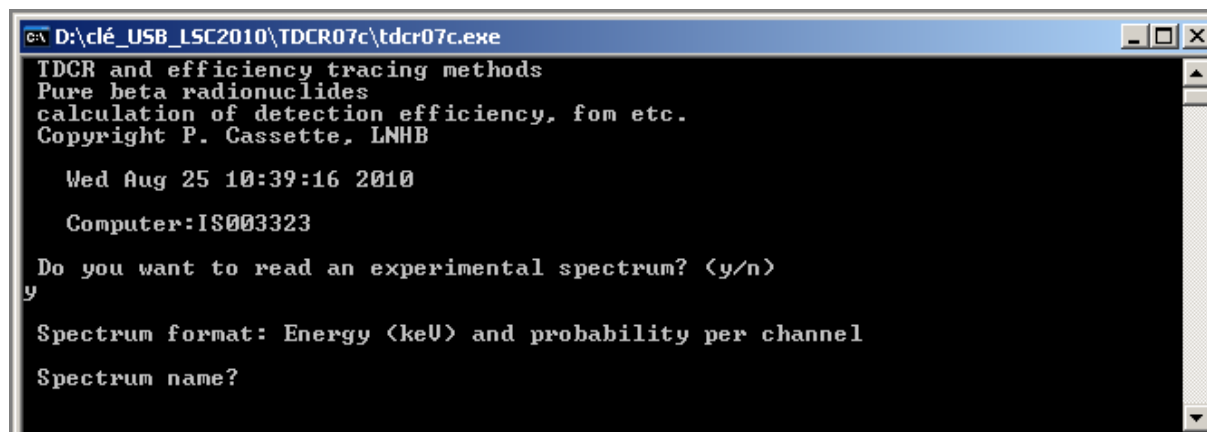


## Tutorial TDCR07c

Start TDCR07c.exe program.

The date, hour and computer name is displayed for QA purposes. You can use an external spectrum file for the calculation, as for example an experimental spectrum or a spectrum calculated by a Monte Carlo simulation program. In this case, the spectrum format is an ASCII file with energy in keV and probability per channel, separated by a blank. The spectrum does not need to be normalized, as this normalization is done, if necessary, by the program.



```
G:\ D:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe
TDCR and efficiency tracing methods
Pure beta radionuclides
calculation of detection efficiency, fom etc.
Copyright P. Cassette, LNHB

Wed Aug 25 10:39:16 2010

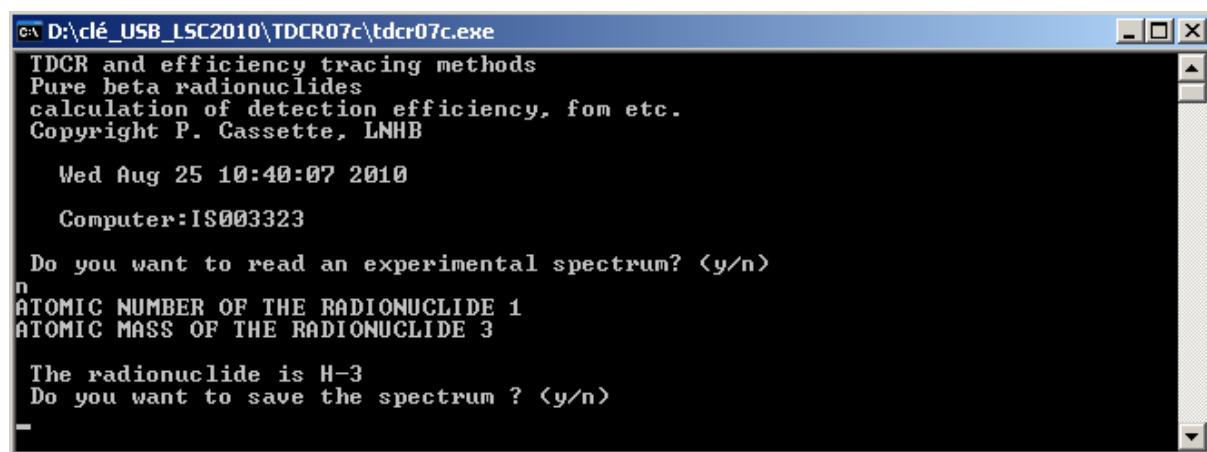
Computer:IS003323

Do you want to read an experimental spectrum? <y/n>
y

Spectrum format: Energy <keV> and probability per channel

Spectrum name?
```

If you do not provide an experimental spectrum file, the spectrum is calculated by the program. You are invited to enter the atomic number and atomic mass of the radionuclide. The program has a small default library of input data for usual radionuclides like  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{63}\text{Ni}$ , etc. If the radionuclide is not in the library, you are invited to enter the maximum beta energy, the nature of the transition and the spectrum shape factor. In the following example ( $Z=1$  and  $A=3$ ), the radionuclide is tritium and is recognized by the program.



```
G:\ D:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe
TDCR and efficiency tracing methods
Pure beta radionuclides
calculation of detection efficiency, fom etc.
Copyright P. Cassette, LNHB

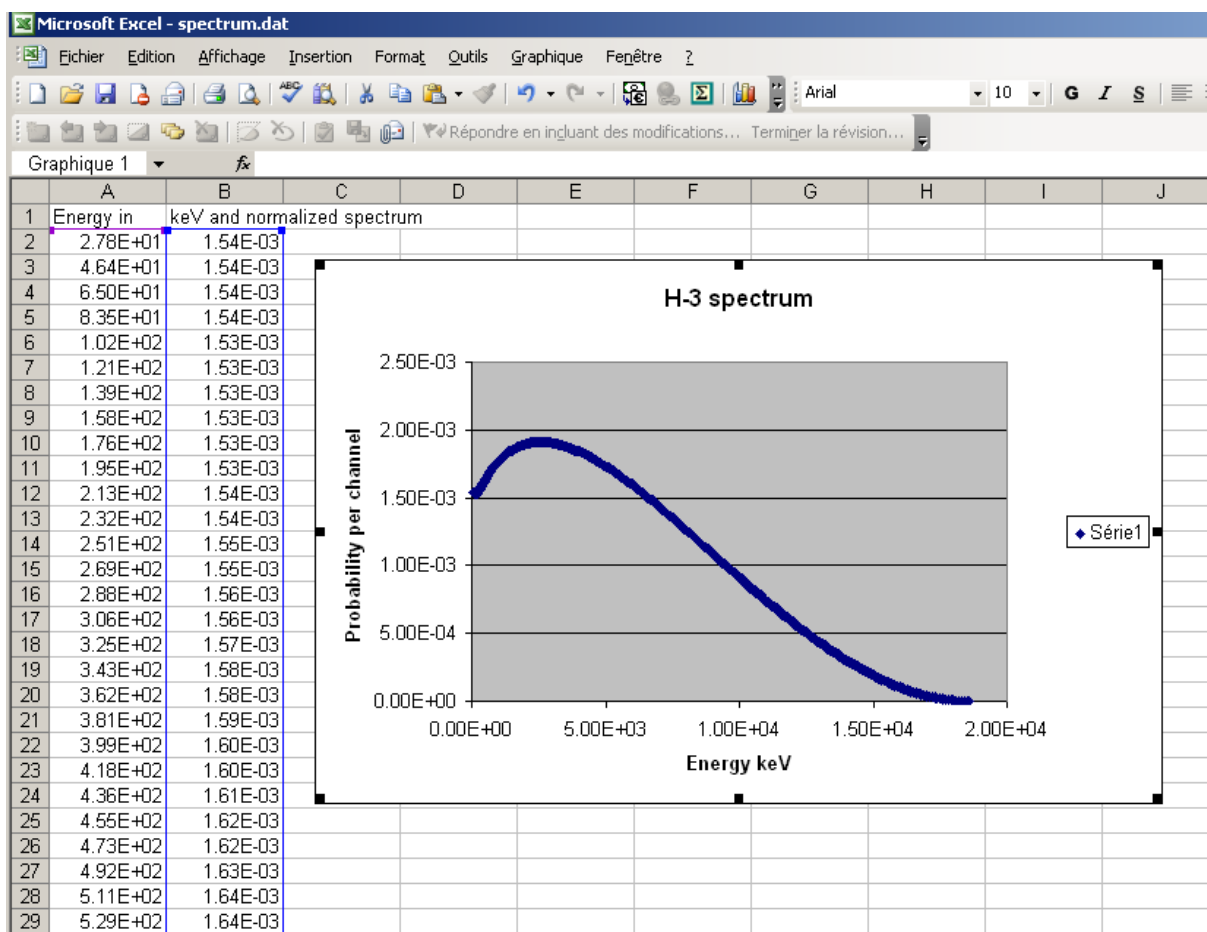
Wed Aug 25 10:40:07 2010

Computer:IS003323

Do you want to read an experimental spectrum? <y/n>
n
ATOMIC NUMBER OF THE RADIONUCLIDE 1
ATOMIC MASS OF THE RADIONUCLIDE 3

The radionuclide is H-3
Do you want to save the spectrum ? <y/n>
-
```

After calculation, the spectrum can be saved in the current directory under the name “spectrum.dat”. This file can be for example opened by Excel for spectrum visualization as shown in the following example:



Then you are asked to enter the nature of the LS cocktail. There is a small library for popular Perkin Elmer cocktail but, if necessary, another cocktail can be selected by entering the density, the Z/A ratio and the ionization potential in keV. This supposes of course the knowledge of the chemical composition of the main components of the scintillator (i.e. solvent and surfactant). The ionization potential (more exactly the mean excitation energy) can be found in the ICRU n°37 report or can be calculated using the “material” subroutine of the PENELOPE Monte Carlo simulation package.

```

C:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe
Liquid Scintillation Cocktail selection

Ultima Gold      : type 1
Ultima Gold XR   : type 2
Ultima Gold AB   : type 3
Ultima Gold LLT  : type 4
Insta-Gel plus   : type 5
Hionic-Fluor     : type 6
Other             : type 7

Enter your choice
?
Cocktail density (g/cm3)
.9
Ratio Z/A
.5
Ionization potential (keV)
.06
  
```

After the cocktail selection you enter the main calculation menu with 5 different options depending on your needs:

### Option 1

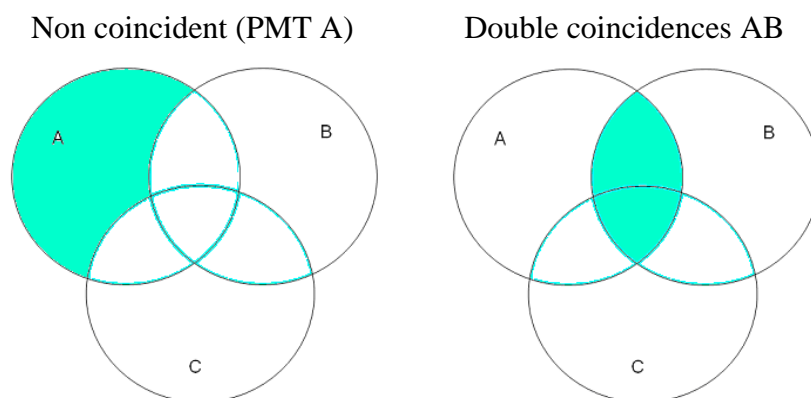
Calculation of the detection efficiency in double and triple coincidences and the figure of merit (number of photoelectrons created per keV absorbed in the scintillator). In case of differences in the quantum efficiency of each photomultiplier tube, this can be taken into account by entering the relative efficiency of each tube. The sum of these relative efficiencies must be equal to 1.

```

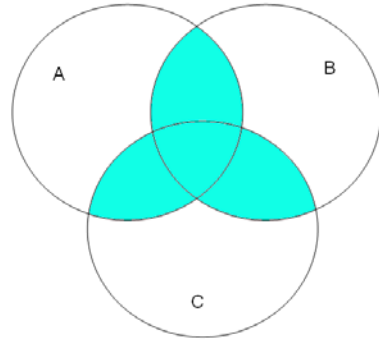
C:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe
Detection efficiency and figure of merit from TDCR      : type 1
Detection efficiency and TDCR from figure of merit     : type 2
Figure of merit and TDCR from detection efficiency     : type 3
Detection efficiency an figure of merit from 3 TDCR    : type 4
Detection efficiency and TDCR from various fom        : type 5
1
Experimental TDCR value ?
.5
PMTs with same quantum efficiencies? (y/n)
n
relative quantum efficiency of PMT A:
.33
relative quantum efficiency of PMT B:
.33
relative quantum efficiency of PMT C:
.34

```

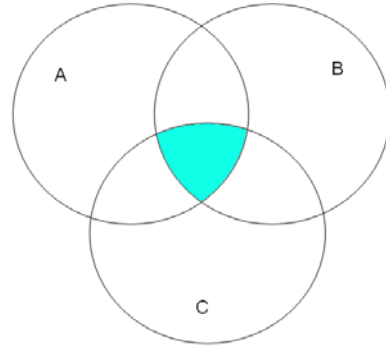
Then the program gives, for kB values in a range of 0.007 to 0.015 cm/MeV with a step of 0.001 cm/MeV, the figure of merit, the detection efficiency of the logical sum of double coincidences, the detection efficiency of triple coincidence and the average detection efficiency for double coincidences. The best estimate of the source activity is the ratio of the count rate in double coincidences to the detection efficiency in double coincidence, which must also be equal to the ratio of the counting rate in triple coincidence to the detection efficiency in triple coincidence. It must be pointed out that the logical sum of double coincidences includes the triple coincidences as shown in the following diagram relative to a counter with 3 PMT's: A, B and C.



Logical sum of double coincidences



Triple coincidences



G:\D:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe	
kB= .007cm/MeU	
figure of merit	= .7550 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5643
Triple coincidence detection efficiency	= .2821
Double coincidence detection efficiency	= .3730
kB= .008cm/MeU	
figure of merit	= .7770 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5602
Triple coincidence detection efficiency	= .2801
Double coincidence detection efficiency	= .3703
kB= .009cm/MeU	
figure of merit	= .7987 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5564
Triple coincidence detection efficiency	= .2782
Double coincidence detection efficiency	= .3678
kB= .010cm/MeU	
figure of merit	= .8201 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5530
Triple coincidence detection efficiency	= .2765
Double coincidence detection efficiency	= .3655
kB= .011cm/MeU	
figure of merit	= .8413 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5498
Triple coincidence detection efficiency	= .2749
Double coincidence detection efficiency	= .3634
kB= .012cm/MeU	
figure of merit	= .8622 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5468
Triple coincidence detection efficiency	= .2734
Double coincidence detection efficiency	= .3614
kB= .013cm/MeU	
figure of merit	= .8830 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5440
Triple coincidence detection efficiency	= .2720
Double coincidence detection efficiency	= .3596
kB= .014cm/MeU	
figure of merit	= .9037 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5414
Triple coincidence detection efficiency	= .2707
Double coincidence detection efficiency	= .3579
kB= .015cm/MeU	
figure of merit	= .9242 e-/keU
TDCR	= .5000
Logical sum of double coincidence detection efficiency	= .5389
Triple coincidence detection efficiency	= .2695
Double coincidence detection efficiency	= .3563

## Option 2

An alternative calculation can be made using the figure of merit, for example obtained from the previous measurement of a radionuclide standard for the same scintillator and the same chemical composition of the source. This is done by selecting option 2 in the menu:

```

D:\clé_USB_L5C2010\TDCR07c\tdcr07c.exe
Detection efficiency and figure of merit from TDCR      : type 1
Detection efficiency and TDCR from figure of merit     : type 2
Figure of merit and TDCR from detection efficiency    : type 3
Detection efficiency an figure of merit from 3 TDCR    : type 4
Detection efficiency and TDCR from various fom        : type 5
2
Figure of merit (e-/keV) ?
1.
PMTs with same quantum efficiencies? (y/n)
y
kB= .007cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5863
Logical sum of double coincidence detection efficiency = .6470
Triple coincidence detection efficiency              = .3793
Double coincidence detection efficiency              = .4685

kB= .008cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5772
Logical sum of double coincidence detection efficiency = .6346
Triple coincidence detection efficiency              = .3663
Double coincidence detection efficiency              = .4557

kB= .009cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5686
Logical sum of double coincidence detection efficiency = .6228
Triple coincidence detection efficiency              = .3541
Double coincidence detection efficiency              = .4437

kB= .010cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5604
Logical sum of double coincidence detection efficiency = .6116
Triple coincidence detection efficiency              = .3427
Double coincidence detection efficiency              = .4324

kB= .011cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5525
Logical sum of double coincidence detection efficiency = .6009
Triple coincidence detection efficiency              = .3320
Double coincidence detection efficiency              = .4217

kB= .012cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5449
Logical sum of double coincidence detection efficiency = .5907
Triple coincidence detection efficiency              = .3219
Double coincidence detection efficiency              = .4115

kB= .013cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5376
Logical sum of double coincidence detection efficiency = .5809
Triple coincidence detection efficiency              = .3123
Double coincidence detection efficiency              = .4018

kB= .014cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5305
Logical sum of double coincidence detection efficiency = .5715
Triple coincidence detection efficiency              = .3032
Double coincidence detection efficiency              = .3926

kB= .015cm/MeV
figure of merit                                     =1.0000 e-/keV
TDCR                                                = .5237
Logical sum of double coincidence detection efficiency = .5624
Triple coincidence detection efficiency              = .2945
Double coincidence detection efficiency              = .3838

New calculation for the same radionuclide (y/n) ?

```

### Option 3

This option allows the determination of the figure of merit from the detection efficiency. This option is used for the implementation of the tracer method, when measuring a radioactive standard and before using option 2.

```

C:\D:\clé_USB_L5C2010\TDCR07c\tdcr07c.exe
Detection efficiency and figure of merit from TDCR : type 1
Detection efficiency and TDCR from figure of merit : type 2
Figure of merit and TDCR from detection efficiency : type 3
Detection efficiency and figure of merit from 3 TDCR : type 4
Detection efficiency and TDCR from various fom : type 5
3
Detection efficiency in double coincidence ?
.5
PMTs with same quantum efficiencies? (y/n)
y
kB= .007cm/MeU
figure of merit = .6180 e-/keU
TDCR = .4384
Logical sum of double coincidence detection efficiency = .5001
Triple coincidence detection efficiency = .2193
Double coincidence detection efficiency = .3129

kB= .008cm/MeU
figure of merit = .6430 e-/keU
TDCR = .4421
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2210
Double coincidence detection efficiency = .3140

kB= .009cm/MeU
figure of merit = .6680 e-/keU
TDCR = .4455
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2228
Double coincidence detection efficiency = .3152

kB= .010cm/MeU
figure of merit = .6928 e-/keU
TDCR = .4487
Logical sum of double coincidence detection efficiency = .5001
Triple coincidence detection efficiency = .2244
Double coincidence detection efficiency = .3163

kB= .011cm/MeU
figure of merit = .7172 e-/keU
TDCR = .4516
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2258
Double coincidence detection efficiency = .3172

kB= .012cm/MeU
figure of merit = .7415 e-/keU
TDCR = .4544
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2272
Double coincidence detection efficiency = .3182

kB= .013cm/MeU
figure of merit = .7658 e-/keU
TDCR = .4571
Logical sum of double coincidence detection efficiency = .5001
Triple coincidence detection efficiency = .2286
Double coincidence detection efficiency = .3191

kB= .014cm/MeU
figure of merit = .7896 e-/keU
TDCR = .4595
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2298
Double coincidence detection efficiency = .3198

kB= .015cm/MeU
figure of merit = .8135 e-/keU
TDCR = .4618
Logical sum of double coincidence detection efficiency = .5000
Triple coincidence detection efficiency = .2309
Double coincidence detection efficiency = .3206

New calculation for the same radionuclide (y/n) ?
```

#### Option 4

This option is used to calculate the detection efficiencies from the 3 values of individual double coincidences, when the asymmetry of the 3 PMT is not negligible. The program calculates the detection efficiency for each 3 double coincidences and also gives the relative quantum efficiencies of each PMT:

```
C:\D:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe
Detection efficiency and figure of merit from TDCR      : type 1
Detection efficiency and TDCR from figure of merit     : type 2
Figure of merit and TDCR from detection efficiency     : type 3
Detection efficiency and figure of merit from 3 TDCR   : type 4
Detection efficiency and TDCR from various fom        : type 5
4
Experimental T/AB value ?
.8
Experimental T/BC value ?
.89
Experimental T/AC value ?
.78
Number of deformations of the simplex= 40
Relative quantum efficiency of PMT A = .4264
Relative quantum efficiency of PMT B = .2772
Relative quantum efficiency of PMT C = .2964

kB= .007cm/MeV
figure of merit                                     =1.1238 e-/keV
TDCR                                                = .6040
Logical sum of double coincidence detection efficiency = .6735
Triple coincidence detection efficiency              = .4068
Double coincidence detection efficiency AB           = .5086
Double coincidence detection efficiency BC           = .4571
Double coincidence detection efficiency AC           = .5216
Number of deformations of the simplex= 54
Relative quantum efficiency of PMT A = .4265
Relative quantum efficiency of PMT B = .2771
Relative quantum efficiency of PMT C = .2964

kB= .008cm/MeV
figure of merit                                     =1.1591 e-/keV
TDCR                                                = .6040
Logical sum of double coincidence detection efficiency = .6696
Triple coincidence detection efficiency              = .4044
Double coincidence detection efficiency AB           = .5056
Double coincidence detection efficiency BC           = .4544
Double coincidence detection efficiency AC           = .5185
Number of deformations of the simplex= 42
Relative quantum efficiency of PMT A = .4266
Relative quantum efficiency of PMT B = .2770
Relative quantum efficiency of PMT C = .2964

kB= .009cm/MeV
figure of merit                                     =1.1940 e-/keV
TDCR                                                = .6040
Logical sum of double coincidence detection efficiency = .6660
Triple coincidence detection efficiency              = .4023
Double coincidence detection efficiency AB           = .5028
Double coincidence detection efficiency BC           = .4520
Double coincidence detection efficiency AC           = .5157
Number of deformations of the simplex= 40
Relative quantum efficiency of PMT A = .4266
Relative quantum efficiency of PMT B = .2770
Relative quantum efficiency of PMT C = .2964
```



## Option 5

This last option is to calculate detection efficiencies and TDCR in a given range of figures of merit. This could be useful when using non-monotonic spectra, when the solution algorithm used in option 1 and 5 does not work, or more generally, in the case where a value of TDCR corresponds to multiples values of detection efficiency. This option generates the file "liste.dat".

```
D:\clé_USB_LSC2010\TDCR07c\tdcr07c.exe

Detection efficiency and figure of merit from TDCR      : type 1
Detection efficiency and TDCR from figure of merit     : type 2
Figure of merit and TDCR from detection efficiency    : type 3
Detection efficiency and figure of merit from 3 TDCR   : type 4
Detection efficiency and TDCR from various fom        : type 5
5
Minimum fom value <e-/keV>?
0.1
Maximum fom value?
1.
fom step?
.1
PMTs with same quantum efficiencies? <y/n>
y
New calculation for the same radionuclide <y/n> ?
n
New calculation for another radionuclide <y/n> ?
n
```

LISTE.DAT - Bloc-notes				
Fichier Edition Format Affichage ?				
wed Aug 25 10:42:01 2010				
Computer:IS003323				
fom	TDCR	DOUBLE	TRIPLE	
kB= .007 cm/MeV				
.100	.0874	.0592	.0052	
.200	.1702	.1642	.0279	
.300	.2463	.2672	.0658	
.400	.3149	.3560	.1121	
.500	.3758	.4297	.1615	
.600	.4295	.4904	.2106	
.700	.4767	.5404	.2576	
.800	.5180	.5821	.3016	
.900	.5543	.6172	.3421	
1.000	.5863	.6470	.3793	
1.100	.6145	.6725	.4133	
kB= .008 cm/MeV				
.100	.0853	.0563	.0048	
.200	.1662	.1571	.0261	
.300	.2407	.2572	.0619	
.400	.3081	.3442	.1061	
.500	.3681	.4171	.1535	
.600	.4212	.4773	.2011	
.700	.4680	.5274	.2468	
.800	.5091	.5692	.2898	
.900	.5453	.6045	.3296	
1.000	.5772	.6346	.3663	
1.100	.6055	.6605	.3999	
kB= .009 cm/MeV				
.100	.0834	.0536	.0045	
.200	.1625	.1506	.0245	
.300	.2355	.2479	.0584	
.400	.3017	.3333	.1005	
.500	.3609	.4052	.1462	
.600	.4133	.4651	.1922	
.700	.4597	.5150	.2368	
.800	.5006	.5570	.2788	
.900	.5367	.5925	.3180	
1.000	.5686	.6228	.3541	
1.100	.5969	.6490	.3874	
kB= .010 cm/MeV				
.100	.0815	.0511	.0042	
.200	.1589	.1446	.0230	



At the end of the calculation, the main results are resumed in the file “result.dat” as shown in the next example corresponding to the sequence of calculations previously described. The program then asks for a new calculation of the same radionuclide or of another radionuclide. When multiple calculations are done, the results are written in the same “result.dat” file.

RESULT.DAT - Bloc-notes							
Fichier Edition Format Affichage ?							
wed Aug 25 10:42:01 2010							
Computer:IS003323							
KB	fom	TDCR	DOUBLE	TRIPLE	EQA	EQB	EQC
.007	.7550	.5000	.5643	.2821	.3300	.3300	.3400
.008	.7770	.5000	.5602	.2801	.3300	.3300	.3400
.009	.7987	.5000	.5564	.2782	.3300	.3300	.3400
.010	.8201	.5000	.5530	.2765	.3300	.3300	.3400
.011	.8413	.5000	.5498	.2749	.3300	.3300	.3400
.012	.8622	.5000	.5468	.2734	.3300	.3300	.3400
.013	.8830	.5000	.5440	.2720	.3300	.3300	.3400
.014	.9037	.5000	.5414	.2707	.3300	.3300	.3400
.015	.9242	.5000	.5389	.2695	.3300	.3300	.3400
KB	fom	TDCR	DOUBLE	TRIPLE	EQA	EQB	EQC
.007	1.0000	.5863	.6470	.3793	.3333	.3333	.3333
.008	1.0000	.5772	.6346	.3663	.3333	.3333	.3333
.009	1.0000	.5686	.6228	.3541	.3333	.3333	.3333
.010	1.0000	.5604	.6116	.3427	.3333	.3333	.3333
.011	1.0000	.5525	.6009	.3320	.3333	.3333	.3333
.012	1.0000	.5449	.5907	.3219	.3333	.3333	.3333
.013	1.0000	.5376	.5809	.3123	.3333	.3333	.3333
.014	1.0000	.5305	.5715	.3032	.3333	.3333	.3333
.015	1.0000	.5237	.5624	.2945	.3333	.3333	.3333
KB	fom	TDCR	DOUBLE	TRIPLE	EQA	EQB	EQC
.007	.6180	.4384	.5001	.2193	.3333	.3333	.3333
.008	.6430	.4421	.5000	.2210	.3333	.3333	.3333
.009	.6680	.4455	.5000	.2228	.3333	.3333	.3333
.010	.6928	.4487	.5001	.2244	.3333	.3333	.3333
.011	.7172	.4516	.5000	.2258	.3333	.3333	.3333
.012	.7415	.4544	.5000	.2272	.3333	.3333	.3333
.013	.7658	.4571	.5001	.2286	.3333	.3333	.3333
.014	.7896	.4595	.5000	.2298	.3333	.3333	.3333
.015	.8135	.4618	.5000	.2309	.3333	.3333	.3333
KB	fom	TDCR	DOUBLE	TRIPLE	EQA	EQB	EQC
.007	1.1238	.6040	.6735	.4068	.4264	.2772	.2964
.008	1.1591	.6040	.6696	.4044	.4265	.2771	.2964
.009	1.1940	.6040	.6660	.4023	.4266	.2770	.2964
.010	1.2285	.6040	.6627	.4003	.4266	.2770	.2964
.011	1.2633	.6040	.6597	.3985	.4271	.2767	.2962
.012	1.2972	.6041	.6569	.3968	.4271	.2768	.2962
.013	1.3311	.6041	.6543	.3953	.4272	.2767	.2961
.014	1.3637	.6040	.6517	.3936	.4272	.2767	.2962
.015	1.3965	.6040	.6493	.3921	.4272	.2767	.2961
KB	fom	TDCR	DOUBLE	TRIPLE	EQA	EQB	EQC

All the files “result.dat”, “spectrum.dat” and “liste.dat” are overwritten for each program execution and thus, it is a good idea to rename these files if necessary. Another consequence is that the program crashes if one of these file is already opened in another application.

For option 4, the input data must be realistic and consistent and entering random data could also lead to an execution error.