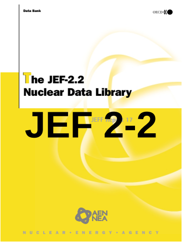

JEF/DOC-604

Water moderated and Lead reflected UO_2 pins array: a benchmark test for Lead cross-sections

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I) INTRODUCTION

The proposed benchmark exercise has been accepted by the OECD/NEA working group for criticality benchmarks evaluation [ref. 1] (ICSBEP). It considers a water moderated and lead reflected array of low enriched UO_2 rods array (pitch = 1.6 cm). The experiments were carried out in December 1983 in the IPSN experimental facility located in Valduc (Apparatus B). This experimental program was partly funded by the Commission of European Communities. The initial measurements and calculation analysis were performed jointly by the Safety and Reliability Directorate (SRD - United Kingdom) and the Service d'Etudes de Criticité (IPSN - France).

II) BENCHMARK CONFIGURATION

Four different experiments were carried out with a water moderated array composed by 14 x 14 UO_2 pins at the optimum of geometry (maximum of material buckling): pitch = 1.6 cm. The array was reflected on four sides by 30 cm lead reflectors. The core and the reflector were immersed in a water swimming pool and the water level was the parameter for the sub-critical approach. The experiments differ in the water gap between the fuel array and the lead reflector. The critical heights obtained with the four water gaps are shown in the following table:

Table 1 : Critical heights

Case No.	Water gap (cm)	Water critical height (cm)
1	0.0	75.13
2	0.5	71.87
3	1.0	72.99
4	1.5	81.23

the water gap being measured after the last array's half pitch. The critical height variation with the water thickness indicates that lead reflection efficiency increases when a thin water gap (below 1 cm) separates the core from the reflector.

These experiments are severe tests for lead cross-sections since the reactivity worth of the reflector is very high. In fact, if the lead reflector is replaced by air, the reactivity decrease is about -33000 pcm; in the same way, when the lead reflector is replaced by water, the reactivity decrease is about -9000 pcm.

II.1. Description of the models

Accurate model: 3 dimensional model ***(Figures 1, 2, 3, 4)***

This model comprises :

- the steel support plate, 120 x 120 cm, 1.0 cm thick, with one hole 8.4 cm diameter in the middle,
- the assembly comprising :

- the fuel rods array (14 x 14 fuel rods - 1.6 cm pitch), rods with 90 cm fuel length zone, plugs, spring zone (without spring),
- the stainless steel fuel basket (with four angled plate corners, grids, top plate, bottom plate 0.40 cm thick homogenised with 121 water holes).

- the stainless steel source support (57 cm long., 0.6 cm dia.)
- four lead shields 60 x 30 x 95 cm high
- the gap between the core and the lead (cases 2, 3, 4)
- the water up to the critical height, inside the assembly, in the gap, around the shields, under the support plate (18 cm).

Slightly Simplified model: 3 dimensional model ***(Figures 1, 2, 3, 5)***

The simplified model is the same as the accurate model except for the assembly.
The assembly of the simplified model comprises :

- the fuel rods arrays (only the 90 cm fuel length zone),
- the four stainless steel angled plate corners,
- the bottom plate, 0.40 cm thick, homogenised with 121 waters holes,
- the bottom plugs, homogenised with water, 1.8 cm high,
- the lower grid described with a stainless steel solid plate 0.14 cm thick,
- no upper outside structure (or simplified upper structure clad + air, upper grid 0.14 cm thick, top plugs + air, top plate, corners).

***Simplified model: 2 dimensional model** (Figures 1, 6)*

This model is not described in the ICSBEP handbook. Its aim is to provide a 2 dimensional model that can be used for deterministic codes. As we will see later, the calculations-experiments discrepancies are higher than 1.5 %. So it can be interesting to define a simplified model that can be easily used for sensitivity studies. The bias introduced by the proposed model is less than 0.5 %. To obtain this model, many structures were removed (plates, grids...), only the core, lead and water reflectors were considered. A cylindrical configuration was then obtained by the conservation of the fuel and reflectors volumes. The critical heights (table 1) were unchanged and all the materials above that height were removed. Figure 6 gives the geometrical description for case # 1. The other cases are obtained by adding the corresponding water gap between the core and the lead reflector.

II.2. Dimensions

Dimensions are given in figures 1, 2, 3, 4, 5 and 6 - critical heights are given in table 1.

II.3. Materials

Atom densities for materials are given in Table 2a and eventually for homogenised material in Table 2b.

II.4. Temperature data

The experimental temperature is 22°C.

Table 2. Atom densities for materials

Table 2a : basic materials

UO_2	^{235}U	1.1114×10^{-3}
	^{238}U	2.2045×10^{-2}
	O	4.6391×10^{-2}
	B_{nat}	2.8910×10^{-7}
AGS (clad, plugs)	Al	5.9556×10^{-2}
	Mg	3.3450×10^{-4}
	Si	2.4894×10^{-4}
	Fe	6.4052×10^{-5}
Water	H	6.6709×10^{-2}
	O	3.3354×10^{-2}
Steel (support plate pedestal)	Fe	8.4488×10^{-2}
	C	2.3765×10^{-4}
	Mn	3.4639×10^{-4}
Stainless Steel (basket) (a) (support source)	Fe	6.0823×10^{-2}
	Cr	1.7532×10^{-2}
	Ni	7.6509×10^{-3}
Lead	Pb	3.2523×10^{-2}

(a) basket includes top plate, angled corners and grid plates (see Figures 4 and 5)

Table 2b : homogenised materials

Bottom plug + water	H	4.3814×10^{-2}
	O	2.1907×10^{-2}
	Al	2.0440×10^{-2}
	Hg	1.1480×10^{-4}
	Si	8.5436×10^{-5}
	Fe	2.1983×10^{-5}
Clad + air (spring region, spring omitted)	Al	3.2520×10^{-3}
	Mg	1.8264×10^{-5}
	Si	1.3592×10^{-5}
	Fe	3.4973×10^{-6}
Top plug + air	Al	1.6140×10^{-2}
	Mg	9.0649×10^{-5}
	Si	6.7462×10^{-5}
	Fe	1.7358×10^{-5}
Stainless steel + water (bottom plate)	Fe	5.3945×10^{-2}
	Cr	1.5407×10^{-2}
	Ni	6.7240×10^{-3}
	H	8.0860×10^{-3}
	O	4.0430×10^{-3}

III) CALCULATION RESULTS

These benchmarks (the model used is the 3 dimensional one, rather the accurate or the simplified) were calculated with the French and the United Kingdom criticality codes: APOLLO-1 (assembly calculation) + MORET-3 using the CEA93 library (derived from JEF2.2) and MONK-7 using an application library derived from JEF2.2. The results are shown in the following table:

Table 3 : Calculation results using JEF2.2

Case No.	MONK-7 results	A1 + MORET-3 results
1	1.0161 (0.0010)	1.0226 (0.0010)
2	1.0184 (0.0010)	1.0253 (0.0010)
3	1.0166 (0.0010)	1.0256 (0.0010)
4	1.0154 (0.0010)	1.0277 (0.0010)

Both calculation scheme using JEF2.2 data show important discrepancies with the experimental value (k_{eff} = 1.0000 +/- 0.0012).

Calculations of these benchmarks with other origins of lead cross sections were also performed [ref. 2]. In fact, the APOLLO-1 libraries contains two other sets of lead cross sections. In the CEA79, lead nuclear data were derived from ENDF/B4 using an old processing code (TRAME-CANTABILLE). A simplification in the cross-sections structure was obtained by removing the inelastic scattering component in order to reduce the removal matrix storage. In the CEA86 library, lead nuclear data were derived from JEF-1 using the NJOY-THMIS system. The calculated keff obtained with these two cross-section sets are: 1.000 ± 0.001 for the incomplete ENDF/B4 set and 1.019 ± 0.001 for the JEF-1 set.

The JEF-1 result is very close to the one obtained with JEF2.2. The incomplete ENDF/B4 data gives, to the great surprise, a very good agreement with the experiment. The comparison of the two sets of lead multigroup scattering cross sections is presented in figure 7 (the absorption component is very low, less than 1 % proportion in the total). The ratio between the incomplete ENDF/B4 and JEF-1 is close to unity except for high energies (above 1 MeV) where JEF-1 cross sections are higher; the ratio is about 0.5 at 10 MeV. This is due to the absence of the inelastic scattering component in the first set. In fact, the threshold of this reaction is about 0.6 MeV, and its contribution increases with energy. We also compared the average cosine of scattering angle (see figure 8). This parameter is close to 0 (which indicate isotropic scattering) except for high energies. The average cosine in the two sets are quite similar up to 1 MeV. For higher energies, the incomplete ENDF/B4 average cosine is higher. This can also be explained by the lack of the inelastic component in this last set. In fact, the anisotropy law is a combination between elastic and inelastic laws. As the inelastic scattering is quite isotropic, the resulting average cosine in the JEF-1 data is roughly equal to the elastic average cosine times the ratio of the elastic cross-section and the total cross section. Of course, this last ratio is equal to one in the incomplete ENDF/B4 set.

IV) CONCLUSION

The considered benchmarks are very sensitive to lead cross-sections and thus represent interesting test. Calculation carried out with JEF-1 and JEF-2.2 data show important disagreements with the experimental values. This may indicate a need to review the evaluated data in JEF2.2.

REFERENCES

G. Poullot, A. Nouri and N. Smith: « Water moderated and Lead reflected 4.75 % enriched uranium dioxide rod arrays », in International Criticality Safety Benchmarks Evaluation Handbook, LEU-COMP-THERM-027.

A. Nouri: « Remarques sur les sections efficaces du plomb », internal report, IPSN/DRS/SEC/T/94.400 (December 94)

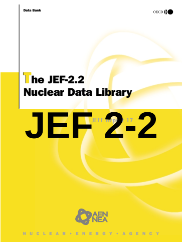

The JEF-2.2
Nuclear Data Library
JEF 2-2

Figure 1

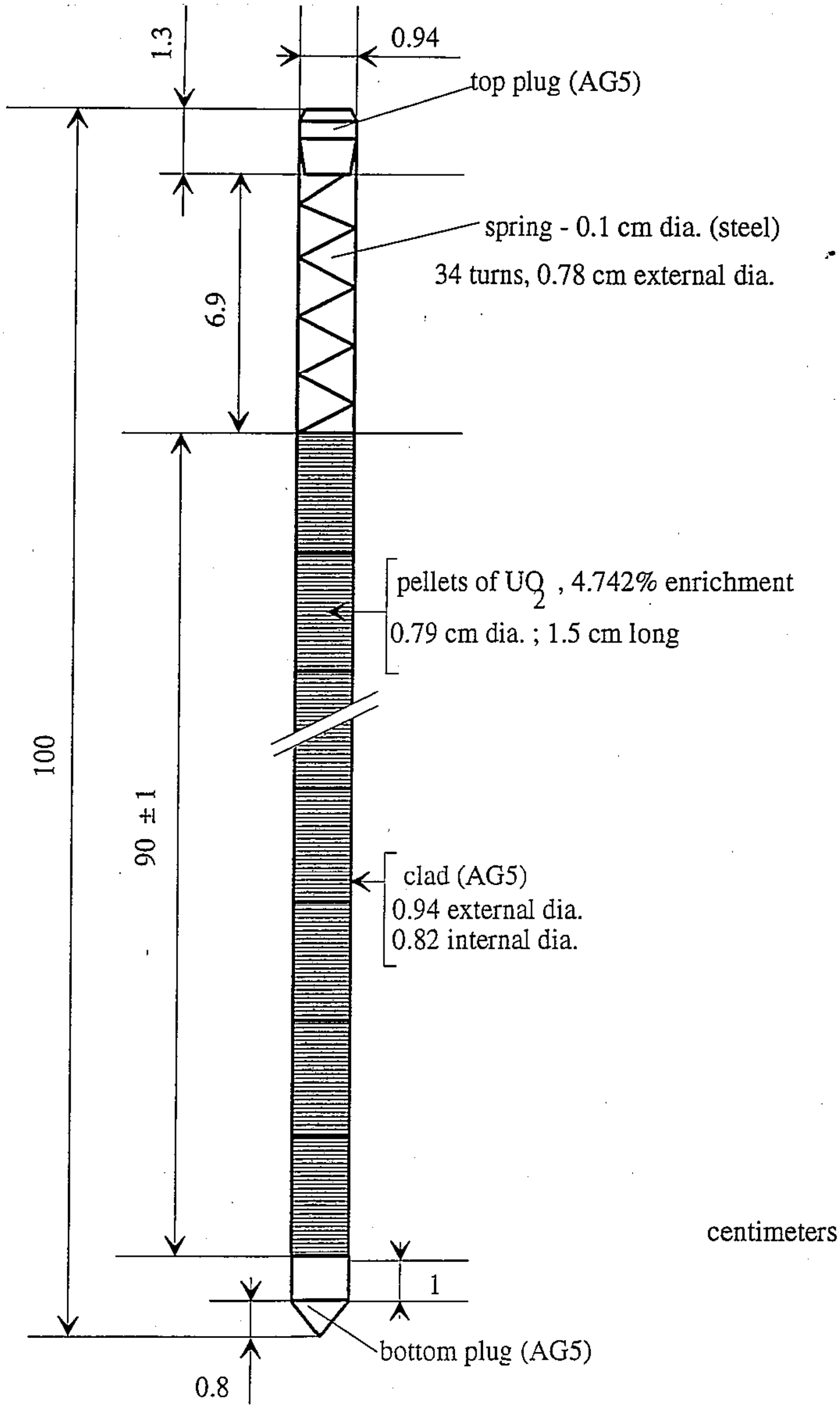
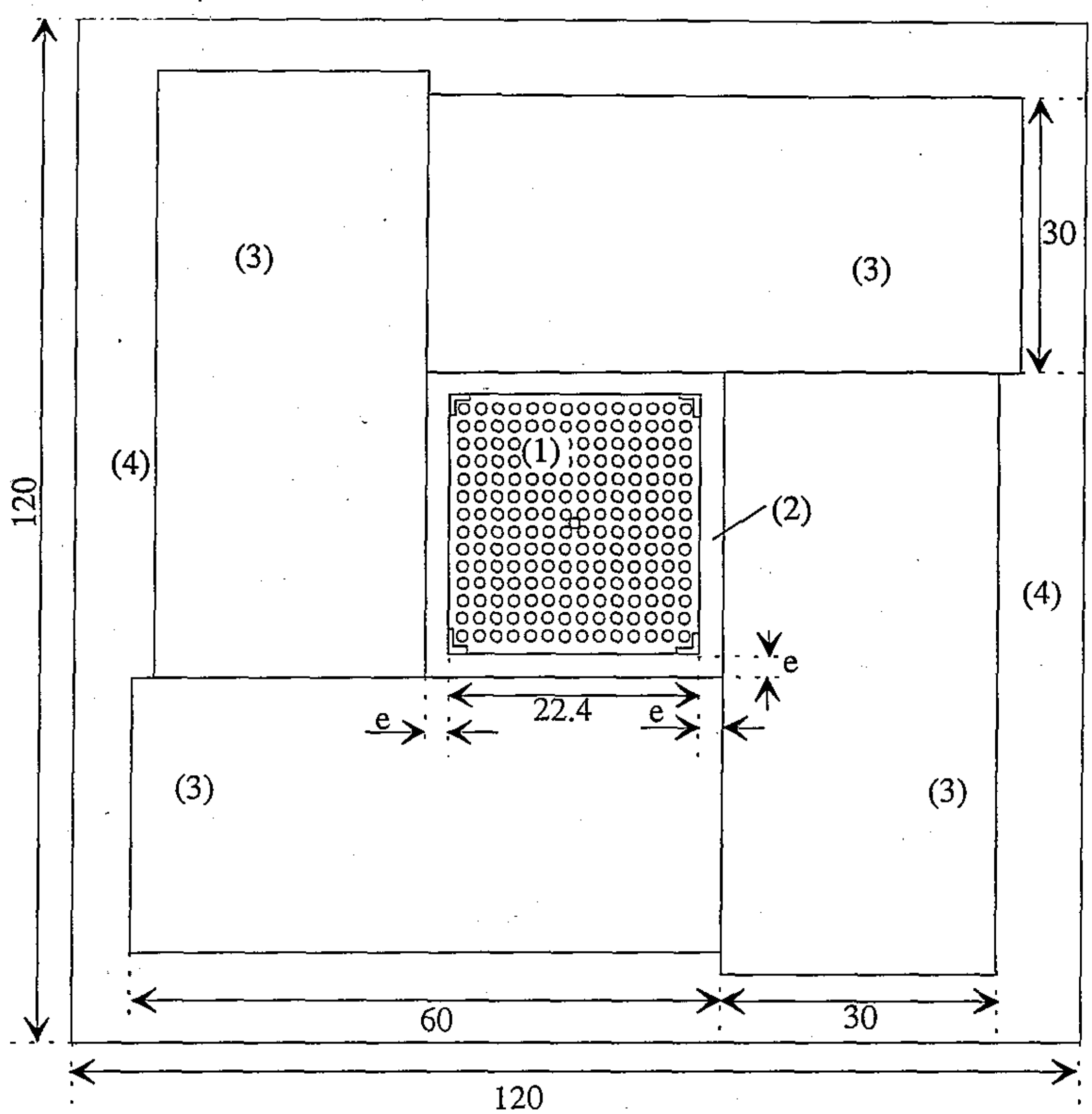

1.3
0.94
top plug (AG5)
spring - 0.1 cm dia. (steel)
34 turns, 0.78 cm external dia.
6.9
pellets of UO_2 , 4.742% enrichment
0.79 cm dia. ; 1.5 cm long
100
90 ±1
clad (AG5)
0.94 external dia.
0.82 internal dia.
centimeters
1
bottom plug (AG5)
0.8

Figure 2



1 : 14 x 14 rods array, 1.6 cm pitch

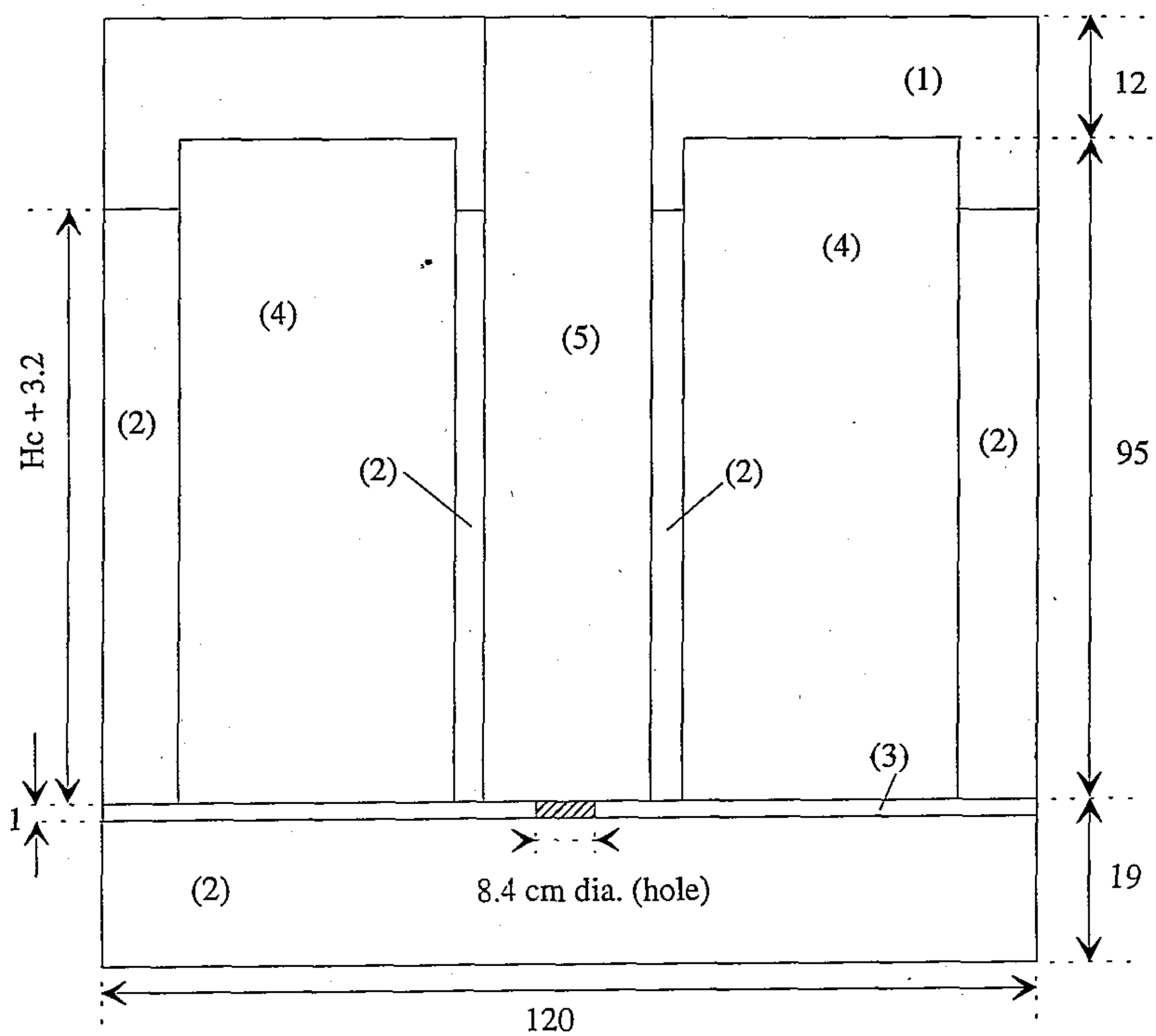
2 : water gap (thicknesses e = 0.0, 0.5, 1.0 or 1.5 cm)

3 : lead 30 x 60 x 95 cm high

4 : water reflector

centimeters

Figure 3



1 : air
2 : water
3 : steel support pedestal
4 : lead reflector
5 : basket + rods array

centimeters

Figure 4

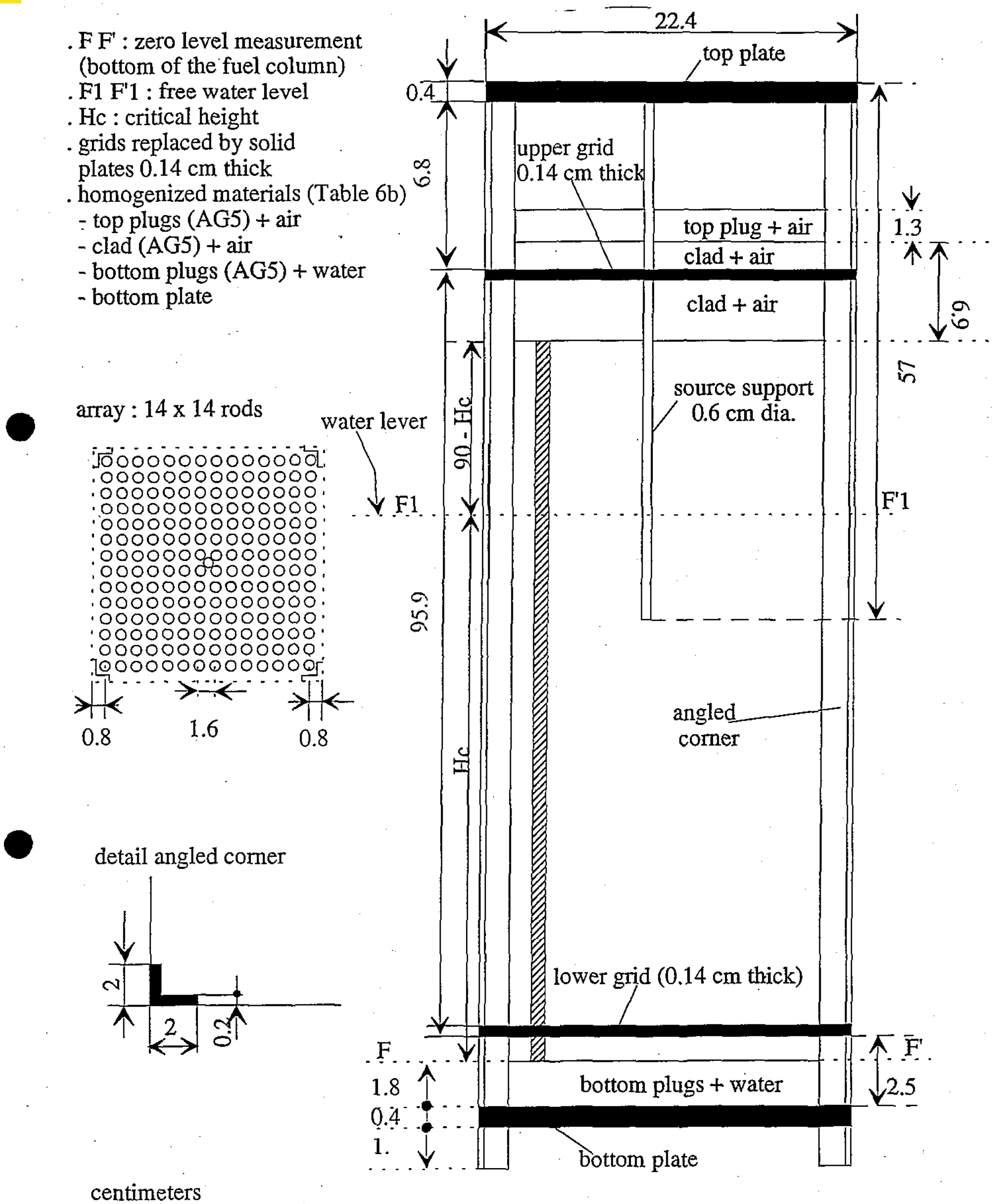
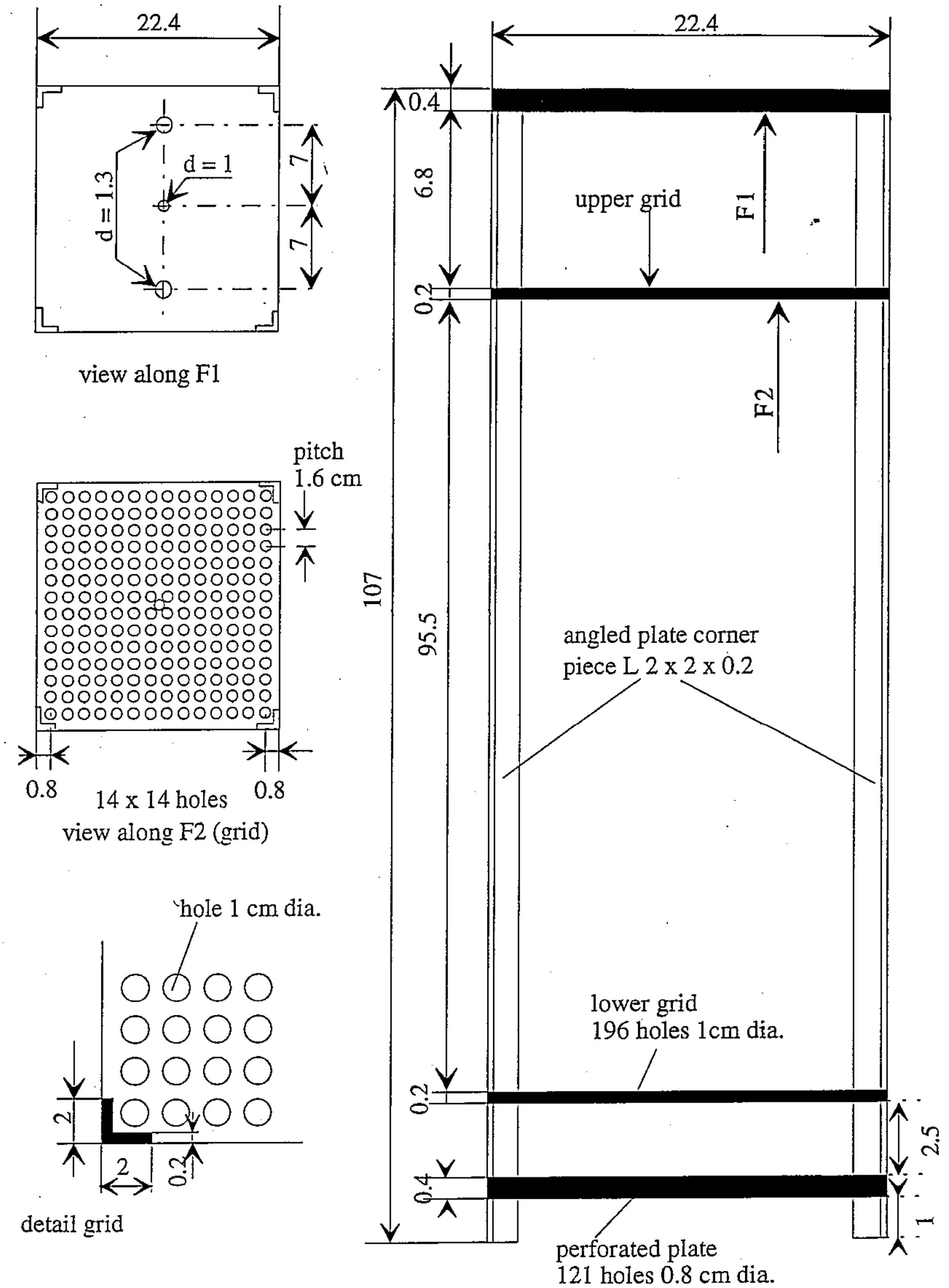


Figure 12. Elevation view of assembly simplified model

Figure 5



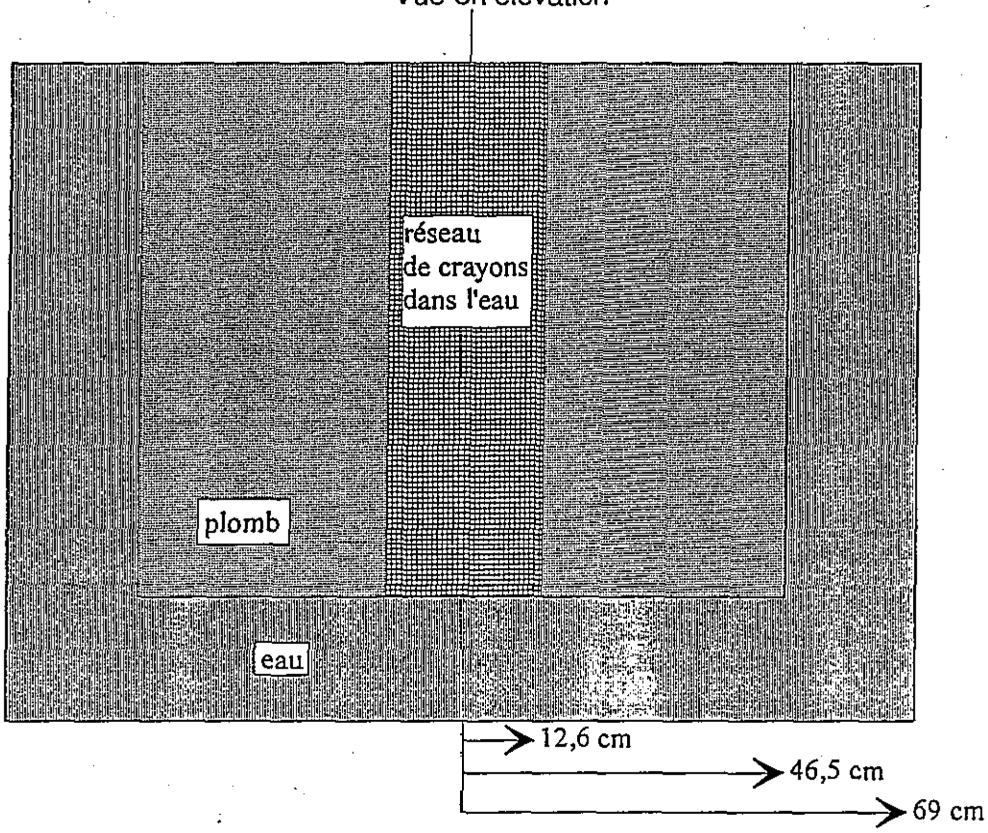
centimeters

14040098

Figure 6

SCHEMA DE LA CONFIGURATION SIMPLIFIEE

Vue en élévation



Coupe horizontale

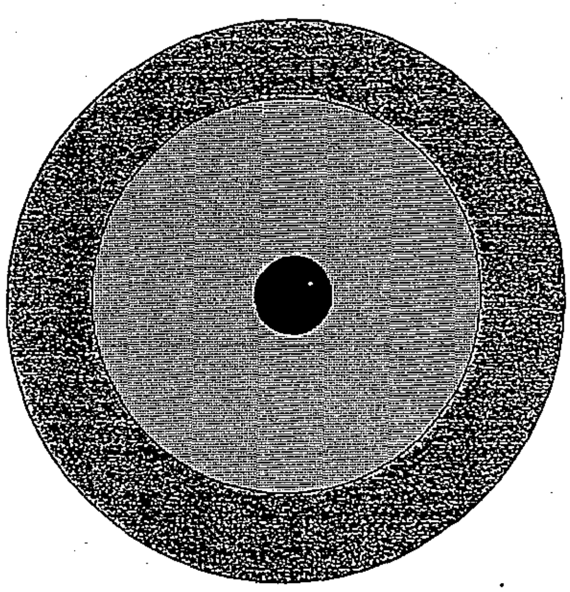


Figure 7

COMPARAISON DES SECTIONS EFFICACES DE DIFFUSION DU PLOMB

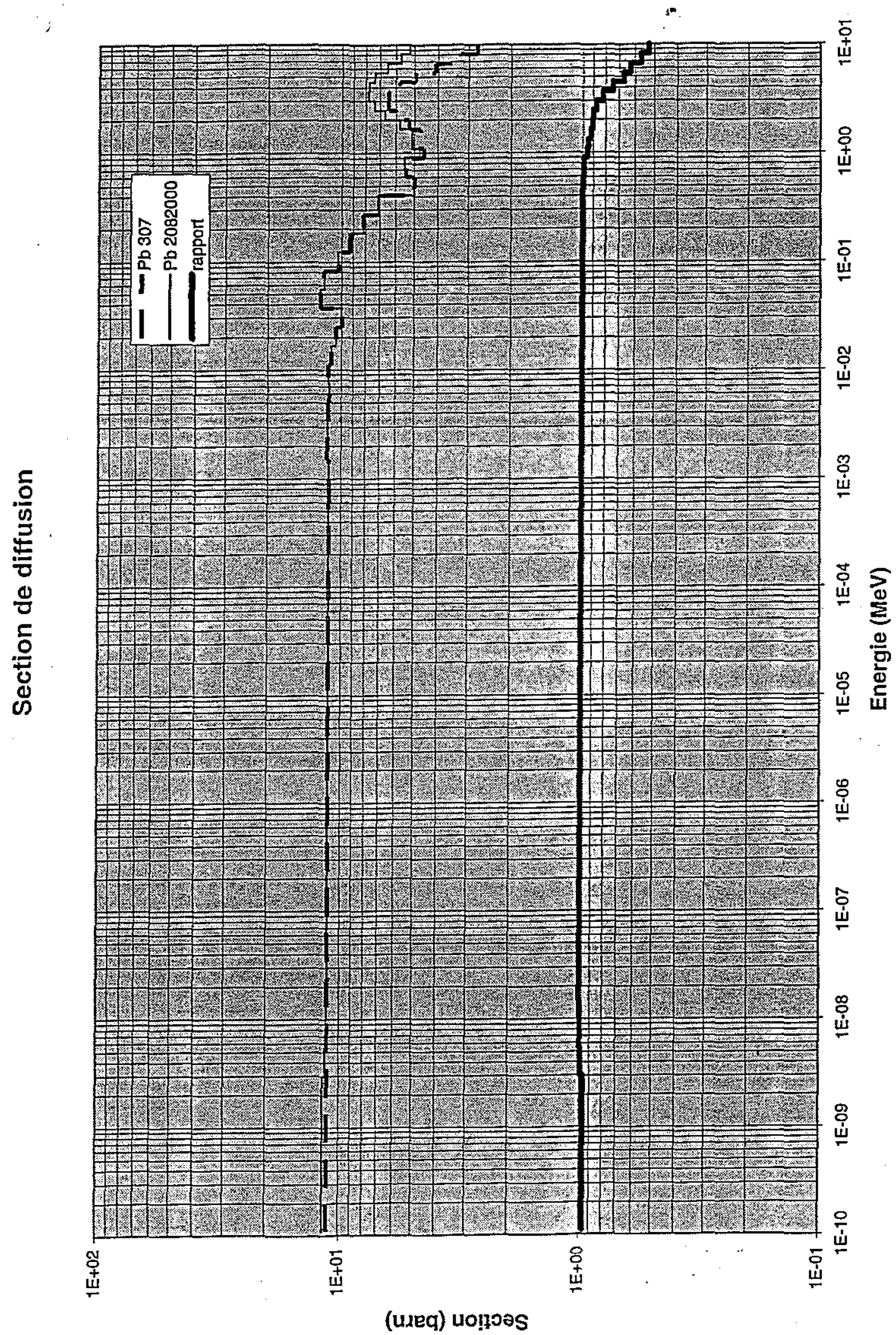


Figure 8

COMPARAISON DES COSINUS MOYENS DE DIFFUSION DU PLOMB

Cosinus moyen de diffusion