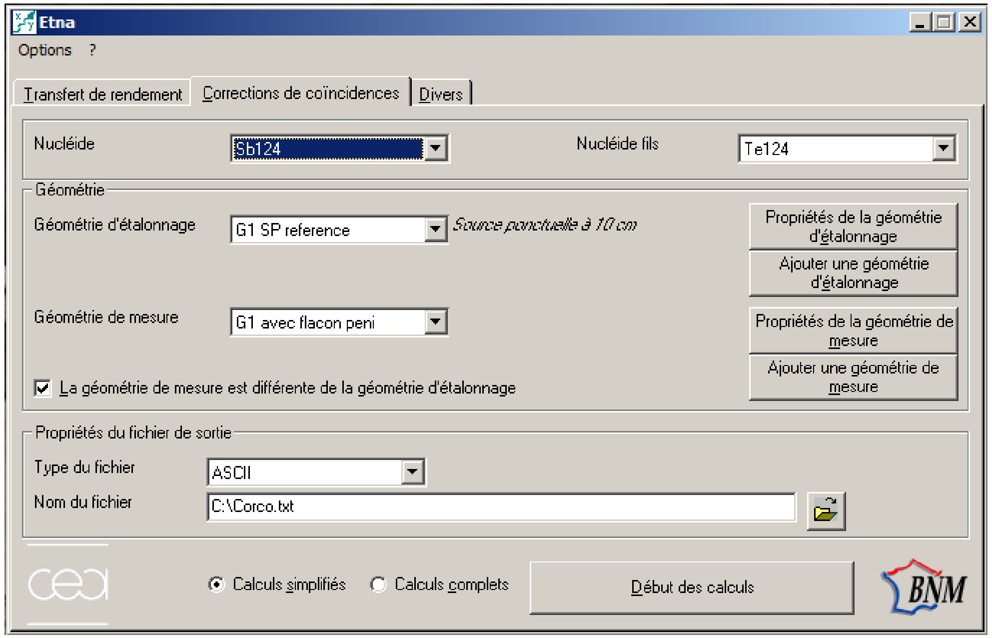
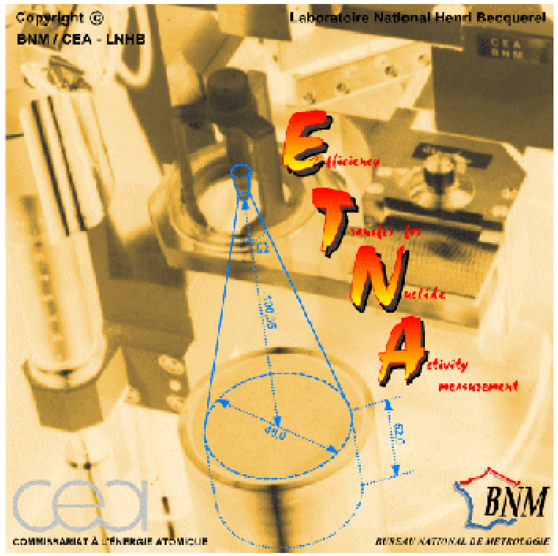
ETNA

(Efficiency Transfer for Nuclide Activity measurement)

ETNA is a software for computing efficiency transfer and coincidence summing corrections for gamma-ray spectrometry.

The software has been developed at the Laboratoire National Henri Becquerel and is available upon request.





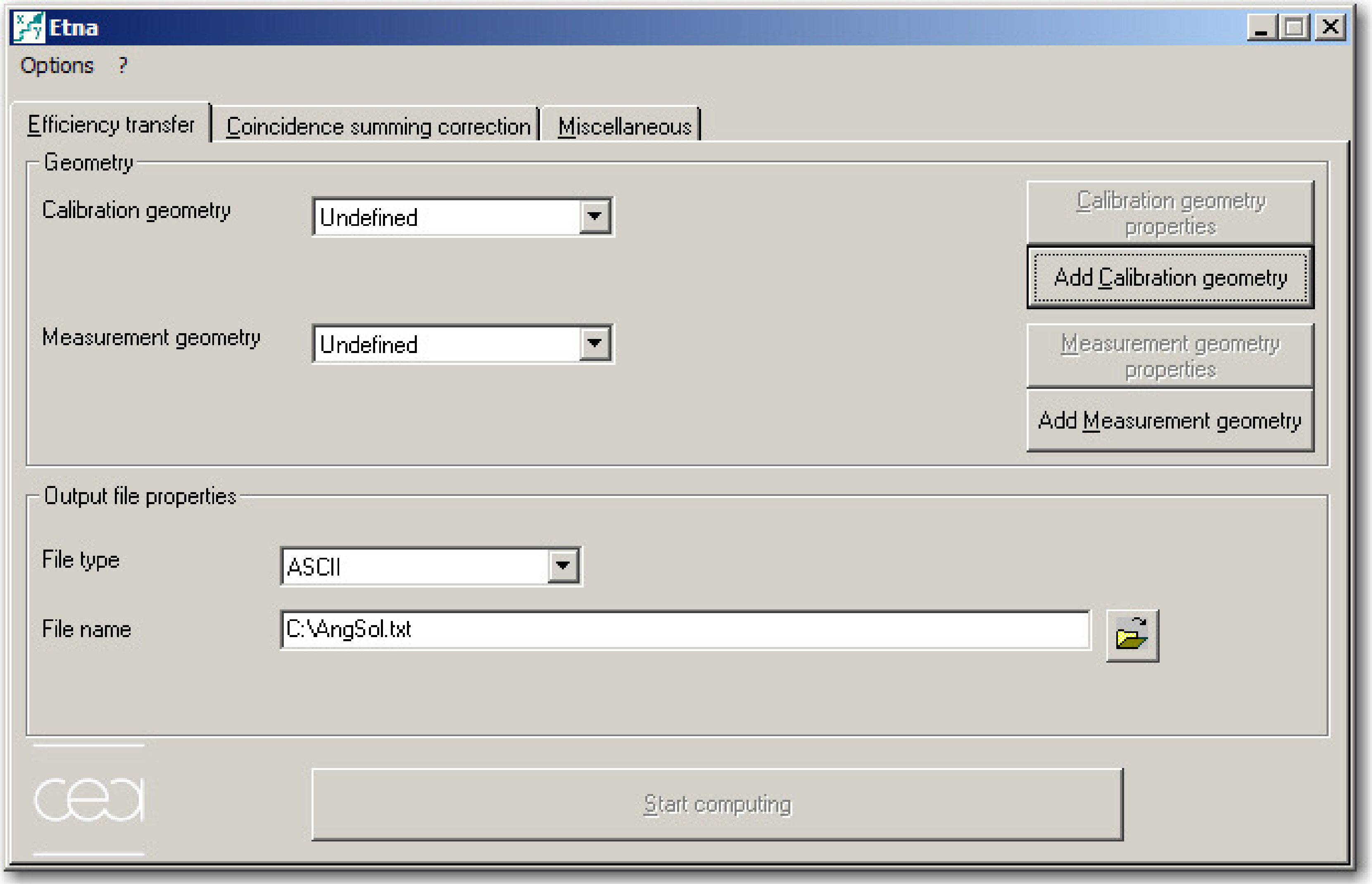
ETNA

- Transfer of efficiency
  - Semi-empirical method (from a reference efficiency)
  - Coaxial cylindrical geometry (point. disk. cylinder. Marinelli)

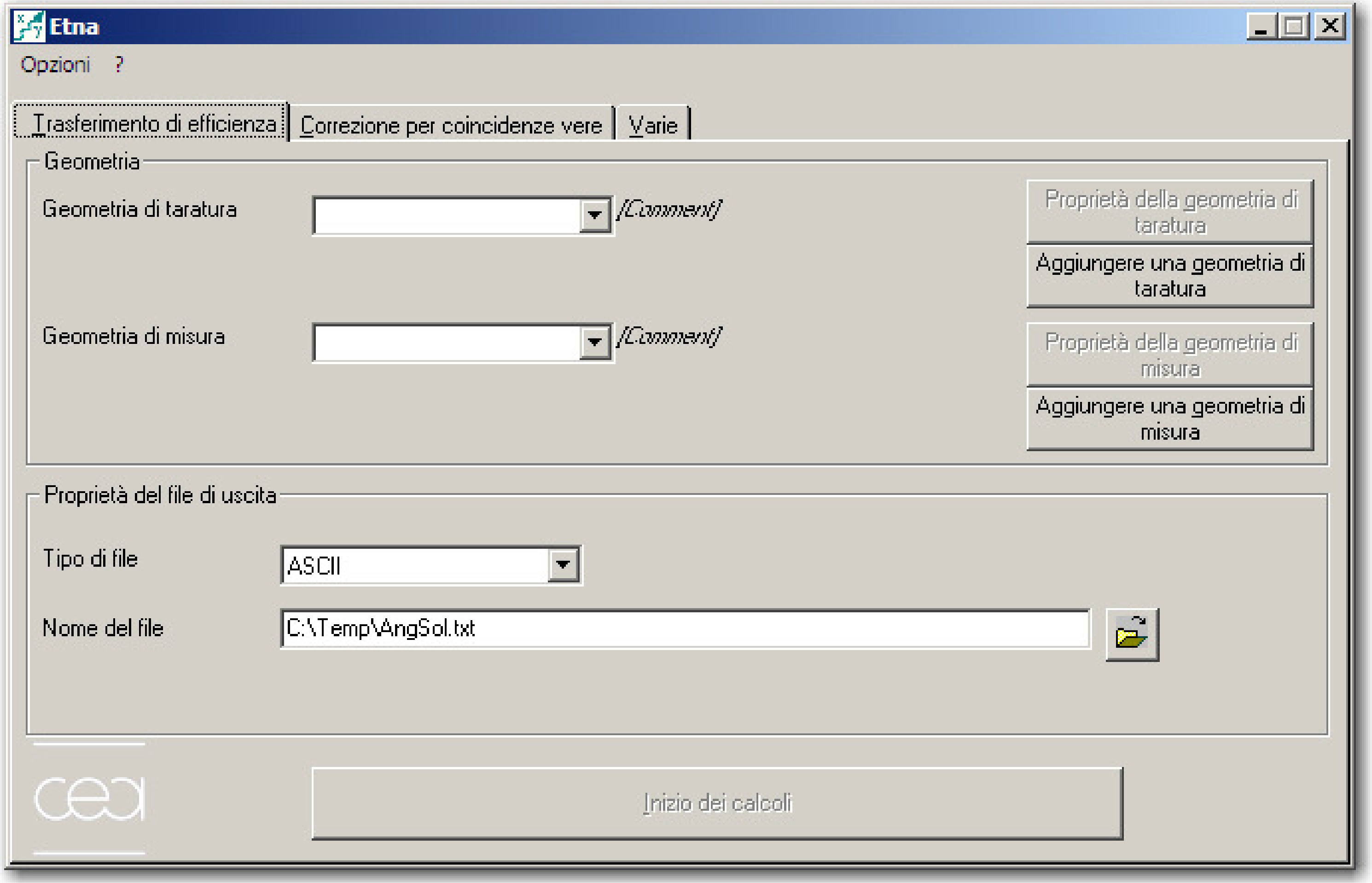
- Coincidence summing corrections
  - Knowledge of the efficiency (total and full-energy peak)
  - Possibility of efficiency transfer
  - Decay scheme from Nucleide

- Data management
  - Decay scheme
  - Attenuation coefficients

ETNA main window



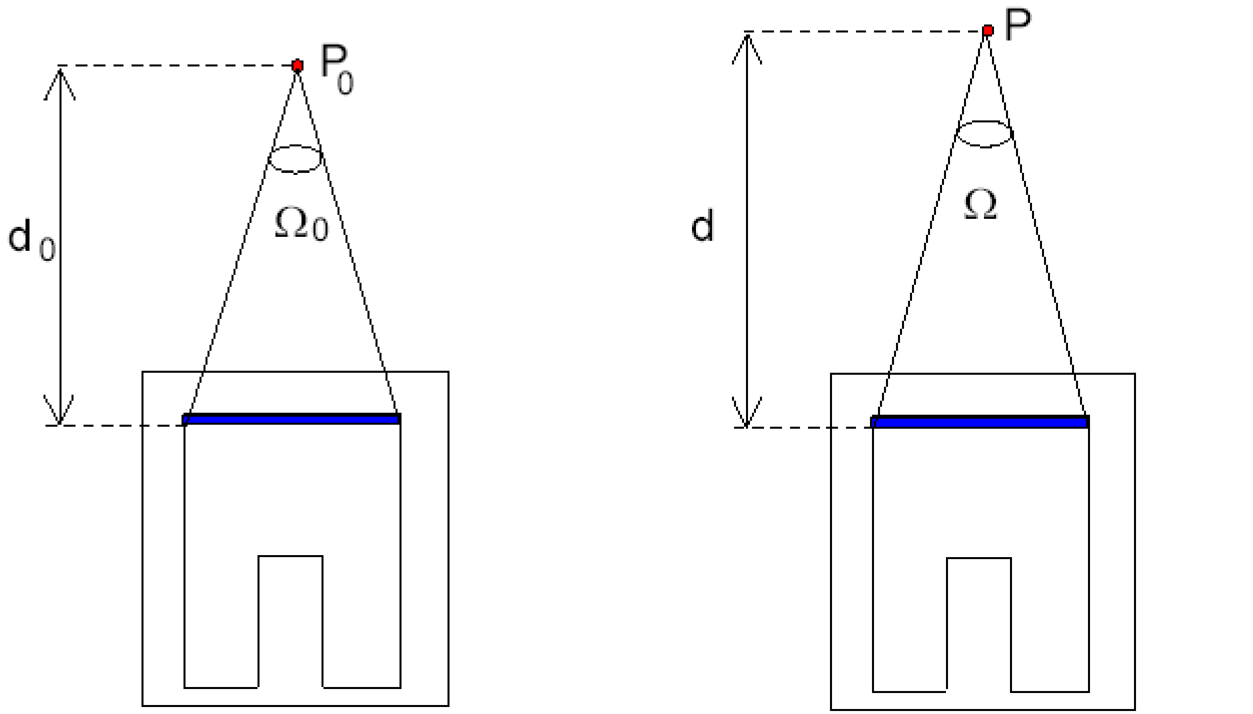
Recent update (04/11/2010)



Thanks to Dr Aldo FAZIO (ENEA) !

Efficiency transfer principle

Point source moving along the detector axis



$\mathcal{E}(E, P_0) = \mathcal{E}I(E).\Omega(P_0)$ $\qquad$ $\mathcal{E}(E, P) = \mathcal{E}I(E).\Omega(P)$

$$\mathcal{E}(E, P) = \mathcal{E}(E, P_0).\frac{\Omega(P)}{\Omega(P_0)}$$

Solid angle for point source

Using polar coodinates. the solid angle Ω(P) between point P (r, ϕ, z_s) and the detector entrance surface (disc) is:

$$\Omega(P) = 2 \cdot z_S \int_0^{\pi} d\varphi \int_0^{R_D} \frac{R \cdot dR}{\left[R^2 - 2 \cdot R \cdot r \cdot \cos\varphi + r^2 + z_S^2\right]^{3/2}}$$

R_D is the detector radius.

The geometrical factor should include:

- attenuation in differents absorbing layers (air, window, dead layer. …) : F_{att}

$$F_{att} = \exp\left(-\sum_{i=1}^{m} \mu_i \cdot \delta_i\right)$$

- absorption in the detector active volume : F_{abs}

$$F_{abs} = f_1 + f_2 \cdot f'$$

$$f_1 = 1 - \exp(-\mu_D \cdot \delta_{1D}) \qquad f_2 = 1 - \exp(-\mu_D \cdot \delta_{2D}) \qquad f' = \exp(-\mu_D \cdot (\Delta + \delta_{1D}))$$

Solid angle for a cylindrical source

- For a volume source (cylindrical symmetry : radius R_{S}, thickness H_{S}, vertical position Z_S):

$$\Omega = \frac{4}{R_S^2 \cdot H_S} \int_{Z_S}^{Z_S+H_S} h \cdot dh \int_0^{R_S} r \cdot dr \int_0^{\pi} d\varphi \int_0^{R_D} \frac{R \cdot dR}{\left[R^2 - 2 \cdot R \cdot r \cdot \cos\varphi + r^2 + h^2\right]^{3/2}}$$

- Fatt and F abs must be included in the integration procedure

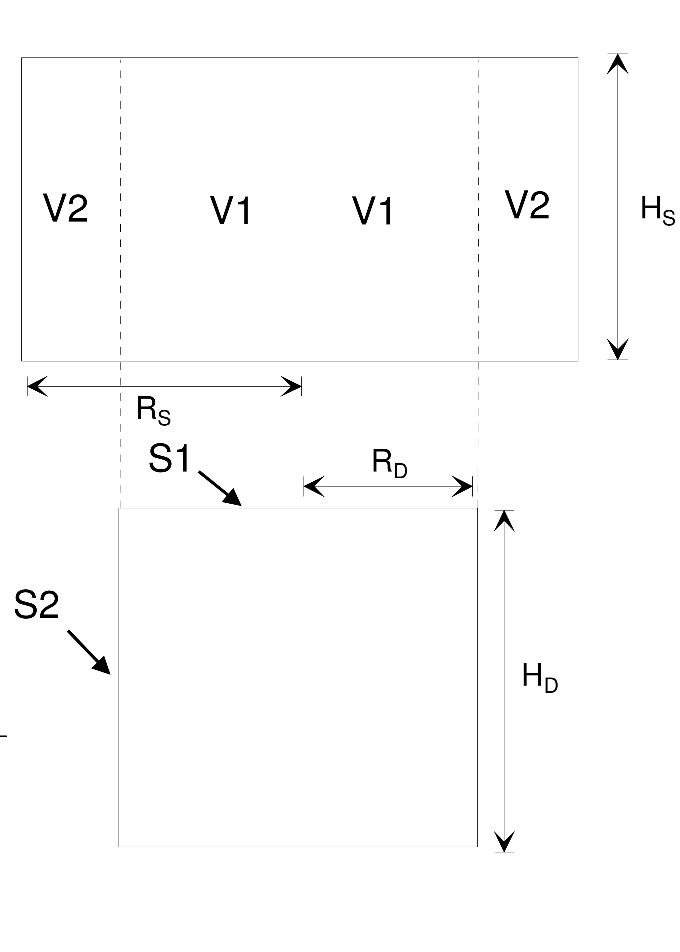
Solid angle for a cylindrical source

If the source diameter is larger than the detector one:

$$\overline{\Omega} = \int_{(V1+V2)S1} d\overline{\Omega} + \int_{(V2)S2} d\overline{\Omega} = \overline{\Omega}_1 + \overline{\Omega}_2$$

$$\overline{\Omega}_1 = \frac{4}{R_S^2 \cdot H_S} \int_{Z_S}^{Z_S+H_S} h \cdot dh \int_0^{R_S} r \cdot dr \int_0^{\pi} d\varphi \int_0^{R_D} \frac{F_{att} \cdot F_{abs} \cdot R \cdot dR}{\left[R^2 - 2 \cdot R \cdot r \cdot \cos\varphi + r^2 + h^2\right]^{3/2}}$$

$$\overline{\Omega}_2 = \frac{4 \cdot R_D}{R_S^2 \cdot H_s} \int_{Z_S}^{Z_S+H_S} dh \int_0^{R_S} r \cdot dr \int_0^{\phi_0} d\varphi \int_{Z_D}^{0} \frac{F_{att} \cdot F_{abs} \cdot (r \cdot \cos\varphi - R_D) \cdot dz}{\left[R^2 - 2 \cdot R \cdot r \cdot \cos\varphi + r^2 + h^2\right]^{3/2}}$$



Integration method

- Integration are numerically performed using the Gauss-Legendre method:

$$\int_a^b f(x)dx = \frac{(b-a)}{2}\sum_{i=1}^{n} w_i f(x_i)$$

$$f(x_i) = \frac{(b-a)}{2}x_i + \frac{(b+a)}{2}$$

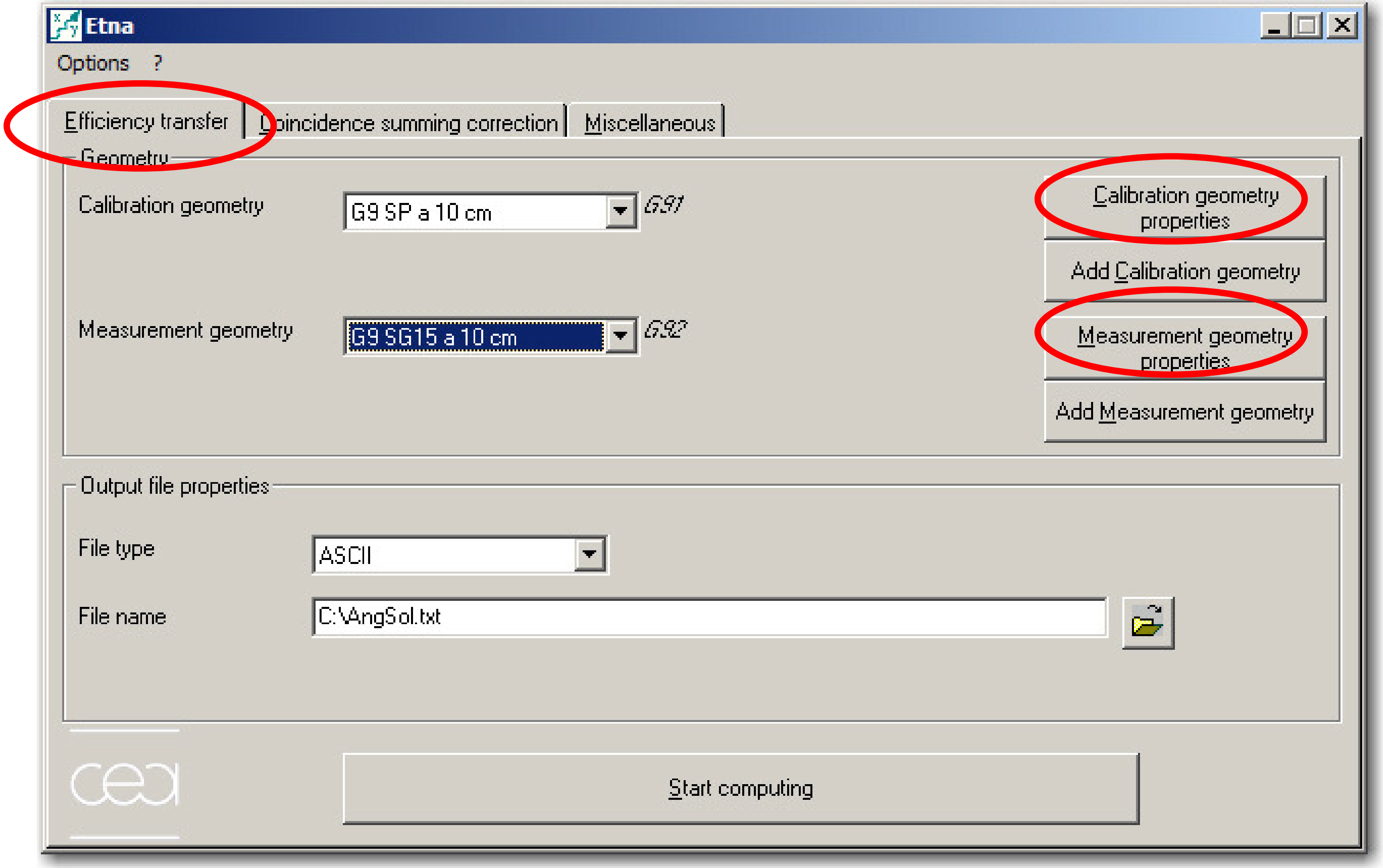
x_i and w_i = roots and weights of Legendre polynomials

- Point sources, discs, cylinders and Marinelli (along the detector axis) are considered.

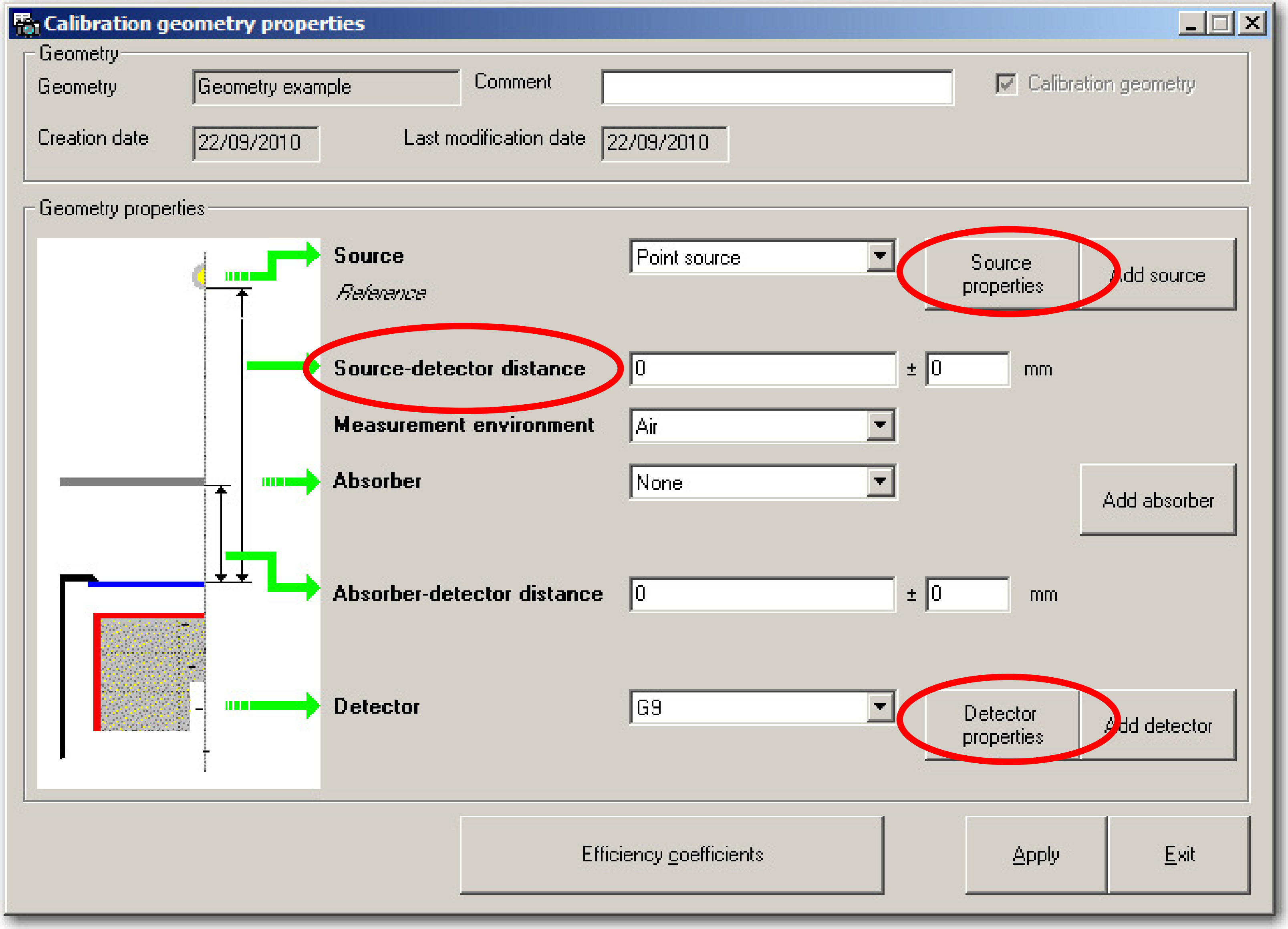
Input of data

- Requires
  - Detector parameters
  - Source parameters
    - Container
    - Matrix
  - Geometry conditions (source-to-detector distance, screen)
  - Reference efficiency
- Recorded in the « user » database

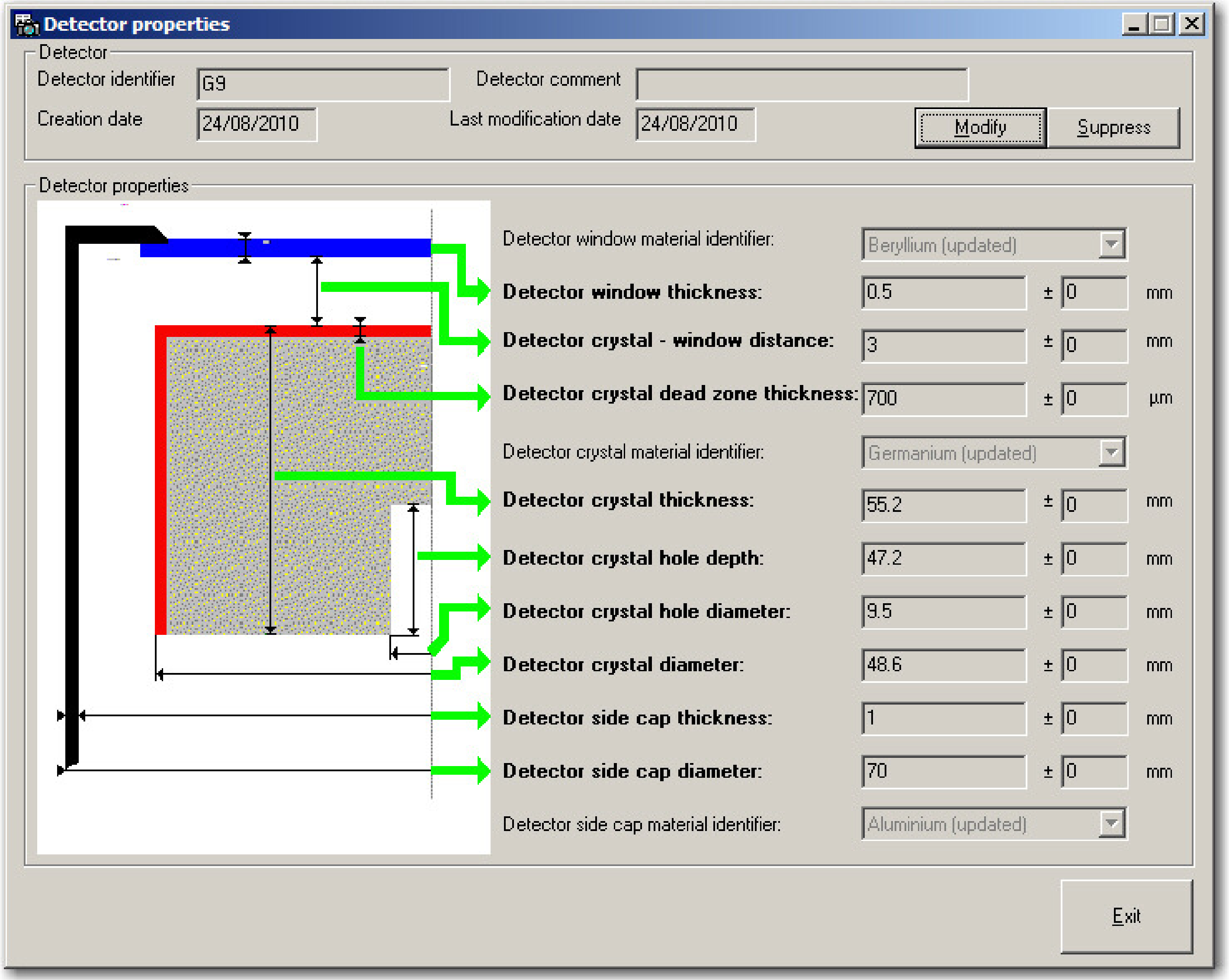
Efficiency transfer window



Input of geometry parameters

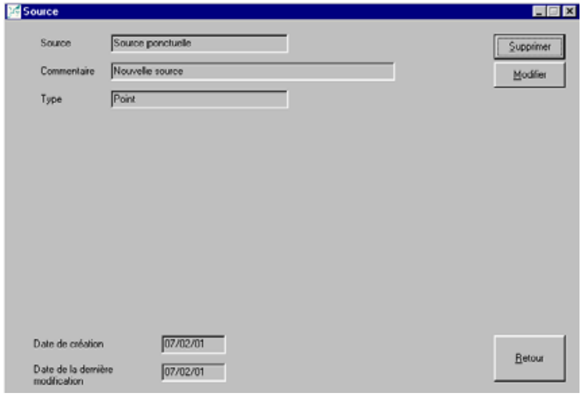


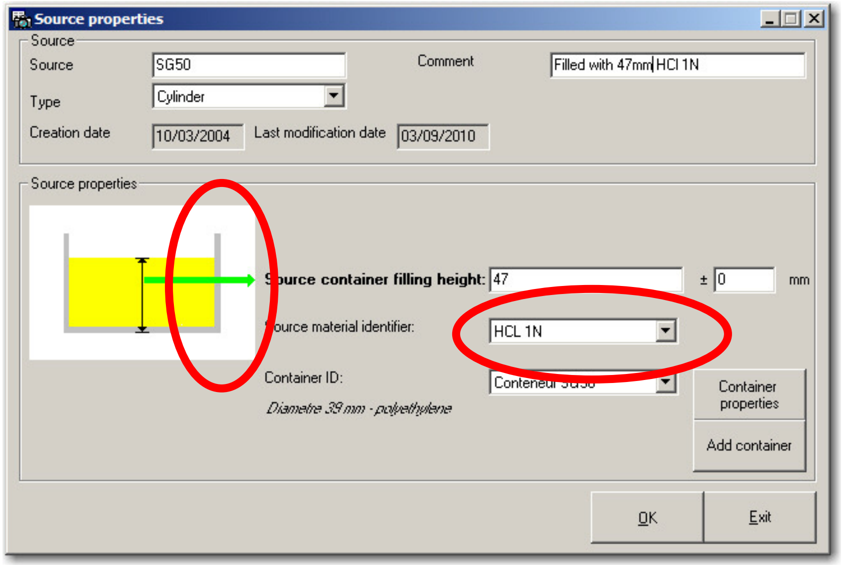
Input of detector parameters

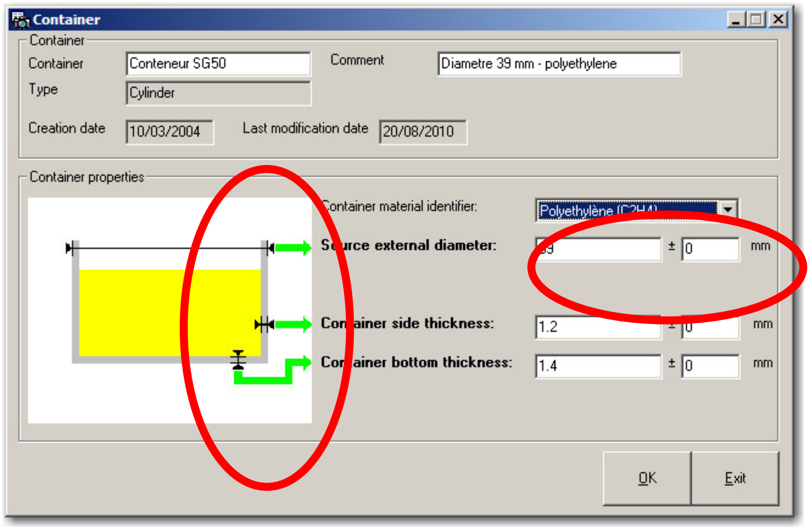


Input of source parameters

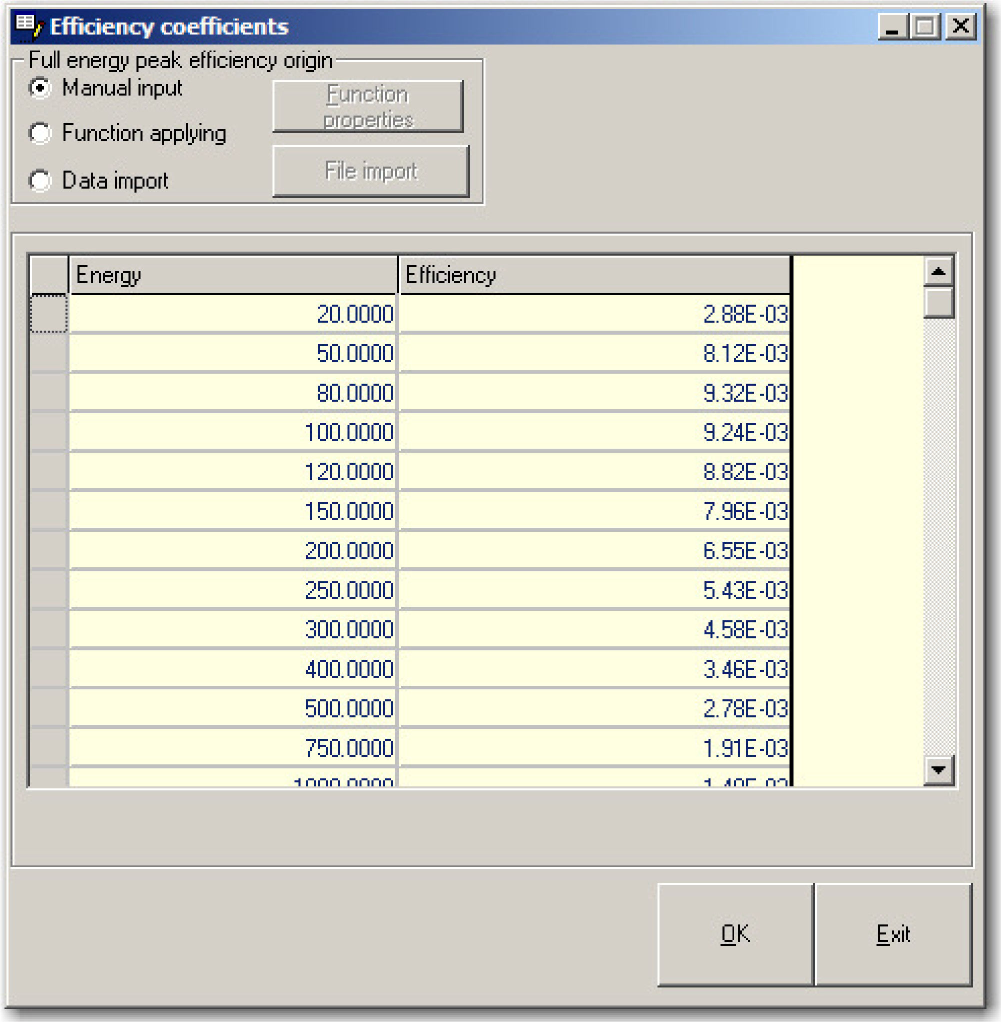
- Source : type and characteristics (container and material)





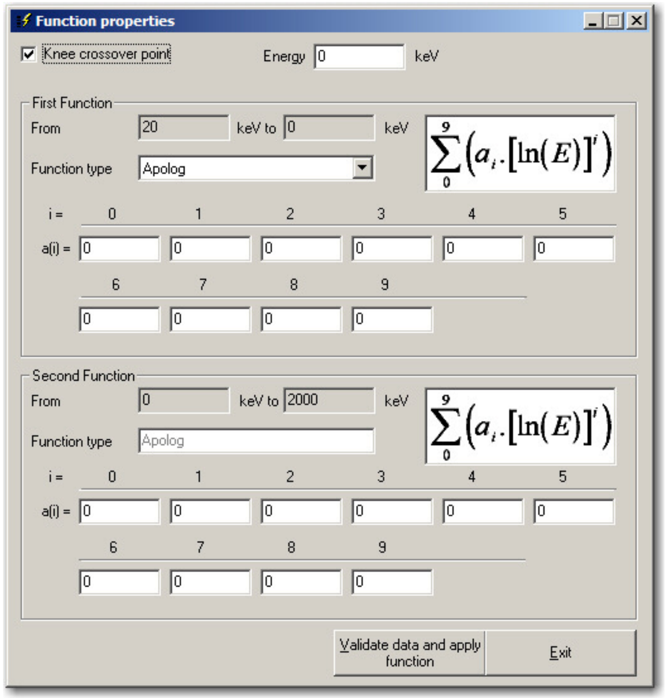


Input of calibration efficiencies



Manual input

Function (APOCOPE or APOLOG)



File import

Efficiency transfer results

```
ETNA                                                    Version 5.5 Rev 55

  Filename : C:\Documents and Settings\LEPY.BECQUEREL\Bureau\test

jeudi 23 septembre 2010
  Processing identification : Efficiency transfer
    Calibration geometry :  G9 SP at 10 cm (G91)
      Calibration source : POint source (Reference)
      Calibration source - detector distance : 103.4 mm
      Calibration absorber : None
      Calibration absorber - detector distance : 0 mm
    Measurement geometry : G9 SG15 a 10 cm (G92)
      Measurement source : Volume SG15 (Filled with HCl 1N 41 mm)
      Measurement source - detector distance : 104 mm
      Measurement absorber : None
      Measurement absorber - detector distance : 0 mm
    Detector : G9

  Results :
```

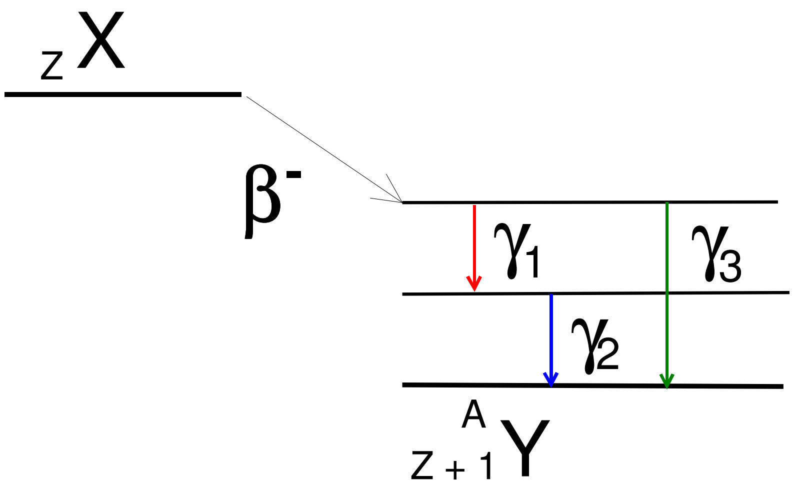
Energy (keV)	Calibration efficiency	Measurement efficiency	Ratio
00020.000	00.00288000	00.00058685	00.20376736
00050.000	00.00812000	00.00391170	00.48173645
00080.000	00.00932000	00.00482243	00.51742811
00100.000	00.00924000	00.00489268	00.52951082
00120.000	00.00882000	00.00476234	00.53994785
00150.000	00.00796000	00.00438473	00.55084548
00200.000	00.00655000	00.00371224	00.56675420
00250.000	00.00543000	00.00313296	00.57697238
00300.000	00.00458000	00.00268981	00.58729476
00400.000	00.00346000	00.00208513	00.60263873
00500.000	00.00278000	00.00170495	00.61329137
00750.000	00.00191000	00.00120835	00.63264398
01000.000	00.00149000	00.00096245	00.64593960
01250.000	00.00123000	00.00080666	00.65582114
01500.000	00.00105000	00.00069649	00.66332381
01750.000	00.00089500	00.00059884	00.66909497
02000.000	00.00076600	00.00051653	00.67432115

CEA / LNE-LNHB

Coincidence summing

Calculation principle

- ETNA uses a numerical method, according to Andreev, Mc Callum principle:



$$C_1 = \frac{1}{1 - P_{12} \cdot \varepsilon_{T2}}$$

$$C_2 = \frac{1}{1 - P_{21} \cdot \varepsilon_{T1}}$$

$$C_3 = \frac{1}{\left(1 + \frac{I_{\gamma 1}}{I_{\gamma 3}} \cdot \frac{\varepsilon_{P1} \cdot \varepsilon_{P2}}{\varepsilon_{P3}} \cdot P_{12}\right)}$$

P_{12} : probability for emitting γ_2 simultaneaously with γ_1

ε_{Pi} : FEP efficiency for energy E_i

ε_{Ti} : Total efficiency for energy E_i

Calculation principle (2)

- Double coincidences
- Coincidences with K X-rays (electron capture or internal conversion) are computed
- Correction for K-X-rays (from gamma or X rays) are computed
- Beta+ emitting nuclides are considered (modification of the decay scheme)
- No angular correlation

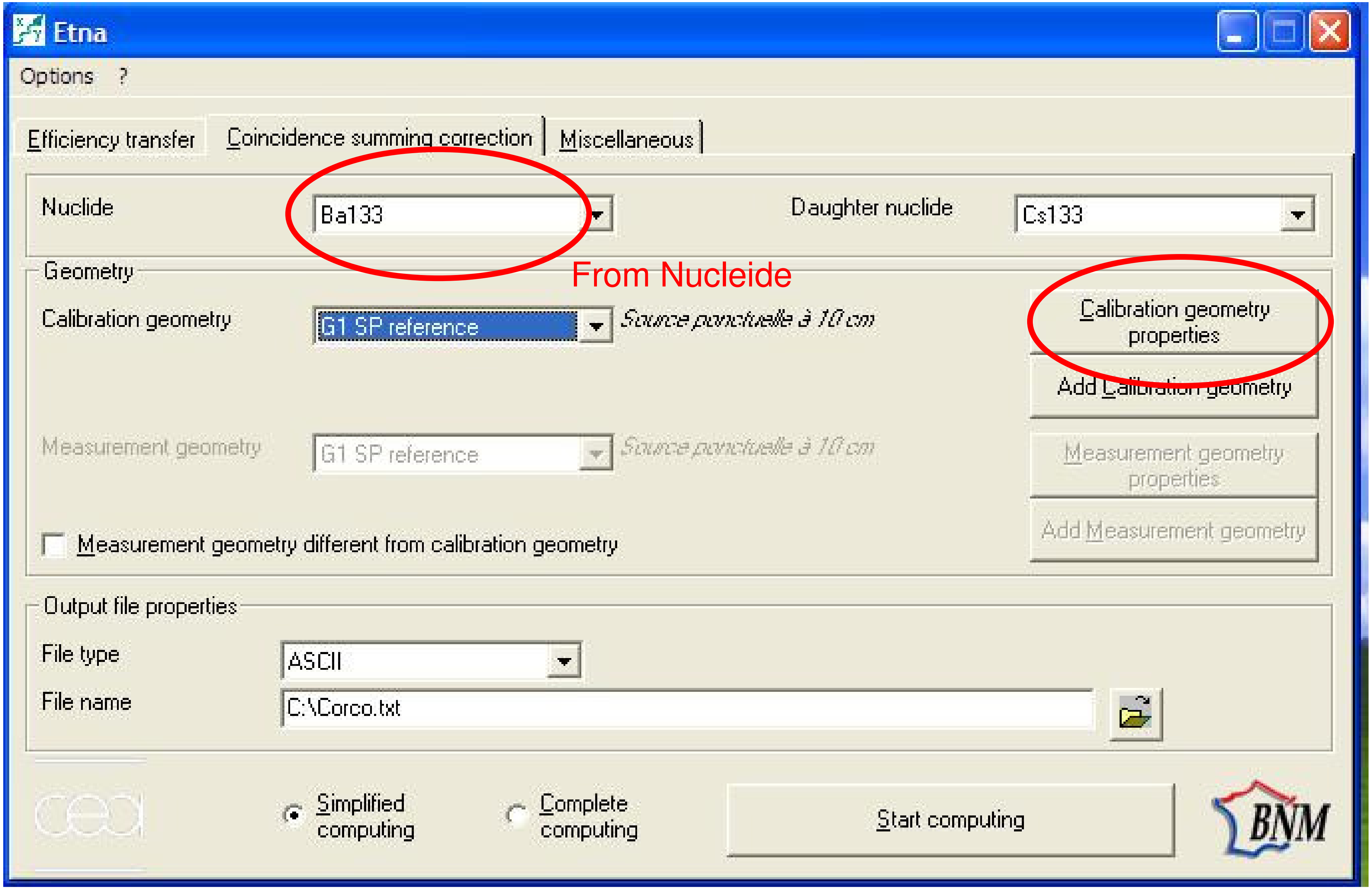
ETNA – Input data

ETNA requires:

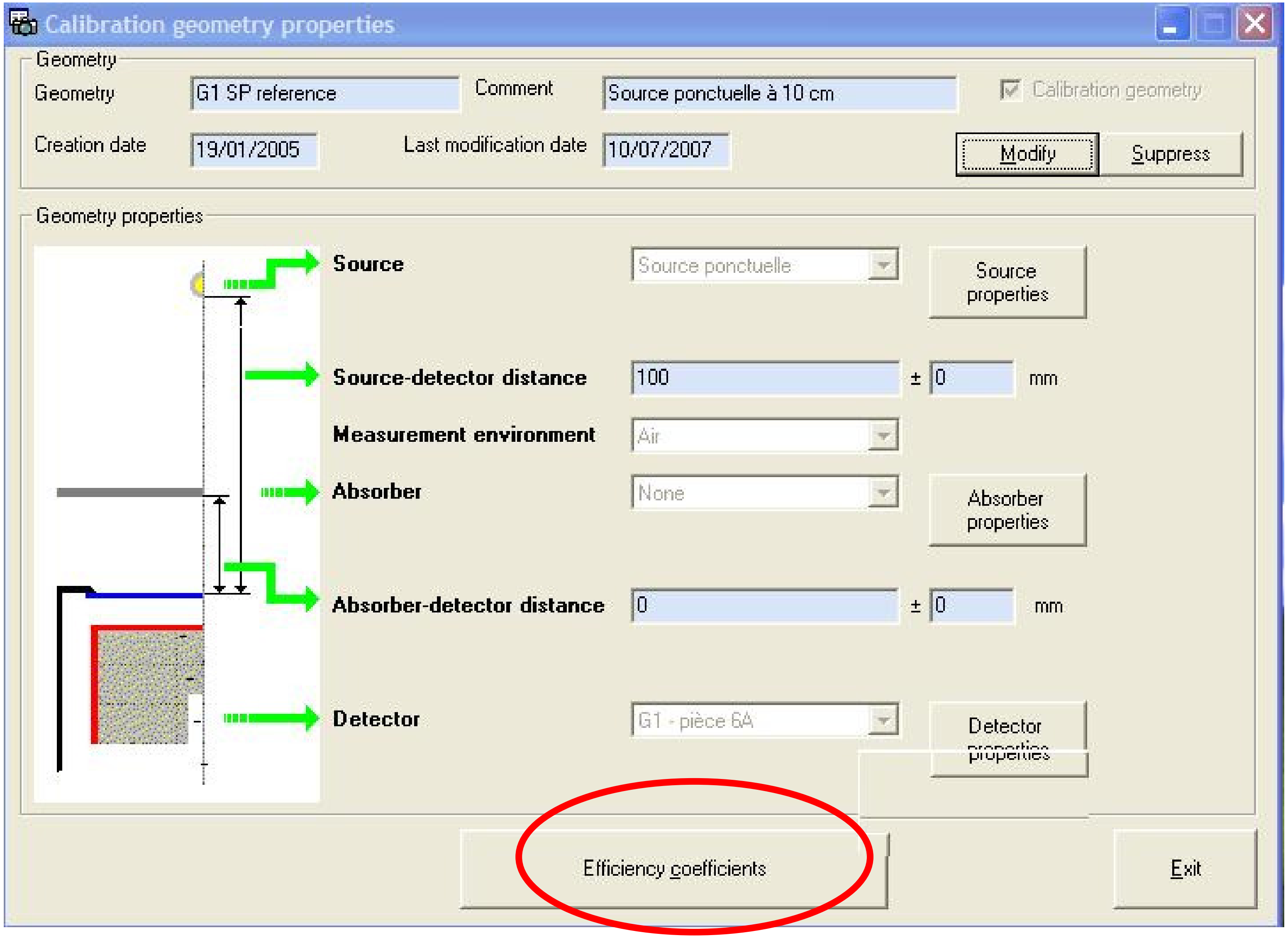
1. Decay scheme (Nucleide database)

2. FEP and total efficiency for at least one source-to-detector geometry («calibration geometry » recorded in the « user » database)

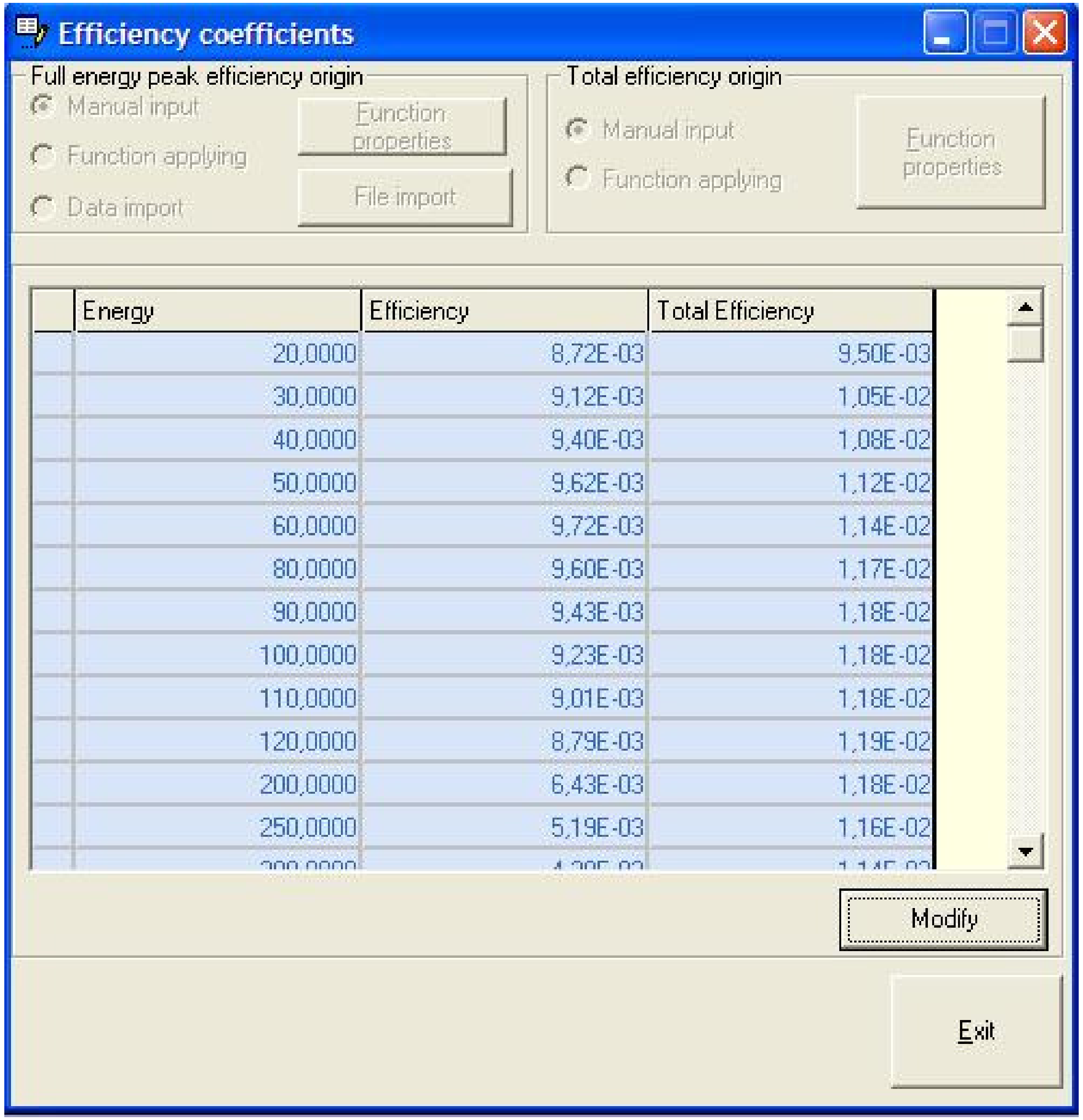
ETNA – Coincidence tab



Calibration geometry window



Efficiency calibration



Coincidence correction results

- dimanche 22 février 2009
- ETNA ________________________________Version 5.5 Rev 51
- Filename :C:\Documents and Settings\ML118236\Bureau\Workshop_ICRM\Presentations\ETNA\test_ETNA
- dimanche 22 février 2009
- Processing identification : Coincidence summing correction (simplified computing)
- Nuclide :Ba133
- Daughter nuclide :Cs133
- Half-life threshold :0.000001 s
- Calibration geometry : G1 SP reference (Source ponctuelle à 10 cm)
- Calibration source :Source ponctuelle
- Calibration source - detector distance :100 mm
- Calibration absorber :None
- Calibration absorber - detector distance :0 mm
- Measurement geometry :Calibration geometry
- Detector :G1 - pièce 6A
- Results :
- Error codes : 0 0
- X-ray correction : 01.015880

Starting level	Arrival level	Energy (keV)	Gamma-gamma correction	Gamma-X correction	Total correction
004	003	00053.162	01.013962	01.010219	01.024324
002	001	00079.614	01.015207	01.012325	01.027720
001	000	00080.998	01.011478	01.007984	01.019554
002	000	00160.612	00.993490	01.007235	01.000678
003	002	00223.237	01.009461	01.019791	01.029439
004	002	00276.399	01.008560	01.015827	01.024522
003	001	00302.851	01.005028	01.015414	01.020519
004	001	00356.013	01.003565	01.011468	01.015074
003	000	00383.849	00.991597	01.010308	01.001818

- :
- CEA\LNHB ______________________________________ BNM

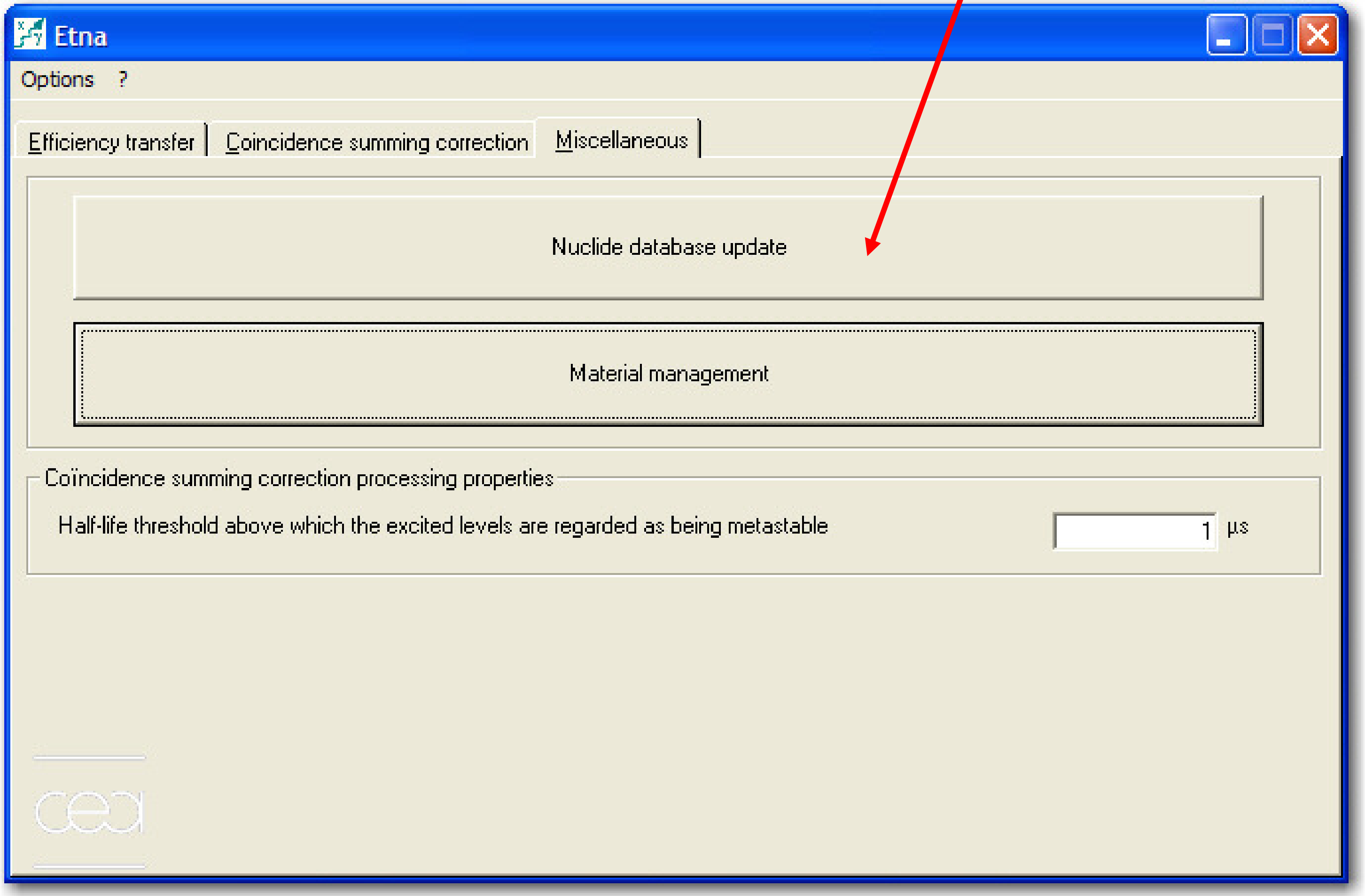
Calculation with efficiency transfer

Data update

Decay scheme data

Attenuation coefficients

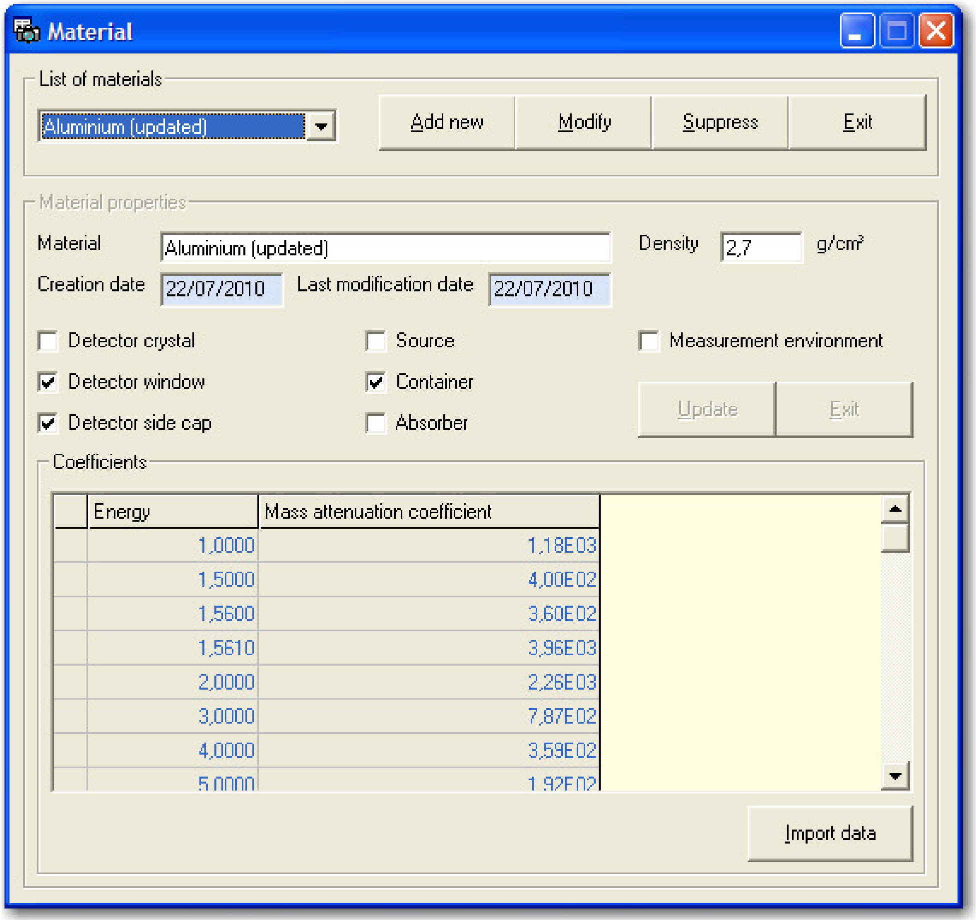
Nucléide: import of updated data (only for LNHB !)



Data update

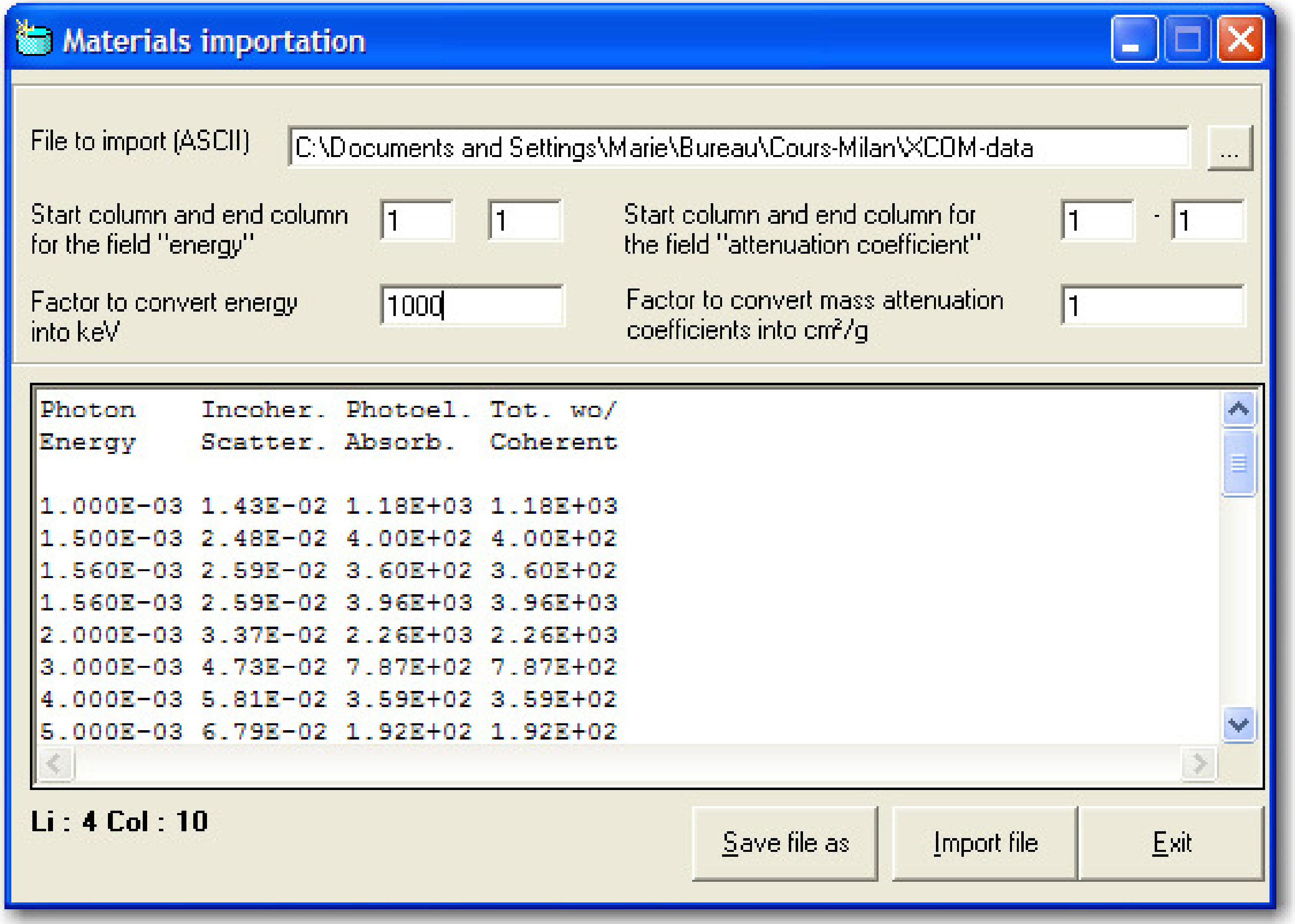
- Attenuation coefficients
  - Manual input
  - File import

  (XCOM or ASCII)



Attenuation coefficients

Import file from XCOM



Experimental validation (1)

- Efficiency transfer: point source from 1 to 25 cm from detector window ^{137}Cs et ^{57}Co (with Al screen): no coincidences
- Reference peak area: 10 cm

	^{137}Cs (662 keV)			^{57}Co (122 keV)		
Source-to-detector distance	Experimental peak relative area	ETNA	Ratio ETNA/Experimental	Experimental peak relative area	ETNA	Ratio ETNA/Experimental
25 cm	0.206 (1)	0.206 (5)	0.998	0.188 (1)	0.188 (4)	0.997
20 cm	0.308 (1)	0.308 (6)	1.000	0.287 (1)	0.286 (6)	0.996
15 cm	0.510 (1)	0.509 (10)	1.000	0.486 (2)	0.486 (11)	0.998
8 cm	1.423 (3)	1.420 (36)	0.998	1.458 (5)	1.46 (40)	1.001
6 cm	2.172 (5)	2.18 (7)	1.006	2.321 (7)	2.32 (8)	1.000
5 cm	2.785 (6)	2.82 (9)	1.013	3.065 (10)	3.06 (11)	0.998
4 cm	3.717 (8)	3.75 (14)	1.008	4.187 (13)	4.18 (18)	0.999
3 cm	5.159 (12)	5.21 (24)	1.010	6.026 (19)	6.00 (30)	0.996
2 cm	7.678 (17)	7.73 (43)	1.006	9.276 (29)	9.19 (55)	0.991
1 cm	12.40 (3)	12.4 (10)	1.000	15.36 (5)	15.1 (13)	0.981

Maximum relative standard uncertainties: (parameters uncertainties)
2.2 % at 15 cm – 2.8 % at 8 cm – 3.7 % at 5 cm – 5 % at 3 cm - 8.5 % at 1 cm

Experimental validation (2)

- EUROMET Exercice
- Comparison of software used to compute transfer efficiency
- Experimental calibration for 3 volume sources
  - HCl 1N (density=1.016)
  - Silica (d=0.25)
  - Sand-resin mixture (d=1.54)

Transfer of Ge detectors efficiency calibration from point source geometry to other geometries
M.C. Lépy et al., *Rapport CEA R5894 (2000)*

Experimental calibration

Energy (keV)	**Efficiency (%) for liquid**	**Efficiency (%) for silica**	**Efficiency (%) for sand/resin**
60	**2.203 (1.3 %)**	**2.863 (1.3 %)**	**1.815 (1.4 %)**
80	**4.034 (1.3 %)**	**5.105 (1.3 %)**	**3.418 (1.4 %)**
100	**4.934 (1.1 %)**	**6.229 (1.2 %)**	**4.274 (1.3 %)**
150	**4.949 (1.1 %)**	**6.201 (1.1 %)**	**4.384 (1.3 %)**
200	**4.222 (1.1 %)**	**5.202 (1.1 %)**	**3.756 (1.3 %)**
250	**3.563 (1.1 %)**	**4.316 (1.1 %)**	**3.177 (1.3 %)**
500	**1.937 (1.1 %)**	**2.240 (1.1 %)**	**1.769 (1.3 %)**
700	**1.450 (1.1 %)**	**1.651 (1.1 %)**	**1.345 (1.3 %)**
1000	**1.084 (1.0 %)**	**1.213 (1.1 %)**	**1.013 (1.3 %)**
1200	**0.938 (1.0 %)**	**1.039 (1.1 %)**	**0.875 (1.3 %)**
1500	**0.782 (1.0 %)**	**0.857 (1.1 %)**	**0.729 (1.3 %)**
1800	**0.664 (1.0 %)**	**0.728 (1.2 %)**	**0.626 (1.4 %)**
2000	**0.599 (1.2 %)**	**0.661 (1.3 %)**	**0.572 (1.7 %)**

Calculation for silica

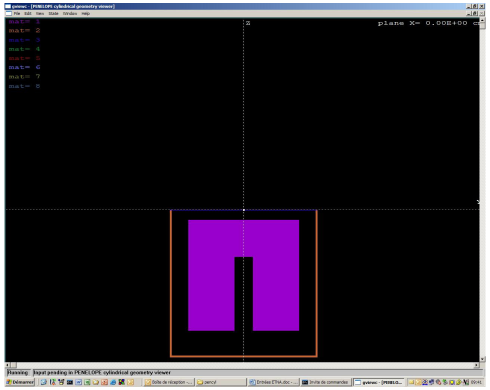
Energy	Exp transfer		ETNA	
(keV)	Silica	Rel unc exp silica (%)	Silica	ETNA/EXP
60	1.300	1.84	1.296	0.997
80	1.265	1.84	1.270	1.003
100	1.262	1.63	1.251	0.991
150	1.253	1.56	1.222	0.975
200	1.232	1.56	1.201	0.975
250	1.211	1.56	1.189	0.982
500	1.156	1.56	1.142	0.987
700	1.139	1.56	1.123	0.986
1000	1.119	1.56	1.103	0.986
1200	1.108	1.56	1.094	0.988
1500	1.096	1.56	1.084	0.989
1800	1.096	1.63	1.076	0.982
2000	1.104	1.77	1.072	0.971

Calculation for sand-resin mixture

Energy	Exp transfer		ETNA	
(keV)	Sand	Rel unc exp sand (%)	Sand	ETNA/EXP
60	0.824	1.91	0.828	1.005
80	0.847	1.91	0.865	1.021
100	0.866	1.70	0.882	1.018
150	0.886	1.70	0.899	1.015
200	0.890	1.70	0.908	1.021
250	0.892	1.70	0.915	1.026
500	0.913	1.70	0.932	1.021
700	0.928	1.70	0.940	1.013
1000	0.935	1.70	0.948	1.015
1200	0.933	1.70	0.952	1.021
1500	0.932	1.70	0.957	1.027
1800	0.943	1.78	0.961	1.020
2000	0.955	2.08	0.963	1.008

Calculation validation

- T. Vidmar intercomparison (IAEA CRP)
- Two detectors
- Simple « school case » geometries
  - Point source
  - Soil
  - Filter
- Reference geometry: liquid



ERROR: undefined
OFFENDING COMMAND: ‘~

STACK: