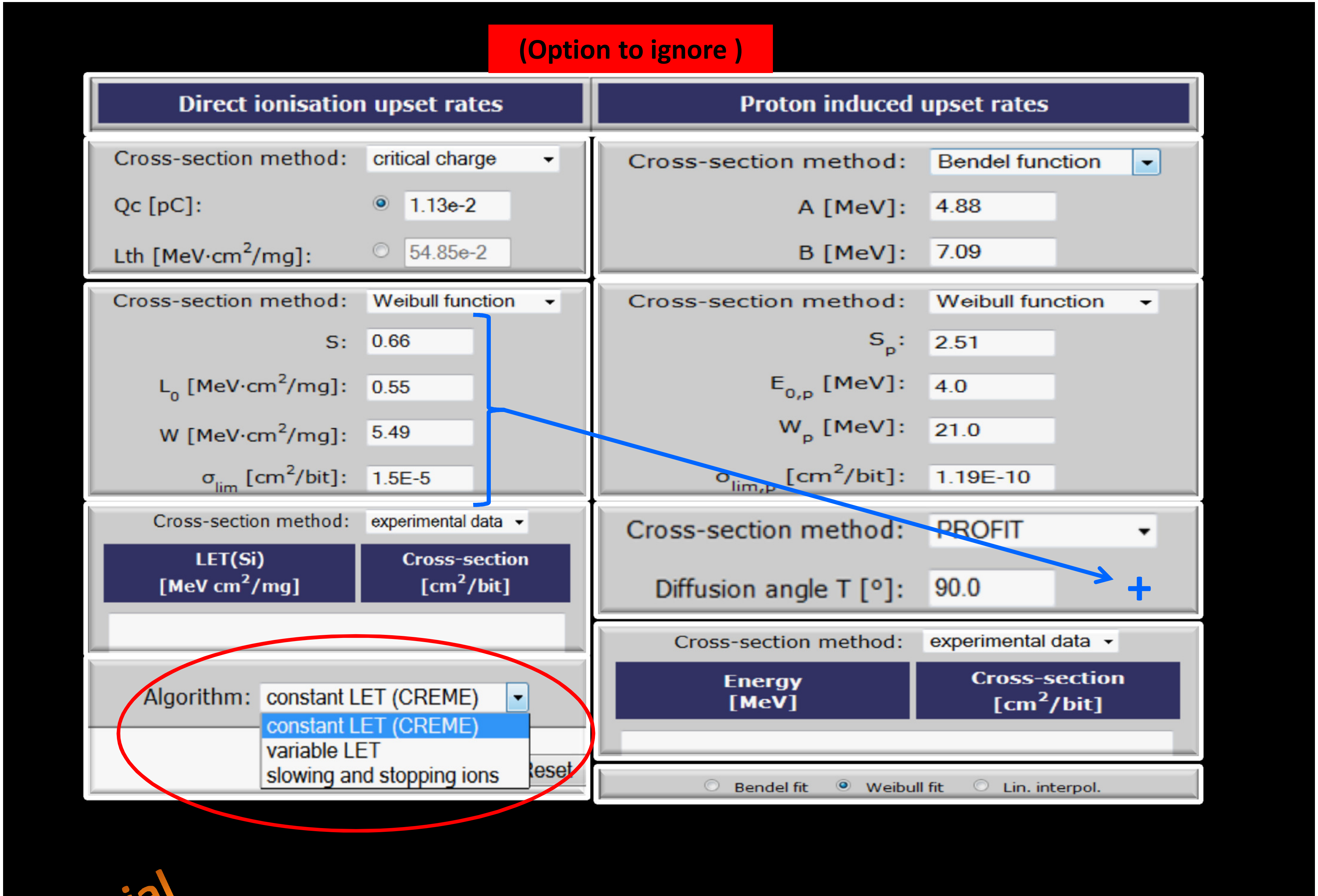
for direct ionisation:

- Q_c (pC) or LET_{th} ($MeV \cdot cm^2/mg$) → $Q_c = \gamma \cdot Z \cdot LET_{th}$
- Weibull: W, LET_{th}, S, σ_{lim} (→$XY=\sqrt{\sigma_{lim}}$)
- Cross section table: σ(cm^2/**bit**) vs. **LET** ($MeV \cdot cm^2/mg$)

for proton induced:

- Bendel: A, B
- Weibull: W_p, $E_{th,p}$, S_p, $\sigma_{lim,p}$
- Cross section table: σ(cm^2/**bit**) vs. **E** (MeV)
- PROFIT: W, LET_{th}, S, σ_{lim}, T (=90°= wc) (only heavy ion data available)


Weibull fit to experimental data
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
σ(cm²/bit)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
LET (MeVcm²/mg)
LETth


(Option to ignore)
Direct ionisation upset rates
Proton induced upset rates
Cross-section method: critical charge
Qc [pC]: 1.13e-2
Lth [MeV·cm²/mg]: 54.85e-2
Cross-section method: Bendel function
A [MeV]: 4.88
B [MeV]: 7.09
Cross-section method: Weibull function
S: 0.66
L0 [MeV·cm²/mg]: 0.55
W [MeV·cm²/mg]: 5.49
σlim [cm²/bit]: 1.5E-5
Cross-section method: Weibull function
Sp: 2.51
E0,p [MeV]: 4.0
Wp [MeV]: 21.0
σlim,p [cm²/bit]: 1.19E-10
Cross-section method: experimental data
LET(Si) [MeV cm²/mg]
Cross-section [cm²/bit]
Cross-section method: PROFIT
Diffusion angle T [°]: 90.0
+
Cross-section method: experimental data
Energy [MeV]
Cross-section [cm²/bit]
Algorithm: constant LET (CREME)
constant LET (CREME)
variable LET
slowing and stopping ions
Reset
Bendel fit
Weibull fit
Lin. interpol.

Rate calculation: upset if $E_{dep} > E_c$ (or $Q > Q_c$ or $LET > LET_{th}$)

- Proton induced ionization:

  Rate ~ ∫ cross section data x diff. particle fluence

- Direct ionisation:

  Rate ~ ∫ SV data x pathlength distribution x (LET or ion) flux

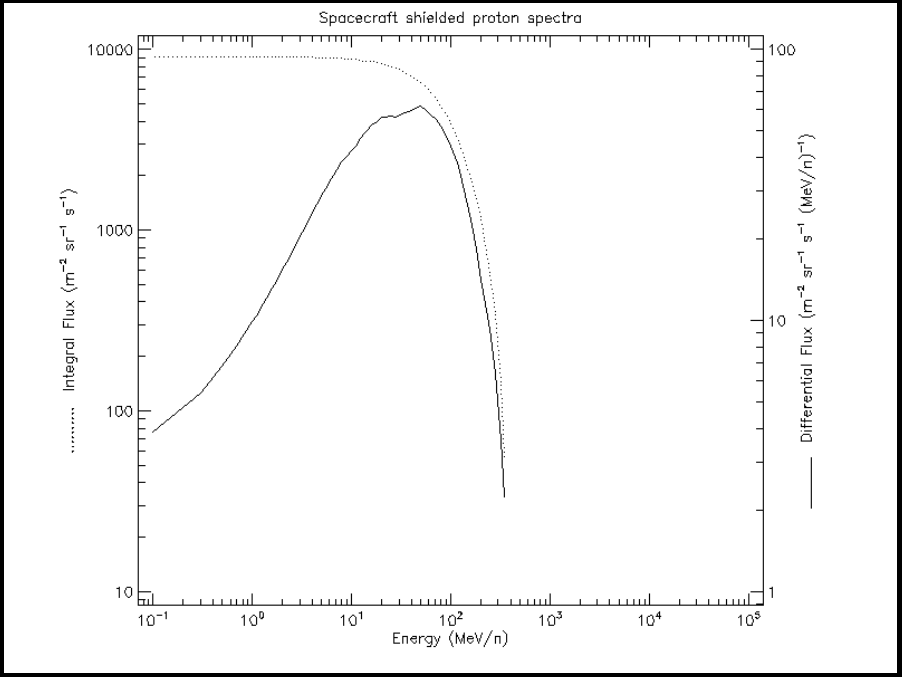
algorithm: **Default**

- **CREME (Constant LET)** : $E_{dep} = \rho \cdot LET \cdot p$ with LET constant in SV (→ok for long-range ions)
- **Variable LET** : $E_{dep} = \rho \cdot \int LET(E) dp$
- **Slowing and Stopping** : $E_{dep} = E - R^{-1}(R(E)-p)$ → ion flux instead of LET flux

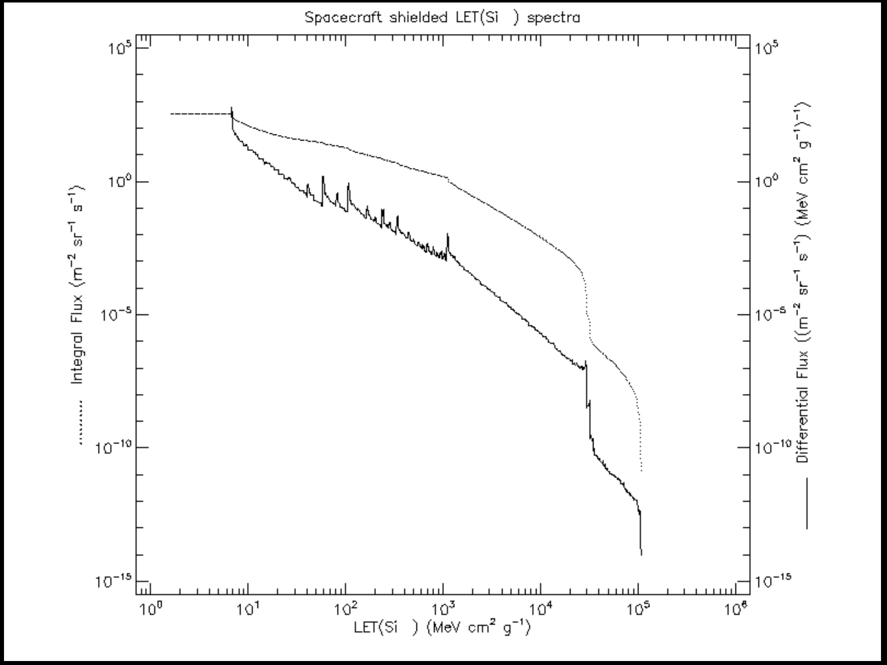
(precise formula's: http://www.spenvis.oma.be/help/background/creme/creme.html#SEU)

Output

Shielded p^+ spectrum

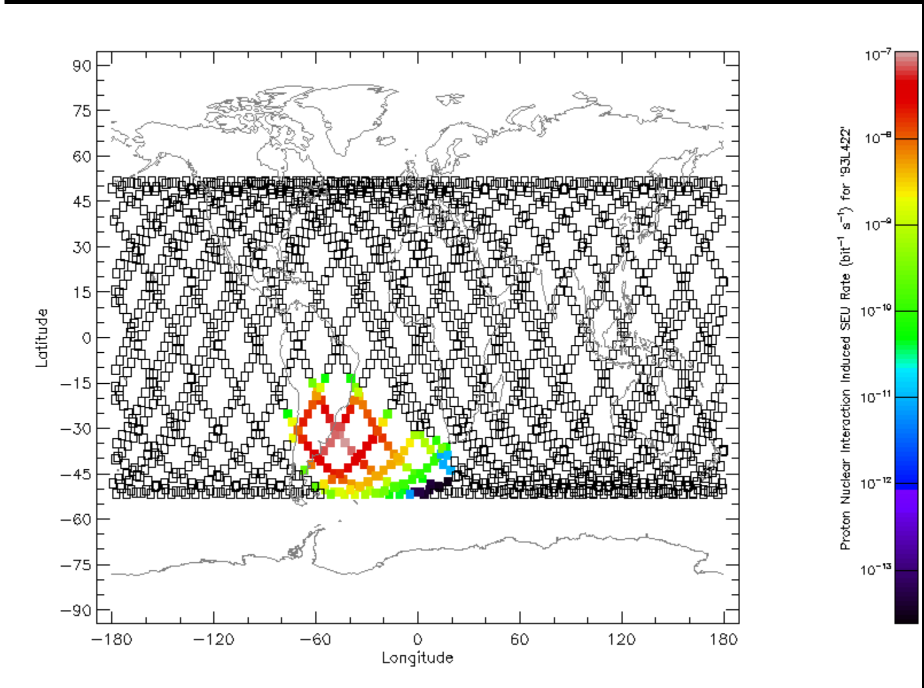


Shielded LET flux

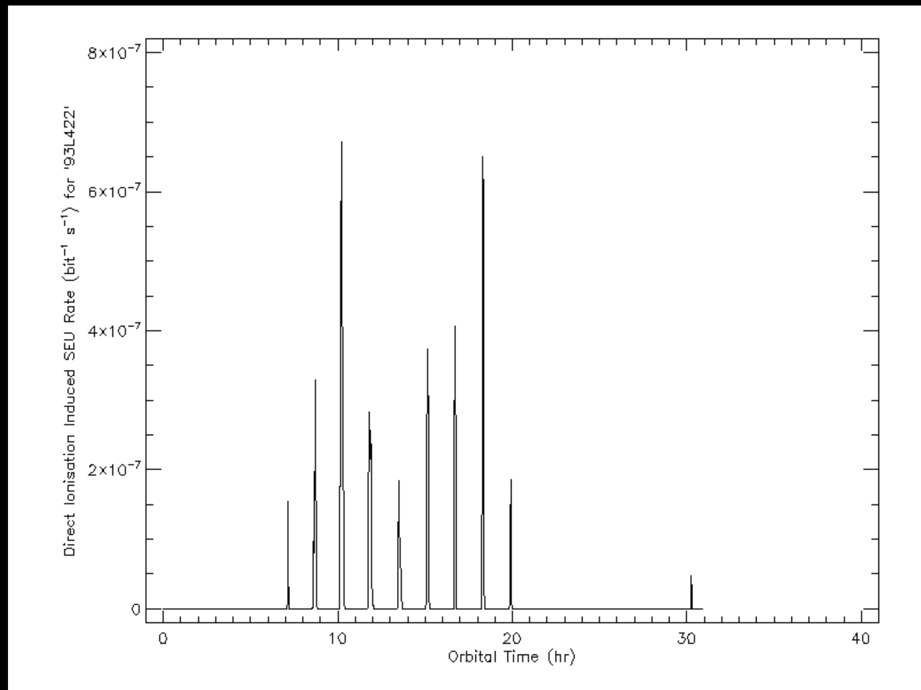


Mission total/Segment averaged SEU rate /bit or (bit/(s or day)) or total mission number (Long-term)

		Mission total			Mission segment 1		
Device	**Effect**	**(bit^{-1})**	**(bit^{-1} s^{-1})**	**(bit^{-1} day^{-1})**	**(bit^{-1})**	**(bit^{-1} s^{-1})**	**(bit^{-1} day^{-1})**
93L422	Direct ionization	3.2152E+00	1.0195E-08	8.8089E-04	3.2152E+00	1.0195E-08	8.8089E-04
	Proton induced ionization	2.7702E-01	8.7844E-10	7.5897E-05	2.7702E-01	8.7844E-10	7.5897E-05
	Total	3.4923E+00	1.1074E-08	9.5679E-04	3.4923E+00	1.1074E-08	9.5679E-04



worldmap



Time plot

Petersen 2011 (126 comparisons of predicted and observed SEU rates from 23 satellites):

"the methods of upset calculation are satisfactory"

But predictions may be wrong because of :

- Poor environment prediction e.g. dynamic nature of radiation belt
- Part to part variation: part location, different lot, …
- Poor choice of device depth
- Insufficient test data
- Incorrect shielding distribution
- …

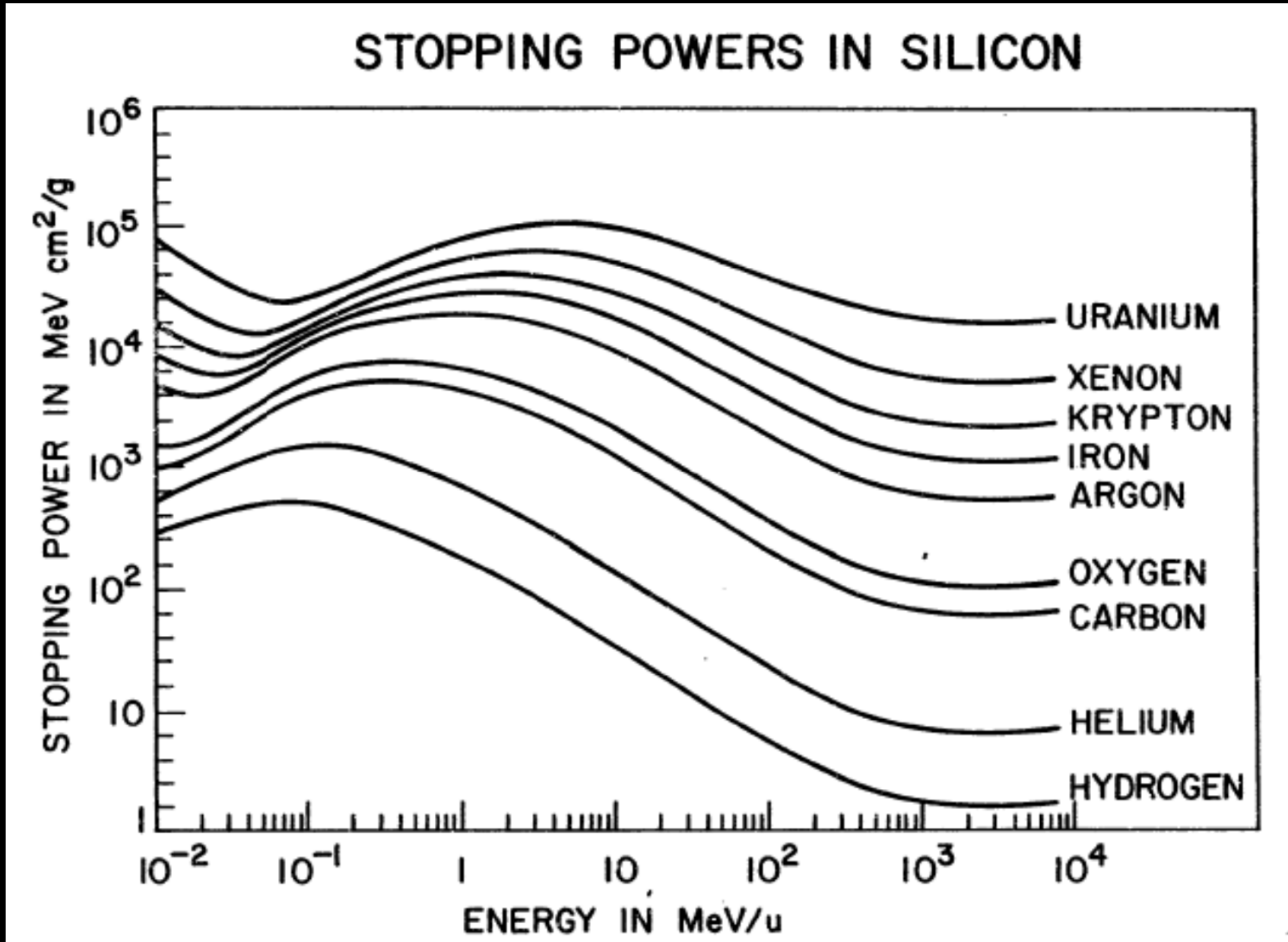
SEU tool in Next Generation SPENVIS

- New environment models e.g. AP9/AE9
- Link to Geant4 tools outputs:
  - Realistic shielding distribution
  - New materials and LET
  - Inclusion of secondary particles
- Extension of device library:
  - Inclusion of user defined devices → available in ≠ projects + sharing with other users
  - Link to ESCIES database
- Interface to framework for IC designers produced by the "Evaluation of the Radiation Effects on Deep Sub Micron CMOS Technologies" project
- **Suggestions from YOU**

Bibliography

- ECSS-E-HB-10-12A (space environment)
- ECSS-E-ST-10-04C (calculation of radiation and its effects and margin policy handbook)
- Single Event Effects in Aerospace, E. Petersen (2011)

Back up slides



- CREME 86/96: $$U = \pi \cdot A \cdot \left(\frac{X}{e}\right) \cdot Q_c \int_{L_{min}}^{L_{max}} \frac{D[p(L)] \cdot F(L)}{L^2} dL$$

- Slowing down and stopping:

$$U = \pi A \sum_{Z=1}^{92} \left(\int_{p_{min}}^{p_{max}} D(p) \int_{E_c}^{E_{max}} F(E,Z) dE dp \right)$$

- Variable LET

$$\langle L(E) \rangle = \frac{\sum_i F_i(E) \cdot L_i(E)}{\sum_i F_i(E)}$$

$$\langle \Delta E(s_{\min}) \rangle = \frac{\int_0^{s_{\min}} \wp(s) \cdot \Delta E(s) \cdot ds}{\int_0^{s_{\min}} \wp(s) \cdot ds} = E_{\min}$$