#### 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			_ 🗆 >
Options ?			
<u>I</u> ransfert de rendement	Corrections de coïncidences		
Nucléide	Sb124	Nucléide fils	Te124
Géométrie			
Géométrie d'étalonnage	e G1 SP reference 💌 Sour	rce ponctuelle à 10 cm	Propriétés de la géométrie d' <u>é</u> talonnage
			Ajouter une géométrie d' <u>é</u> talonnage
Géométrie de mesure	G1 avec flacon peni		Propriétés de la géométrie de <u>m</u> esure
✓ La géométrie de me	esure est différente de la géométrie d'étaloni	nage	Ajouter une géométrie de <u>m</u> esure
- ⊢ Propriétés du fichier de	sortie		
Type du fichier	ASCII		
Nom du fichier	C:\Corco.txt		<u>à</u>
	Calculs gimplifiés C Calculs comp	olets <u>D</u> ébut des calcu	





# **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

🚰 Etna	
Options ?	
Efficiency transfer	
Geometry	Calibration docmatry
Calibration geometry Undefined	properties
	Add <u>Calibration geometry</u>
Measurement geometry Undefined	Measurement geometry properties
	Add <u>M</u> easurement geometry
Cutput file properties	
File type ASCII	
File name C:\AngSol.txt	<u></u>
<u>Start computing</u>	

# Recent update (04/11/2010)

ienza   Correzione per coincidenze vere   Varie	
a [Comment]	Proprietà della geometria di taratura
	Aggiungere una geometria di taratura
▼ [Comment]	Proprietà della geometria di misura
	Aggiungere una geometria di misura
uscita	
ASCII	
C:\Temp\AngSol.txt	
Inizio dei calcoli	
	ienza Correzione per coincidenze vere Varie a  //Comment/ uscita uscita ASCII C:\Temp\AngSol.txt Inizio dei calcoli

Thanks to Dr Aldo FAZIO (ENEA) !

## Efficiency transfer principle



### Solid angle for point source

Using polar coodinates. the solid angle  $\Omega(P)$  between point P (r,  $\phi$ ,  $z_s$ ) and the detector entrance surface (disc) is:

$$\Omega(\mathbf{P}) = 2 \cdot \mathbf{z}_{\mathrm{S}} \int_{0}^{\pi} \mathrm{d}\boldsymbol{\varphi} \int_{0}^{\mathrm{RD}} \frac{\mathbf{R} \cdot \mathbf{d} \mathbf{R}}{\left[\mathbf{R}^{2} - 2 \cdot \mathbf{R} \cdot \mathbf{r} \cdot \cos \boldsymbol{\varphi} + \mathbf{r}^{2} + \mathbf{z}_{\mathrm{S}}^{2}\right]^{3/2}}$$

 $R_D$  is the detector radius.

The geometrical factor should include:

- attenuation in differents absorbing layers (air, window, dead layer. ...) : F<sub>att</sub>

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

- 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<sub>S</sub>, thickness H<sub>S</sub>, vertical position Z<sub>S</sub>):

$$\Omega = \frac{4}{R_S^2 \cdot H_S} \int_{Z_S}^{Z_S + H_S} h \cdot dh \int_{0}^{R_S} r \cdot dr \int_{0}^{\pi} d\phi \int_{0}^{R_D} \frac{R \cdot dR}{\left[R^2 - 2 \cdot R \cdot r \cdot \cos \phi + r^2 + h^2\right]^{3/2}}$$

 Fatt and F abs must be included in the integration procedure

#### Solid angle for a cylindrical source



# 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

🖣 Etna		
Options ?		
Efficiency transfer	idence summing correction	
Geometry Calibration geometry	G9 SP a 10 cm ▼ <i>G91</i>	<u>Calibration geometry</u> properties
Measurement geometry	G9 SG15 a 10 cm	Add <u>Calibration</u> geometry <u>Measurement</u> geometry properties
- Output file properties		Add <u>M</u> easurement geometry
File type	ASCII	
File name	C:\AngSol.txt	<b></b>
	Charle agency diver	
	<u>Start computing</u>	

# Input of geometry parameters

📸 Calibration ge	eometry proper	ties					
Geometry-							
Geometry	Geometry exam	ple	Comment			🔽 Calibratio	on geometry
Creation date	22/09/2010	Last mo	odification date	22/09/2010			
Geometry proper	rties						
	<b>∢</b> ₽→	Source <i>Releience</i>		Point source		Source properties	dd source
		Source-detec	tor distance		± 0	mm	
		Measurement	environment	Air	<u> </u>		
		Absorber		None	•		Add absorber
		Absorber-det	ector distance	0	± 0	mm	
	-	Detector		G9		Detector properties	dd detector
			Ef	ficiency <u>c</u> oefficients		Apply	<u>E</u> xit

### Input of detector parameters

Detector prope	rties				
Detector					
Detector identifier	G9	Detector comment			
Creation date	24/08/2010	Last modification date 24/08/2010	<u>M</u> odify	<u>S</u> uppre	ss
Detector properties	3				
-	I	Detector window material identifier:	Beryllium (updated)	~	
		Detector window thickness:	0.5	± 0	mm
		Detector crystal - window distance:	3	± 0	mm
		Detector crystal dead zone thickness	700	± 0	μm
		Detector crystal material identifier:	Germanium (updated	i) 🔽	
	Ť	Detector crystal thickness:	55.2	± 0	mm
		Detector crystal hole depth:	47.2	± 0	mm
	ļ.	Detector crystal hole diameter:	9.5	± 0	mm
-	<b>I</b>	Detector crystal diameter:	48.6	± 0	mm
▶ ←		Detector side cap thickness:	1	± 0	mm
,		Detector side cap diameter:	70	± 0	mm
		Detector side cap material identifier:	Aluminium (updated)	7	
				<u>E</u> ×	it

#### Input of source parameters

• Source : type and characteristics (container and material)



🖥 Container				_ 🗆 🗙
Container				
Container	Conteneur SG50	Comment Diametre 39 r	nm - polyethylene	
Туре	Cylinder			
Creation date	10/03/2004 Last modifie	cation date 20/08/2010		
Container prope	erties			
		Container material identifier:	Polyethylène (C2H4)	
		Source external diameter:	23 ±	0 mm
	, start and sta	Con ainer side thickness:	1.2	U mm
		Cor ainer bottom thickness:	1.4 ±	0 mm
			<u>D</u> K	<u>E</u> xit



#### Input of calibration efficiencies

Efficiency coefficients		_ 🗆 ×
Full energy peak efficiency origin     Manual input     Funct     Function applying     Data import	on ties	
Energy	Efficiency	<b>_</b>
20.000	0 2.88E-0	)3 📃
50.000	0 8.12E-0	03
80.000	0 9.32E-0	03
100.000	0 9.24E-0	03
120.000	0 8.82E-0	03
150.000	0 7.96E-0	03
200.000	0 6.55E-0	03
250.000	0 5.43E-0	03
300.000	0 4.58E-0	03
400.000	0 3.46E-0	03
500.000	0 2.78E-0	03
750.000	0 1.91E-0	)3
1000.000	ol	
		[
	<u></u> K	<u>E</u> xit

Manual input

Function (APOCOPE or APOLOG)

🖌 Function p	oroperties					_ 🗆 🗡	
Knee cros	Knee crossover point Energy 0 keV						
			,				
First Function	n				0		
From	120	6	kev to ju	Kev	$\hat{\Sigma}(a)$	$\left[\ln(E)\right]'$	
Function typ	e Apolog	)		-	2 (%)		
i =	0	1	2	3	4	5	
a(i) = 0	0		0	0	0	0	
	6	7	8	9			
0	0		0	0	-		
C Second Fun	ction						
From	Jo		keV to  2000	keV	$\hat{\mathbf{v}}(\mathbf{z})$	$\left[1_{m}(E)1^{\prime}\right)$	
Function type	e Apolog	1			$\sum_{i} (a_i)$		
i =	0	1	2	3	4	5	
a(i) = 0	0		0	0	0	0	
	6	7	8	9			
0	0		0	0	-		
				Validate data functio	and apply on	<u>E</u> xit	

File import

#### Efficiency transfer results

ETNA				Version	5.5	Rev	55
Filename :	C:\Documents a	nd Settings\LEPY.	BECQUEREL\Bureau\test				
jeudi 23 sen	tembre 2010						
Processing	identification	: Efficiency tra	ansfer				
Calibrat	ion geometry :	G9 SP at 10 cm (	(691)				
Calibr	ation source :	POint source (Ref	erence)				
Calibr	ation source -	detector distance	e : 103.4 mm				
Calibr	ation absorber	: None					
Calibr	ation absorber	<ul> <li>detector distar</li> </ul>	ice:0mm				
Measurem	ent geometry :	G9 SG15 a 10 cm (	(G92)				
Measur	ement source :	Volume SG15 (Fill	ed with HCl 1N 41 mm)				
Measur	ement source -	detector distance	e : 104 mm				
Measur	ement absorber	: None					
Measur	ement absorber	<ul> <li>detector distar</li> </ul>	ice:0mm				
Detector	: G9						
Desville .							
Results :	Calibustian	Management	Datia				
(kov)	efficiency	efficiency	RALIO				
00020 000	00.00288000	00 0005 8685	00 20376736				
00050.000	00.00233000	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				
01/50.000	00.00089500	00.00059884	00.65909497				
02000.000	00.000/0000	00.00031033	00.0/432113				
CEA / LNE-LN	ІНВ						

# Coincidence summing

## Calculation principle

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



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

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

 $\begin{array}{l} \mathsf{P}_{12} : \text{probability for emitting } \gamma_2 \\ \text{simultaneaously with } \gamma_1 \\ \epsilon_{\mathsf{Pi}} : \mathsf{FEP} \text{ efficiency for energy } \mathsf{E}_i \\ \epsilon_{\mathsf{Ti}} : \text{Total efficiency for energy } \mathsf{E}_i \end{array}$ 

$$C_{3} = \frac{1}{\left(1 + \frac{I_{\gamma l}}{I_{\gamma 3}} \cdot \frac{\varepsilon_{Pl} \cdot \varepsilon_{P2}}{\varepsilon_{P3}} \cdot P_{l2}\right)}$$

# 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

🚰 Etna					
Options ?					
Efficiency transfer	<u>C</u> oincidence summing co	prrection <u>Miscellaneou</u>	\$		
Nuclide	Ba133	·	Daughter nuclide	Cs133	•
Geometry		From N	ucleide		
Calibration geometry	G1 SP referen	ce 🚽 Source	ponctuelle à 10 cm	<u>C</u> alibration g	jeometry ies
				Add <u>Lalibration</u>	r geometry
Measurement geom	G1 SP referen	ce 🚽 Source	ponctuelle à 10 cm	Measurement propert	geometry ies
☐ Measurement g	eometry different from ca	ibration geometry		Add <u>M</u> easureme	ent geometry
Cutput file propertie	18				
File type	ASCII	•			
File name	C:\Corco.txt			<b></b>	
cea	<ul> <li><u>Simplified</u></li> <li>computing</li> </ul>	C Complete computing	<u>S</u> tart compu	iting	BNM

### Calibration geometry window

Calibration	geometry pro	perties			
Geometry					
Geometry	G1 SP referen	ce Comment s	Source ponctuelle à 10 cm	Calibration	n geometry
Creation date	19/01/2005	Last modification date	10/07/2007	Modify	<u>S</u> uppress
Geometry proper	ties				
	<b>♦</b>	Source	Source ponctuelle	Source properties	
		Source-detector distance	100	± 0 mm	
		Measurement environment	Air	*	
-		Absorber	None	Absorber properties	
		Absorber-detector distance	0	± 0 mm	
	- -	Detector	G1 - pièce 6A	Detector properties	
		Effic	ciency <u>c</u> oefficients		<u>E</u> xit

## Efficiency calibration

Efficiency coefficients		
Full energy peak efficiency origin Manual input Function applying Data import	Eunction properties File import	iciency origin ual input <u>Eunction</u> properties
Energy	Efficiency	Total Efficiency
20,0000	8,72E-03	9,50E-03
30,0000	9,12E-03	1,05E-02
40,0000	9,40E-03	1,08E-02
50,0000	9,62E-03	1,12E-02
60,0000	9,72E-03	1,14E-02
80,0000	9,60E-03	1,17E-02
90,000	9,43E-03	1,18E-02
100,0000	9,23E-03	1,18E-02
110,0000	9,01E-03	1,18E-02
120,0000	8,79E-03	1,19E-02
200,0000	6,43E-03	1,18E-02
250,0000	5,19E-03	1,16E-02
000,000	4 005 00	1 1 40 00
		Modify
		<u>E</u> xit

### **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	Arrival	Energy	Gamma-gamma	a Gamma-	X Total
•	level	level	(keV)	correction corr	ection corre	ection
•	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

🗧 Etna					
Options ?					
Efficiency transfer	<u>Coincidence</u> summing corre	ction <u>M</u> iscellaneous			
Nuclide	Ba133	•	Daughter nuclide	Cs133	•
Geometry					
Calibration geome	G1 SP reference	👻 Source p	oonctuelle à 10 cm	<u>C</u> alibration prope	n geometry erties
				Add <u>C</u> alibrati	ion geometry
Measurement geo	ometry G1-SG50 à 10 cm			<u>M</u> easureme prope	nt geometry
	geometry different from calibra	ation geometry		Add <u>M</u> easuren	ment geometry
Output file propert	ties				
File type	ASCII	-			
File name	C:\Corco.txt			<b></b>	
		C Complete computing	<u>S</u> tart compu	Iting	BNM

#### Data update



## Data update

- Attenuation coefficients
  - Manual input
  - File import (XCOM or ASCII)

🐻 Material					
List of materials					
Aluminium (updated)	-	<u>A</u> dd new	<u>M</u> odify	<u>S</u> uppress	<u>E</u> xit
Material properties				5.0	
Material Aluminium (	updated)			Density 2,7	g/cm³
Creation date 22/07/2010	D Last modi	fication date 22	/07/2010		
Detector crystal	Г	Source		Measurement	environment
Detector window	R	Z Container		1	
Detector side cap	Г	Absorber		Update	Exit
Coefficients					
Energy	Mass attenua	tion coefficient			<u> </u>
1,0000			1,18E03		
1,5000			4,00E02		
1,5600			3,60E02		
1,5610			3,96E03		
2,0000			2,26E03		
3,0000			7,87E02		
4,0000			3,59E02		1
5 0000			1.92E02		
					Import data

# Attenuation coefficients

#### Import file from XCOM

Haterials importation	
File to import (ASCII)       C:\Documents and Settings\Marie\Bureau\Cours-Milan\XCOM-data         Start column and end column for for the field "energy"       1       1       1       1       1         Factor to convert energy into keV       1000       Factor to convert mass attenuation coefficients into cm²/g       1       1	· 1
Photon Incoher. Photoel. Tot. wo/ Energy Scatter. Absorb. Coherent 1.000E-03 1.43E-02 1.18E+03 1.18E+03 1.500E-03 2.48E-02 4.00E+02 4.00E+02 1.560E-03 2.59E-02 3.60E+02 3.60E+02 1.560E-03 2.59E-02 3.96E+03 3.96E+03 2.000E-03 3.37E-02 2.26E+03 2.26E+03 3.000E-03 4.73E-02 7.87E+02 7.87E+02 4.000E-03 5.81E-02 3.59E+02 3.59E+02 5.000E-03 6.79E-02 1.92E+02 1.92E+02	
Li : 4 Col : 10	<u>E</u> xit

# Experimental validation (1)

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

	$^{137}$ Cs (662 keV)			<sup>57</sup> Co (122 keV)		
Source-to-	Experiment		Ratio	Experiment		Ratio
detector	al peak		ETNA/Expe	al peak	<b>Ε</b> ΤΝΙ Δ	ETNA/Expe
distance	relative	EINA	rimental	relative	EINA	rimental
	area			area		
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
  - HCI 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 tr	ansfer	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: