Influence of RPP SEPR Prediction Parameters

Implementation of Uncertainty Statistical Estimation for SEPR Calculation in OMERE

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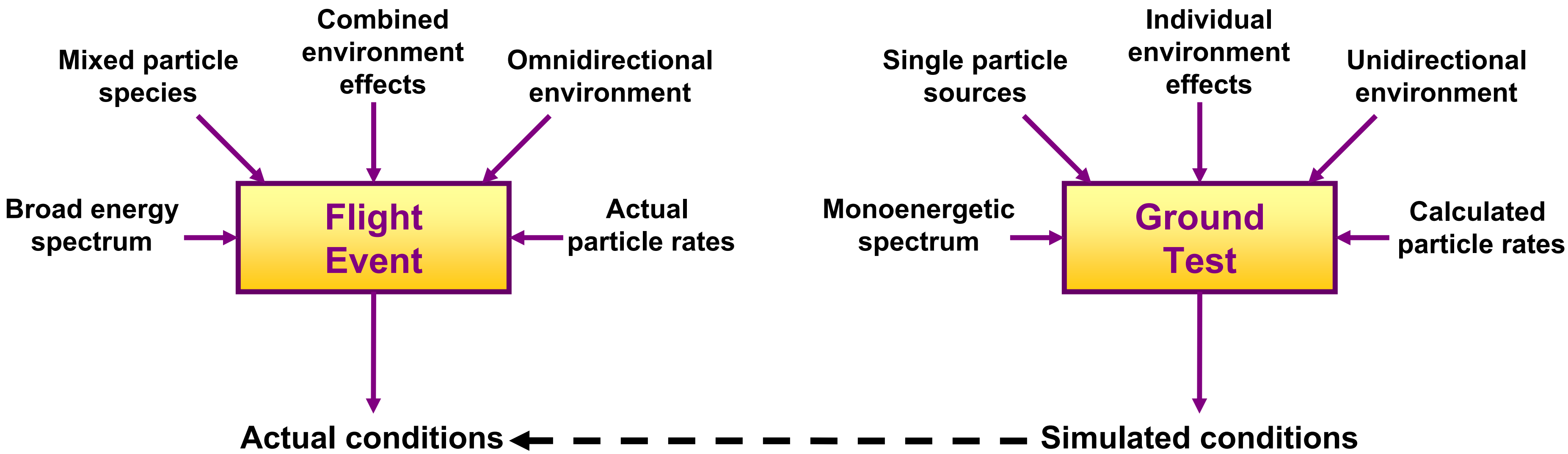
Outline

- **Introduction**
- **Influence of SEE rate prediction parameters**
  - Influence of device parameters
  - Influence of Weibull fit adjustment parameters
  - Influence of radiation environment
- **Implementation of uncertainty statistical estimation for SEPR calculation in OMERE**
  - Weibull fit optimisation
  - Statistical approach
  - Confidence interval
- **Conclusion**

Introduction



How accurate is the ground test in predicting space performance?

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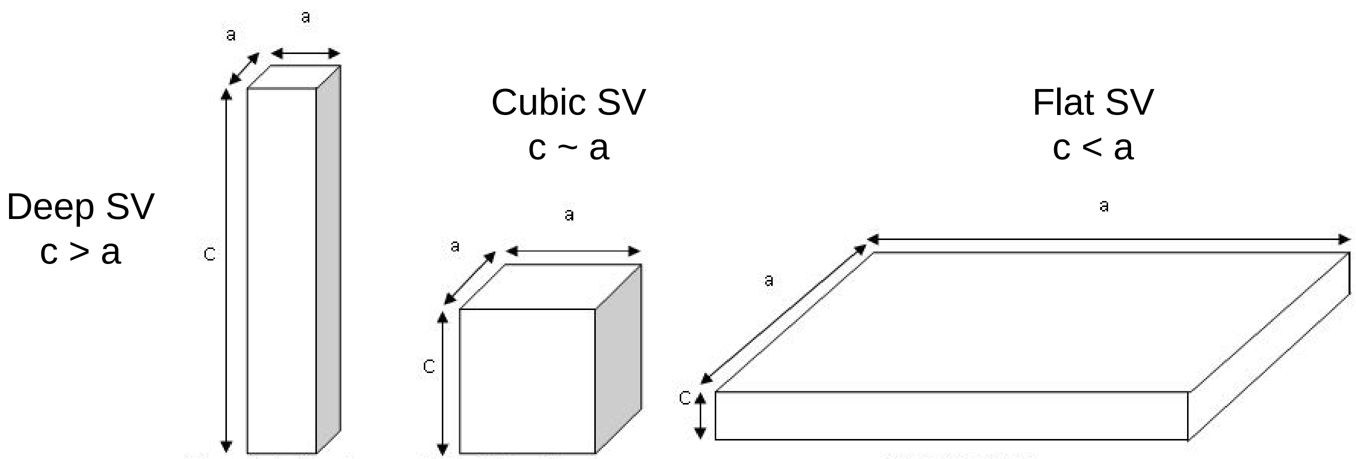
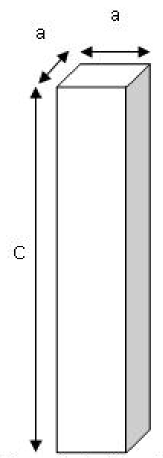
Influence of device parameters

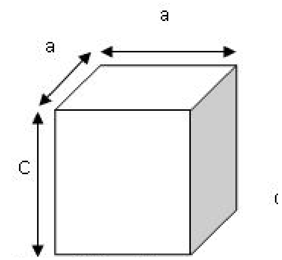
- **Parameters studied**
  - Saturation cross section σ_{SAT}
  - Depth of the sensitive volume c
  - LET threshold LET_{th}
- **OMERE (freeware www.trad.fr) component database created with over 2000 theoretical components**
  - $10^{-9} < \sigma_{SAT} < 10^{-3}$ cm^{-2}
  - 1<c<100 µm
  - $1 < LET_{th} < 40$ $MeV.cm^2.mg^{-1}$
  - 1<W<50
  - 1<S<20
- **The SER calculations have been performed with 3 sensitive volume (SV) types**



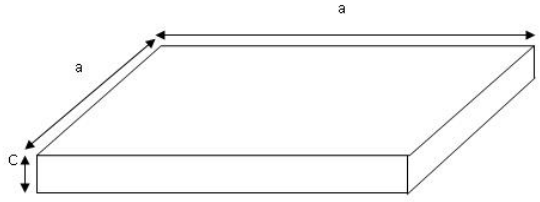
Influence of device parameters



- For deep SV, the SER is mainly due to particles with LET values around (and above) the LET_{th}
  - Direct relation tolerable between the LET_{th} measured during the test and the LET spectrum of the environment
  - Conclusion → the LET_{th} must be carefully measured during the test in order to avoid a significant increase of the error margin
- For cubic SV
  - The c value has a great impact on the SER



- For flat SV
  - For commonly used variation of c (1 to 10 µm), the impact on SER is negligible

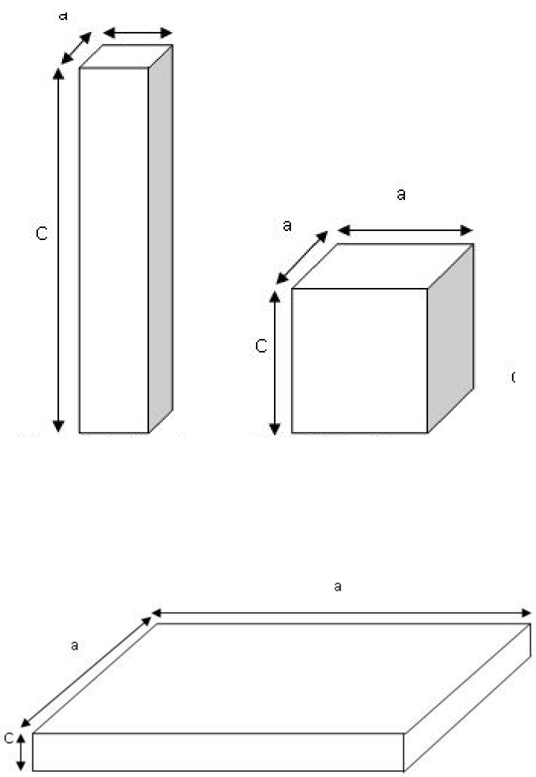


Adjustment parameters

- **For W,S wide variation, the ratio between the lowest and highest SER can reach 10^5**
  - W,S define the "elbow" region of σ(L) → LET range of particles involved in SEE occurence

- **W and S have a significant impact on SEE rate**
  - Greater impact for deep and cubic SV than for flat SV

- **W and S parameters must be carefully adjusted**
  - LET_{th} and saturated cross section are not sufficient to fully characterize a device



Influence of environment

Contribution of the different ion species

- **Identification of predominant contribution elements**
  - Fe for flat SV at all LET_{th}
  - Ions heavier than Fe for deep SV when $LET_{th}>30$
- **Determination of LET range for those elements**
  - Deep SV: elements with LET at least equal to LET_{th}
  - Flat SV: low LET have predominant contribution on SER, even at high LET_{th}
  - At high W and S values, SEE are mainly due to high LET particles
- **Determination of energy range involved in SEE rate**
  - A wide range of energy is involved in SER prediction

Influence of environment

- **Result table summary**

	LET_{th}	Cubic SV	Deep SV	Flat SV
Predominant elements	1	Fe (48%)	Fe (54%)	Fe (35%)
	10	Fe (59%)	Fe (63%)	Fe (39%)
	35	Fe (23%)	Pb (23%)	Fe (43%)
Range of LET involved in MeVcm2/mg with 1g/cm² shielding de (with 10g/cm2 shielding LET involved are lower)	1	0< LET <10	> à 1	LET< 5
	10	5< LET <30	> à 10	LET< 5
	35	20< LET <60	> à 35	LET< 5
Range of Energy for Predominant elements in MeV/nucl (1 g/cm² shielding)		100 - 200	100 - 200	all energies
Range of Energy for Predominant elements in MeV/nucl (10 g/cm² shielding)		200 - 500	200 - 500	all energies

- **The most important contribution to the SEE rate in the incident radiation environment depends on the device parameters and SV shape**

Parameter analysis conclusion

- **The shape of the sensitive volume (c parameter) remains as a major issue**
  - LET threshold and saturated cross section determined with heavy ions test are not sufficient to fully characterize a device sensitivity
  - The direct relation between the measured LET threshold and the LET spectrum environment is not always representative
- **The Weibull function shape fitted to test data (W,S parameters) impacts significantly the calculated SEE rate**
  - The "elbow" region of the cross section curve should be well described as it impacts directly the LET range of the particles involved in SER

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Weibull fit optimisation

- **Context**

  - **Device SEE sensitivity characterized by heavy ion test**
  - **Number of test achieved <u>limited</u> (cost, time schedule…)**
  - **There is an <u>uncertainty</u> in determining the Weibull parameters (W, S, σ_{sat}, L_0)**
    → uncertainty in the rate calculation

- **Problem**

  - **Uncertainty direct calculation impossible**
    - RPP model too complicated
    - Strong hypothesis admitted for the rate calculation
  - **Find a method able to estimate the uncertainty in the rate calculation with a <u>statistical approach</u> [R. Ladbury 2007]**

Statistical approach

- **Estimation of the uncertainty in the calculation of the 4 Weibull parameters**
  - Independent information of L, # et Φ
  - Calculation of the best fit (W, S, σ_{sat}, L_0) for the test data
  - Calculation of a confidence interval
- **Hypothesis**
  - Existing test data L, # et Φ
  - Poisson statistical distribution

- **Poisson distribution included in the fit calculation to determine the most probable Weibull parameters**
  - Most probable equation for the test data
  - Most realistic rate according to the cross section measurements performed

Weibull fit optimisation

- **The input for the calculation is a set of test data**
  - LET L, number of event # and fluence Φ
- **At each LET, the Poisson distribution is inserted in the calculation**
  - via a statistical mean value μ

$$p(\#,\mu) = e^{-\mu}\frac{\mu^{\#}}{\#!}$$

  - μ is proportional to Φ and σ_{cal}(L)

$$\mu(L) = \Phi\sigma_{cal}(L)$$

  - At a given LET, the likelihood for # to equal μ is p

Weibull fit optimisation

- **A global likelihood P is calculated from the Poisson likelihood<u>s</u> p at <u>each</u> LET**
  - **The global likelihood P is the product of the Poisson likelihoods**

$$P(\{\#_i\}) = \prod_i p(\#_i, \mu_i)$$

- **The cross section parameters are determined by optimizing the likelihood P with respect to the 4 Weibull parameters**

$$\sigma_{cal}(L) = \sigma_{sat}\left(1 - \exp\left[-\left(\frac{L - L_0}{W}\right)^S\right]\right)$$

Variation of the <u>4 Weibull parameters</u> to maximize the global likelihood P

  - **The (W, S, σ_{sat}, L_0) values maximizing P give the best fit equation for the test data**

- **The Weibull fit is optimized thanks to a <u>genetic algorithm</u>**
  - **Non-determinist global optimisation method**
  - **The global optimum is calculated via probabilistic transition rules applied to an initial « population »**

Confidence interval

- **The P value associated to the best fit is called P_{max}**
  - A maximum likelihood ratio method is used to calculate a confidence interval for the fit

$$\ln\left(\frac{P}{P_{\max}}\right) \geq -0.5\chi^2(1-\alpha,4) \qquad P_{\max} = \max(P)$$

- **X(1-α,4) is the chi-squared statistic**

- **For a given space enviromnent, a set of 4 Weibull parameters lead to only one rate value**
  - The confidence interval defined for the fit enables to calculate a confidence interval for the rate

Confidence interval

- **The Weibull function depends on 4 parameters**
  - To visualize the confidence interval, only the variation of two parameters can be represented

#	PHI	L	smes
	cm2	MeV.cm2.mg-1	cm2
1	9.99E+06	28.8	1.00E-07
50	7.95E+06	40.73	6.29E-06
100	3.59E+06	53.1	2.79E-05
100	2.50E+06	57.6	4.00E-05
100	9.46E+05	75.09	1.06E-04
100	4.23E+05	106.2	2.36E-04

Test data

Best fit

W \ S	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
60	-67.2	-49.8	-35.8	-24.9	-16.7	-11.2	-7.9	-6.7
62	-51.9	-36.3	-24.2	-15.2	-9.0	-5.4	-4.0	-4.7
64	-39.1	-25.4	-15.3	-8.2	-3.9	-2.2	-2.7	-5.3
66	-28.7	-17.0	-8.7	-3.5	-1.1	-1.2	-3.6	-8.0
68	-20.4	-10.5	-4.1	-0.8	-0.3	-2.3	-6.5	-12.7
70	-14.0	-6.0	-1.4	0.0	-1.3	-5.1	-11.1	-19.0
72	-9.2	-3.1	-0.4	-0.8	-3.9	-9.4	-17.2	-26.9
74	-6.0	-1.7	-0.8	-2.9	-7.8	-15.1	-24.6	-36.0
76	-4.1	-1.6	-2.5	-6.4	-13.0	-22.0	-33.2	-46.2
78	-3.4	-2.7	-5.3	-11.0	-19.3	-30.0	-42.8	-57.4
80	-3.8	-4.8	-9.2	-16.6	-26.5	-38.9	-53.3	-69.5

Yellow area represents ln(P/P_{max}) confidence interval

L0 \ ssat	2.40E-04	2.60E-04	2.80E-04	3.00E-04	3.10E-04	3.20E-04	3.40E-04	3.60E-04
24	-6.4	-3.3	-2.9	-4.9	-6.6	-8.8	-14.5	-21.8
25	-8.9	-3.7	-1.2	-0.9	-1.6	-2.7	-6.2	-11.3
26	-14.6	-7.3	-2.7	-0.4	-0.02	-0.1	-1.6	-4.6
27	-23.5	-14.3	-7.8	-3.5	-2.2	-1.3	-0.9	-2.0
28	-36.3	-25.3	-17.0	-11.0	-8.7	-7.0	-4.7	-4.1

Confidence interval

- **The <u>calculated rate uncertainty can be limited</u> according to the test data used for the calculation**
  - Confidence interval for the rate

Max rate value

Rate calculated for the best fit

Min rate value

Yellow area represents Rate confidence interval

CREME86 *1e-5 $dev^{-1}.day^{-1}$

W \ S	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
60	2.93	2.83	2.74	2.66	2.59	2.52	2.46	2.41
62	2.80	2.71	2.62	2.54	2.47	2.40	2.35	2.29
64	2.69	2.59	2.51	2.43	2.36	2.30	2.24	2.18
66	2.58	2.49	2.40	2.33	2.26	2.19	2.14	2.09
68	2.48	2.38	2.30	2.23	2.16	2.10	2.04	1.99
70	2.38	2.29	2.21	2.13	2.07	2.01	1.95	1.90
72	2.29	2.20	2.12	2.05	1.98	1.92	1.87	1.82
74	2.20	2.12	2.04	1.97	1.90	1.85	1.79	1.75
76	2.12	2.04	1.96	1.89	1.83	1.77	1.72	1.67
78	2.05	1.96	1.89	1.82	1.76	1.70	1.65	1.61
80	1.97	1.89	1.82	1.75	1.69	1.63	1.59	1.54

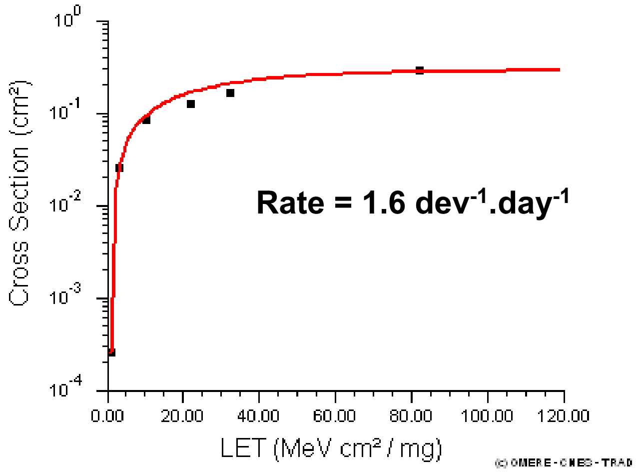
L0 \ ssat	2.40E-04	2.60E-04	2.80E-04	3.00E-04	3.10E-04	3.20E-04	3.40E-04	3.60E-04
24	1.65	1.83	2.02	2.21	2.31	2.41	2.60	2.80
25	1.57	1.75	1.92	2.11	2.20	2.29	2.49	2.67
26	1.50	1.67	1.84	2.02	2.11	2.20	2.38	2.56
27	1.44	1.60	1.76	1.93	2.02	2.10	2.28	2.45
28	1.38	1.53	1.69	1.85	1.93	2.01	2.18	2.35

Weibull fit comparison

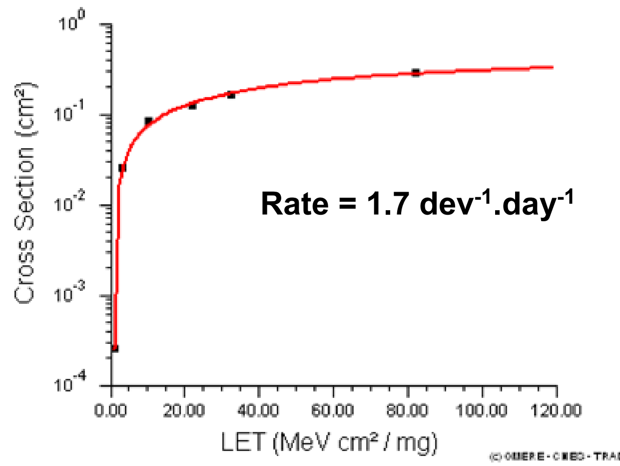
Least-squares / Genetic algorithm

KM684000

Least-squares:



Genetic algorithm:



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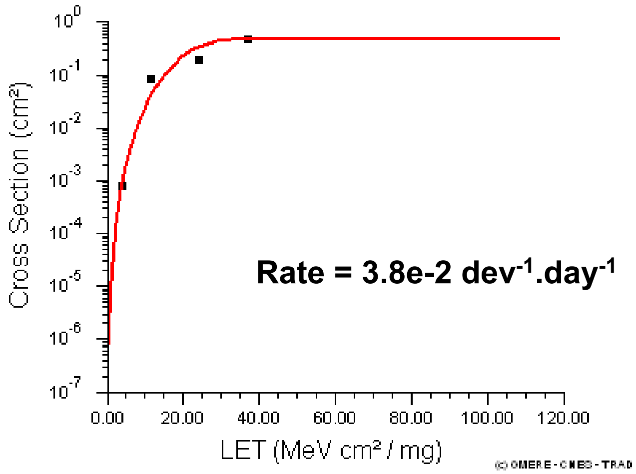
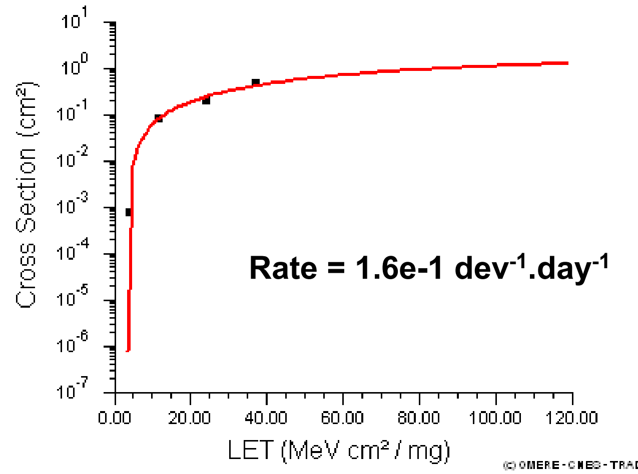
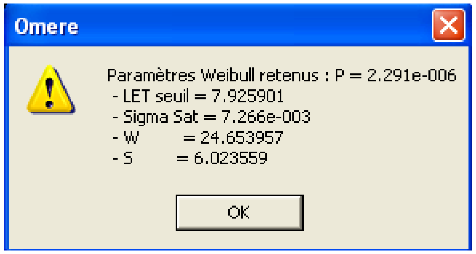
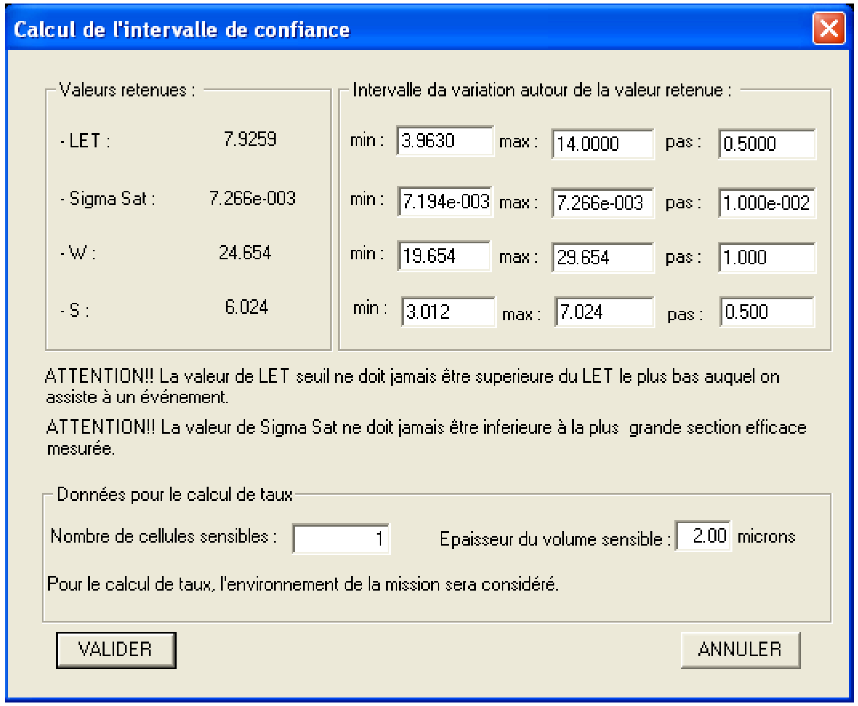




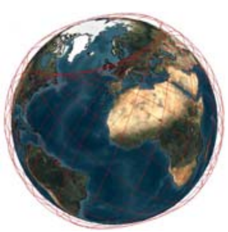
(Calculation performed with OMERE default environment)

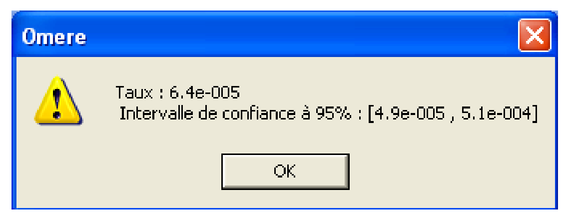
Confidence interval calculation





OMERE





Conclusion

- **TRAD studies realized with CNES support in the frame of SEE prediction improvement is going on in 2011…**

  - **OMERE uncertainty beta version improvement**
    - Automatic calculation of the confidence interval
  - **Charge deposition and LET variation in the SV**
    - A charge deposition calculation methodology has been proposed in 2010 → development of a software prototype to test it in 2011
  - **Method to adapt the RPP model to the different types of SEE**
    - Application of different methodologies for SEU, SET, SEL, SEB…