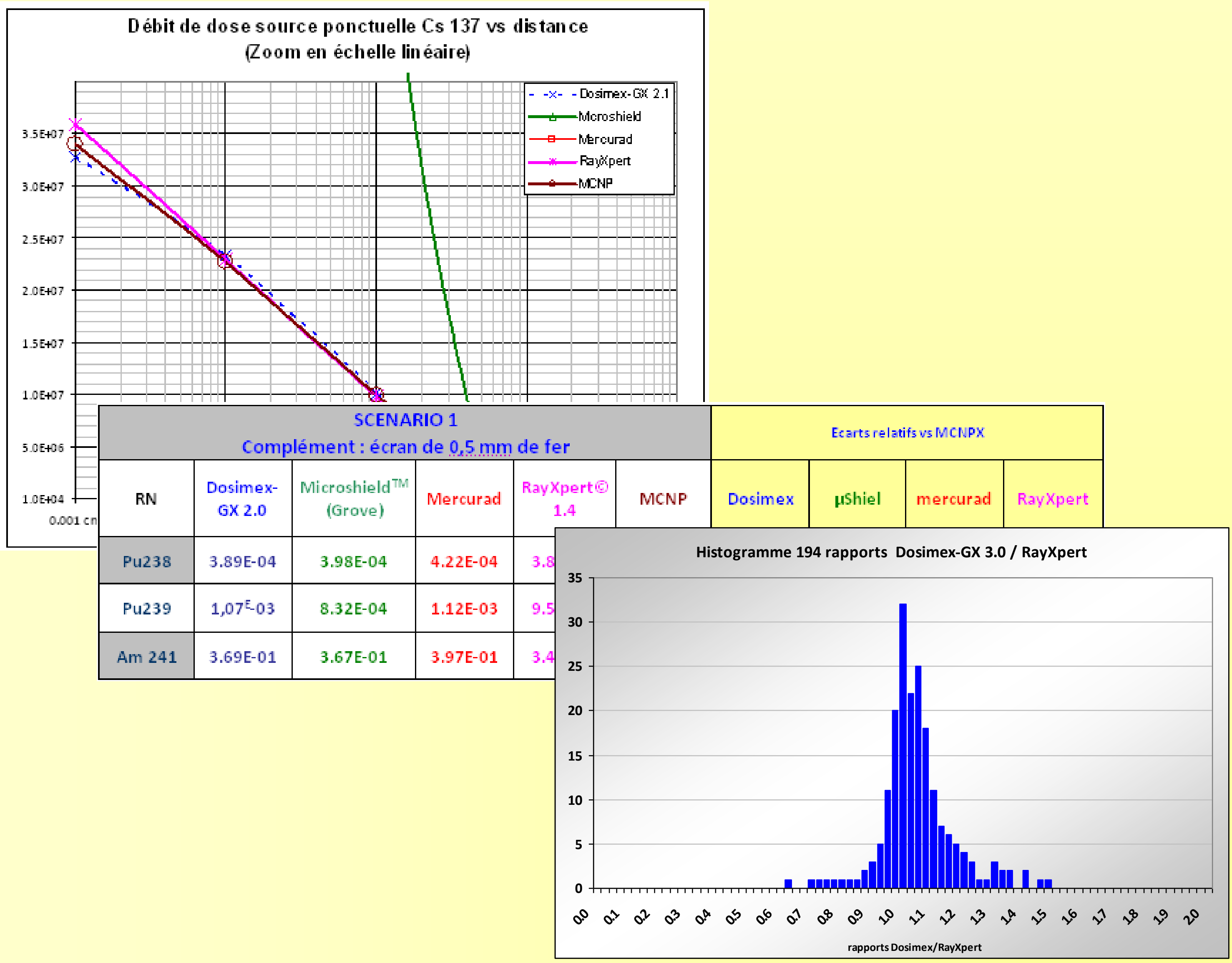
DOSIMEX-GX 3.0

✓ *GAMMA EMISSION VALIDATION FILE (RADIONUCLIDES)*

✓ *PART 1 :*



SCENARIO 1 Complément : écran de 0,5 mm de fer						Ecarts relatifs vs MCNPX			
RN	Dosimex-GX 2.0	Microshield™ (Grove)	Mercurad	RayXpert© 1.4	MCNP	Dosimex	µShiel	mercurad	RayXpert
Pu238	3.89E-04	3.98E-04	4.22E-04	3.8					
Pu239	1,07E-03	8.32E-04	1.12E-03	9.5					
Am 241	3.69E-01	3.67E-01	3.97E-01	3.4					

Alain VIVIER, Gérald LOPEZ

SEPTEMBER 2019

Contents

Partie I. DOSIMEX-GX 3.0 VALIDATION FILE FOR GAMMA SOURCES

PREAMBLE: GENERAL CONTEXT OF VALIDATION FOR THE PART "GAMMA SOURCES" OF DOSIMEX-GX 3.0

In order to qualify the code DOSIMEX-GX 3.0, a large number of configurations, 196 spread over 17 generic scenarios, were tested.

- ✓ **Out of these 196 configurations, 143 were benchmarked against 4 other codes:**

  - ❖ **2 deterministic codes:**
    - MICROSHIELD® V 9
    - MERCURAD ™
  - ❖ **2 Monte-Carlo type codes:**
    - RayXpert © 1.5
    - MCNP 4v2

It is this last code, MCNP, which is considered as the reference code for this benchmark

- The calculations were performed on Dosimex-GX and on Microshield by ourselves.

- The calculations on Mercurad were carried out at the School of Military Applications of Atomic Energy (EAMEA Cherbourg) by Mr Jean-Lionel TROLET.

- The calculations with RayXpert were essentially carried out by ourselves and were the occasion for collaborative work with the designers of this code (Société TRAD, Toulouse). Note that this code itself has benefited from numerous validations vs MCNP: https://www.rayxpert.com/http-www-rayxpert-com-fiches-validation-du-logiciel-v1-6.html

- The calculations on MCNP were carried out at the request of INSTN at the calculation unit of the AREVA Projects BU (AREVA NP, La Hague site). The results are presented in the NoteTechnical NT 101 682 42 001 A

- ✓ **The other 53 configurations were compared to RayXpert only.**

This validation will therefore have required a total of 810 calculation values distributed over 5 different codes

The main result of this validation campaign is as follows: the mean quadratic relative deviation, all values combined (196 in total), is equal to 12.5%, with 90% of the results showing a deviation of less than 20% (see details of the conclusions in part II)

We have finally referenced 4 end-of-study dissertations whose main or secondary objective was to validate Dosimex-GX (see last page of this document)

The 196 configurations are distributed according to the following 17 generic scenarios:

1: BENCHMARK VS MCNP

Scenario 1 : The quality of the results as a function of radionuclides (33 different RNs in point sources to *10 cm*)

Scenario 2 : Evolution of results as a function of distance (point source of Cs 137)

Scenario 3 : Point sources + screen.

Scenario 4 : The influence of the geometry of the radiation source (volumetric, surface, linear sources)

Scenario 5 : Volume source + screen coupling (cylindrical sources + water or lead screen)

Scenario 6 : The influence of the nature of materials on self-absorption in volume sources (spherical source).

Scenario 7 : The ability to take into account very large source dimensions (Am 241 + cylindrical lead source).

Scenario 8 : Validation of parallelepiped geometry introduced with version 1.3

Scenario 9 : Validation for a multi-radionuclide source (CSDV and concrete wall) and activity gradient (activated concrete wall, comparison with the Mercury code)

2: DOSIMEX VS RAYXPERT © COMPARISONS

Scenario 10 : The skyshine

Scenario 11 : The braking radiation generated by the beta emission

Scenario 12 : Cylindrical screen ("pipe") with cylinder geometry. Option implemented in the Dosimex-GX 2.1 version (April 2017)

Scenario 13 : Hollow cylindrical matrix.

Scenario 14 : Primary reactor contaminated on internal surface.

Scenario 15 : Offset on cylindrical source and wire

Scenario 16 : The offset function on cylindrical source and wire

Scenario 17 : Blockhouse calculation with a Co source of 50 Ci

GAP MANAGEMENT

Relative deviations are calculated from the reference code on dose equivalent rate values, in general $\dot{H}*(10)$,::

$$\overline{e}_{(\%)} = \frac{\left(\dot{H}_i - \dot{H}_{iref}\right)}{\dot{H}_{iref}}$$

When the scenarios include several datasets, as for example for scenario 1 with 33 different radionuclides, we then calculate the mean square deviation (EQM):

$$\overline{eqm}_{(\%)} = \sqrt{\frac{\sum_{i=1}^{n} \overline{e}_{i\,(\%)}^{2}}{n}}$$

This statistical indicator adds to the other statistical dispersion indicators such as the population or sample standard deviation. Indeed the mean square deviation takes into account the dispersion of the values around the mean but also the mean deviation with respect to 0, obtained with the algebraic mean of the values.

In terms of this mean square deviation calculated over all of the configurations tested, it is possible to quantify the overall mean “precision” of the codes (see page) or even an mean uncertainty that can be associated with all the results not appearing in this document.

For the final synthesis of the results, we also give this mean square deviation for the calculation in relative deviation.

We will also use for this synthesis the relationship between the tested code and the reference code:

$$r = \frac{\dot{H}_{testé}}{\dot{H}_{ref}}$$

This quantity then makes it possible to construct histograms for all the values, histograms which make it possible to better understand the intrinsic quality of the codes

For these data we will also give the mean algebraic deviation, revealing an overall bias, and the standard deviation, which represents the dispersion around this mean.

MANAGEMENT OF OUTLIERS

Relatively arbitrarily, we decided to qualify as "outliers" values for which the relative deviations greater, in absolute value, than 50%.

These special cases are highlighted by pink cells:

-87%

To be qualified as outliers, it is necessary that such values are relatively few (see summary table in part II):

- For DOSIMEX –GX: 1 outlier on all 196 values, i.e. 0.5% of cases
- For MICROSHIELD: 13 out of 133 outliers, or 10% of cases
- For MERCURAD: 13 out of 139 outliers, i.e. 9% of cases
- For RayXpert: no outlier

Beyond this statistical aspect, we set out to give the origin of these outliers: defect in the emission table, build-up etc....

These studies have allowed us, over the years, to readjust our codes, in particular for example on emission tables or on build-up factors in low atomic number environments, for which the reference values (ANS / ANSI) did not stop giving outliers which are largely overestimated (see appendix N)

1: BENCHMARK DOSIMEX-GX, MICROSHIELD, MERCURAD, RAYXPERT, MCNP

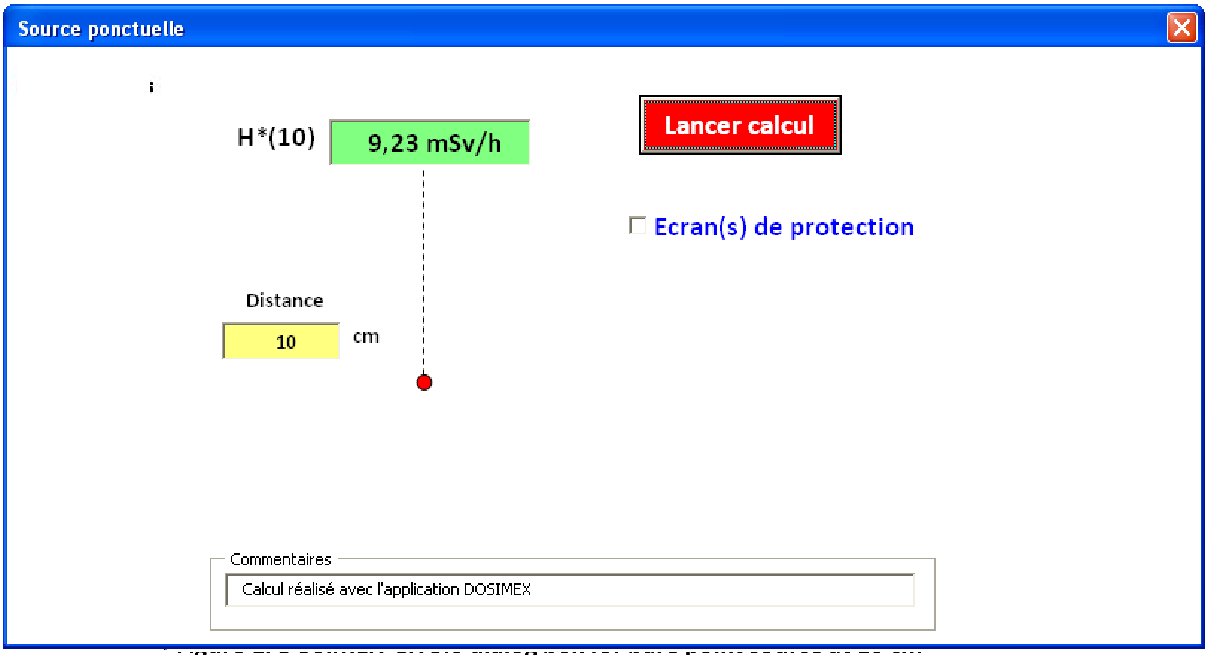
SCENARIO 1 : RESULTS COMPARISONS FOR 33 MAIN RADIONUCLIDES

Scenario.1.1 POINT SOURCES WITHOUT SCREEN

The 33 radionuclides tested here were taken:

- On the list of radionuclides cited in the EDF radiation protection reminder
- In the document "Categorization of radioactive sources", safety guide n ° RS-G-1.9, IAEA (2011)
- Among the radionuclides used in nuclear medicine or in imaging.

The configuration for all these radionuclides is a point source of 1 GBq to 10 cmwithout screen. They are presented in order of decreasing dose equivalent flow rate, from the most metering (Ag 110-m) to the least metering (K 85).



(1 GBq Cs 137).

SCENARIO 1 33 RN point source 1 GBq to 10 cm mSv / h						Relative deviations vs MCNPX			
RN	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.5	MCNPX	Dosimex	µShiel	mercurad	RayXpert
Ag110m	41.50	40.68	42.96	42.60	42.00	-1.2%	-3.1%	2.3%	1.4%
N16	37.42	38.52	38.34	39.70	37.50	-0.2%	2.7%	2.2%	5.9%
Y88	37.25	37.91	36.40	38.40	37.00	0.7%	2.5%	-1.6%	3.8%
Co60	34.80	35.03	35.34	35.00	34.80	0.0%	0.7%	1.6%	0.6%
La140	31.70	31.93	32.32	31.70	32.10	-1.2%	-0.5%	0.7%	-1.2%
Sb124	26.20	25.73	26.64	26.60	26.40	-0.8%	-2.5%	0.9%	0.8%
Cs134	24.70	24.70	24.82	25.50	24.80	-0.4%	-0.4%	0.1%	2.8%
NB94	24.40	24.76	24.72	24.90	24.40	0.0%	1.5%	1.3%	2.0%
Fe59	16.80	16.92	17.05	17.40	16.80	0.0%	0.7%	1.5%	3.6%
F18	16.50	16.62	17.08	15.51	16.60	-0.6%	0.1%	2.9%	-6.6%
Co58	15.30	15.42	15.41	14.70	15.40	-0.6%	0.1%	0.1%	-4.5%
Ir192	13.85	14.57	13.88	14.50	14.00	-1.1%	4.1%	-0.9%	3.6%
Mn54	12.90	12.98	13.00	12.00	13.00	-0.8%	-0.2%	0.0%	-7.7%
Cs137	9.23	9.52	9.27	8.98	9.26	-0.3%	2.8%	0.1%	-3.0%
Ba133	8.84	8.69	9.06	8.93	8.98	-1.6%	-3.2%	0.9%	-0.6%
In111	8.82	8.83	8.97	8.67	9.08	-2.9%	-2.8%	-1.2%	-4.5%
Zn65	8.40	8.44	8.50	7.97	8.32	1.0%	1.4%	2.2%	-4.2%
Se75	6.89	6.83	6.63	6.86	6.97	-1.1%	-2.0%	-4.9%	-1.6%
I131	6.46	6.70	6.57	6.11	6.60	-2.1%	1.5%	-0.5%	-7.4%
Cf252	5.80	0.14	5.48	5.96	5.71	1.6%	-97.5%	-4.0%	4.4%
I125	3.52	3.45	3.61	3.64	3.50	0.6%	-1.4%	3.1%	4.0%
Rh106	3.30	3.39	3.38	3.19	3.33	-0.9%	1.8%	1.5%	-4.2%
U235	3.56	3.65	2.78	3.36	3.61	-1.4%	1.1%	-23.0%	-6.9%
Mo99	2.41	2.30	2.43	2.56	2.40	0.4%	-4.2%	1.3%	6.7%
Tc99m	2.33	2.50	2.34	2.47	2.49	-6.4%	0.4%	-6.0%	-0.8%
Bi212	1.63	2.39	1.63	1.73	1.63	0.0%	46.6%	0.0%	6.1%
Xe133	1.56	1.63	1.23	1.62	1.64	-4.9%	-0.6%	-25.0%	-1.2%
Am 241	1.39	1.60	0.60	1.33	1.38	0.7%	15.9%	-56.5%	-3.6%
Cr51	0.540	0.520	0.540	0.540	0.550	-1.8%	-5.5%	-1.8%	-1.8%
Pu238	0.240	0.320	0.001	0.220	0.230	4.3%	39.1%	-99.6%	-4.3%
Ra226	0.135	0.160	0.120	0.133	0.139	-2.9%	15.1%	-13.7%	-4.3%
Pu239	0.099	0.040	0.002	0.092	0.100	-1.4%	-60.0%	-98.5%	-8.0%
Kr85	0.038	0.037	0.037	0.035	0.037	2.7%	0.0%	0.0%	-5.4%
			Mean square deviation			2.0%	23.3%	27.3%	4.4%
			Mean quadratic deviation excluding outliers			*2.0%*	*8.5%*	*7.0%*	*4.4%*

Table 1: benchmarking for 33 radionuclides as a point source at 10 cm. Dose rate values and relative deviations

RESULTS ANALYSIS :

This first scenario shows that on the one hand:

- Good results obtained with Dosimex GX 3.0 with a mean square deviation equal to 2%. This value must be compared to the mean square deviation of 20% for all codes all results combined, deviation which increases to 8% if we exclude the 6 outliers obtained with Microshield and Mercurad

- Differences actually very high (factor 40 to 270 in terms of ratios) which appear with 4 particular radionuclides: Cf252 (see graph 2), Am241 (see graph 3), Pu238 and Pu239 (see graph 4).

It is important to identify the cause of these deviations. They are of two different natures:

See 252 : Fission products for Microshield® and MercuradTM are not taken into account.
The spontaneous fission of heavy nuclei is accompanied by a very intense and very energetic gamma emission, with gamma rays of more than 5 MeV. This emission, having a continuous spectrum, is not mentioned in the usual databases. Paradoxically, MercuradTM gives a good result in point source without screen, which must result from an ad hoc adjustment of the intensities. This adjustment cannot then be suitable in a calculation in the presence of a significant screen (see below)

Am 241, Pu8 and Pu9 : Not taking into account XL radiation for MercuradTM.
These emissions, around 15 keV, often have significant intensities. Unlike the case of Cf252, the installation of a screen, even a relatively thin one, should make it possible to eliminate these differences. In these 3 cases, MercuradTM can no longer be considered as the reference. MercuradTM underestimates the dose equivalent rate by a factor of 330, for example for the Pu8 in point source without screen.

Note: We can also note for the Bi 212 a relative difference close to + 50% between the value given by Microshield and the others. This difference comes from a difference in the emission intensities for the predominant line of 727 keV: 11.8% for Microshield © and approximately 6.65% for other codes, in accordance with Laraweb 2019 data.

This first scenario highlights the importance of the emission tables implemented. The disparities come either from the difference between the reference table, or from simplifications implemented too abruptly, such as for example the elimination of emissions deemed to be not very intense compared to the predominant emissions, without taking into account the energy of these emissions.

Scenario.1.2 ADDITIONAL CALCULATIONS WITH SCREENS

1) Previous case Pu8, PU 9 and Am 241, with addition of a screen of 0.5mm of iron.

We note, as expected, that the presence of the screen, quite modest tends to quickly equalize the results for the 4 codes. The relative difference between RayXpert © and Mercurad TM is only 14% in this case (5% respectively between Dosimex-GX and RayXpert ©):

SCENARIO 1 Complement: screen of 0.5mm of iron						Relative deviations vs MCNPX			
RN	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShiel	mercurad	RayXpert
Pu238	3.89E-04	3.98E-04	4.22E-04	3.85E-04	4.10E-04	-5.1%	-2.9%	2.9%	-6.1%
Pu239	1.07E-03	8.32E-04	1.12E-03	9.54E-04	1.22E-03	-12.3%	-31.8%	-8.2%	-21.8%
Am 241	3.69E-01	3.67E-01	3.97E-01	3.48E-01	3.60E-01	2.5%	1.9%	10.3%	-3.3%

Table 2: Pu8, PU 9 and Am 241, with addition of a screen0.5mm of iron

%

2) See 252 with adding screen of1 cm from Pb

The presence of the screen 1 cmof lead completely crushes low energies. Microshield © and MercuradTM then underestimate the dose equivalent rates in such a case dramatically:

SCENARIO 1 Complements: Cf 252. 1 GBq with 1 cmPb. d = 10 cm						Relative deviations vs MCNPX			
RN	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShiel	mercurad	RayXpert
See 252.	2.76	3.83E-20	2.13E-09	2.90	2.81	-1.8%	-100.0%	-100.0%	3.2%

Table 3

SUMMARY OF SCENARIO 1 RESULTS

For the 37 configurations (calculations without screen and with screen), i.e. 185 DED values and 148 deviations vs MCNPX (tables 1 + 2 + 3) we obtain:

- **Between DOSIMEX-GX 3.0 and MCNPX: mean square deviation 3%**
- **Between MICROSHIELD® V.9 and MCNPX: :mean square deviation 28%. *(-3 outliers: 10%)***
- **Between MERCURADTM and MCNPX:: mean square deviation%. 31%*(-4 outliers: 7%)***
- **Between RayXpert © 1.4 and MCNPX: : mean square deviation% .6%**
- **Quadratic average over all deviations for all codes: 21%**
- **After deletion of the extreme values: 8%**

Conclusion:

For these simple geometric conditions (absence of material) the results for Dosimex-GX 3.0 are excellent. Note that in this type of calculation, the differences generally come from differences in the emission tables

SCENARIO 2 : EVOLUTION OF RESULTS AS A FUNCTION OF THE DISTANCE

The calculations were made for a point source of cesium 137 of 1 GBq at different distances between 0 (when the code allows) and200 cm.

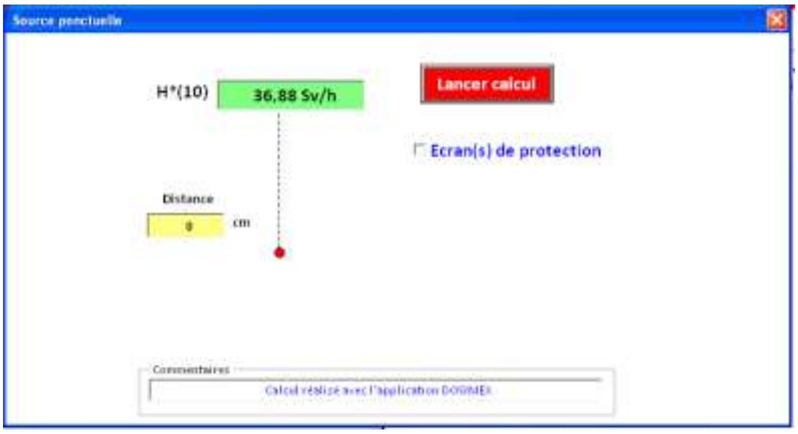
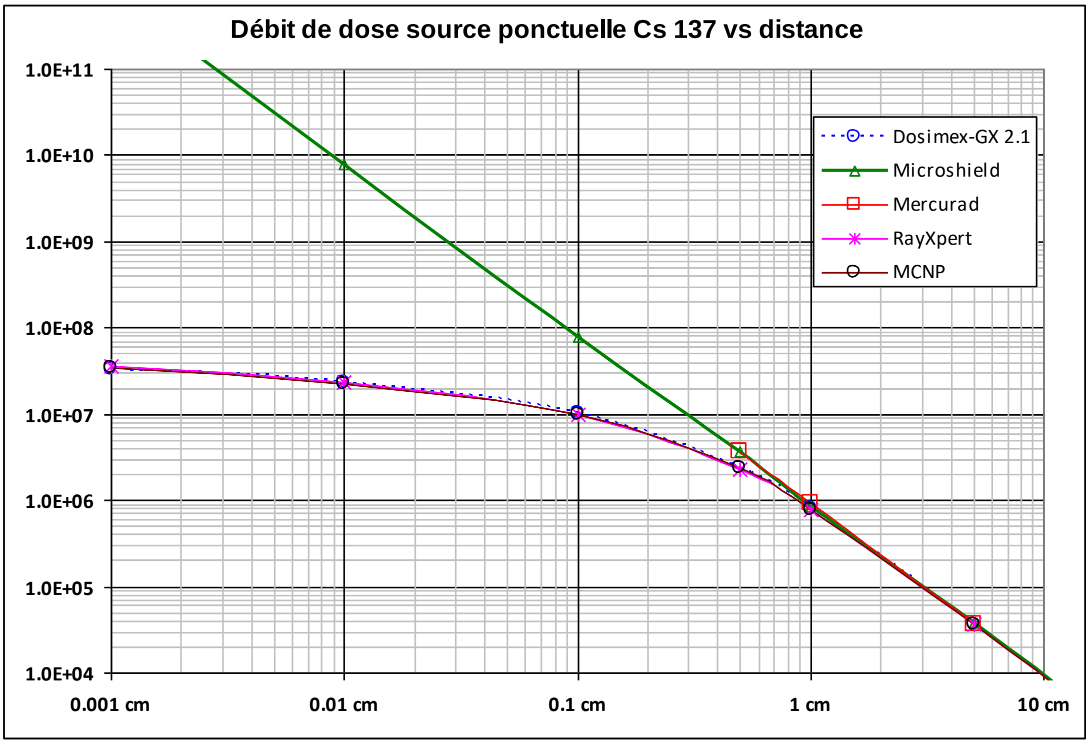


Figure 2: DOSIMEX-GX dialog box for bare point source on contact (1 GBq Cs 137).

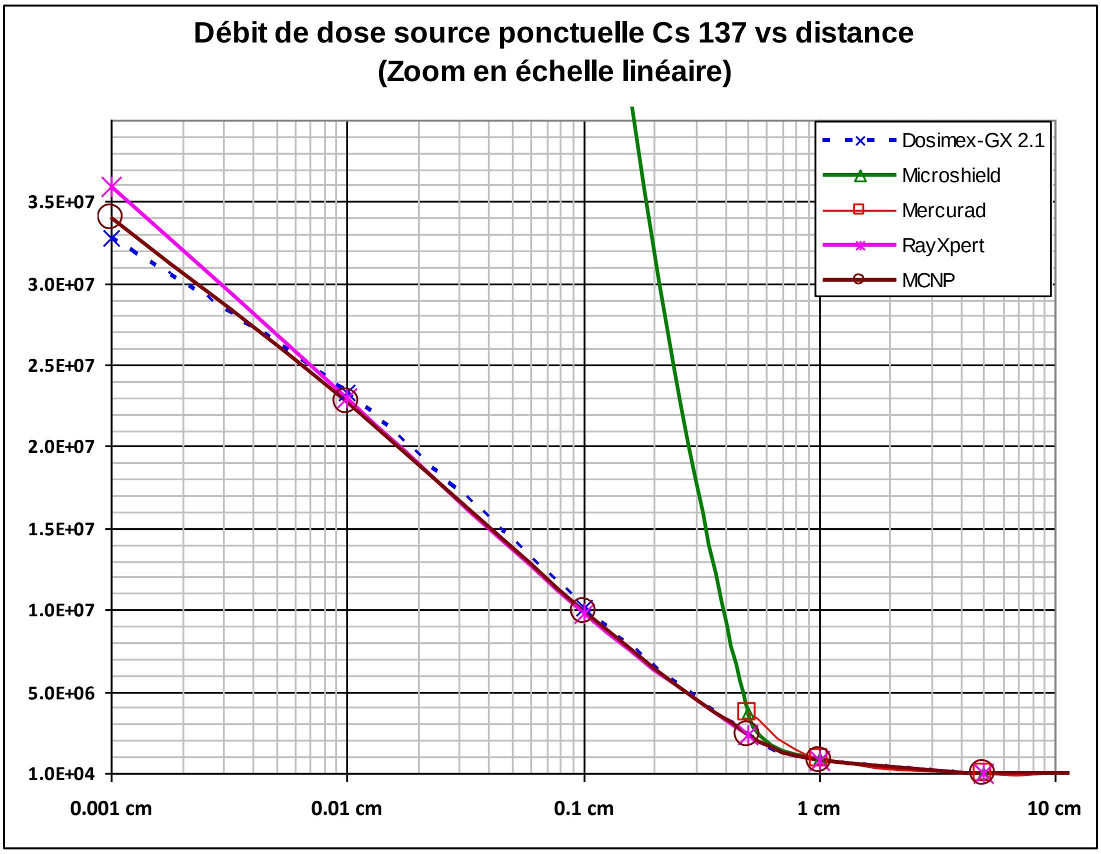
The following table summarizes the results obtained:

Point source Cs 137 1 GBq H * (10) in µSv / h						Relative deviations vs MCNPX			
Distance (cm)	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	Microshield	Mercurad	RayXpert
0	3.8E + 07	NC	NC	3.8E + 07	3.6E + 07	5.9%	NC	NC	5.9%
0.001	3.3E + 07	7.9E + 11	NC	3.6E + 07	3.4E + 07	-3.4%	NC	NC	5.9%
0.01	2.3E + 07	7.9E + 09	NC	2.3E + 07	2.3E + 07	2.2%	NC	NC	0.9%
0.1	1.0E + 07	7.9E + 07	NC	9.9E + 06	9.9E + 06	1.7%	NC	NC	-1.0%
0.5	2.4E + 06	3.7E + 06	3.7E + 06	2.3E + 06	2.3E + 06	1.9%	57.9%	57.9%	-1.0%
1	8.0E + 05	8.6E + 05	9.3E + 05	7.8E + 05	7.9E + 05	1.8%	9.0%	17.4%	-1.1%
5	3.7E + 04	3.8E + 04	3.7E + 04	3.6E + 04	3.6E + 04	1.5%	5.0%	2.3%	-0.2%
15	4.1E + 03	4.2E + 03	4.1E + 03	4.1E + 03	4.0E + 03	1.7%	4.4%	1.7%	0.2%
30	1.0E + 03	1.1E + 03	1.0E + 03	1.0E + 03	1.0E + 03	1.6%	4.2%	1.9%	-0.1%
50	3.7E + 02	3.8E + 02	3.7E + 02	3.7E + 02	3.6E + 02	1.5%	3.9%	1.7%	2.6%
100	9.2E + 01	9.5E + 01	9.3E + 01	9.3E + 01	9.1E + 01	1.8%	4.1%	2.0%	2.2%
150	4.1E + 01	4.2E + 01	4.1E + 01	4.0E + 01	4.0E + 01	1.9%	3.9%	2.2%	-1.3%
200	2.3E + 01	2.4E + 01	2.3E + 01	2.3E + 01	2.3E + 01	2.2%	3.9%	2.4%	-0.1%
			Mean square deviation (values d ≥ 0)			2.5%	NC	NC	2.6%
			Mean square deviation (values d ≥ 0.5 cm)			1.8%	19.9%	20.2%	1.3%
			Mean square deviation (values d ≥ 1 cm)			1.7%	4.8%	6.1%	1.3%

Table 4: Inter-comparisons H * (10) point source versus distance



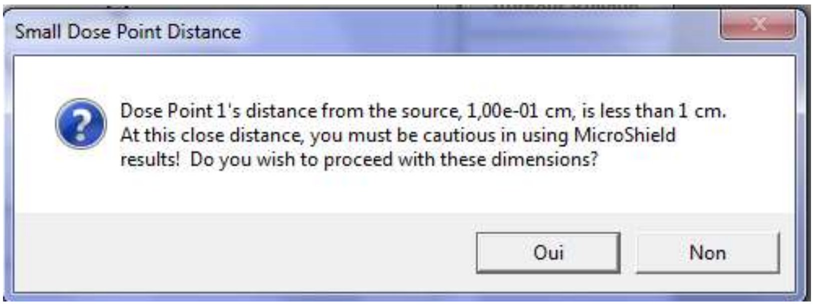
Graph 5: Evolution H * (10) point source versus distance with MICROSHIELD® MERCURADTM and RayXpert ©



RESULTS ANALYSIS

The relative differences between the 4 codes are of the order of 2% for distances greater than 1 cm. From1 cm and below, the results given by MICROSHIELD® and MERCURADTM diverge significantly from the results of DOSIMEX-GX and RayXpert ©, while between the latter two, the relative differences remain around 3% even below 1 cm, including for a strictly zero distance (contact).

MICROSHIELD® and MERCURADTM perform a calculation according to a simple $1 / d^2$ law which loses its meaning for these short distances, and give a result which tends towards infinity when the distance tends to 0 (singularity effect). MERCURADTM no longer gives results for distances less than0.5mmto avoid such effects. MICROSHIELD® warns the user for distances less than 1 cm:



The DOSIMEX-GX application calculates fluence with an elementary surface of 1 cm2, thus avoiding the effects of singularities (see method in detail below). The calculations made with RayXpert, a Monte-Carlo type code, confirms that this singularity effect does not occur when the distance decreases.

Note : the estimation of the doses generated by a point source below a distance of 1 cmis not of practical interest in radiation protection, if only because the sources are never really punctual, and on the other hand because most measurement systems have volume sensitive zones whose effective center is not not in contact with the source. The fact remains that it is interesting not to overestimate dose rates at a short distance, especially in the case of volume sources for which it is legitimate to estimate the doses received for tissues (hands for example) actually in contact.

CALCULATION AT VERY SHORT DISTANCES. METHOD IMPLEMENTED BY DOSIMEX-GX 3.0.

a) The limits of the law in "$1/d^2$"

Consider a point source containing a radionuclide emitting energy photons E_γ and intensity I_γ. The number of photons emitted by the source during an exposure time $T_{exp.}$ is equal to : $N = A\ I_\gamma\ T_{exp.}$ The objective is to determine the dose rate generated by this source at point P, at the distance d from the source By drawing around the source a virtual sphere of radius d, we can then state:

➢ That in the absence of attenuation, the number of photons crossing the sphere, during the exposure time, is equal to the number N of photons emitted.

➢ That because of the isotropy[1] of the emission, the mean fluence on the surface of the sphere is homogeneous on mean, and therefore simply equal to the number N divided by the area of the sphere.

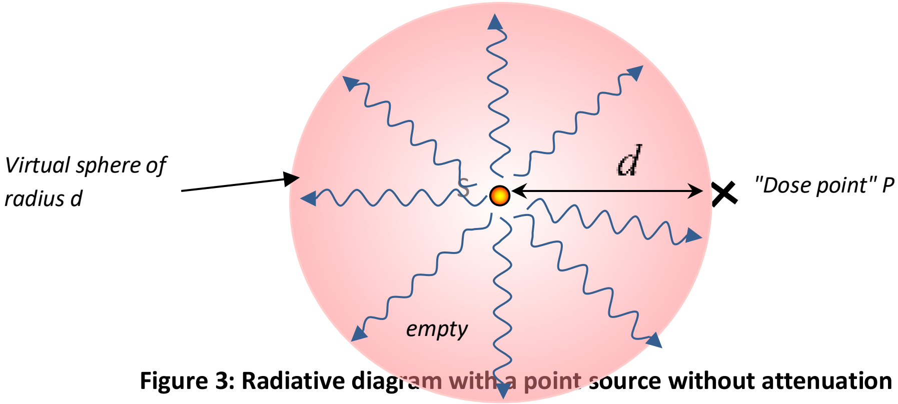


Figure 3: Radiative diagram with a point source without attenuation

The surface of the sphere being equal to $S_{sphère} = 4\pi d^2$, photonic fluence at a distance d Equals :

$$\Phi(P) = \frac{N}{S_{sphère}} = \frac{A\ I_\gamma\ T_{exp}}{4\pi d^2}$$

Fluence flow is obtained by dividing by exposure time: $\varphi(P) = \dfrac{A\ I_\gamma}{4\pi d^2}$

Here we see the term in "$1/d^2$", well known to radiation protectionists. More specifically, the quantity $1/4\pi d^2$ represents the report:

- the number of incident photons on a surface of $1\,cm^2$ placed in the distance d from a source.
- the total number of photons emitted by this source, always assuming no attenuation.

This quantity is called the solid angle fraction[2] and noted $\Omega/4\pi$, Ω being the solid angle and 4π the total solid angle (see annex H on solid angles).

The calculation of the solid angle fraction by the quantity $1/4\pi d^2$ poses an obvious problem: when the distance d decreases, the quantity $1/4\pi d^2$ increases very quickly, tending to the limit towards infinity when d tends towards zero. This effect affects the dose or dose rate estimates.

Dose values obtained at very short distance, very high, lose their meaning. They are representative of the dose only in an elementary volume very close to the source point, but of very small dimension. Such a hot spot is less and less representative of the real mean dose in an extended object, or even an organ. At the limit $d = 0$, that is to say in contact with the source, the dose is no longer calculable (for a mathematician, it is infinite!). More prosaically, the calculation in "$1/d^2$" is only valid when the virtual sphere has a surface at least greater than 1 cm2. In the opposite case, we would see a number of incident particles per cm2 greater than the number of particles emitted by the source.

[1] All directions are equiprobable
[2] In the field of radiation detection, it is also called "geometric efficiency"

Numerical example:

Consider a point source emitting 1 particle (photon or electron) per second. If we wish to calculate the dose equivalent H '(0.07) with this source in contact with the skin under 70 µm of dead layer then the direct calculation in "$1/d^2$" *would give a fluence flow equal to 1620 particles per cm2 per second.*

b) Realistic calculation with a non-point detector

To avoid such singularities[3], you have to calculate the geometric efficiency with a $1\,cm^2$ placed at a distance d centered on the source – dose point axis, and perpendicular to this axis.

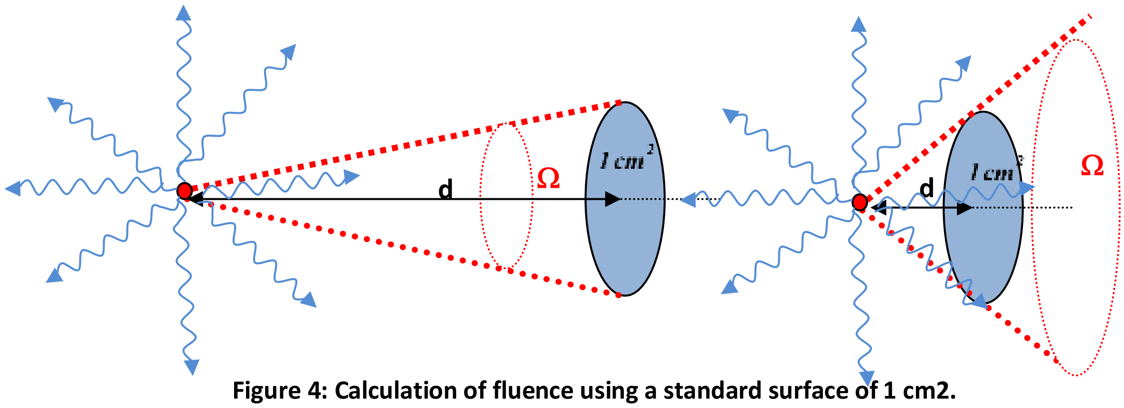


Figure 4: Calculation of fluence using a standard surface of 1 cm2.

The solid angle fraction obtained with this diagram (Figure 4) is equal to:

$$\frac{\Omega}{4\pi}(d) = \frac{1}{2} \times \left(1 - \frac{d}{\sqrt{d^2 + \frac{1}{\pi}}} \right) \quad \text{(relation 1)}$$

This expression is equivalent to the expression $1/4\pi d^2$ when the distance d is greater than a few centimeters (see appendix H), but avoids the effect of singularity when approaching the source. It also allows you to calculate a solid angle fraction on contact, thus avoiding the appearance of infinite mathematics:

$$\frac{\Omega}{4\pi}(d = 0) = 0,5\,(50\,\%)$$

It is moreover coherent:

- With the designs ofthe ICRP, since it amounts to calculating a “hot spot” dose on a minimum area of $1\,cm^2$ in all cases.
- With the methods used in Monte-Carlo type calculations, which requires the modeling of volume pseudo-detectors. Among others, the calculations performed in the RayXpert © simulation implements a thin cylinder (h = 0.01 mm) with a surface of 1 cm2 (radius $r_0 = 0,564\,cm$, see figure 5...)

[3]In physics, a singularity is a point in the vicinity of which certain quantities become infinite. A black hole is a gravitational singularity (see part 1 §5.2).

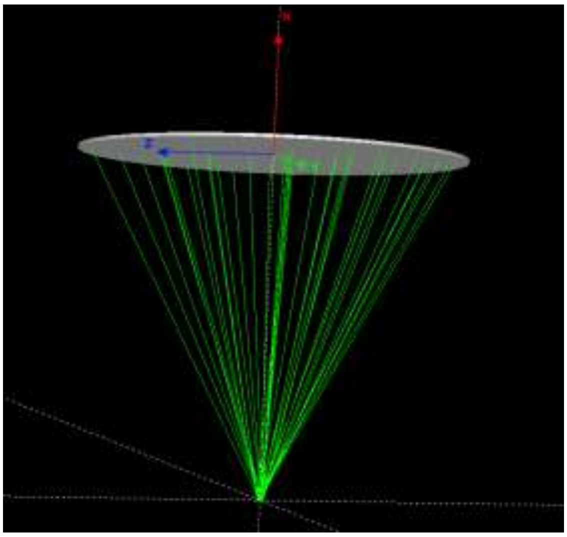


Figure 5 : standard detector of 1 cm2 and thickness 0.01mm at a distance of 1 cm, uniform illumination. Tracking carried out with RayXpert © (with agreement fromTRAD Company)

Numerical example:
By taking again the case of the point source emitting 1 particle per second, the relation 2 makes it possible to obtain a first more realistic estimate of the order of 0.49 incident particle per cm2.

c) Correction of the angular effects for the calculation of fluence

The relation 1 makes it possible to calculate the geometrical yield for a standardized detector of 1 cm2. It calculates the number of particles reaching the detector per unit area, a value which would correspond, for example, to the actual count value obtained with charged particles. To measure a dose, the angular effects must be taken into account. Indeed an incident particle with an angle α (deviation from normal incidence) travels $h' = h/\cos\alpha$ in a thickness detector h. This effect is taken into account in the definition of fluence in the sense of Chilton (see appendix A)

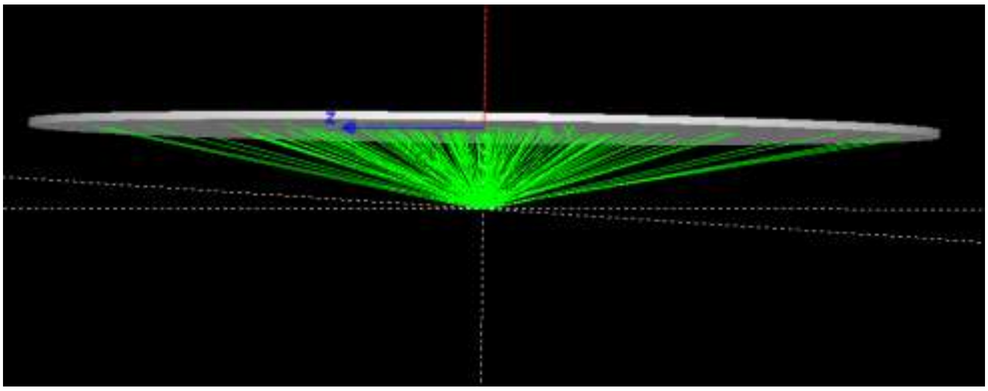


Figure 6: detector standardized to 0.1 cm. Tracking carried out with RayXpert (with agreement ofTRAD Company)

Calculation of the mean cosine of the angle of incidence :

$$\overline{\cos\alpha} = \int_0^{\alpha_{max}} \cos\alpha \, dS \Big/ \int_0^{\alpha_{max}} dS \quad \text{with } dS = 2\pi y \, d\alpha \text{ and } y = d\,\mathrm{tg}\alpha \text{ is } \overline{\cos\alpha} = \int_0^{\alpha_{max}} \cos\alpha \, \mathrm{tg}\alpha \, d\alpha \Big/ \int_0^{\alpha_{max}} \mathrm{tg}\alpha \, d\alpha$$

We obtain any calculation made:

$$\overline{\cos\alpha} = \frac{\cos\alpha_{max} - 1}{\ln(\cos\alpha_{max})}$$

Either an angular correction coefficient:

$$FC = \frac{1}{\overline{\overline{\cos\alpha}}} = \frac{\ln(\cos\alpha_{max})}{\cos\alpha_{max} - 1} \qquad \text{(relation 2)}$$

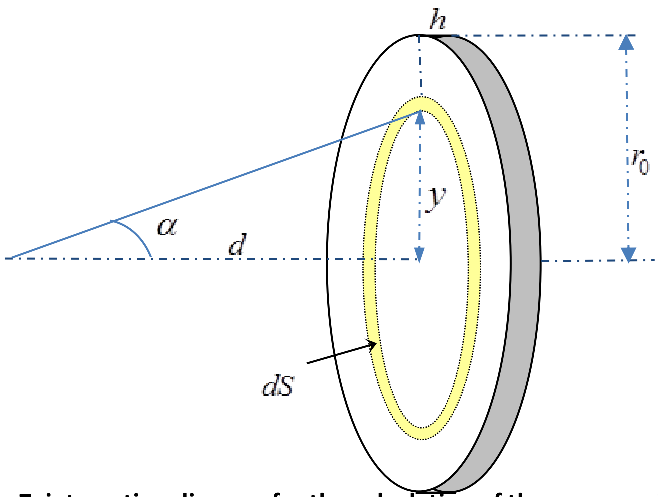


Figure 7: integration diagram for the calculation of the mean cosine

Determination of the maximum angle:

This angle takes into account the non-zero thickness h of the detector, thus avoiding an infinite correction factor for a calculation on contact:

$$\alpha_{max}(d) = \mathrm{Arctg}\left(\frac{r_0}{d+h}\right).$$

This relationship remains relatively insensitive to the value of h for distances $d > h$.

The choice made in Dosimex is $h = 0{,}001\,\mathrm{cm}$, is :

$$\alpha_{max}(d) = \mathrm{Arctg}\left(\frac{0{,}564}{d+0{,}001}\right)$$

The function allowing to evaluate the particulate fluence in the sense of Chilton used in Dosimex– G 2.0 is written:

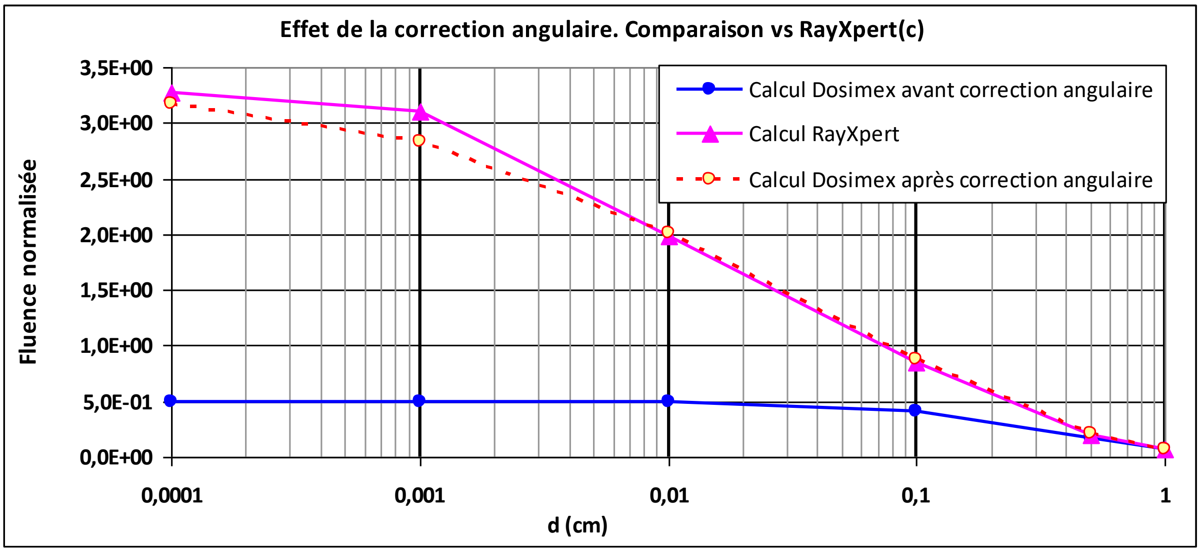
$$\varphi(P) = \frac{1}{2} \times \left(1 - \frac{d}{\sqrt{d^2 + \frac{1}{\pi}}}\right) \frac{\ln(\cos\alpha_{max})}{\cos\alpha_{max} - 1} A\ I_\gamma \quad \text{(relation 3)}$$

Angular correction did not exist in previous versions of Dosimex-GX.

Numerical application for an emission rate of 1 photon per second under 4π $(A\ I_\gamma = 1)$:

Fluence rate (gamma / cm2 / s) normalized to 1 gamma emitted by s under 4pi					
Distance (cm)	**geometric yield (relation 1)**	**Angular correction FC (relation 2)**	**Fluence Chilton (relation 3)**	**RayXpert ©**	***Relative gap***
0	5.00E-01	6.35	3.17E + 00	3.28E + 00	*-3%*
0.001	5.00E-01	5.66	2.83E + 00	3.10E + 00	*-9%*
0.01	5.00E-01	4.02	2.01E + 00	1.98E + 00	*1%*
0.1	4.14E-01	2.11	8.72E-01	8.49E-01	*3%*
0.5	1.69E-01	1.22	2.06E-01	2.00E-01	*3%*
1	6.47E-02	1.07	6.92E-02	6.73E-02	*3%*
2	1.88E-02	1.02	1.92E-02	1.87E-02	*2%*
5	3.16E-03	1.00	3.17E-03	3.11E-03	*2%*

Table 5: point source calculation method with angular correction


Effet de la correction angulaire. Comparaison vs RayXpert(c)
Fluence normalisée
3,5E+00
3,0E+00
2,5E+00
2,0E+00
1,5E+00
1,0E+00
5,0E-01
0,0E+00
0,0001
0,001
0,01
0,1
1
d (cm)
Calcul Dosimex avant correction angulaire
Calcul RayXpert
Calcul Dosimex après correction angulaire

Graph 6

SUMMARY OF SCENARIO 2 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 2.5% (calculated up to*0 cm)***
- **Between MICROSHIELD® V.9 and MCNPX average deviation 19.9% (calculated up to*0.5 cm*)**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 20.2%. (calculated up to*0.5 cm*)**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 2.6% (calculated up to *0 cm*)**

Conclusion:

Outside distances less than 1 cm, we see that the differences are small between the 5 codes, of the order of 3%. The original deterministic method implemented by Dosimex-GX 2.0 avoids the appearance of unrealistic high values below1 cm and allows you to find the values obtained by Monte-Carlo codes until contact.

SCENARIO 3 : POINT SOURCES WITH SCREEN. BUILD-UP IMPACT

The calculations were made with point sources. The H * dose equivalent flow rate calculations (10) were performed at100 cm from the point source of 1GBq for the following radionuclides:

1. **Americium 241**
2. **Cesium 137,**
3. **Cobalt 60,**

This choice covers a standard energy range between 60 keV and 1300 keV.
The calculations were carried out first without a screen and then with different types of screens:

- **2 cm lead**
- **10 cm aluminum**
- **50 cm of water**

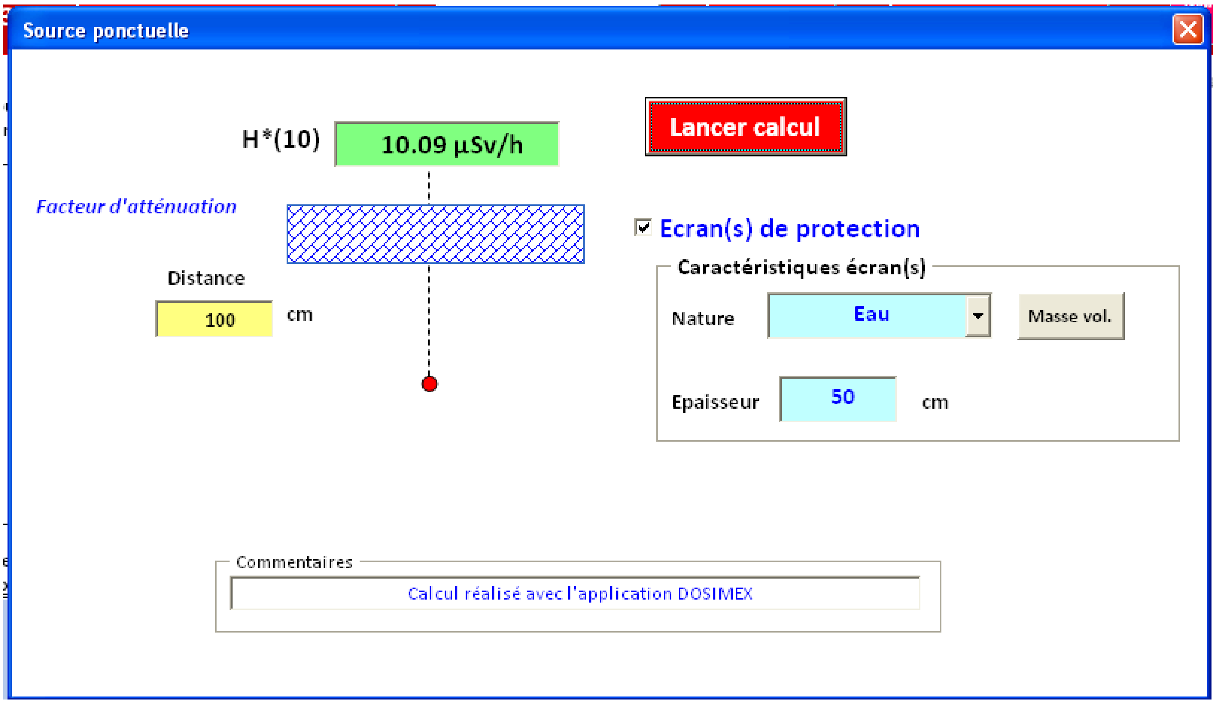


Figure 8: DOSIMEX-GX dialog for point source (1 GBq Cs 137).

+ water screen 50 cm

	SCENARIO 3 point sources 1 GBq to 100 cm H * (10) in µSv / h						Relative deviations vs MCNPX			
	RN	Dosimex-GX 3.0	Microshield	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShiel	mercurad	RayXpert
Am 241	*Naked source*	13.4	16	6.1	13.3	13.3	0.8%	20.3%	-54.1%	0.0%
	source + 10cm Alu screen	2.0E-02	3.30E-02	3.70E-02	1.67E-02	1.77E-02	10%	86.4%	109.0%	-5.6%
	Source + 2cm Pb screen	1.30E-04	7.40E-21	1.00E-04	1.40E-04	1.44E-04	-9.7%	-100.0%	-30.6%	-2.8%
	Source + 50cm screen of water	1.53E-02	4.09E-02	3.75E-02	1.10E-02	1.33E-02	15.0%	207.5%	182.0%	-17.3%
Cs 137	*naked source*	92.5	93.6	92.8	90.7	90.8	1.9%	3.1%	2.2%	-0.1%
	source + 10cm Alu screen	38.45	45.3	51.7	35.9	35.5	8.3%	27.6%	45.6%	1.1%
	Source + 2cm Pb screen	13.3	14.16	13.7	13.1	13	2.3%	8.9%	5.4%	0.8%
	Source + 50cm screen of water	10.1	14.4	16.5	9.33	9.2	9.8%	56.5%	79.3%	1.4%
Co 60	*naked source*	349	347	353	352	347	0.6%	0.0%	1.7%	1.4%
	source + 10cm Alu screen	183	192	210	181	174	5.2%	10.3%	20.7%	4.0%
	Source + 2cm Pb screen	143	141	152	146	145	-1.4%	-2.8%	4.8%	0.7%
	Source + 50cm screen of water	51	76	87	60	60.3	16%	26.2%	44.3%	-0.5%
				Mean square deviation			12%	74%	71%	5%
				Mean quadratic deviation excluding outliers			12%	16%	31%	5%

We note here significant systematic deviations for the 2 deterministic codes Microshield, and Mercurad vs the 2 Monte-Carlo codes of RayXpert and MCNP references, notably with Am 241.

These differences are essentially linked to the method of correcting the diffusion effects using a build-up coefficient (Document ANSI / ANS 6.4.3, 1991).

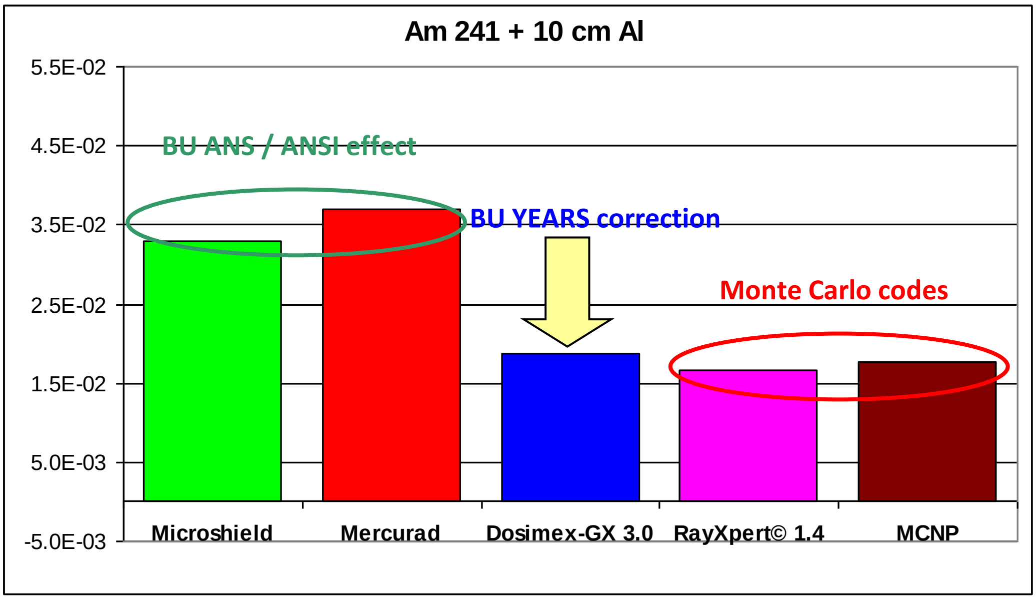
BUILD-UP EFFECT WITH AM 241:

Americium 241 awas chosen here because it is a low energy transmitter (main component at 59 KeV). The effects of Build-up are maximized by choosing materials with low atomic numbers such as Aluminum and water.

For 10 cmof aluminum at 59 keV the number of relaxation length n is 6.8 and the "infinite" Build-up factor is 5.8 (ANSI / ANS 6.4.3). We note that for deterministic codes such a factor overestimates the more realistic values obtained with Monte-Carlo type codes by a factor of around 2.

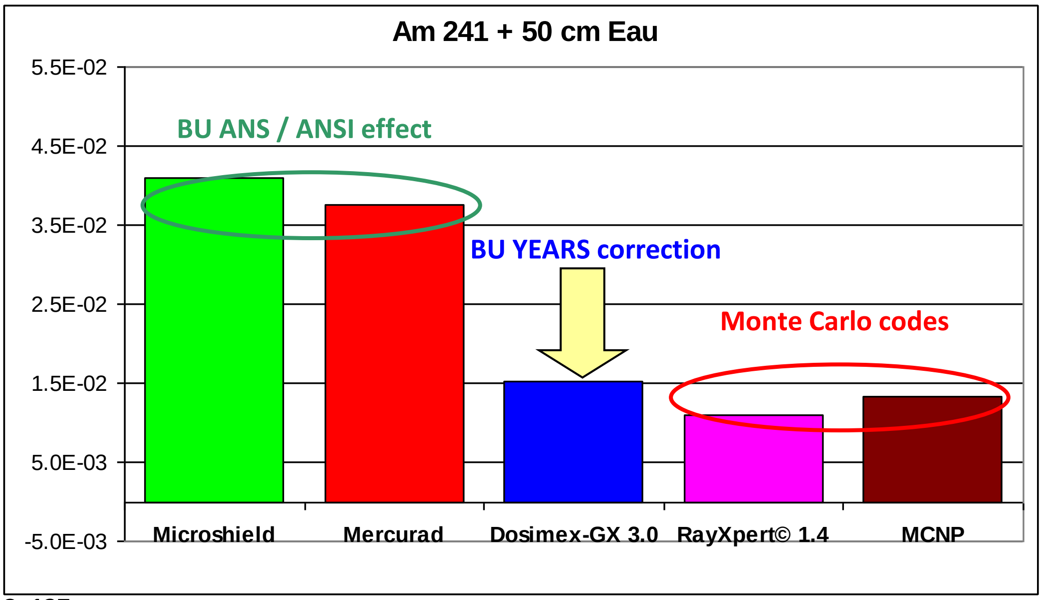
For the DOSIMEX-GX 3.0 version, and after years of study (see appendix N) and validation, we decided to readjust the Build-up factors not with had-hoc factors, but with correction functions monotonic function of the factor of the length of relaxation µx. Such an operation is equivalent to a recalibration vs the reference codes.

So for 10 cm of aluminum at 59 keV the build-up is now taken at 2.7



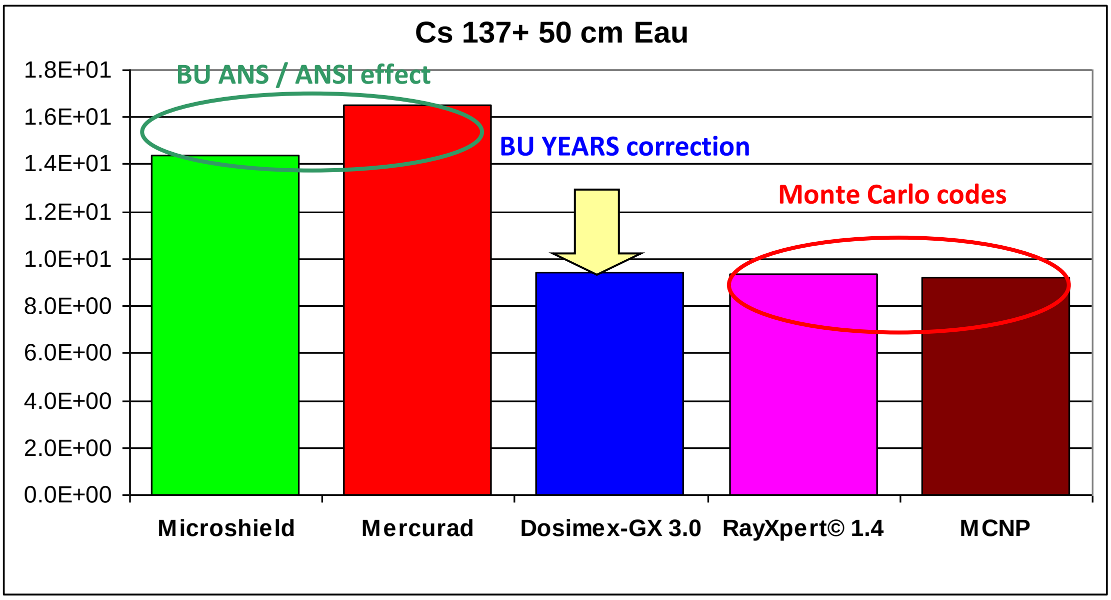
For 50 cm of water at 59 keV the number of relaxation length n is equal to 9.7 and the “infinite” ANS / ANSI build-up factor is equal to 87. We find the same effect of systematic deviation between deterministic code and Monte-Carlo codes with a factor of around 3:

The correction functions introduced with Dosimex now give in this case a buid-up factor equal to 41



SOURCE OF CS 137 WITH WATER SCREEN

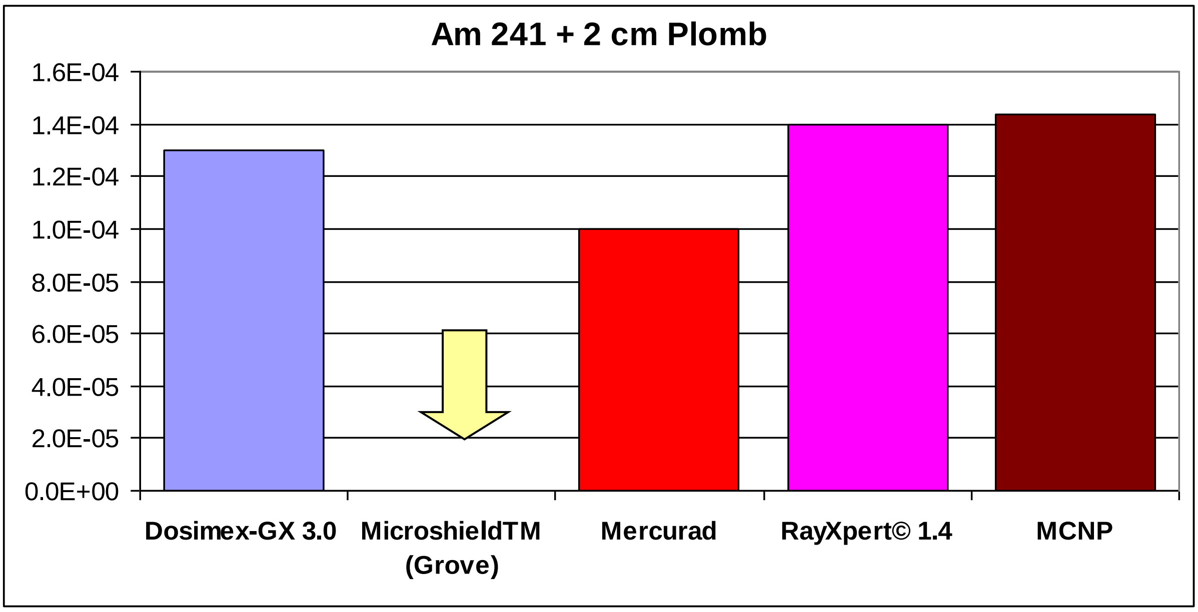
For 50 cm of water at 661 keV the number of relaxation length n is equal to 4.3 and the "infinite" ANS / ANSI Build-up factor is equal to 11. The correction made to Dosimex-GX 3.0 changes this coefficient to 7.5



EFFECT WITH LEAD SCREEN WITH AM 241:

The deviation of Microshield® compared to the other 4 codes is more than notable: astronomical with factor of **10-21**.

This difference is linked to differences in the gamma and X emission tables. Microshield® only takes into account the low energy emissions of americium 241, which are effectively predominant in terms of dose in the absence of any screen. With the presence of a screen, in particular lead, these emissions are quickly and almost completely attenuated (attenuation equal to 3.10-4 with *1 mm Pb only*). Only emissions of low intensity, but high energy, then contribute to the dose. As these emissions are absent in the Microshield® database, the error factor is effectively unacceptable.



SUMMARY OF SCENARIO 3 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 11%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 74% ((16% excluding outliers)**
- **BetweenMERCURADTM *and* MCNPX : average deviation 71%. ((31% excluding outliers)**
- **BetweenRayXpert © 1.4 TM *and* MCNPX : average deviation 5%**

Conclusion :

The differences obtained here for Microshield and Mercurad may be surprising, but they are linked to the use of tabulated factors for the Build-up coefficients which are found for all deterministic codes. Let us recall here that the examples chosen, excluding Co 60, tend to maximize the overestimates encountered with these build-up factors. It is this type of calculation, along with others, that led us to make corrections to the build-up factors.

Note: we find here the factor 2 existing between the result given by MercuradTM and the other codes, for the naked source Am241 (cf scenario1). Recall that this difference comes from not taking into account XL and gamma emissions of low energies grouped around 17 keV and a high total intensity of around 40%. Even more than for the 59 keV emission, this emission disappears quickly in the presence of the slightest screen.

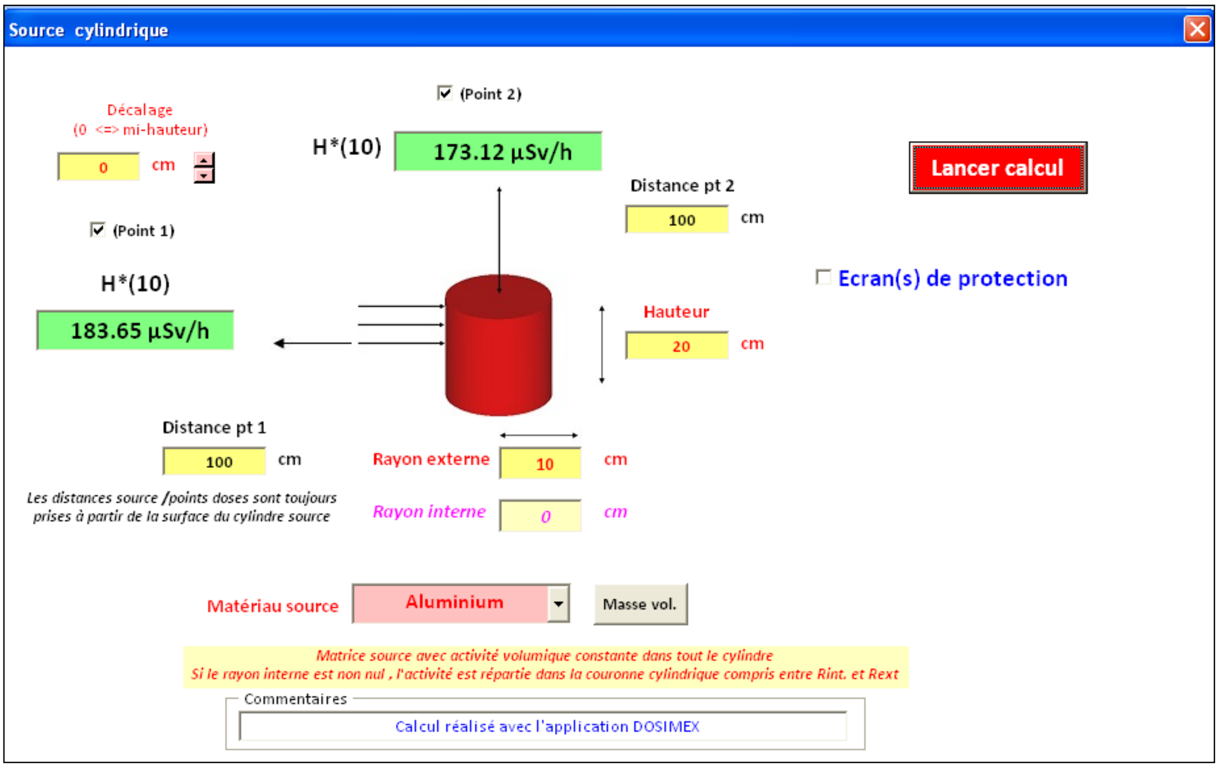
SCENARIO 4 : INFLUENCE OF SOURCE GEOMETRY

Different source geometries were compared:

1. a linear source of 100 cm length,
2. a disk source from 100 cm radius,
3. a cylindrical source of 10 cm radius and 20 cm tall made of aluminum.

The calculations were carried out for three radioactive sources of 1 GBq respectively of americium 241, cesium 137 and cobalt 60, always at a distance of 100 cm.

For cylindrical sources, two dose equivalent rate results are provided by DOSIMEX-GX, one perpendicular to the axis of revolution (point 1) with zero offset (see manual on the "offset" function) and the other on the axis of revolution (point 2)



DOSIMEX-GX dialog box for cylindrical source (1 GBq Co 60) with zero offset

	SC. 4 linear, surface and volume sources (Al) 1 GBq to100 cm H * (10) in µSv / h						Relative deviations vs MCNPX			
	RN	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Am 241	Wire	12.45	6.2	5.7	11.9	12.39	0.5%	-50.0%	-54.0%	-4.0%
	Disk	9.32	4.7	4.3	9.5	8.99	3.7%	-47.7%	-52.2%	5.7%
	Pt1 cylinder	0.799	0.9	0.96	0.77	0.79	1.1%	13.9%	21.5%	-2.5%
	Pt2 cylinder	0.644	0.89	0.84	0.69	0.7	-8.0%	27.1%	20.0%	-1.4%
Cs 137	Wire	86	75	86	83	85	1.2%	-11.8%	1.2%	-2.4%
	Disk	64	65	64	63	63	1.6%	3.2%	1.6%	0.0%
	Pt1 cylinder	44.53	46	50	41	40	11.3%	15.0%	25.0%	2.5%
	Pt2 cylinder	40.5	42	46	37	36	12.5%	16.7%	27.8%	2.8%
Co 60	Wire	323	322	327	326	322	0.3%	0.0%	1.6%	1.2%
	Disk	242	240	245	244	236	2.5%	1.7%	3.8%	3.4%
	Pt1 cylinder	183	186	188	173	171	7.0%	8.8%	9.9%	1.2%
	Pt2 cylinder	173	173	206	156	155	11.6%	11.6%	32.9%	0.6%
				Mean square deviation			6.8%	23.4%	27.5%	2.7%

Board 9 : Dose rate sources of various geometries and comparisons with MICROSHIELD® and MERCURADTM

SUMMARY OF SCENARIO 4 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 6.8%**
- **Between MICROSHIELD® V.9 and MCNPX mean deviation 23.4 %**
- **BetweenMERCURADTM *and* MCNPX : average difference 27.5%.**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX : average deviation 2.7%**

Conclusion:

We find, with the wire and disc source, the problem encountered with the Am 241 for which Microshield © and MercuradTM do not take into account XL emissions of low energies but of high intensity. This problem disappears with the volume source due to the significant self-absorption for these energies. Apart from this case already reported and identified, there is good agreement for these different geometries between these 5 codes.

In this benchmark vs MCNP, and for geometries which become more complex, there is an excellent agreement between RayXpert and MCNP, which implement similar calculation principles

SCENARIO 5 : VOLUME SOURCES + SCREEN COUPLINGS

Comparisons have been made with larger cylindrical sources in the absence and then in the presence of a screen:

- Cylindrical source of 100 cm of height and 20 cm aluminum spoke
- Screens:
  - 10 cm aluminum;
  - 2 cm lead ;
  - 15 cm of water.

- Radionuclides: 1 GBq of Cesium 137 then Cobalt 60

- Dose point at 100 cm of the cylinder surface

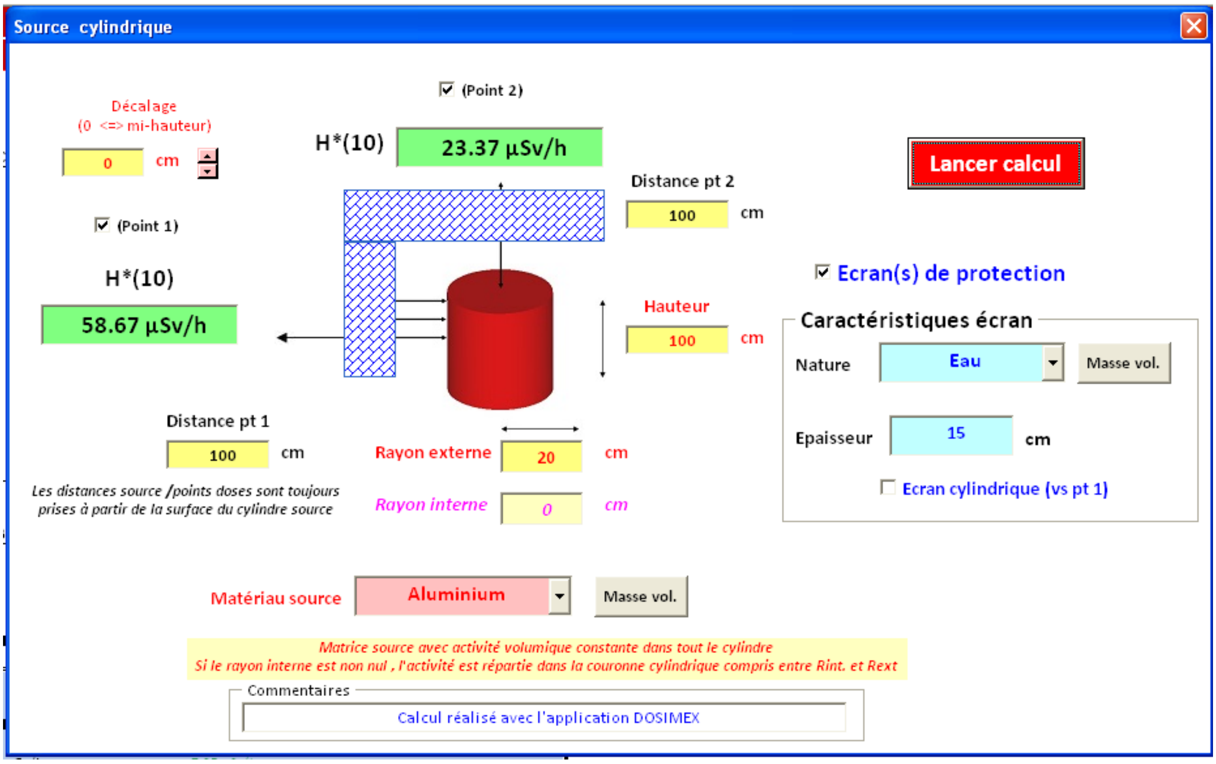


Figure 11: DOSIMEX-GX dialog box for cylindrical source 1 GBq Co 60+ 15 cm of water

	SCENARIO 5: cylinder + screen; lateral (point1) H * (10) in µSv / h						Relative deviations vs MCNPX			
	RN	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Cs 137	Naked source	21.11	22	24	21.5	20	6%	10%	20%	8%
	Source + 2cm of Pb	2.16	4.1	1.7	1.8	1.6	35%	156%	6%	13%
	Source + 15 cm of water	11.81	11	15	10	11	7%	0%	36%	-9%
Co 60	Naked source	92.7	96	104	90	90	3%	7%	16%	0%
	Source + 2cm of Pb	36.67	44	29	28	26	41%	69%	12%	8%
	Source + 15m of water	52.67	55	69	50.1	54	1%	2%	28%	-7%
				Mean square deviation			22%	70%	22%	8%

Table 9: Dose rate cylindrical sources + screen calculated laterally (point 1)

	SCENARIO 5: cylinder + screen; central axis (point 2) H * (10) in µSv / h						Relative deviations vs MCNPX			
	RN	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Cs137	Naked source	8.16	9	7.6	8.3	8	2%	13%	-5%	4%
	Source + 2cm of Pb	0.866	2.4	0.72	0.71	0.75	15%	220%	-4%	-5%
	Source + 15 cm of water	4.65	4.7	6.4	5.4	5.5	-15%	-15%	16%	-2%
Co 60	Naked source	36.6	39	35	36	35	5%	11%	0%	3%
	Source + 2cm of Pb	12.6	18	12	11	12	5%	50%	0%	-8%
	Source + 15m of water	21	22	29	24.2	26	-20%	-15%	12%	-7%
				Mean square deviation			13%	93%	9%	5%

Table 10: Cylindrical source dose rate + screen on the axis of symmetry (point 2)

SUMMARY OF SCENARIO 5 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 13%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 82% (- 2 outliers 29%)**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 17%.**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 7%**

Microshield® overestimates the dose rate with the 2 cm lead by a factor of around 3 with Cs 137 and 1.6 with Cobalt 60. In general, there is an overestimation of the 3 deterministic vs RayXpert codes linked again to an overestimation of the build-up in screen.

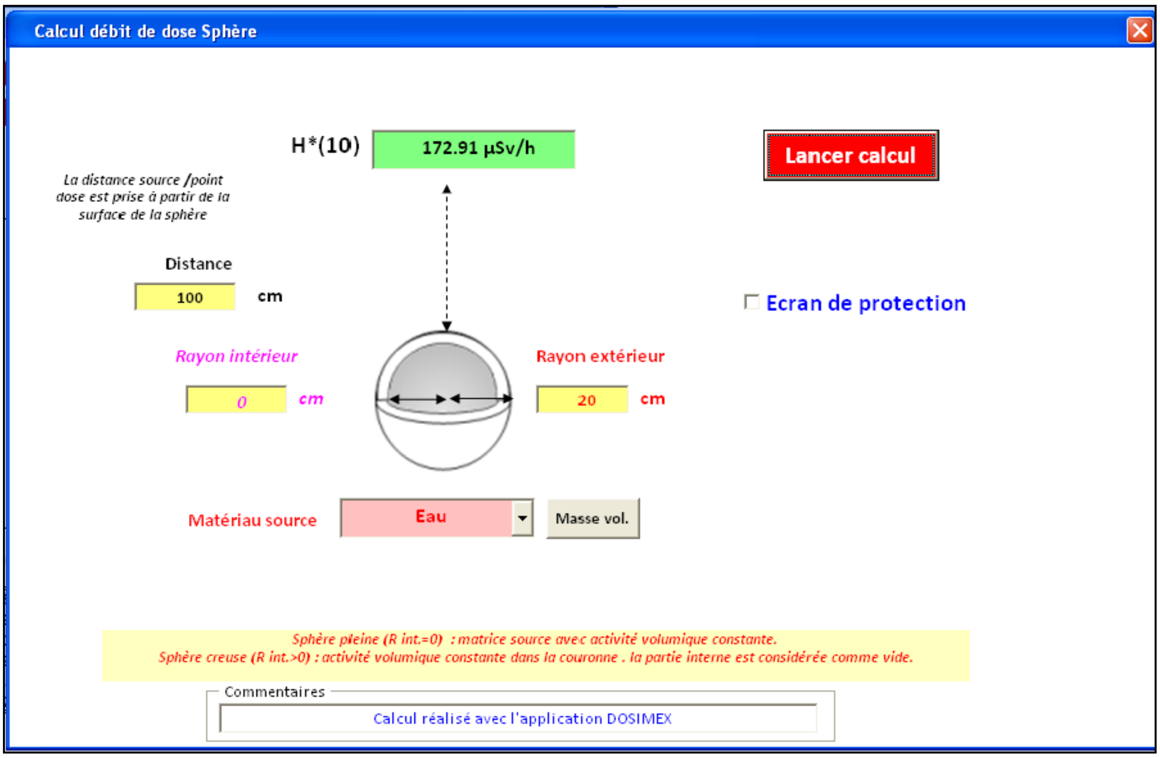
SCENARIO 6 : **MATERIAL INFLUENCE**

These comparisons were made for:

- Validate spherical geometry
- Test the different materials used (13 materials predefined in the ANSI standard)
- Compare Taylor's build-up with Linear Berger build-up.

The configuration is:

- sphere full of radius 20cm
- dose point 100 cm from the edge of the sphere
- 1 GBq of Co60.



The different materials are used with their reference densities (modifiable in DOSIMEX-GX)

Taylor's build-up (ANS / ANSI 1991) Miscellaneous Materials Sphere						Relative deviations vs MCNPX			
Material (density)	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Air (1.3.10-3)	244	243	247	244	243	0.4%	0.0%	1.6%	0.4%
Water (1)	158	180	191	170	164	-5%	9.8%	16.5%	3.7%
Aluminum (2.7)	97.5	108	118	102	99	-1.5%	9.1%	19.2%	3.0%
Concrete (2.35)	117	116	126	114	107	9.3%	8.4%	17.8%	6.5%
Iron (7.86)	36	40	44	42	38	-5.3%	5.3%	15.8%	10.5%
Lead (11.34)	16	19	21	18	19	-15.8%	0.0%	10.5%	-5.3%
Uranium (19)	8	10	11	10	10	-20.0%	0.0%	10.0%	0.0%
Beryllium (1.85)	174	*NC*	181	150	138	26.1%	NC	31.2%	8.7%
Carbon (2.25)	133	131	141	115	113	17.7%	15.9%	24.8%	1.8%
Sodium (0.97)	191	*NC*	200	171	174	9.8%	NC	14.9%	-1.7%
Silicon (2.2)	111	*NC*	134	115	112	-0.9%	NC	19.6%	2.7%
Tunsten (19.25)	10	12	13	13	13	-23.1%	-7.7%	0.0%	0.0%
Tin (6.52)	41	44	49	45	44	-6.8%	0.0%	11.4%	2.3%
			Mean square deviation			14.2%	8%	17%	5%

Board 12: Spherical source dose rate vs materials. Taylor's build-up

Berger build-up (1 + µx) Miscellaneous Materials Sphere						Relative deviations vs MCNPX			
Material (density)	**Dosimex-GX 2.0**	**MicroshieldTM (Grove)**	**Mercurad**	**RayXpert © 1.4**	**MCNP**	**Dosimex**	**µShield**	**Mercurad**	**RayXpert**
Air (1.3.10-3)	243	243	247	244	243	0.0%	0.0%	1.6%	0.4%
Water (1)	180	180	191	170	164	9.8%	9.8%	16.5%	3.7%
Aluminum (2.7)	105	108	118	102	99	6.1%	9.1%	19.2%	3.0%
Concrete (2.35)	117	116	126	114	107	9.3%	8.4%	17.8%	6.5%
Iron (7.86)	38	40	44	42	38	0.0%	5.3%	15.8%	10.5%
Lead (11.34)	24	19	21	18	19	26.3%	0.0%	10.5%	-5.3%
Uranium (19)	13	10	11	10	10	30.0%	0.0%	10.0%	0.0%
Beryllium (1.85)	148	*NC*	181	150	138	7.2%	NC	31.2%	8.7%
Carbon (2.25)	119	131	141	115	113	5.3%	15.9%	24.8%	1.8%
Sodium (0.97)	193	*NC*	200	171	174	10.9%	NC	14.9%	-1.7%
Silicon (2.2)	121	*NC*	134	115	112	8.0%	NC	19.6%	2.7%
Tunsten (19.25)	14	12	13	13	13	7.7%	-7.7%	0.0%	0.0%
Tin (6.52)	49	44	49	45	44	11.4%	0.0%	11.4%	2.3%
			Mean square deviation			13%	8%	17%	5%

Board 13: Spherical source dose rate vs materials. Berger build-up

SUMMARY OF SCENARIO 6 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 14%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 8%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 17%.**
- **BetweenRayXpert © 1.4 TM *and* MCNPX :: average deviation 5%**

These results show good consistency between the 4 codes for the materials used. The calculations performed with the linear Berger build-up show that, despite its great rusticity, the results obtained in this configuration are just as admissible.

SCENARIO 7 : ADAPTIVE POWER MESH AND CONSIDERATION OF LARGE DIMENSIONS

PRESENTATION OF THE PROBLEM.

The first customer feedback that reached us in 2012 reported a strange problem:
Our user (IRSN) noted during his calculations that the DED decreases when the calculation distance decreases, which is an a priori surprising result (but not always impossible!). After a moment of great solitude, the problem became obvious when this user gave us the dimensions of his source: it was a silo of9 m high and 5 m of diameter !

It then became obvious that our division of the volume of the source matrix into 15x15x15 on the 3 axes of integration therefore gave us too voluminous volume elements (voxel) (globally cubes of*60 cm next to !)*, thus generating crippling geometric aberrations (attenuation, angles of incidence, etc.). Our digital integration was therefore seriously flawed.

The characteristics of the mesh of the extended sources, linear, surface or voluminal, have a determining influence on the result of computation. In general, the mesh must be fine enough to be suitable for transporting photons in the material or, said differently, of the order of magnitude of the mean free paths. Problems arise when the dimensions of the source become significantly large. In such a case, a uniform mesh (figure*15 a*) adapted imposes a large number of meshes on each axis of integration, which can quickly generate prohibitive computation times. For example, the mean free path of 59 keV photons (Am241) in lead is 180 µm. Considering only two axes of integration, a cylinder of10 cmin radius and height would require more than a million voxels to be properly modeled. An interesting solution, requiring only a fairly small number of mesh, is a power mesh (Figure 15 b) according to the law $\Delta H_n = a^n \times \Delta H_0$, with:

- ΔH_0 : the width of the first stitch, opposite the dose point
- ΔH_n : the width of the nth mesh
- a : the reason for the potential law

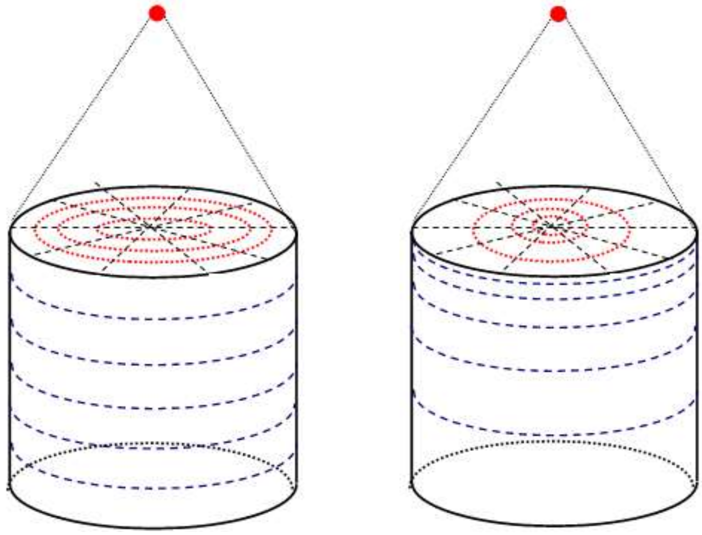


Figure 15: Uniform mesh (a) and power mesh (b) for a cylinder

Adaptation of the cutting vs the energy of the photons: the value ΔH_0 of the first mesh is a fraction of the harmonic mean of the mean free paths of the photons, weighted by the emission intensity and the activity (in the case of multiple RNs).

The value of reason a is calculated by an internal solver to ensure the relation $\sum_n \Delta H_n = H_{tot}$. The limits of this solver range from a minimum thickness of0.01 cm at a maximum thickness of about 1025 cm.

For a lead cylinder loaded with americium 241, a power mesh adapted to a lead cylinder of 100 cm in height, with a number of meshes equal to only 15, and obtained in DOSIMEX-GX, is the following (1st column):

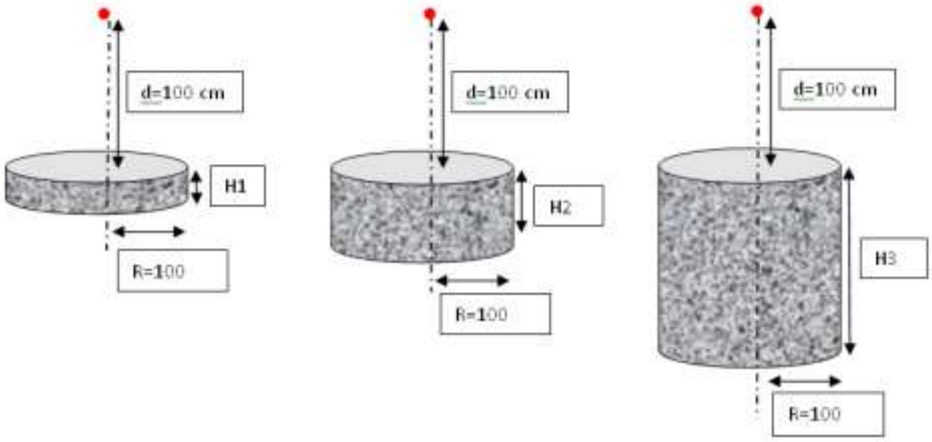
	ΔH_n (cm)	
N° maille	Am 241	Co 60
1	0,007	0,62
2	0,013	0,80
3	0,025	1,03
4	0,046	1,34
5	0,086	1,74
6	0,16	2,25
7	0,30	2,92
8	0,57	3,79
9	1,07	4,91
10	2,01	6,37
11	3,77	8,26
12	7,07	10,71
13	13,27	13,89
14	24,91	18,01
15	46,73	23,35

Table 14: Power mesh for A241 and Co 60 lead cylinder height 1m

We note that the first decisive layers are meshed very finely, while the bottom of the cylinder is meshed very roughly, in inverse proportion to its actual contribution to the total dose (in this case for the last layer infinitely negligible)

The same mesh method adapted to cobalt 60 (2nd column) in the same geometry gives a more uniform mesh, due to significantly higher mean free paths (1.5 cm).

The advantage of a suitable power mesh can be highlighted quite simply. We consider the dose rate generated by a lead cylinder with a constant volume activity in Am 241, for an increasing cylinder height, the dose rate being always calculated at the same distance from the surface (see Figure 16).



ation

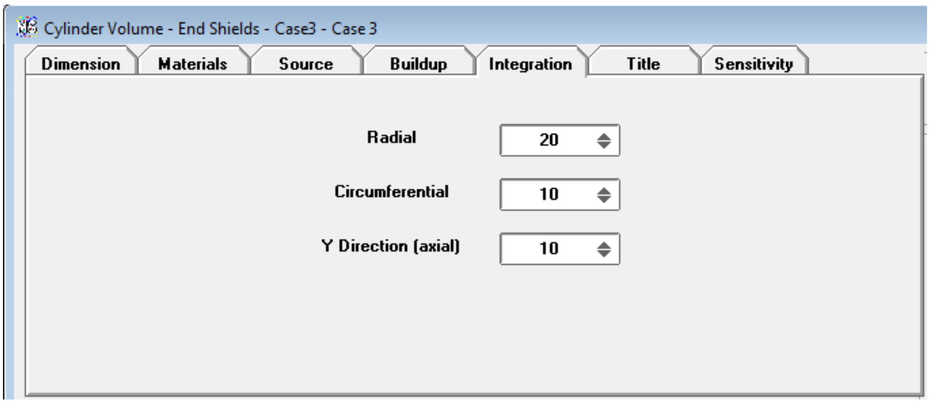
Starting from a very low cylinder height, 100 µm, up to very high thicknesses, 100 cm, one can expect, for obvious physical considerations, to observe a dose rate which increases then ends up stabilizing when the 59 keV component of the sections added successively is almost –totally attenuated by the first layers on the surface (the attenuation corrected for *2 mm lead is 2.10-5*) The increase linked to the photons of higher energies, less attenuated, should remain essentially masked by the initial surface component of 59 keV.

But in any case, the dose should not decrease when the height of the cylinder increases! (Which would be the case if one made a calculation with not a constant volume activity, but a constant total activity)
The calculation performed with DOSIMEX shows (see following pages) that the dose rate actually increases rapidly and then stabilizes from a thickness of 0.07 cm. There is a slight decrease, not significant (≈7%), when going from 0.07 cm at 1 m.

With Microshield® and MercuradTM, problems can arise if the operator is not aware of this type of problem. Indeed, the default integration options (case 1) lead to significant errors when the lead thickness increases. The operator can modify these integration parameters to overcome these problems (case 2)

CASE 1: RESULTS WITH DEFAULT OPTIONS FOR MICROSHIELD AND MERCURAD

Microshield® default option: Limited number of meshes



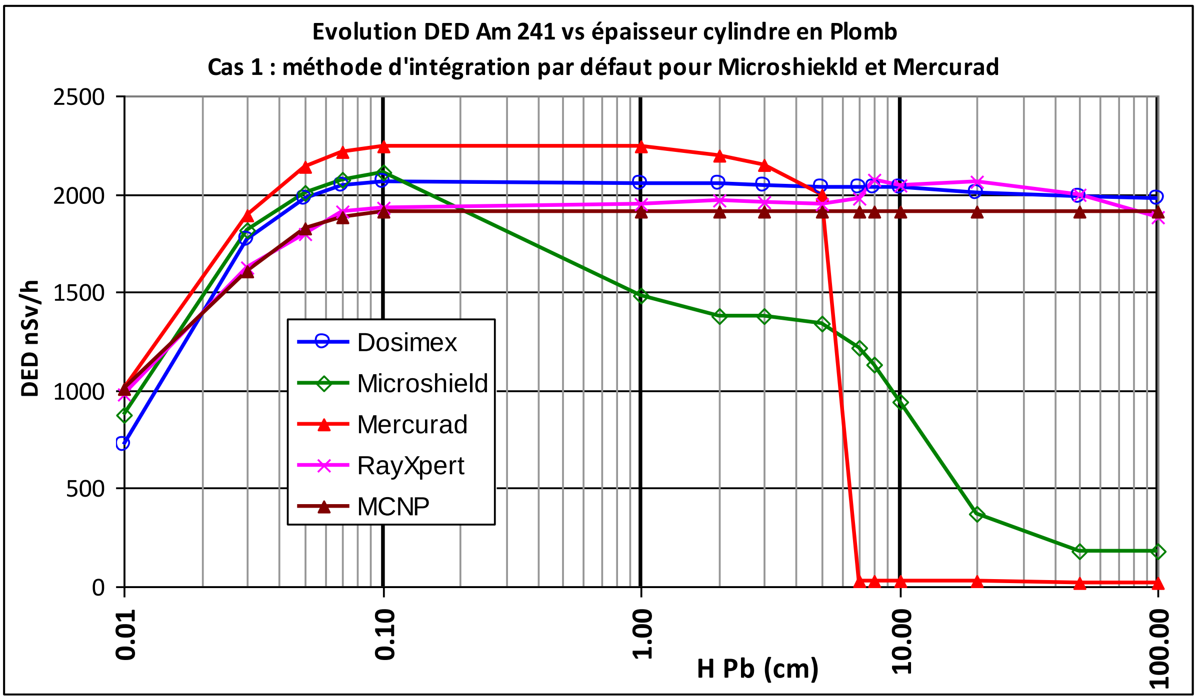
MercuradTM default option: uniform cutting

Picture

On the same thickness variation, the dose rate calculated by Microshield® drops significantly by a factor of the order of 10. Mercurad suffers from the same defect and drops by a factor of 100.

Scenario 7 version 1 vs Microshield and Mercurad Pb barrel						Relative deviations vs MCNPX			
Pb thickness (cm)	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
0.01	721	878	1010	976	1008	-28%	-13%	0%	-3%
0.03	1770	1813	1894	1625	1607	10%	13%	18%	1%
0.05	1960	2008	2142	1796	1822	9%	10%	18%	-1%
0.07	2040	2075	2218	1914	1886	8%	10%	18%	1%
0.1	2060	2112	2246	1926	1908	8%	11%	18%	1%
1	2050	1480	2241	1950	1913	7%	-23%	17%	2%
2	2050	1383	2200	1970	1913	7%	-28%	15%	3%
3	2040	1376	2150	1960	1913	7%	-28%	12%	2%
5	2030	1336	2000	1952	1913	6%	-30%	5%	2%
7	2030	1212	25	1961	1913	6%	-37%	-99%	4%
8	2030	1128	25	2069	1913	6%	-41%	-99%	8%
10	2030	943	24	2047	1913	6%	-51%	-99%	7%
20	2010	371	24	2060	1913	5%	-81%	-99%	8%
50	1990	178	20	1999	1913	4%	-91%	-99%	4%
100	1960	177	18	1883	1913	4%	-91%	-99%	-2%
			Mean square deviation			10%	46%	64%	4%

Table 15



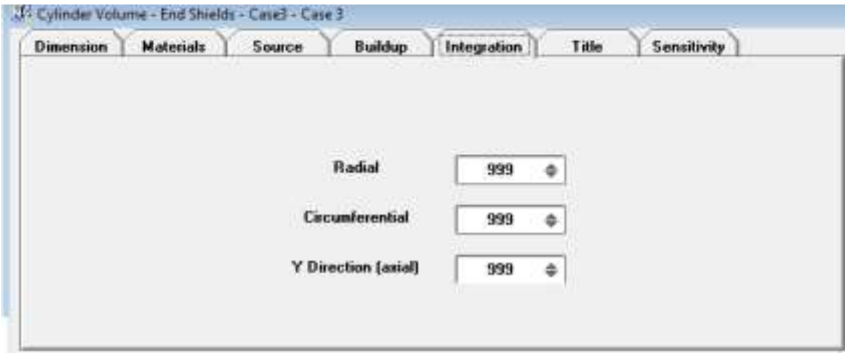
Graph 10

Note: these results are not taken into account in the final benchmark

CASE 2: RESULTS WITH OPTIMIZED OPTIONS (CHOICE VALIDATED BY THE OPERATOR)

- ✓ **Optimized Microshield® option: Maximum number of meshes**

Microshield® offers the possibility of refining the mesh with a maximum division into 999 meshes on each axis:

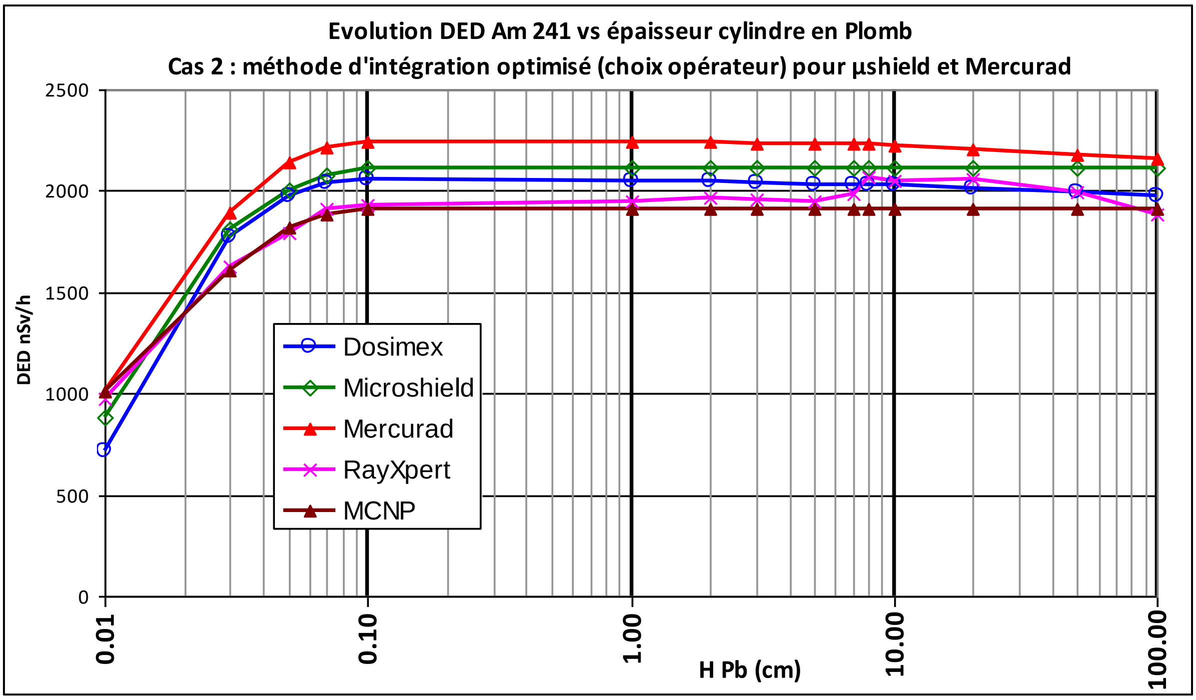


- ✓ **Optimized MercuradTM option: power split**

The uniform MERCURAD mesh is the one proposed by default to the user. This code however proposes a mesh in power which makes it possible to ensure the stability of the calculation beyond 50 mean free path.
With these optimized options, the results become consistent again:

Scenario 7 version 2 vs Microshield and Mercurad Pb barrel loaded in Am 241						Relative deviations vs MCNPX			
RN	Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
0.01	721	878	1010	976	1008	-28%	-13%	0%	-3%
0.03	1770	1811	1894	1625	1607	10%	13%	18%	1%
0.05	1960	2008	2142	1796	1822	9%	10%	18%	-1%
0.07	2040	2075	2218	1914	1886	8%	10%	18%	1%
0.1	2060	2112	2246	1926	1908	8%	11%	18%	1%
1	2050	2114	2241	2040	1913	7%	11%	17%	7%
2	2050	2114	2239	1970	1913	7%	11%	17%	3%
3	2040	2114	2237	1960	1913	7%	11%	17%	2%
5	2030	2114	2234	1952	1913	6%	11%	17%	2%
7	2030	2114	2231	1961	1913	6%	11%	17%	4%
8	2030	2114	2229	2069	1913	6%	11%	17%	8%
10	2030	2114	2226	2047	1913	6%	11%	16%	7%
20	2010	2114	2209	2060	1913	5%	11%	15%	8%
50	1990	2114	2180	1999	1913	4%	11%	14%	4%
100	1960	2114	2160	1883	1913	4%	11%	13%	-2%
			Mean square deviation			10%	11%	16%	4%

Table 16



Graph 11: Am 241 dose rate vs lead cylinder height and comparisons with MICROSHIELD®, MERCURADTM and RayXpert ©

Application : DOSIMEX-GX's ability to take into account large dimensions makes it possible, for example, to find the order of magnitudes of the surface activity-dose rate conversion factors at 1 m given by the Federal Guidance for "infinite" surfaces.

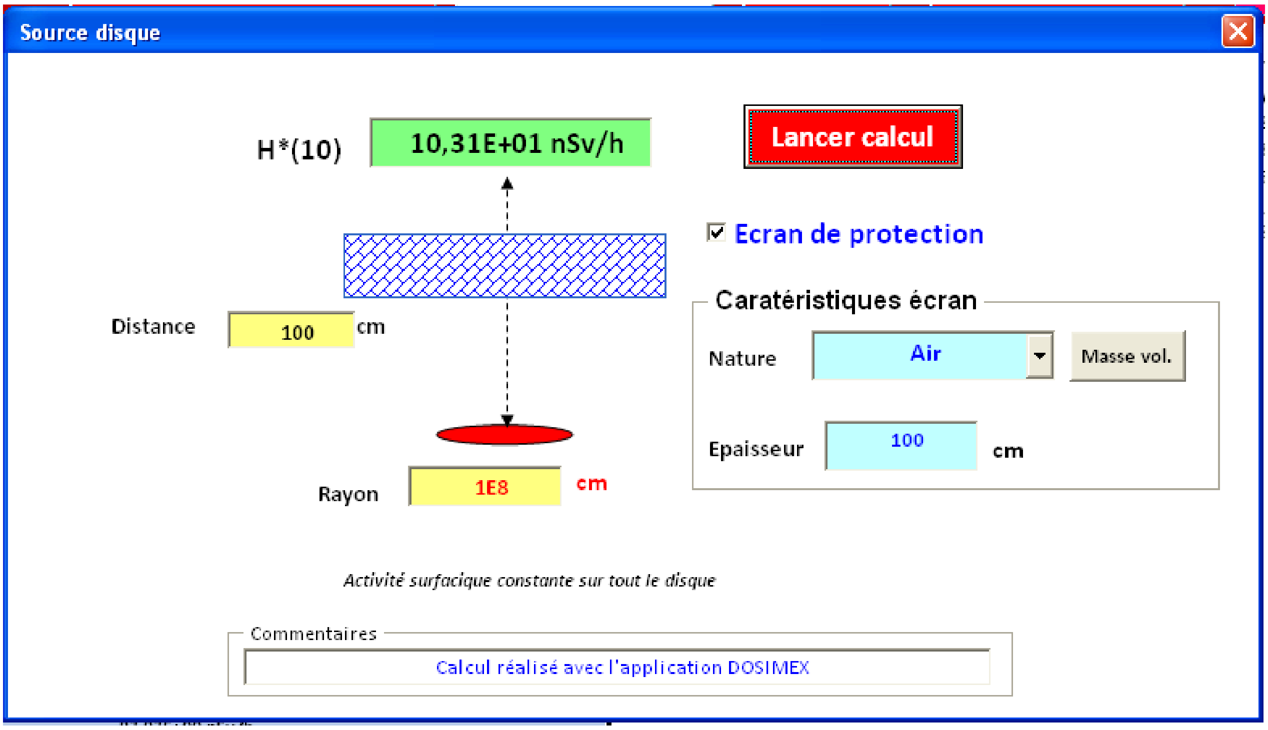


Figure 17: DOSIMEX-GX dialog box for calculation of the surface activity-dose rate conversion coefficient at 1m (1 Bq.cm-2 in Co 60, R = 108 cm)

Calculations performed with DOSIMEX-GX, with an air screen of 1 m and for radii between 104 and 108 cm ((1000 km) again display stabilized values:

Radionuclide	Federal Guidance	DOSIMEX-GX
Cesium 137	21 $nSv.h^{-1}.Bq^{-1}.cm^{2}$	27 $nSv.h^{-1}.Bq^{-1}.cm^{2}$
Cobalt60	87 $nSv.h^{-1}.Bq^{-1}.cm^{2}$	103 $nSv.h^{-1}.Bq^{-1}.cm^{2}$

Table 17: surface activity conversion coefficients - dose rate at 1 m

SUMMARY OF SCENARIO 7 RESULTS

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 10%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 11% (default method: 46%)**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 16%. (default method: 64%)**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 4%**

The approach proposed by DOSIMEX-GX thus ensures the user to obtain admissible results, whatever the dimensions of the source, without on the one hand having to worry about knowing if the mesh is adapted or not to these dimensions, and on the other hand having to choose between one method or another.

SCENARIO 8 : LARGE PARALLELEPIPED GEOMETRY WITH AND WITHOUT SCREEN

This scenario allows to validate the parallelepiped geometry introduced with version 1.3.1. With a large matrix (lpm of2.8 cm at 1836 keV vs 100 cm)

- Source matrix: $100\,\text{cm} \times 100\,\text{cm} \times 50\,\text{cm}$ iron
- Radionuclide: Yttrium 88, 1TBq
- Detector distances: 100 cm relative to the surface
- Case 1: without screen
- Case 2: with screen: 20 cm of concrete

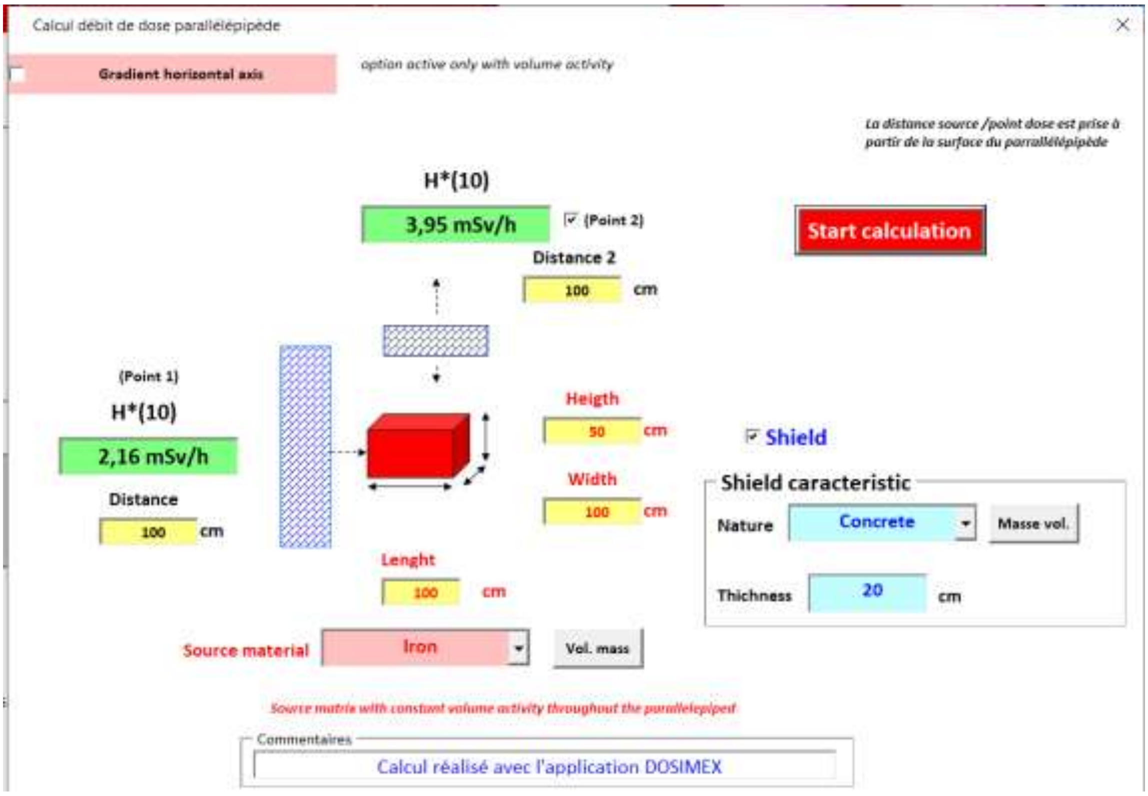


Figure 18: DOSIMEX-GX dialog box for parallelepiped source geometry

		Scenario 8: iron parallelepiped + Y 88 without screen H * (10) in mSv / h					Relative deviations vs MCNPX			
		Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Without screen	Pt1	13.43	12	13.17	13.8	13.68	-1.8%	-12.3%	-3.7%	0.9%
	Pt2	25.9	22.2	24.44	26.4	25.6	1.2%	-13.3%	-4.5%	3.1%
				Mean square deviation			2%	13%	4%	2%

		Scenario 8: iron + Y 88 parallelepiped with H * screen (10) in mSv / h					Relative deviations vs MCNPX			
		Dosimex-GX 2.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
With screen 20 cm concrete	Pt1	2.16	2.21	2.8	2.6	2.6	-20%	-15.0%	7.7%	0.0%
	Pt2	3.95	3.9	5.02	4.4	4.24	-5%	-8.0%	18.4%	3.8%
				Mean square deviation			20%	12%	14%	3%

SUMMARY OF SCENARIO 8 RESULTS

WITHOUT SCREEN

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 2%**
- **Between MICROSHIELD® V.9 and MCNPX mean deviation 13%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 4%.**
- **BetweenRayXpert © 1.4 TM *and* MCNPX :: average deviation 2%**

SUMMARY OF SCENARIO 8 RESULTS

WITH SCREEN

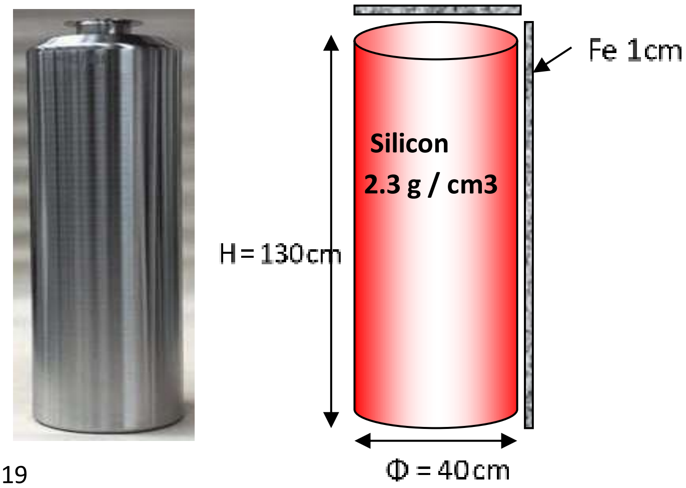
- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 15%**
- **Between MICROSHIELD® V.9 and MCNPX mean deviation 12%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 14%.**
- **BetweenRayXpert © 1.4 TM *and* MCNPX :: average deviation 3%**

Here we find a slight overestimation in the case with screen due to Build-up

SCENARIO 9 : MULTIRADIONUCLIDE MODELING

Scenario.9.1 SOLID VITRIFIED WASTE CONTAINER (CSDV)

A simplified modeling of a vitrified waste source container CSDV was carried out according to the diagram below:



This container was loaded with the following activities:

- Cs 137: 2E16 Bq
- Cs 134: 5E15 Bq
- Rh 106: 2E15 Bq

Figure 19

Air dose equivalent rates have been calculated at 1 m of the container (Si) on the vertical axis and on the transverse median axis, successively without protection then with a screen of 15 cm lead :

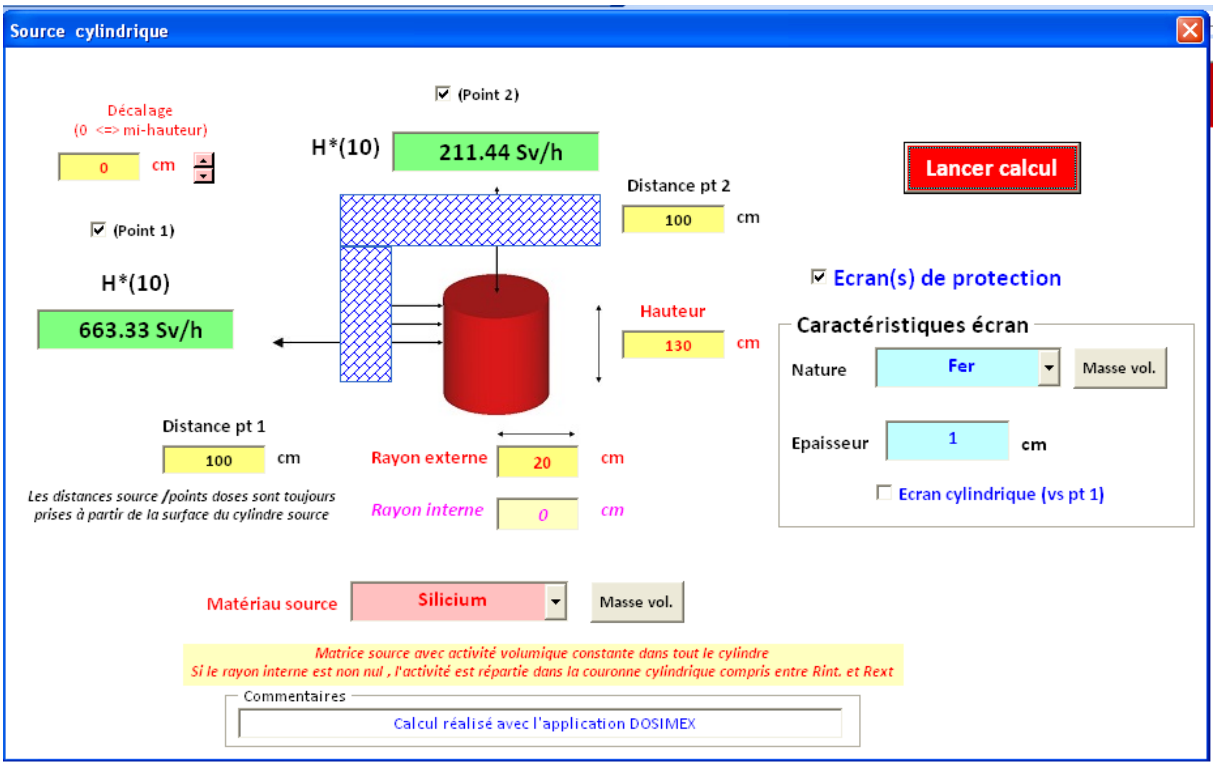


Figure 20: DOSIMEX-GX dialog for CSDV without screen

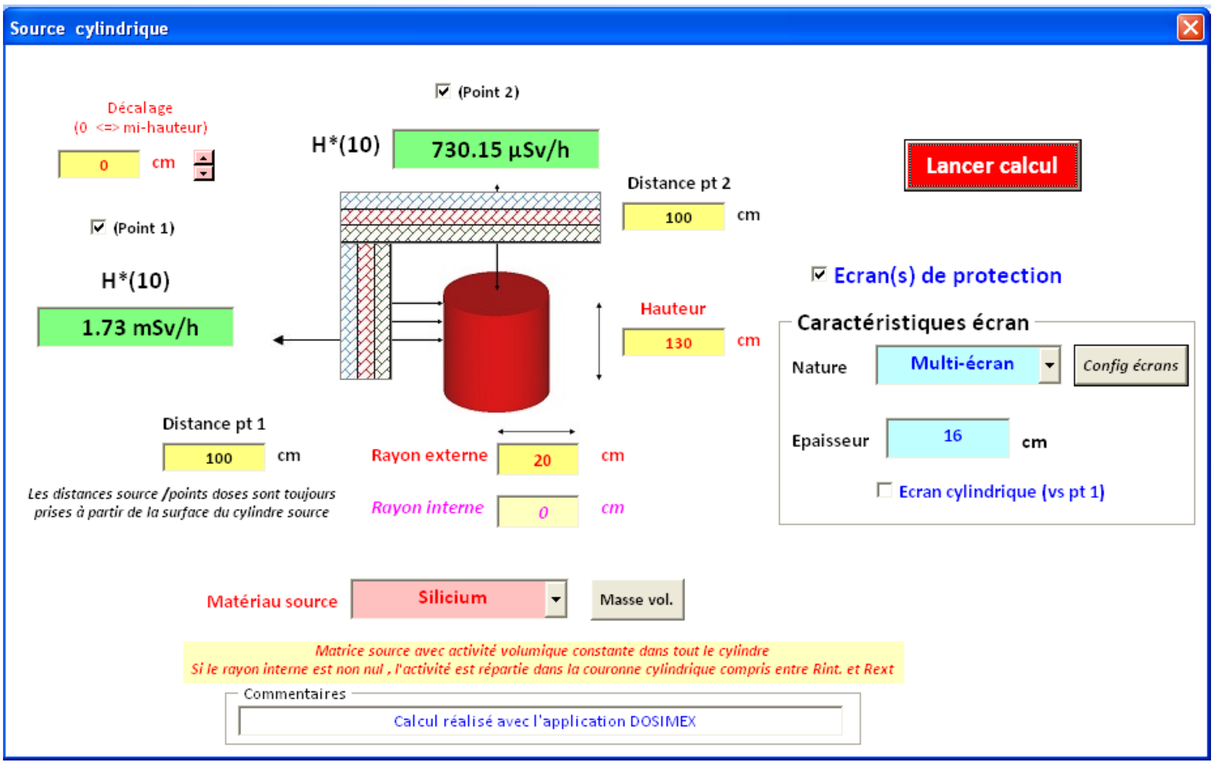


Figure 21: DOSIMEX-GX dialog for CSDV with lead screen

The case with the lead screen was modeled using the multi-screen option: 1 cm iron and 15 cm lead

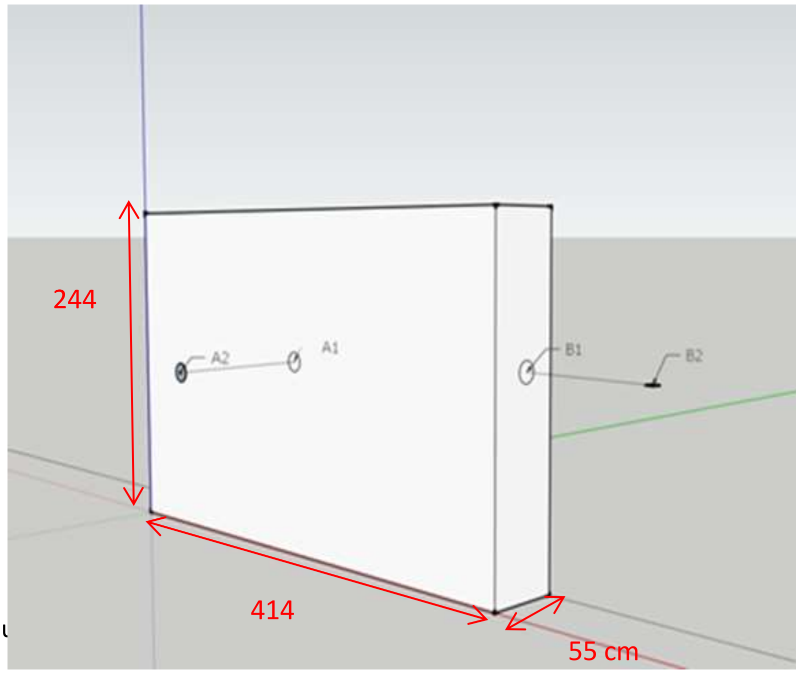
	Scenario 9 CSDV						Relative deviations vs MCNPX			
	RN	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Without protection	Pt 1	663 Sv / h	544 Sv / h	748 Sv / h	465 Sv / h	449 Sv / h	48%	21%	67%	4%
	Pt2	211 Sv / h	196 Sv / h	246 Sv / h	168 Sv / h	164 Sv / h	29%	20%	50%	2%
With protection 15 cm Pb	Pt 1	1.73 mSv / h	1.00 mSv / h	1.26 mSv / h	1.30 mSv / h	1.27 mSv / h	36%	-21%	-1%	2%
	Pt2	0.73 mSv / h	0.54 mSv / h	1.02 mSv / h	0.50 mSv / h	0.48 mSv / h	52%	13%	113%	4%
				Mean square deviation			42%	19%	70%	3%

Table 19

Scenario.9.2 CONCRETE WALL CONTAMINATION (ULYSSE REACTOR)

As part of the MNE master thesis " *Dose rate calculation for future ULYSSE reactor dismantling »* realized by Slavica Ivanovic (CEA / INSTN / SAclay, September 2014), a particular case was the subject of a more complete benchmarking

The source is a concrete wall irradiated by neutron activation:



The source term u

Co60	Eu152	Eu154	Ba133
3.955E + 08 Bq	5.02E + 10 Bq	2.23E + 09 Bq	4.22E + 10 Bq

Table 20

The calculations were carried out on the assumption of homogeneous contamination (for the more realistic case with exponential gradient see § I.10.1) with two different concrete densities:

- Light concrete 2.3 g / cm3
- Heavy concrete: 3.5 g / cm3

The calculation distances are 1 cm (points A1 and B1) and 100 cm (points A2 and B2)

Scenario 9 Heavy concrete case (3.5 g / cm3) H * (10) (µSv / h)						Relative deviations vs MCNPX			
RN	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Point A1	967	1131	938	923	1055	-8.3%	7.2%	-11.1%	-12.5%
Point A2	481	541	467	480	526	-8.6%	2.9%	-11.2%	-8.7%
Point B1	941	809	892	1075	979	-3.9%	-17.4%	-8.9%	9.8%
Point B2	123	145	118	135	136	-9.6%	6.6%	-13.2%	-0.7%
			Mean square deviation			8%	10%	11%	9%

Table 21

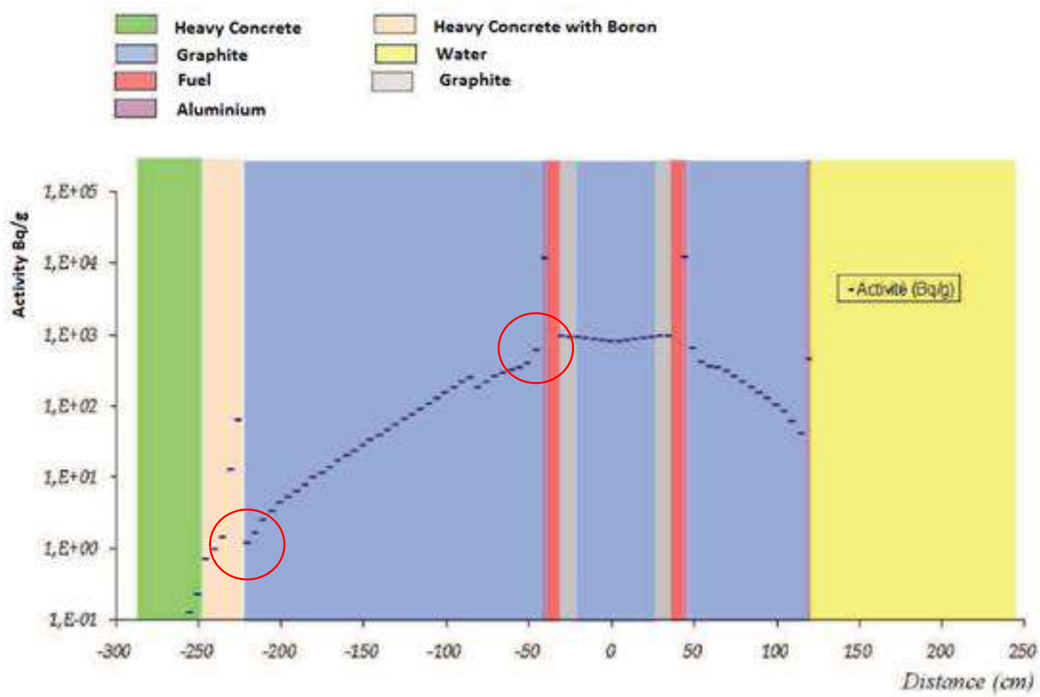
Scenario 9 Light concrete case (2.3 g / cm3) H * (10) (µSv / h)						Relative deviations vs MCNPX			
RN	Dosimex-GX 3.0	MicroshieldTM (Grove)	Mercurad	RayXpert © 1.4	MCNP	Dosimex	µShield	Mercurad	RayXpert
Point A1	1450	1729	1238	1493	1589	-8.7%	8.8%	-22.1%	-6.0%
Point A2	710	813	627	740	791	-10.2%	2.8%	-20.7%	-6.4%
Point B1	1390	1392	1196	1300	1480	-6.1%	-5.9%	-19.3%	-12.2%
Point B2	179	208	158	193	199	-10.1%	4.5%	-20.6%	-3.0%
			Mean square deviation			9%	6%	21%	8%

Table 22

Scenario.9.3 VALIDATION OF ACTIVITY GRADIENT OPTION (ADDED WITH THE VERSION 1.4)

The activity profile for parallelepiped geometry could be tested as part of the dissertation " Dose rate calculation for future ULYSSE reactor dismantling "(Slavica Ivanovic,*CEA / INSTN / SAclay, September 2014*)

This scenario takes up the characteristics of the light concrete wall, no longer considering a constant volume activity but an exponential activity gradient generated by a neutron activation phenomenon. Only the Mercure code has this option, which has enabled this Dosiemx-G option to be verified. the calculation is carried out on point A2 on the maximum activity side and the minimum activity side.



Graph 12

The dose rate calculation was validated using the Mercury Code with the results below:

	Coded	maximum	Minimum
Density: 3.5 g / cm3 Point A1	Mercury	926 µSv / h	14 µSv / h
	Dosimex	905 µSv / h	12 µSv / h
	Relative gap	-2%	-12%

Table 23

This result shows that this option of Dosimex-GX3.0 available on parallelepiped geometry is admissible.

SUMMARY OF SCENARIO 9 RESULTS

CSDV

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 45%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 19%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 70%.**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 3%**

NORMAL CONCRETE (2.3 g / cm3)

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 8%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 10%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 11%.**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 9%**

HEAVY CONCRETE (3.5 g / cm3)

- **Between DOSIMEX-GX 3.0 and MCNPX : average deviation 8%**
- **Between MICROSHIELD® V.9 and MCNPX average deviation 6%**
- **BetweenMERCURADTM *and* MCNPX :: average deviation 21%.**
- **BetweenRayXpert © 1.4 ™ *and* MCNPX :: average deviation 6%**

Despite the large source dimensions, there is good consistency between the 4 codes here. It will be noted that the values of dose rates are, as expected, in the inverse ratio of the densities of heavy and light concrete) with an mean of 1.5.

2: COMPARISONS DOSIMEX-GX VS RAYXPERT

SCENARIO 10 : "SKYSHINE" VALIDATION
Scenario.10.1 SKYSHINE VS VARIOUS MATERIALS)

The skyshine calculated analytically with Dosimex (differential effective sections of Klein and Nishina, attenuation in the screen, etc.) was compared with RayXpert® software from TRAD (see http://www.trad.fr/RayXpert-R.html)

Scenario:

- Radionuclides: Cs 137 then Co 60
- Mono E 100 keV source
- Activity 1 GBQ Bq
- Nature screens: water, aluminum, concrete, lead
- Distance to screen source: 45 cm
- Screen distance (to the right of the source) - dose point:63 cm
- Angle: 45 °

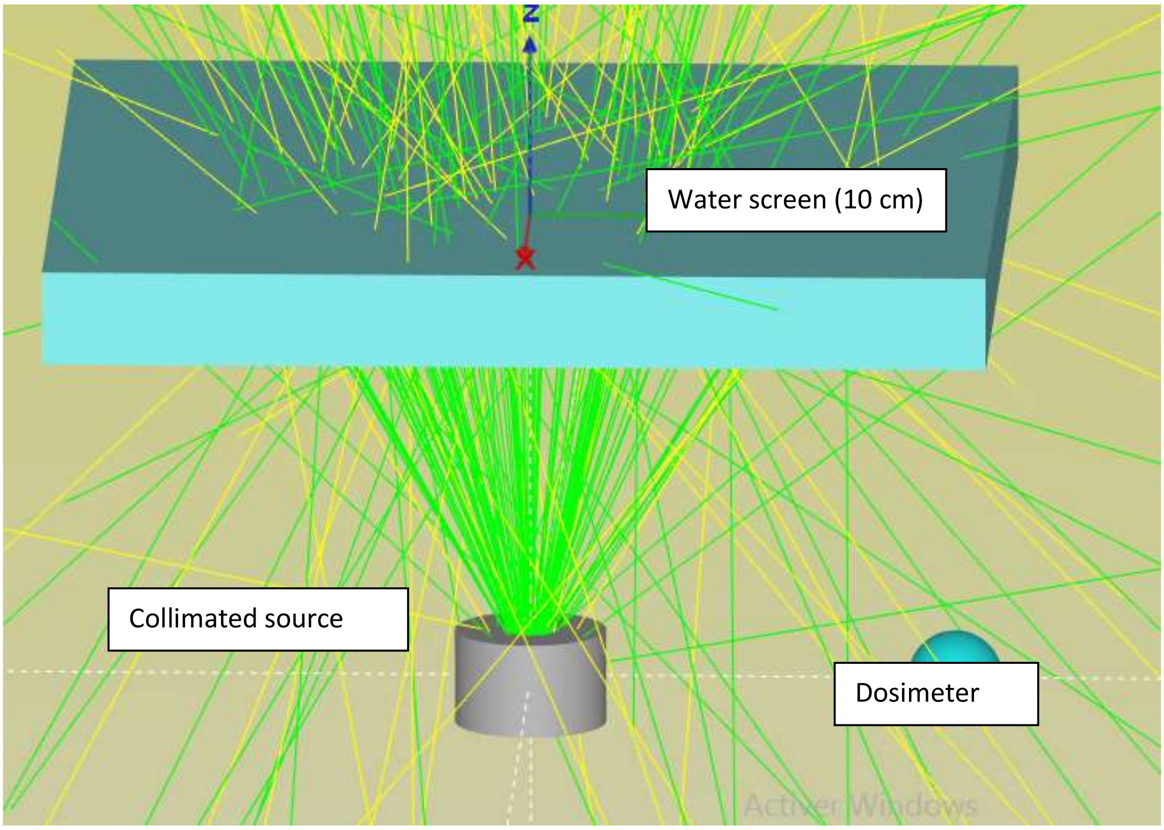


Figure 23: RayXpert tracking - water screen (green: gamma photons, yellow: X bremsstrahlung)

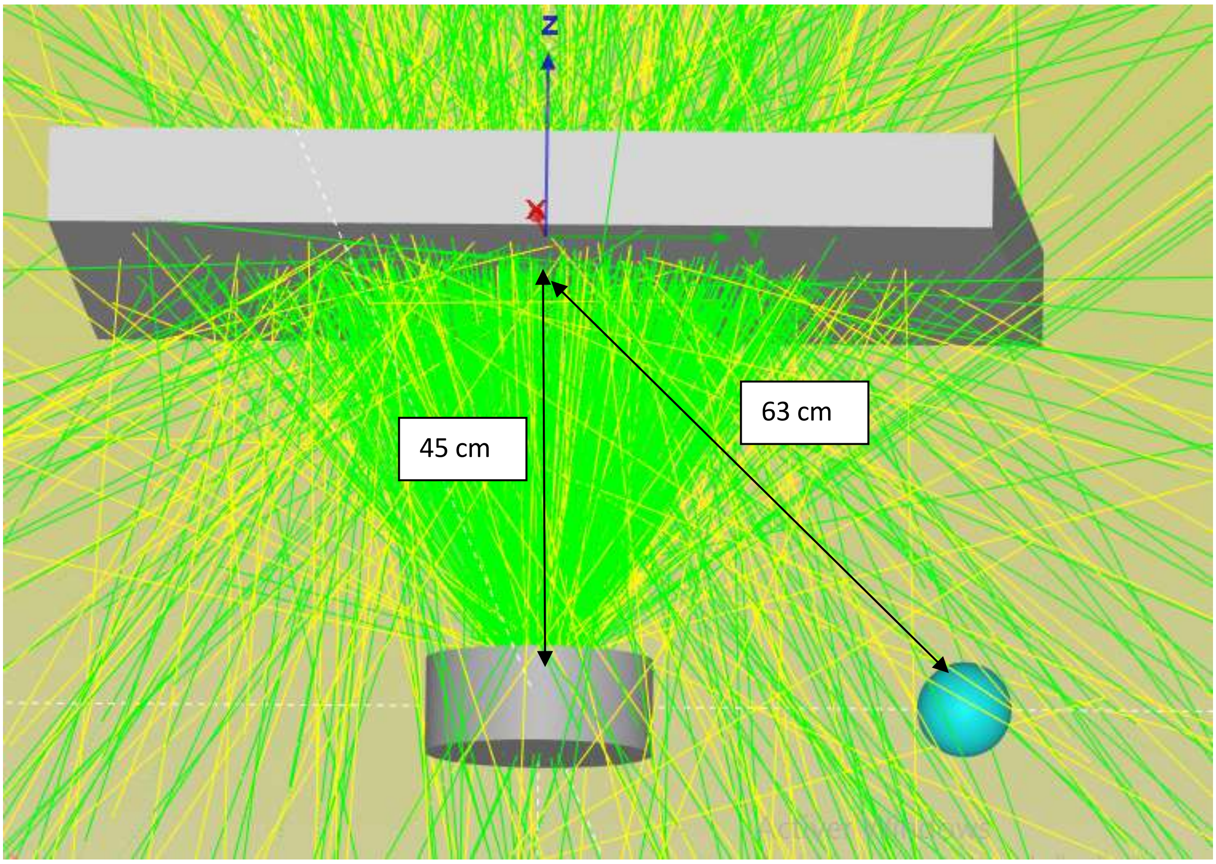
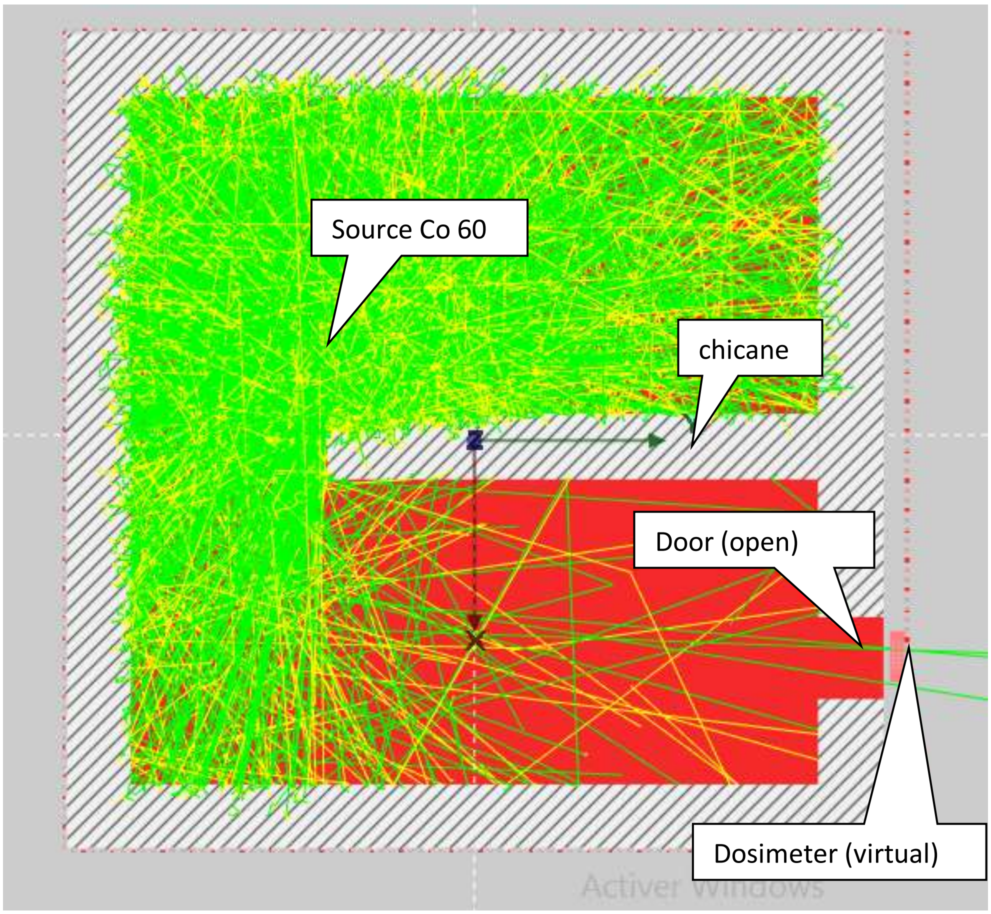


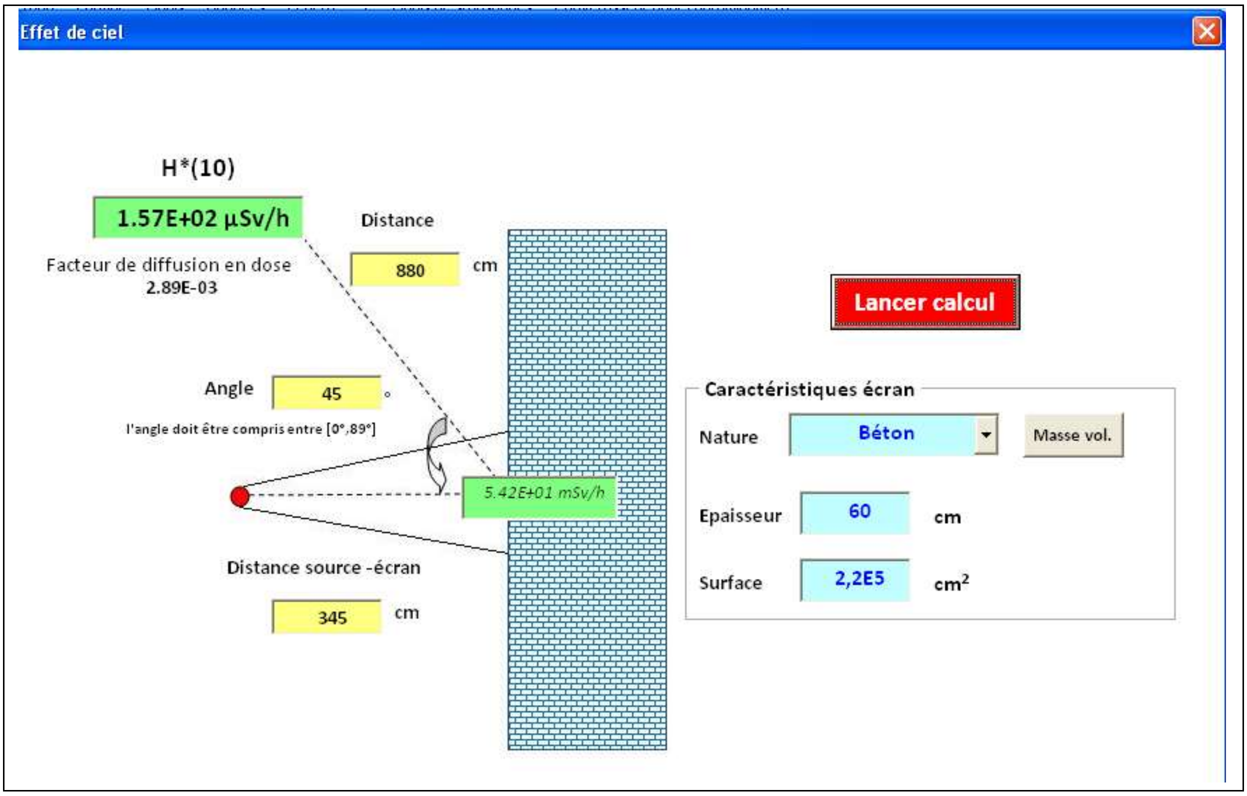
Figure 23: RayXpert tracking - lead screen (green: gamma photons, yellow: X bremsstrahlung)

	Scenario 11: skyshine			
	Screen	**DOSIMEX-GX**	**RayXpert®**	***Relative gap***
Cs 137	**Water**	**3.67 µSv / h**	**3.62 µSv / h**	**1%**
	Aluminum	**4.37 µSv / h**	**4.51 µSv / h**	**-3%**
	Concrete	**4.18 µSv / h**	**4.28 µSv / h**	**-2%**
	Lead	**0.52 µSv / h**	**0.43 µSv / h**	**21%**
Co 60	**Water**	**6.72 µSv / h**	**6.47 µSv / h**	**4%**
	Aluminum	**9.01 µSv / h**	**9.22 µSv / h**	**-2%**
	Concrete	**8.61 µSv / h**	**9.42 µSv / h**	**-9%**
	Lead	**1.00 µSv / h**	**1.01 µSv / h**	**1%**
			EQM	**8%**

Table 24

Scenario.10.2 CALCULATION OF SKYSHINE IN A CHICANE OF RADIOGRAPHY BLOCKAUS





Chicane calculation	DOSIMEX-GX	RayXpert®	*Relative gap*
Co 60 50 Ci	231 µSv / h	236 µSv / h	-2%
Ir 192 120 Ci	488 µSv / h	506 µSv / h	-4%
Se 75 80 Ci	200 µSv / h	206 µSv / h	-3%
		EQM	3%

SCENARIO 11 : "BRAKING RADIATION" VALIDATION

A) VALIDATION VS RAYXPERT

The braking radiation for the option implemented in Dosimex-GX allows to calculate the DED due to the braking radiation generated by the electrons emitted from a point beta source. The Betas are stopped by an absorbent of minimum dimension equal to the range of the electrons in this medium.

For our study we used Oxygen 15, beta + emitter with Qmax = 1735keV, without taking into account the annihilation of positrons after their stop (possible option in Dosimex-GX)

- Activity: 1 GBq

- Absorbents:
  - Water 1Cm
  - Aluminum 4 mm
  - Iron 1.2mm
  - Lead 1 mm

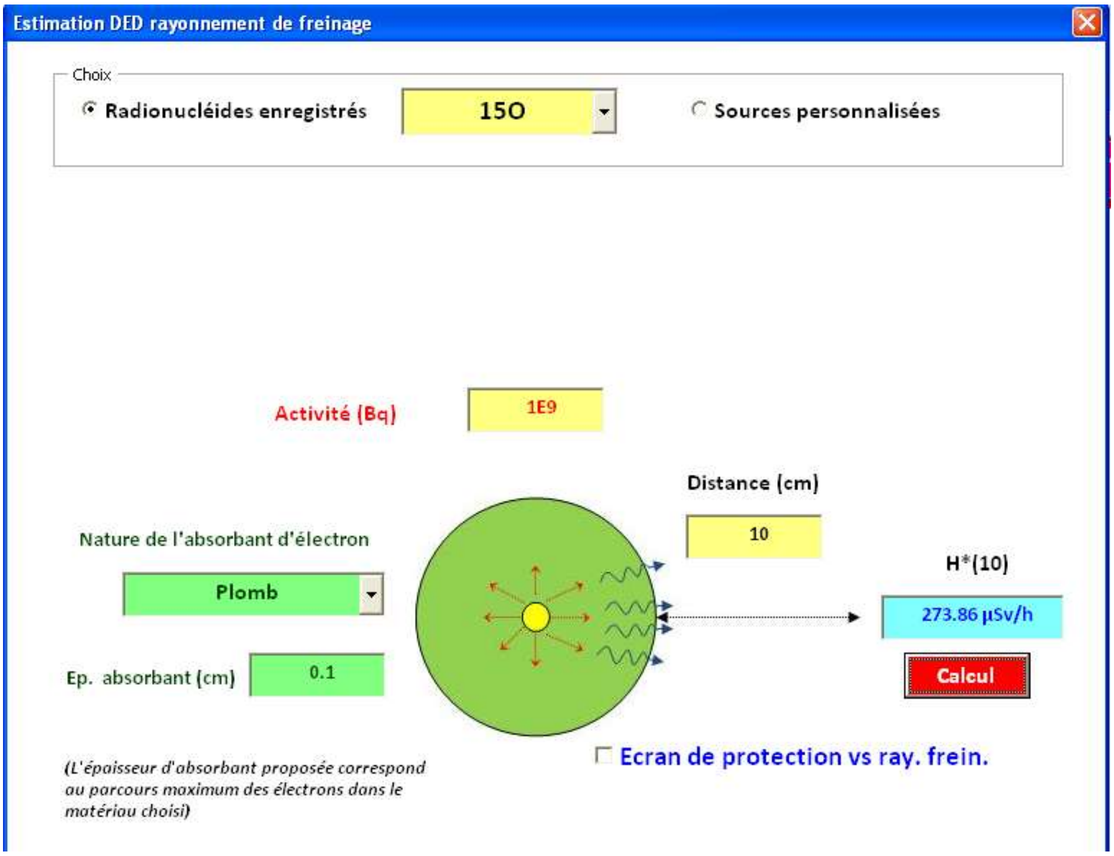


Figure 25: Dosimex-GX 3.0 result with the water absorbent

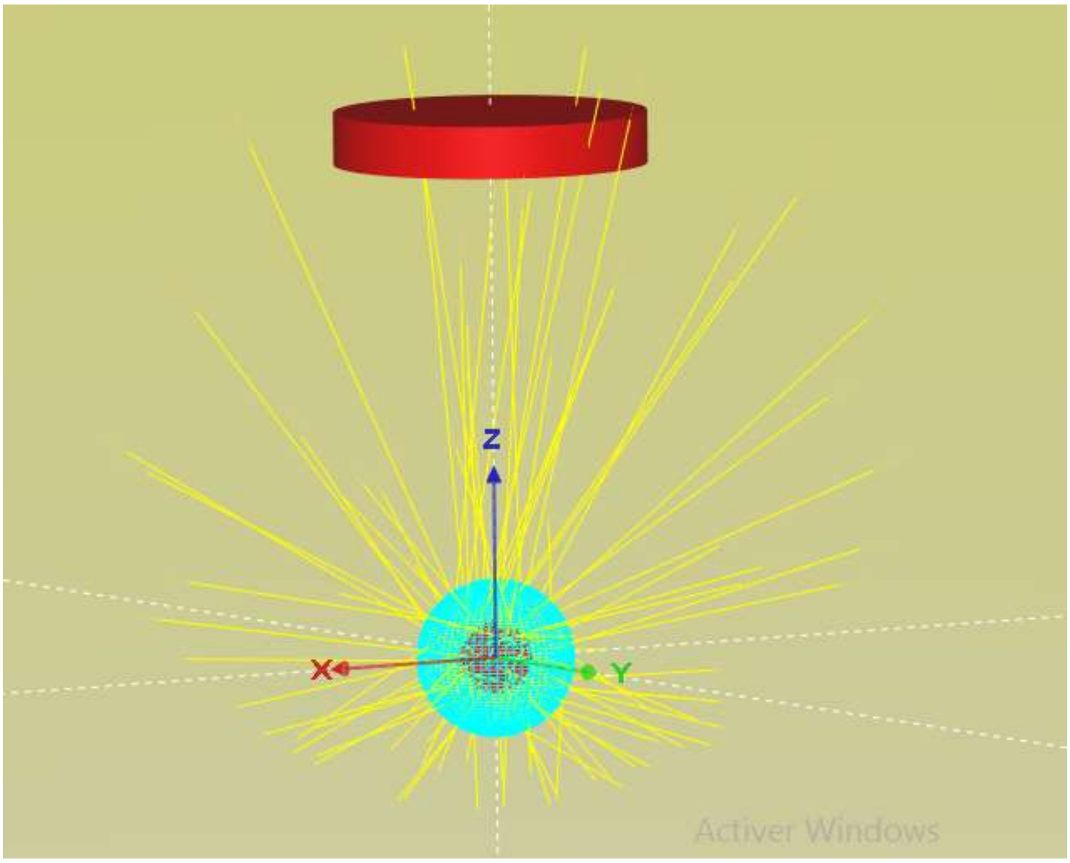


Figure 26: RayXpert © tracking: braking radiation in water

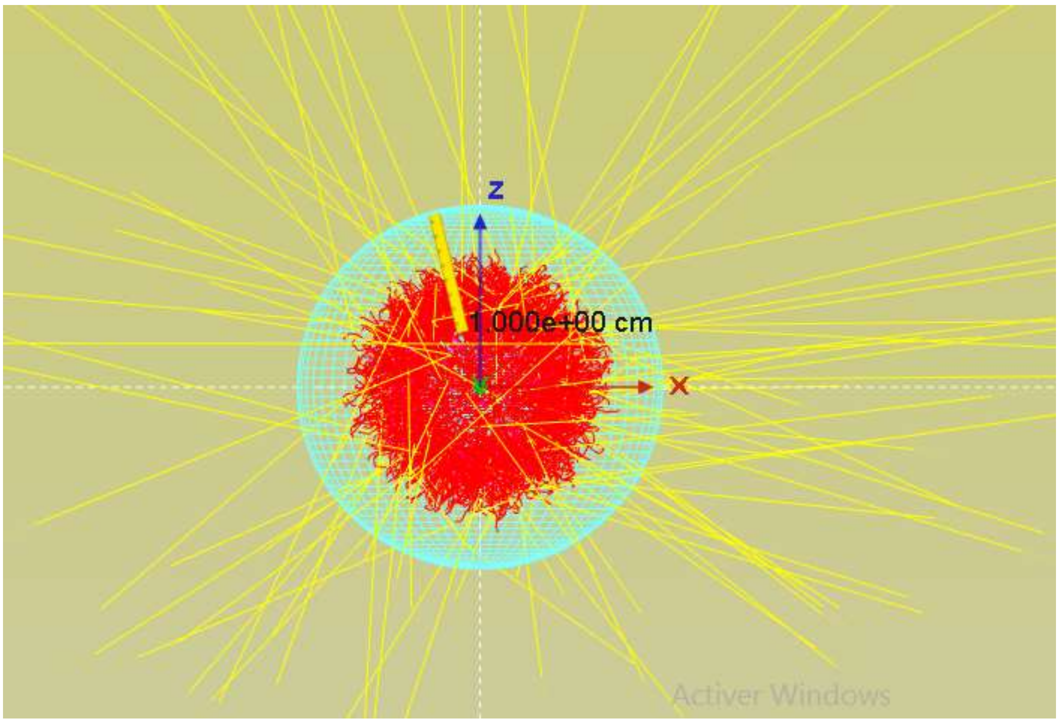


Figure 26: RayXpert © tracking: zoom on the source (red: electrons, yellow: RX)

	SC 11: braking radiation with O15; 1 GBq; d =5 cm		
Absorbent	Dosimex	RayXpert	*Relative gap*
Water (1 cm)	27 µSv / h	43 µSv / h	*-38%*
Lead (1 mm)	274 µSv / h	210 µSv / h	*31%*
Iron 1.2 mm	128 µSv / h	112 µSv / h	*14%*
Alu (4 mm)	53 µSv / h	73 µSv / h	*-28%*
	Mean square deviation		29%

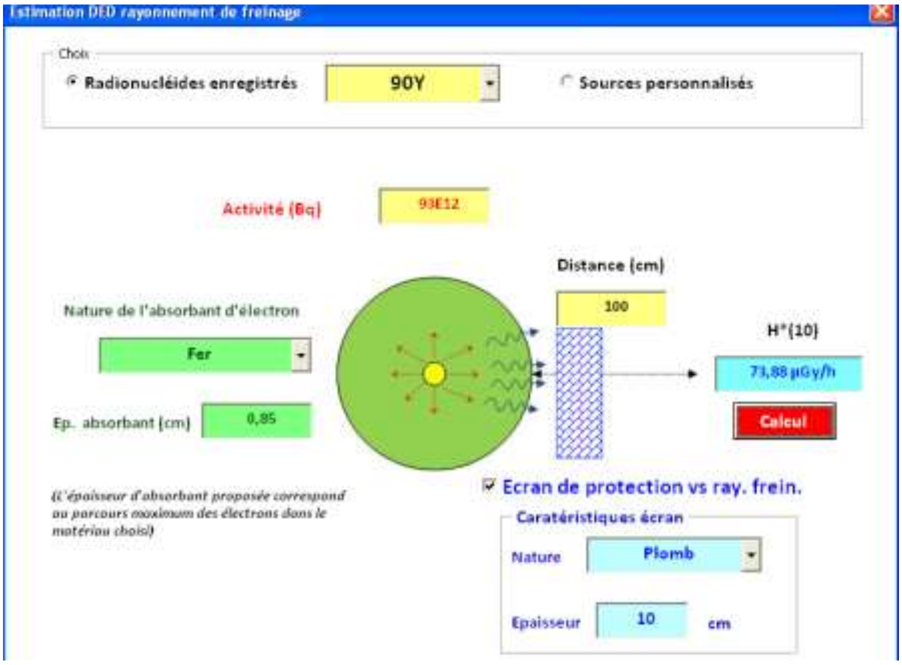
Table 25

Given the complexity of the calculations: transformation of a continuous electron spectrum to a continuous spectrum in RX + self-attenuation of the latter in the absorbent, these results are more than acceptable, they are unexpected!

B) Validation vs measurement on source Y 90 (Qmax 2275 keV)

Study of a concrete case (AREVA NC the hague)

- Radionuclide: Y 90
- Activity: 93TBQ
- Absorbent: 8.5 mmm steel casing
- Biological protection: 10 cm Pb
- Distance 100 cm



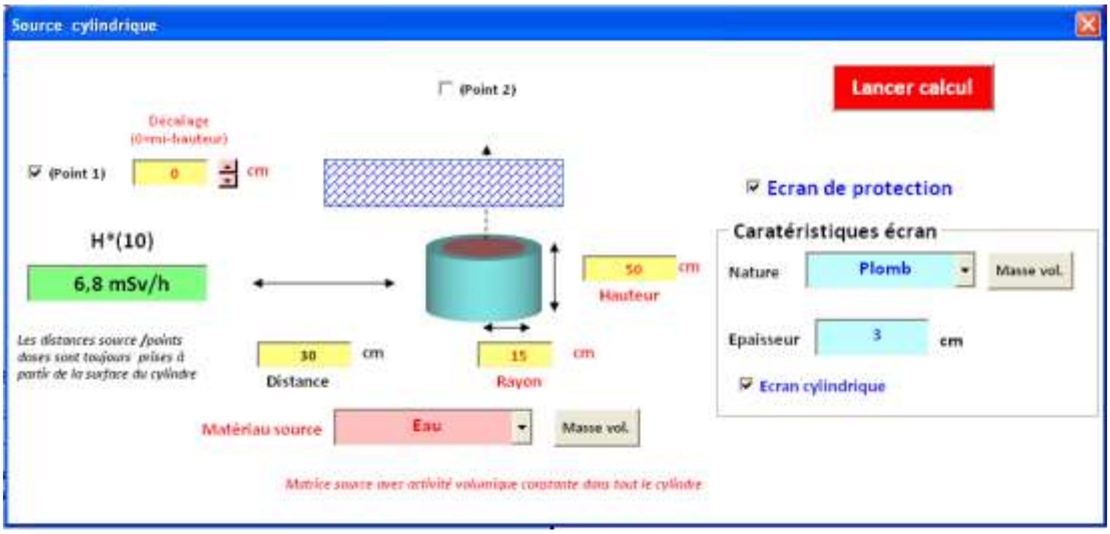
- ✓ **Measured value: 60 µSv / h at 1 m**
- ✓ **Value calculated by Dosimex-GX 2.0: 73 µSv / h at 1 m**

SCENARIO 12 : CYLINDRICAL SCREEN. DOSIMEX-GX 2.1 OPTION APRIL 2017

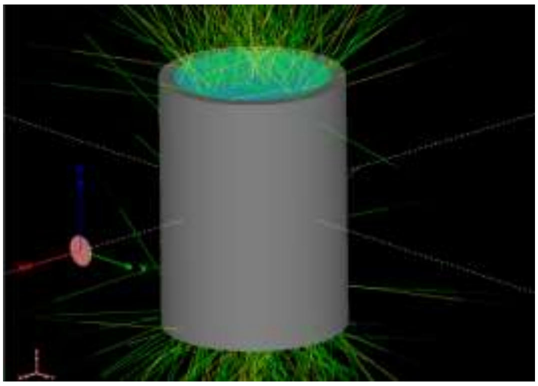
Scenario 1: industrial piping full cylindrical matrix

- Cylindrical source
- Ray 15 cm (Rint = 0)
- Height 50 cm
- Radionuclide Cs 137
- Cylindrical screen (pipe): 3 cm Pb
- Activity 1 TBq
- Distance: 30 cm
- Configuration 1: air matrix
- Configuration 2: water matrix

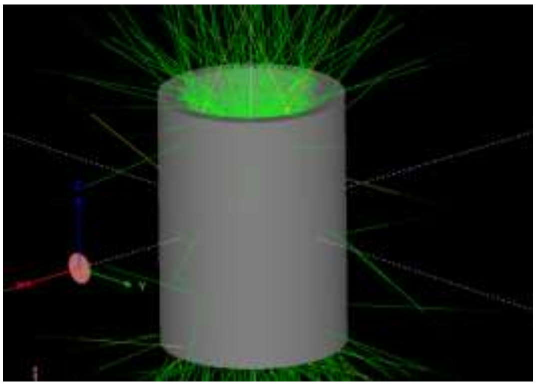
Dosimex calculation



RayXpert calculation



Air Matrix



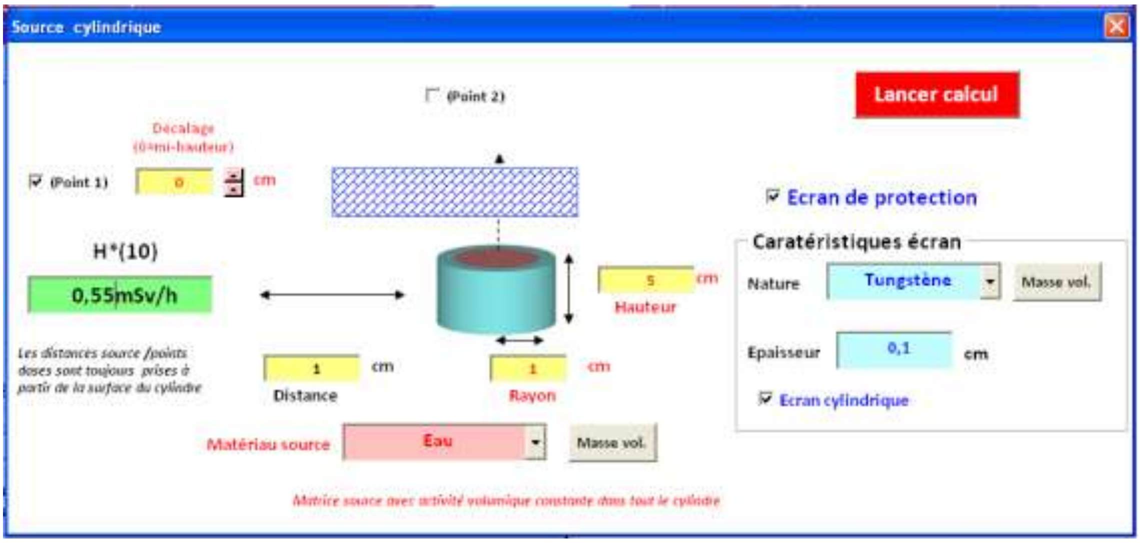
Water matrix

Pipe thickness 3 cm Lead H = 50 cm, R = 15 cm water matrix 1TBq Cs 137 distance 30 cm			
Configuration	**Dosimex-GX 2.1**	**RayXpert 1.5**	**Relative gap**
Air	**12.2 mSv / h**	**13 mSv / h**	**-6%**
Water	**6.8 mSv / h**	**6.4 mSv / h**	**6%**

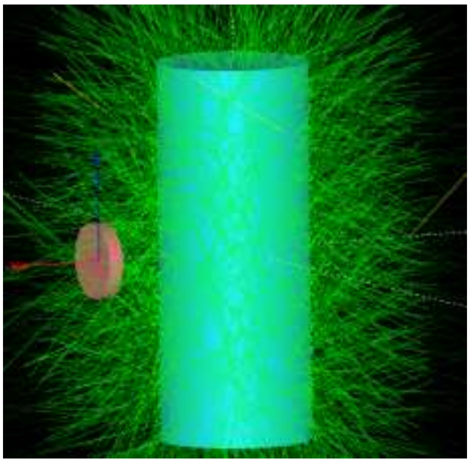
Scenario 2: Technetium syringe. Evaluation of the effectiveness of a cylindrical syringe guard

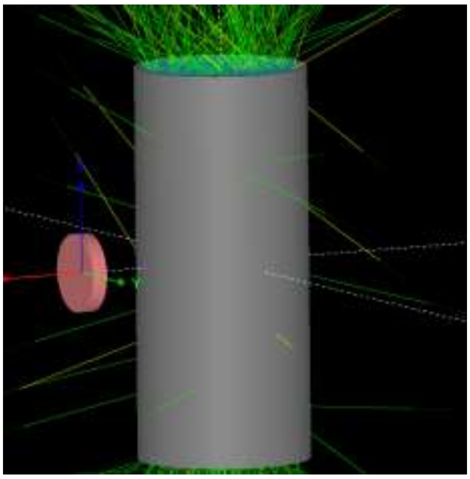
- Cylindrical source
- Ray 1 cm
- Height 5 cm
- Radionuclide TC 99m
- Activity 800 MBq
- Distances: 1cm and0.1 cm
- Configuration 1: without screen
- Configuration 2: with syringe guard 1 mm tungsten

Dosimex calculation1 cm with syringe guard



RayXpert calculation





Without syringe guard **With syringe guard (1 mm W)**

TC 99m syringe 800 MBq d = 1 cm			
Configuration	**Dosimex-GX 3.0**	**RayXpert 1.5**	**Relative gap**
Without syringe guard	**35 mSv / h**	**33 mSv / h**	**7.3%**
With syringe guard (1 mm W)	**0.387 mSv / h**	**0.475 mSv / h**	**25.7%**
Mitigation factor	***59***	***69***	**-14.6%**

Syringe TC 99m 800 MBq d = 0.1 cm			
Configuration	**Dosimex-GX 2.1**	**RayXpert 1.5**	**Relative gap**
Without syringe guard	**83.9 mSv / h**	**79.8 mSv / h**	**5.1%**
With syringe guard (1 mm W)	**0.783 mSv / h**	**0.897 mSv / h**	**-12.7%**
Mitigation factor	***107***	***89***	**20.4%**

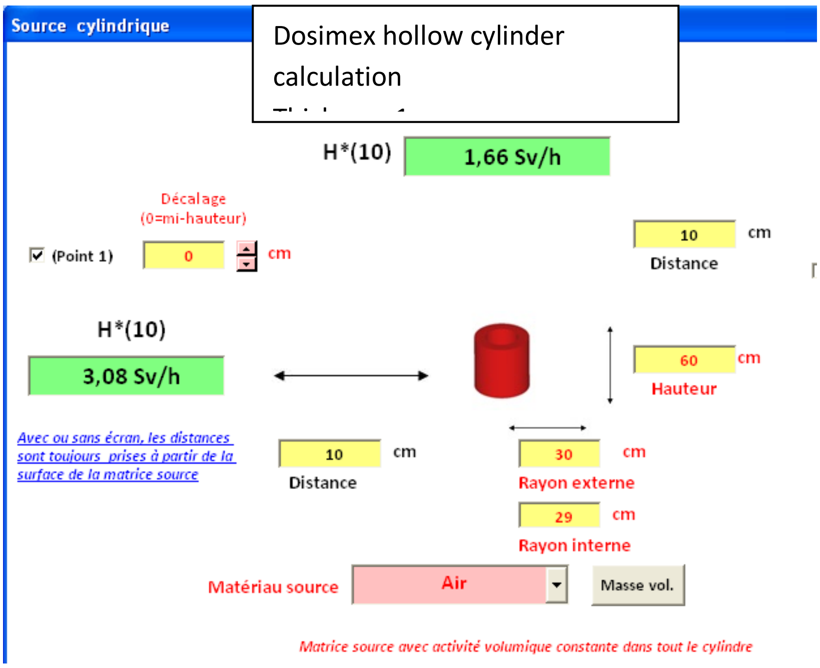
SCENARIO 13 : HOLLOW CYLINDRICAL MATRIX.

A. MATRIX HOLLOW CYLINDER, AIR MATERIAL

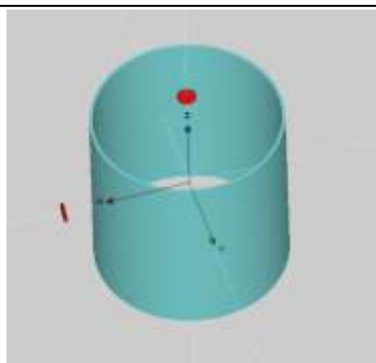
This scenario with a little absorbent material allows to judge the quality of the geometric calculation of the hollow cylinder

- Air material matrix
- H = 60 cm
- Rext = 30 cm
- 1TBq Cobalt 60
- Dosimeter distance point 1 and point 2:10 cm

Dosimex hollow cylinder calculation



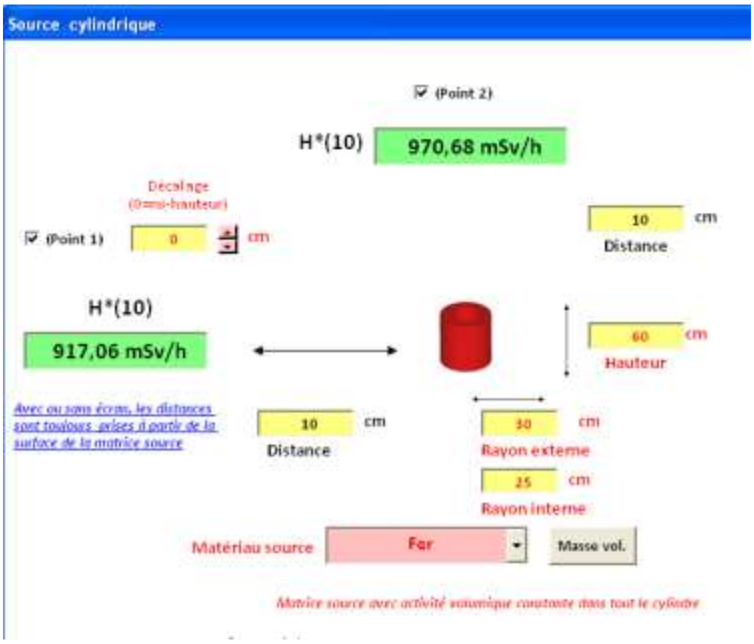
RayXpert hollow cylinder calculation

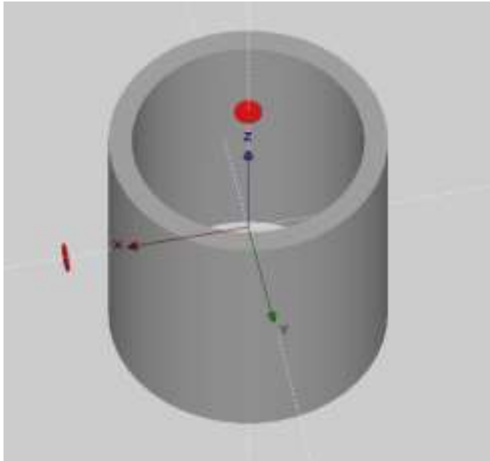


	Air cylinder H = 60 cm, Co 60 1TBq, d = 10 cm					
	Dosimex-GX 2.1		**RayXpert**		***Relative deviations***	
Thickness	**Point 1**	**Point 2**	**Point 1**	**Point 2**	***Point 1***	***Point 2***
e = 1 cm	**3.1 Sv / h**	**1.7 Sv / h**	**3 Sv / h**	**1.7 Sv / h**	***3%***	***-3%***
e = 5 cm	**2.8 Sv / h**	**1.8 Sv / h**	**2.9 Sv / h**	**1.9 Sv / h**	***-1%***	***-3%***
e = 10 cm	**2.6 Sv / h**	**2 Sv / h**	**2.7 Sv / h**	**2 Sv / h**	***-1%***	***-4%***
e = 20 cm	**2.4 Sv / h**	**2.4 Sv / h**	**2.4 Sv / h**	**2.4 Sv / h**	***0%***	***-4%***
Full matrix	**2.4 Sv / h**	**2.6 Sv / h**	**2.4 Sv / h**	**2.7 Sv / h**	***-1%***	***-3%***

B. MATRIX HOLLOW CYLINDER, IRON MATERIAL

The calculation with the iron material makes it possible to qualify the calculation of autoabsorption in the hollowed out matrix





	Cylinder Iron H = 60 cm, Co 60 1TBq, d = 10 cm					
	Dosimex-GX 2.1		RayXpert		*Relative deviations*	
Thickness	**Point 1**	**Point 2**	**Point 1**	**Point 2**	***Point 1***	***Point 2***
e = 5 cm	0.91 Sv / h	0.97 Sv / h	0.948 Sv / h	1.09 Sv / h	*-4%*	*-11%*
e = 10 cm	0.52 Sv / h	0.62 Sv / h	0.556 Sv / h	0.732 Sv / h	*-6%*	*-15%*

SCENARIO 14 : INTERNAL CONTAMINATED PRIMARY REACTOR

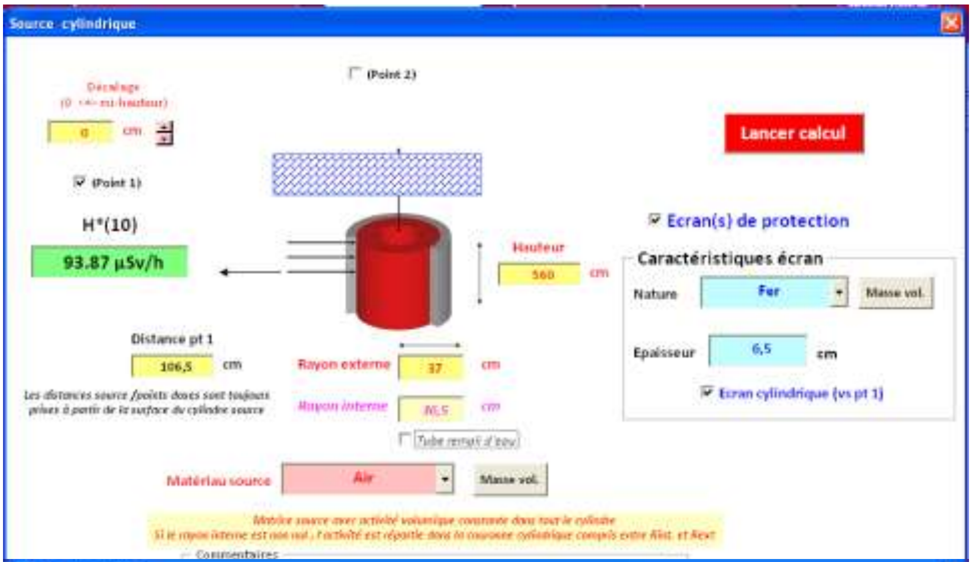
The real case treated here is to compare, in an ALARA approach, the DED generated by a reactor primary pipe contaminated on the internal surface with and without water

The pipe dimensions are (REP 1300 MW):

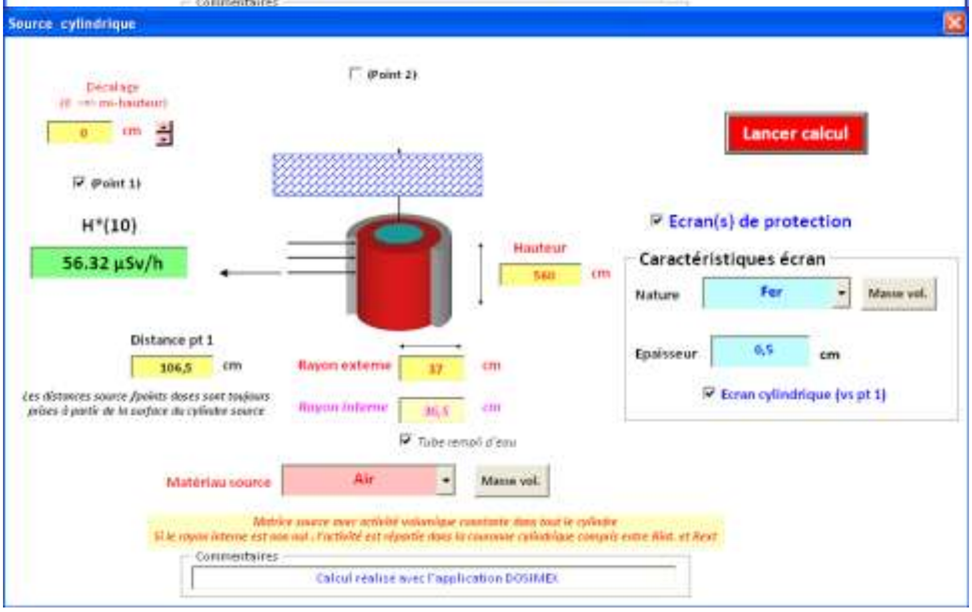
- Length 560 cm
- Inner diameter = 74 cm
- Thickness = 6.5 cm of steel
- DED calculated at 1 m then in contact with the surface of the pipe
- internal surface contamination: Co 60 54 kBq / cm2 (1.41 E10 Bq)

AT CALCULATION A 100 CM

Result with Dosimex –GX 3.0
Empty pipe: 93.9 µSv / h

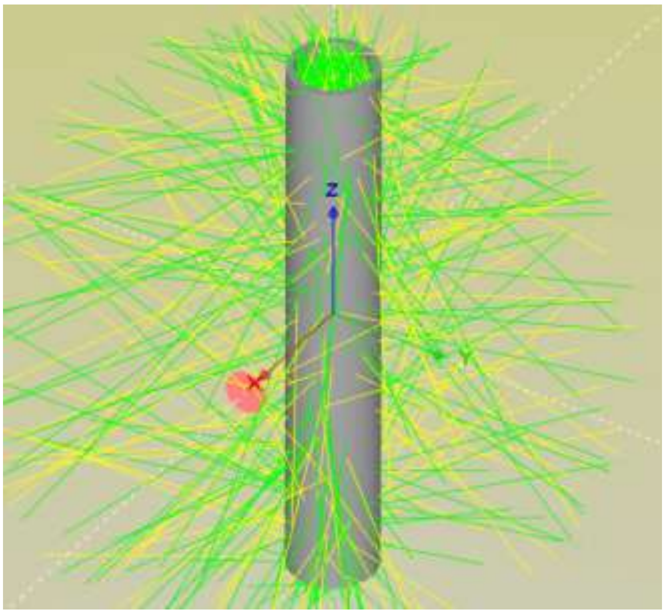


Result with Dosimex –GX 3.0
Full pipe: 56.3 µSv / h

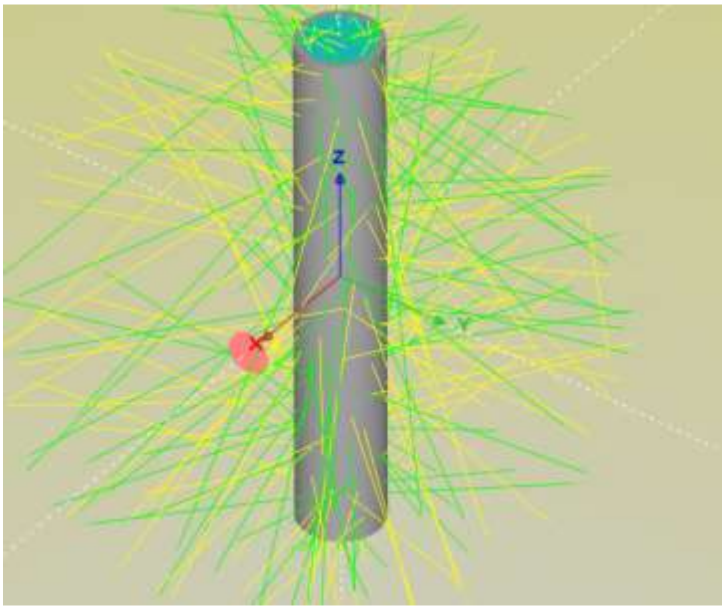


Calculations with RayXpert:

Empty pipe

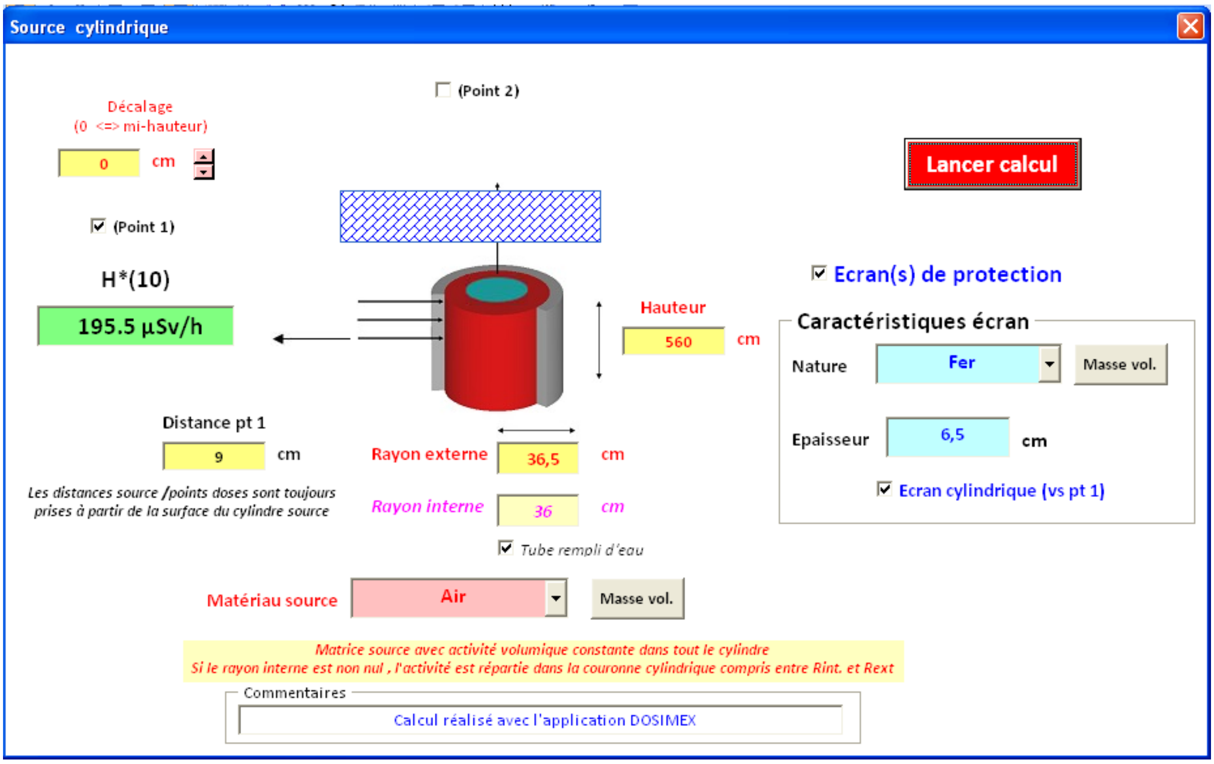


water pipe



d = 100 cm	DOSIMEX-GX 3.0	**RayXpert**	***Relative gap***
Without water	93.9 µSv / h	**92.8 µSv / h**	***1.2%***
With water (74 cm)	56.3 µSv / h	**50.7 µSv / h**	***11.0%***
Mitigation factor	***1.67***	***1.83***	***-8.9%***

B CALCULATION ON CONTACT



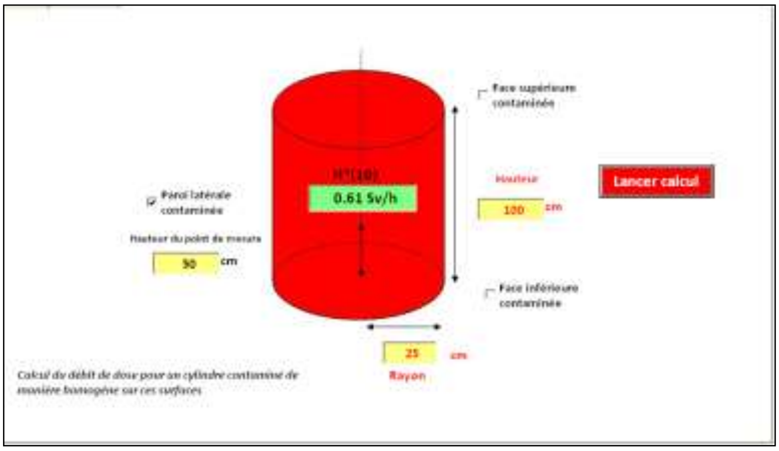
Contact	DOSIMEX-GX 3.0	RayXpert	***Relative gap***
Without water	345. µSv / h	**340. µSv / h**	***1.5%***
With water (74 cm)	195. µSv / h	**175. µSv / h**	***11.4%***
Mitigation factor	***1.77***	***1.94***	***-8.9%***

In both cases, and despite a relatively complex geometry, there is excellent matching.
The water calculation is once again revealing, with positive deviations of the order of e10%, is once again revealing the high and pessimistic build-up in water

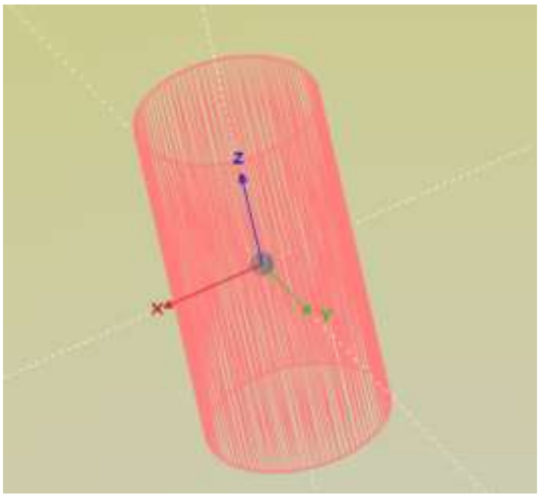
SCENARIO 15 : INTERNAL PIPE DED MEASUREMENT

Contaminated cylinder on its internal surface:
Radionuclide: Se 75; 1 TBq
Cylinder height 100; Ray25 cm

DED calculated at mid-height (50 cm), at ¾ (75 cm) and at the edge of the cylinder (100 cm)



RayXpert simulation:



Height	DOSIMEX-GX 3.0	**RayXpert**	***Relative gap***
50 cm	610 mSv / h	**634 mSv / h**	***-3.8%***
75 cm	560 mSv / h	**575 mSv / h**	***-2.6%***
100 cm	***366 mSv / h***	***344 mSv / h***	***6.4%***
	Mean square deviation		5%

SCENARIO 16 : "OFFSET" FUNCTION ON CYLINDRICAL SOURCE AND WIRE.

This function was introduced with the Dosimex-GX 2.0 version. (see manual). The 2 configurations tested are as follows:

- Cylindrical source
- Water matrix
- Ray 50 cm
- Height 100 cm
- Co 60 radionuclide
- Activity 10 GBq

- Configuration 1: distance: 10 cm

- Configuration 2: distance = 100 cm

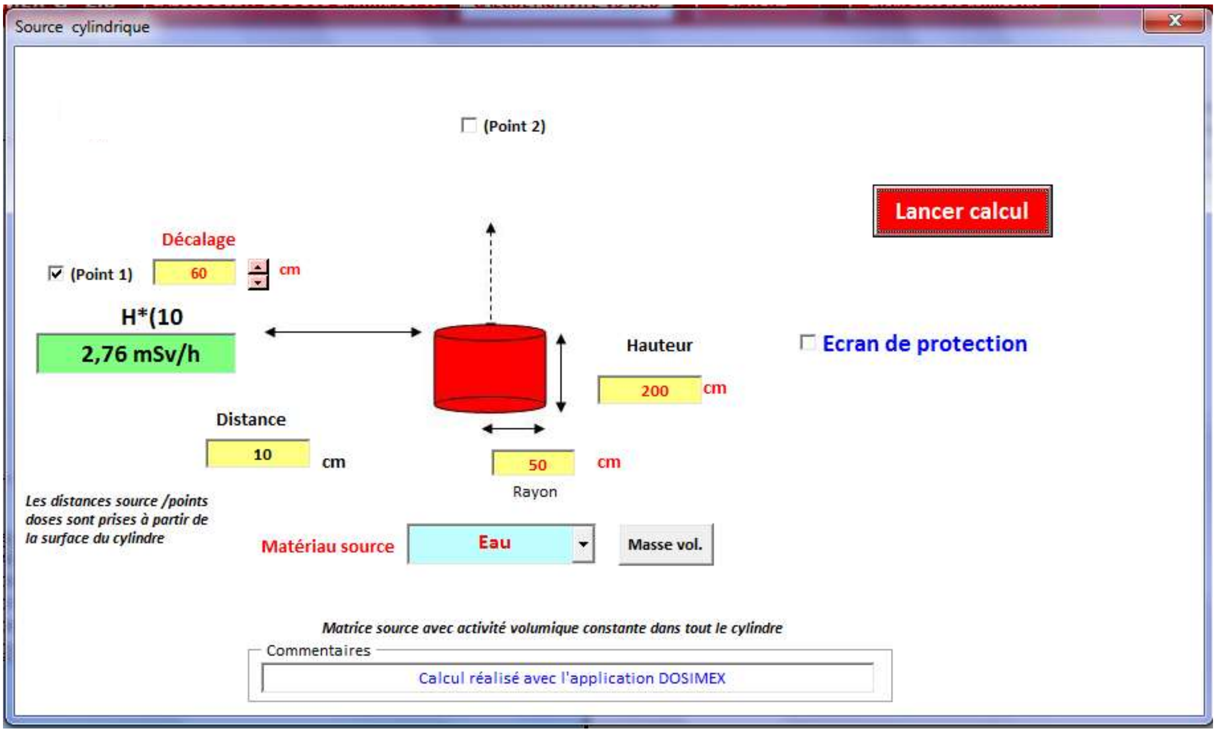
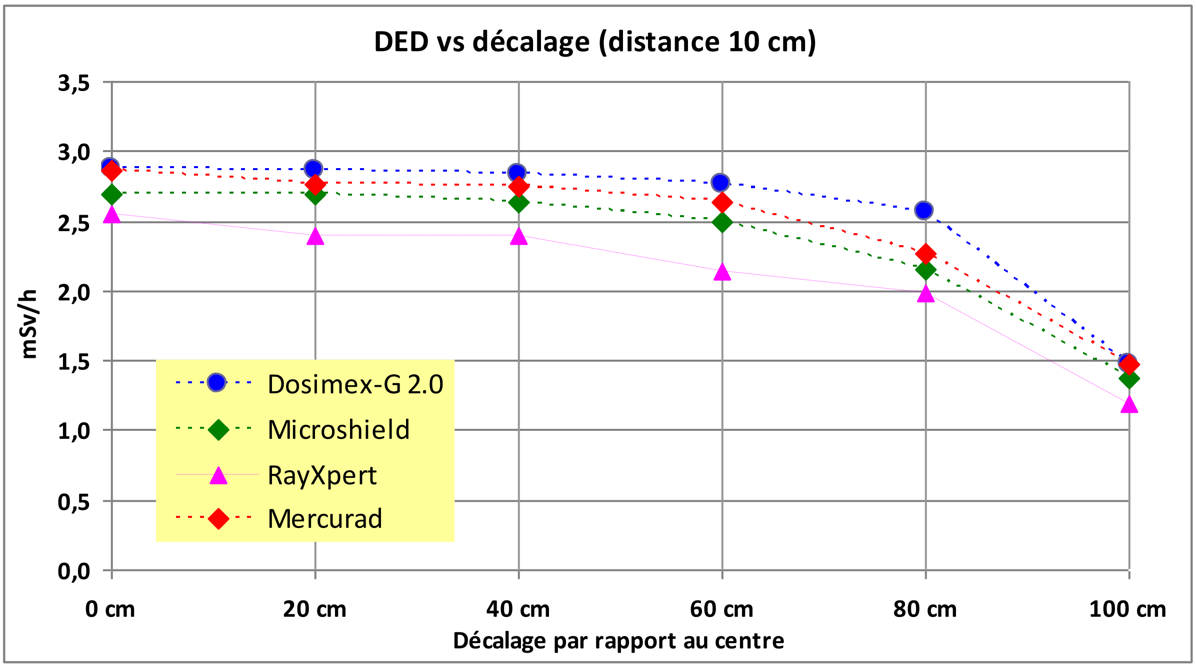


Figure 28: configuration 1 with offset 60 cm

R = 50; H = 200; A = 10 GBq; Co 60; d = 10 cm; Water (mSv / h)					Benchmark vs RayXpert		
Offset	DOSIMEX-G	MICROSHIELD®	MERCURADTM	RayXpert ©	Dosimex / RayXpert	Microshield vs RayXpert	mercurad vs RayXpert
0 cm	2.87	2.7	2.86	2.55	13%	6%	12%
20 cm	2.86	2.69	2.76	2.4	19%	12%	15%
40 cm	2.83	2.63	2.75	2.39	18%	10%	15%
60 cm	2.76	2.49	2.64	2.14	29%	16%	23%
80 cm	2.56	2.15	2.27	1.99	29%	8%	14%
100 cm	1.48	1.38	1.47	1.19	24%	16%	23%
	Mean square deviation				23%	12%	18%



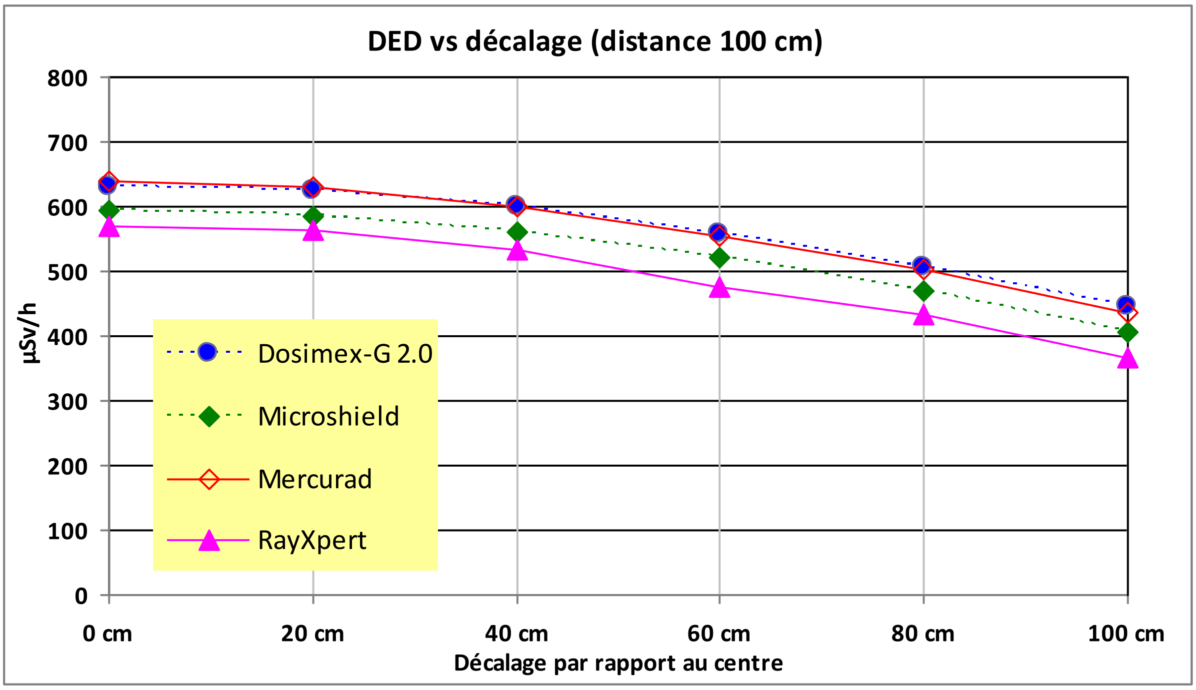
RAYXPERT © V 1.4 BENCHMARK

Case 1: Source distance 10 cm

- **Between DOSIMEX-GX 2.0 and RayXpert © 1.4: mean deviation 22%**
- **Between MICROSHIELD® V.9 and RayXpert © 1.4 :: mean deviation 11%.**
- **BetweenMERCURADTM andRayXpert © 1.4 :: mean deviation 18%.**

R = 50; H = 200; A = 10 GBq; Co 60; d = 100 cm; Water (µSv / h)					Benchmark vs RayXpert		
Offset	DOSIMEX -G	MICROSHIELD ®	MERCURADT M	RayXpert ©	Dosimex / RayXpert	Microshiel vs RayXpert	mercurad vs RayXpert
0 cm	631	593	640	569	11%	4%	12%
20 cm	623	584	630	564	10%	4%	12%
40 cm	599	560	600	532	13%	5%	13%
60 cm	559	521	554	477	17%	9%	16%
80 cm	506	470	502	432	17%	9%	16%
100 cm	445	406	437	367	21%	11%	19%
		Mean square deviation			15%	7%	15%

Table 19



BENCHMARK VS RAYXPERT © V 1.4

Case 2: Source distance 100 cm

- **Between DOSIMEX-GX 2.0 and RayXpert © 1.4: mean deviation 15%**
- **Between MICROSHIELD® V.9 and RayXpert © 1.4 :: mean deviation 7%.**
- **BetweenMERCURADTM andRayXpert © 1.4 :: mean deviation 15%.**

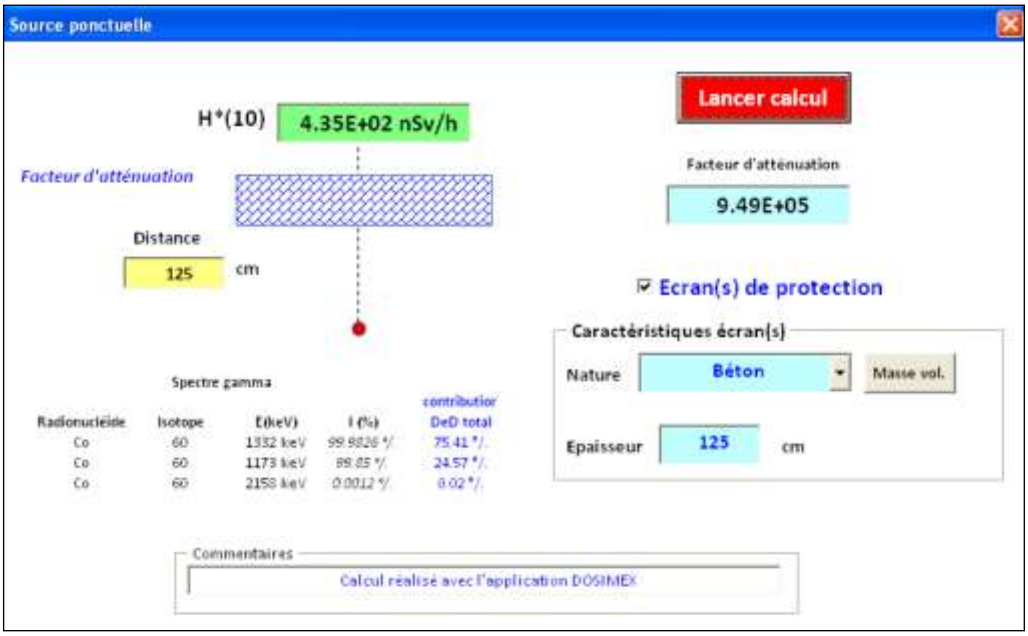
SCENARIO 17 : BLOCKHOUSE CALCULATION WITH AN IRIDIUM SOURCE OF CO 60 OF 50 CI

For operational calculations we had to determine the thickness of concrete necessary to obtain 0.5 µSv from a Cobalt 60 source of 50 Ci (1.85 TBq)

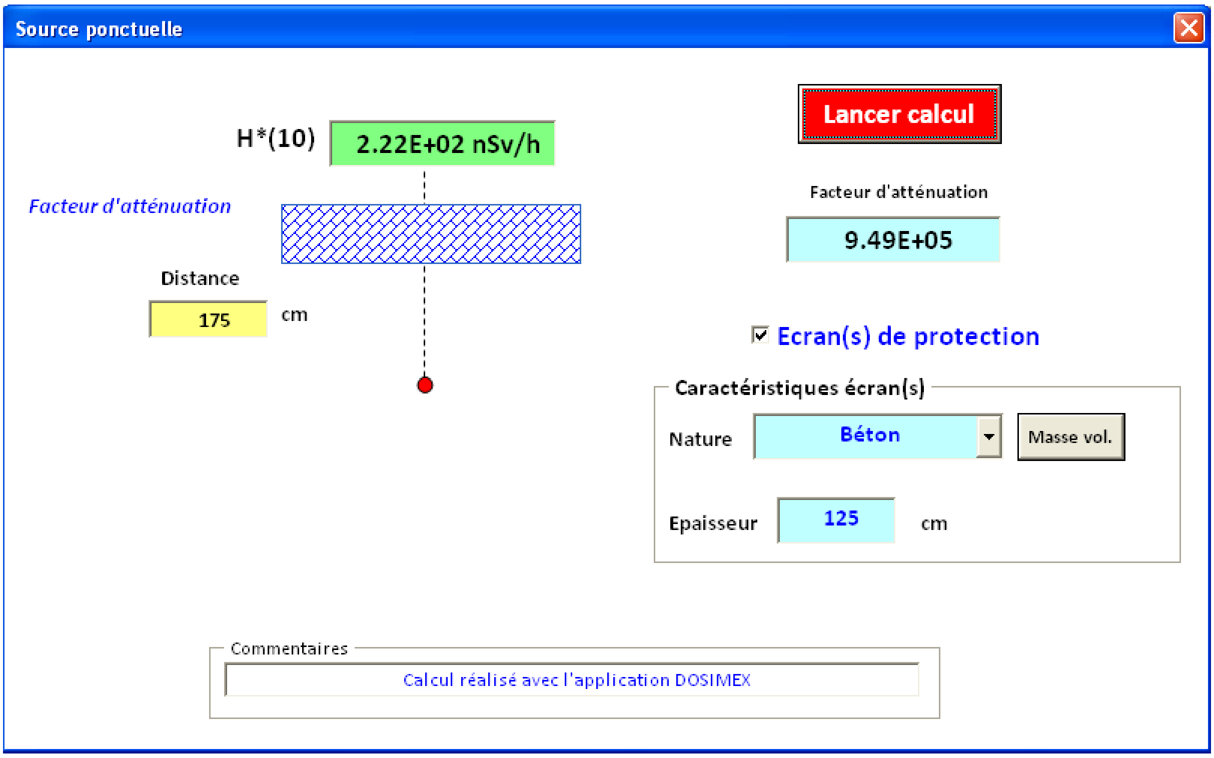
For operational validation reasons, we had to validate these calculations with a Monte-Carlo code. The calculation times quickly becoming very high (several hours to several tens of hours)) for thicknesses of the order of a meter, we first compared the DEDs for smaller thicknesses:

	0 cm (reference)	6.45E + 06 µSv / h	6.49E + 06 µSv / h	*Relative gap*
Co 50 Ci d = 100 cm	40 cm concrete (2.35)	3.84E + 04 µSv / h	4.37E + 04 µSv / h	
	Mitigation factor 40 cm	168	149	13%
	80 cm concrete (2.35)	133 µSv / h	177 µSv / h	
	Mitigation factor 40 cm	5.E + 04	4.E + 04	32%
	100 cm concrete (2.35)	14.6 µSv / h	12.3 µSv / h	
	Mitigation factor 40 cm	4.42E + 05	5.27E + 05	-16%

The quality of the results then allowed us to grope for a DED of the order of 0.5 µSv / h, then obtaining the necessary thicknesses greater than 1 m:



Taking into account a set distance requiring the source to be close to 50 cm of the protective wall; a DED of less than 0.5 µSv / h is obtained with a reasonable margin of safety:



Such a calculation under RayXpert would have required a considerable number of hours on a "normal" computer, or else to have a computer with very high computing power (multi-core or cluster), while the calculation with Dosimex is instantaneous

A. DOSIMEX-GX 3.0, MICROSHIEL®, MERCURADTM AND RAYXPERT © BENCHMARK SYNTHESIS VS MCNPX

Out of 143 configurations divided into 9 scenarios we obtain :

BENCHMARK VS MCNP ALL VALUES COMBINED

- **Between DOSIMEX-GX 3.0 and MCNPX : mean square deviation 12%**
- **Between MICROSHIELD® V.9 and MCNPX mean square deviation 38%**
- **BetweenMERCURADTM *and* MCNPX :: mean square deviation 32%.**
- **BetweenRayXpert © 1.5 *and* MCNPX :: mean square deviation 5%**

BENCHMARK VS MCNP EXCLUDING OUTLIERS (SEE TABLE ON NEXT PAGE)

- ***Between DOSIMEX-GX 3.0 and MCNPX : mean squared deviation 11.2% (1 ab values.)***
- ***Between MICROSHIELD® V.9 and MCNPX mean square deviation 12% ((14 ab values.)***
- ***Between MERCURADTM and MCNPX :: mean square deviation 17%. ((10 ab values.)***

Other configurations may allow these mean deviations and the resulting qualitative classification to be modified. The scenarios initially chosen were not sorted and kept to favor Dosimex-GX. Beyond the fact that such a bias approach would have appeared to us intellectually unbearable, it would have required us more work!

It is up to the user to decide whether or not these results demonstrate that DOSIMEX-GX 3.0 is a reliable code that can be used in his own radiation protection studies.

B. SUMMARY OF SIGNIFICANT DIFFERENCES: TABLE OF REPORTS

	Dosimex / MCNP	Microshield / MCNP	Mercurad / MCNP
SC1	/	Cf252 point source: $1/40$	Am 241 point source $1/2,3$
SC1	/	/	Pu 8 point source: $1/270$
SC1		Pu9 point source: $1/2,5$	Pu9 point source: $1/66$
SC1	/	Cf252 + 1 cm Pb: $1/8E19$	Cf252 + 1 cm Pb: $1/1,4E9$
SC2	/	Point source Cs 137 at 0.5 cm without screen: **1.59**	Point source Cs 135 to 0.5 cm without screen: **1.59**
SC3	/	Am 241 +10 cm Alu: **1.86**	Am 241 +10 cm Alu: **2.09**
SC3		Am 241 + 2 cm Pb: $1/1,9E16$	
SC3	/	Am 241 +50 cm of water: **3.08**	Am 241 +50 cm of water: **2.82**
SC3	/	Cs137 point. + 50 cm water: **1.57**	Cs137 point. + 50 cm water **: 1.79**
SC4	/	Am 241 wire: **2.0**	Am 241 wire: **2.2**
SC4	/	/	Am 241 disc: 2.1
SC5	/	Cs137 Cyl.pt 1 +2 cm Pb: **2.56**	/
SC5	/	Co60 Cyl.pt 1 +2 cm Pb: **1.69**	/
SC5	/	Cs137 Cyl.pt 2 + 2 cm Pb: **3.20**	/
SC5	/	Co60 Cyl.pt 2 +2 cm Pb: **1.50**	/
SC 9	CSDV pt 1 with screen: **1.52**	/	CSDV pt 1 without screen: **1.67**
SC 9			CSDV pt 2 without screen: **1.50**
SC 9	/	/	CSDV pt 2 with screen: **2.13**

TABLE 27: OUTLIER BENCHMARK RESULTS

- Value in red: underestimation compared to MCNP
- Blue value: overestimation compared to MCNP

We therefore see:

- **For DOSIMEX –GX: 1 outliers, less than 1% of cases**
- **For MICROSHIELD: 13 outliers or 10% of cases**
- **For MERCURAD: 13 outliers, i.e. 70% of cases**
- **For RayXpert: no outlier**

Particularly low ratios, less than 1/10, appear for Microshield and Mercurad with radionuclides of high mass numbers and often complex emission tables. The origin of these differences comes mainly from:

- Very intense XL emissions but sometimes not taken into account because of low energies (<20 keV) then leading to significant differences in point or surface sources without screen.

- In contrast to low intensity but high energy emissions leading to large differences, when neglected, in the presence of thick screens

Particular care has been taken in this regard to the “Radionuclides” database used in version 3.0 of Dosimex-GX to avoid such results

Note that for Dosimex the outlier is overestimated and the maximum ratio is equal to 1.52 ((*respectively 3.08 and 2.82 for Microshield and Mercurad*)

For the most part, these overestimates come from standardized low-energy build-up factors in light environments.

C. HISTOGRAMS OF REPORTS VS MCNP

The histogram of the reports vs MCNP for each code is another way of presenting the set of results, which makes it possible to visually assess the quality of the results in terms of accuracy, dispersion and outliers:

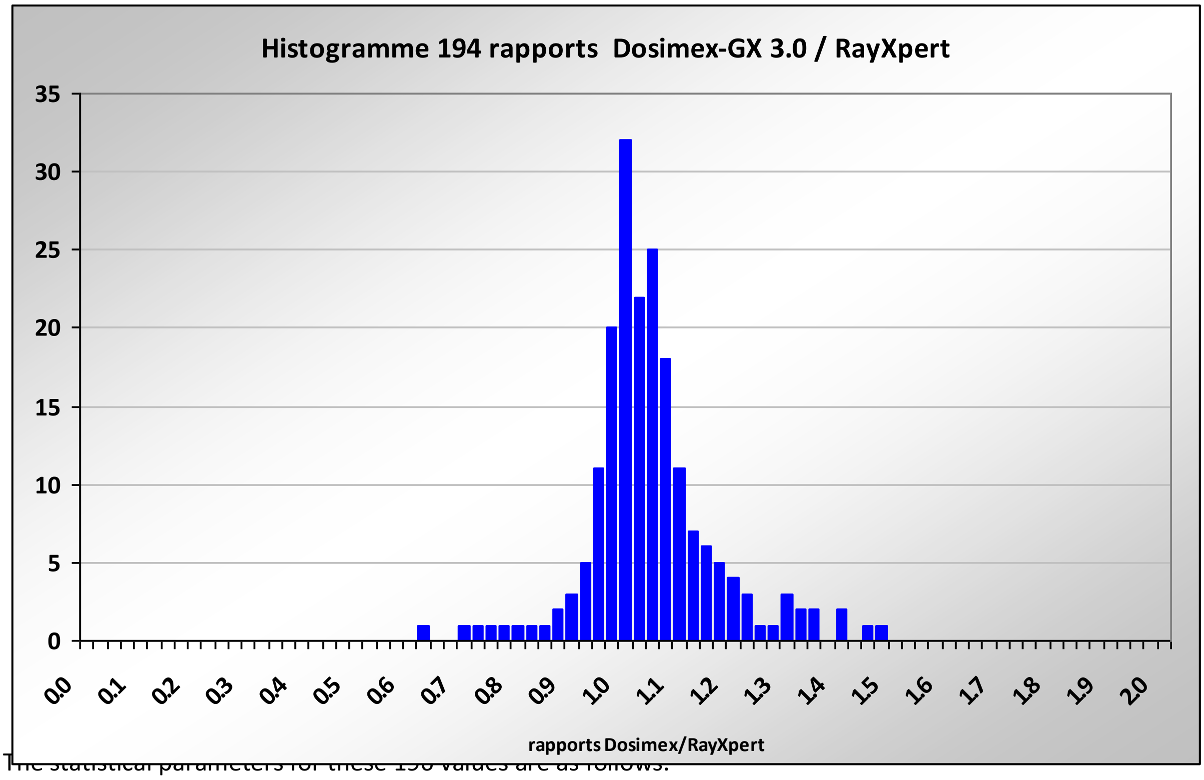
With such a representation (see next page), it is interesting to present the mean of the following results 2 statistical parameters:

- The algebraic mean, allowing to judge the overall deviation (trueness or bias)
- The standard deviation, allowing to judge the dispersion around the algebraic mean.

The reader will be able to verify that the mean square deviation used before is indeed the square root of the quadratic sum of these 2 statistical parameters

D. Summary of Dosimex vs RayXpert results (sc1 to 16)

All the values tested and compared with RayXpert form a sample of 196 values.
The Dosimex-GX / RayXpert report histogram is shown below



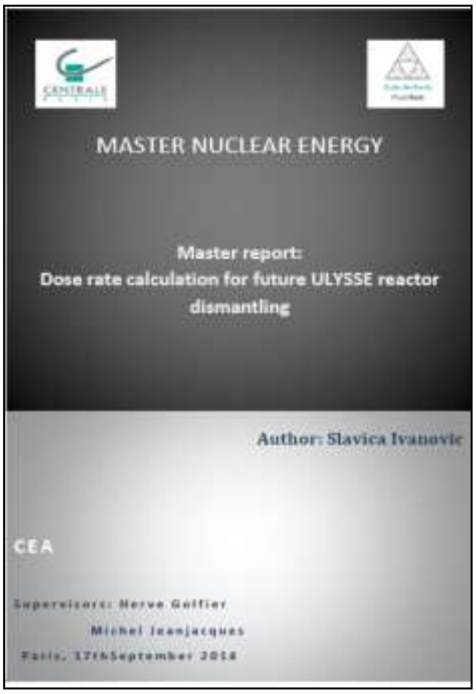
The statistical parameters for these 196 values are as follows:

- Mean: 1.034, representative of a slight mean tendency to overestimate (+ 3.4%)
- Standard deviation: 0.12, again a relative dispersion of **12%** around the mean
- Mean quadratic relative deviation: **12.5%,** representative of the mean dispersion around 1
- Minimum value (underestimation): **0.62**, obtained in scenario 11 with braking radiation in water
- Maximum value (overestimation): **1.46** corresponding to the case of the CSDV (scenario 91, point 2 with screen)

Note: this last case also represents the only outlier (ratio 1.52) obtained in the benchmark, but the value of 0.73 mSv / h is reported here at 0.50 mSv / h (rayXpert) instead of 0, 48 mSv / h (MCNP).

It is thus possible, in the case of a calculation not involved in this validation file, to announce with a good degree of confidence an uncertainty of the order of 13% for any calculation carried out with Dosimex-GX 3.0 (37% and 31% respectively with Microshield and Mercurad)

E. END OF STUDY INTERNSHIP MEMORIES INVOLVING DOSIMEX-GX



MASTER NUCLEAR ENERGY

Master report:
Dose rate calculation for future ULYSSE reactor dismantling

Author: Slavica Ivanovic

CEA

Supervisors: Herve Golfier
Michel Jeanjacques
Paris, 17thSeptember 2018

UNIVERSITE BLAISE PASCAL
Clermont-Ferrand
U.F.R. Sciences et Technologies
DÉPARTEMENT de PHYSIQUE

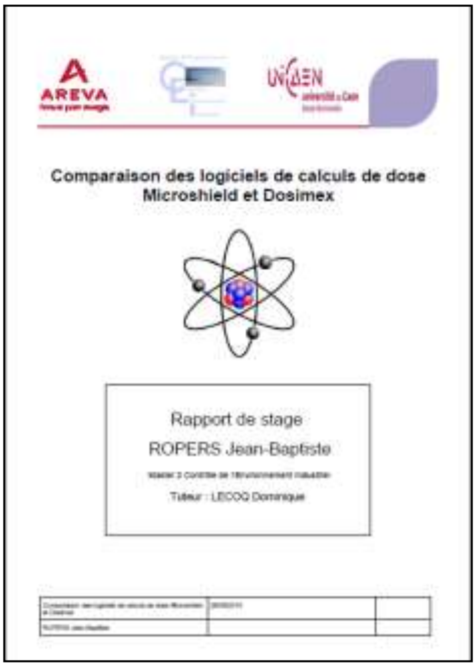
Mémoire en vue de l'obtention
de la
1ère année du Master mention PTR-IPM
Physique et Technologies des Rayonnements pour l'Industrie et la Physique Médicale

Année Universitaire 2015-2016

JOLY Clément

Calculs de débits de doses et comparaison de logiciels de modélisation

AREVA Nuclear Power



Comparaison des logiciels de calculs de dose Microshield et Dosimex

Rapport de stage
ROPERS Jean-Baptiste
Tuteur : LECOQ Dominique

Brevet de Technicien Supérieur pour le Contrôle des Rayonnements Ionisants et Application des Techniques de Protection

Année Scolaire 2015 - 2016

Comparaison des logiciels de calculs de dose Microshield et Dosimex
Application au sein de l'INB 123

CEA Cadarache