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NEW INTERPRETATION OF THE NAÏADE 1 EXPERIMENTS

PART 2 : FISSION NEUTRON PROPAGATION IN LIGHT WATER - SOURCE DIAMETER 60 CM

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PART G

NAÏADE experiments relating to Fission Neutron Propagation in Light Water Source Diameter 60 cm

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I General

The NAÏADE 1 [1] experimental facility consists of a uranium plate (converter) irradiated by a beam of neutrons thermalised at 27°C originating from the graphite reflector of the ZOE heavy water reactor. A boral shield separates this fissile plate from an experimental pit with an internal volume of 27 cubic metres housing an aluminium vessel containing the experimental mock-up. A detailed description of the NAÏADE 1 facility, including dimensions and composition, is given in reference [2]. Part B of the latter reference also describes:

1. The expression of results in the form of conventional fluxes (§II)
2. Calibration procedures for the dosimeters used to make measurements (§IV)
3. Our proposed re-evaluation (§V) of the detector coefficients providing conventional fluxes. This re-evaluation is to take account of improvements to certain physical constants (cross-sections, periods, etc.) between the time of calibration (1960) and the present. The multiplying factors for the conventional fluxes reported at the time the measurements were made are recalled in Table G11.

The power of the fissile plate expressed in n/s as well as its spatial and energy distribution are very important points which are analysed in Part C of reference [2]. The beam of thermal neutrons irradiating the plate generate first generation fissions in the U235 of the converter. The natural uranium plate and surrounding structures diffuse these first generation neutrons which in turn produce subsequent generations of fissions primarily in the U238 and to a lesser extent in the U235 of the converter. The two calculation procedures for the complete sources of fission neutrons are described in detail in part C of [2]. These procedures have been used to study the propagation of fission neutrons in iron (part E reference [2]) and for the study on neutron propagation in graphite (part F reference [2]). An analysis of the contribution of background noise from the occasional fast neutrons emitted from the core of ZOE is proposed.

II Description of the NAÏADE 1 light water experiment

In this experiment, the aluminium vessel installed in the experimental pit is filled with ordinary water and has a volume of 300cm×300cm×250cm. A comprehensive description of this light water experiment is given in page 21 of reference [1] reproduced overleaf.

Experiment in water *(extrat from Bibliography [1])*

The experiments were conducted by filling the aluminium vessel with ordinary water.

1) Positioning of instrumentation

The experiments with counters were conducted with the aid of an "instrument bridge". This bridge had been designed to allow the counters to be moved in 3 orthogonal directions, namely parallel to the axis of the converter plate and parallel, both horizontally and vertically, to the converter plate. It consisted of a perfectly rigid rectangular frame measuring 50 cm x 300 cm. Two wheels mounted on each of the two 50 cm sides allowed the frame to run along 2 rails placed on either side of the Naïade vessel (parallel to the axis of the plate). A vertically mounted cylindrical steel shape (10 cm in diameter) moving inside the framework was driven by 2 motors, one to move it vertically and the other to move in the direction of the largest dimension of the frame (i.e. horizontally parallel to the plate).

An instrument hatch was attached to the shape.

The horizontality of the frame was regulated by micrometer screws and two spirit levels.

The position of the counter in relation to a reference position could be determined to within 1 mm by means of an index sliding in front of graduated scales.

2)Positioning of detectors

The experiments with detectors were conducted by placing the detectors on Plexiglas ladders.

The perpendicularity of the ladders in relation to the plate was ensured by securing them extensively to the wall of the aluminium vessel.

3) Experiments conducted

Bibliography [1]

4) Results

Bibliography [1]

The dosimeters employed were based on the following reactions:

1. P31 (n,p)
2. Rh103 (n,n')
3. silicon diodes (WIGNER effect)
4. S32 (n,p)
5. dose equivalent rate measured by a photomultiplier
6. In115 (n,γ) under cadmium.
7. Au197 (n,γ) under cadmium
8. BF3/Cd chamber
9. Mn55 (n,γ) under cadmium
10. bare chamber, BF3 counter up to 180cm penetration
11. Mn55 (n,γ) (bare metal)

III Raw experimental results

We take experimental results to mean the conventional flux values published in reference [1], that is to say with the non-readjusted detector coefficients used in the 1960s. All these results are normalised for a ZOE power rating of 100 kW. The diameter of the diaphragm restricting the beam of thermal neutrons striking the converter is 60 cm. A few measurements were made with a 40 cm diameter diaphragm as well as some measurements using as source the pure thermal neutrons emitted by the ZOE reflector. Since we did not have a neutron source distribution model available for these cases, we have not interpreted these measurements by means of the TRIPOLI-4 Monte-Carlo software [5].

In the following Tables, the measurement results are given along the converter axis, with the X abscissas counted from the face of the aluminium vessel on the opposite side of the ZOE reactor. X=0 is therefore the plane between the vessel and the water it contains. Since measurements were sometimes repeated, we have specified the date on which they were made to show the dispersion.

Distance X in cm	Equivalent P31/Cd fission flux density		
	12/4/65	26/4/65	7/7/65
0.		2.22E7	
1.5			1.50E7
2.25		1.37E7	
6.0		6.50E6	6.41E6
10.		3.22E6	
15.		1.35E6	
20.5	6.05E5		
25.5	2.56E5		
30.5	1.25E5		

Table G-1

Distance X in cm	Equivalent Rh/Cd fission flux density	
	14/4/65	26/4/65
0.		3.26E7
3.7		1.25E7
6.8		6.48E6
10.9		3.23E6
27.	2.22E5	
32.	1.03E5	
37.	4.78E4	

Table G-2

Distance X in cm	Equivalent Si Wigner/Cd fission flux density		
	6-7/4/65	5-6-7/7/65	7/7/65
0.5	3.10 & 3.05E7		3.10E7
3.	1.75E7	1.75E7	
3.5	1.34E7		
6.0	7.50E6	7.42E6	7.48E6
10.	3.78E6		
15.	1.64E6		
20.	7.40E5	7.40E5	
25.	3.65E5		

Table G-3

“Equivalent Si Wigner/Cd fission flux density” measurements are made with silicon diodes calibrated to a given reference flux whose spectrum is close to the fission spectrum of U235. This type of measurement is described in reference [3] of January 1965. Note the excellent reproducibility of multiple measurements:

- 3 measurements at 0.5 cm;
- 2 measurements at 3.0 cm;
- 3 measurements at 6.0 cm;
- 2 measurements at 20 cm.

This reflects:

- The low spread of calibration coefficients;
- The proper positioning of diodes (1 mm error in positioning is equivalent to between 1.7% and 2.% uncertainty for equivalent Si fission flux density).

The reproducibility of measurements is not quite as good in measurements of equivalent S32/Cd fission flux density (see Table G-4 below).

Distance X in cm	**Equivalent S/Cd fission flux density**	
	5-6-7/7/65	**12-13/7/65**
0.	**2.10E7**	**2.20E7**
5.	**7.51E6**	**8.02E6**
10.		**3.20E6**
15.		**1.36E6**
20.		**6.22E5**
25.		**2.63E5**
30.		**1.20E5**
34.7	**6.00E4**	
40.	**2.71E4**	
44.8	**1.38E4**	
53	**4.26E3**	

Table G-4

Distance X in cm	**Dose equivalent rate (rapid PM) in mRem/h**			
	11/2/58	**5/7/58**	**7/7/58**	**9/7/58**
0.0	**1.49E6**	**1.48E6**		
10.	**2.15E5**	**2.37E5**		**1.77E5**
15.5			**6.91E4**	
20.	**3.81E4**	**4.16E4**	**3.86E4**	**3.00E4**
30.	**8.55E3**	**8.74E3**	**7.75E3**	**6.55E3**
35.55			**3.32E3**	
40.	**1.86E3**	**2.08E3**		**1.46E3**
50.	**4.67E2**	**5.24E2**	**4.40E2**	
58.75	**1.28E2**			
70.	**3.20E1**	**3.67E1**		
80.	**8.76**	**9.51**		
90.	**3.05**	**3.04**		

Table G-5

The measurements of fast neutron dose using a photomultiplier are older (1958). Reference [4] provides details of this type of measurement and in particular its response as a function of neutron energy. Note the non-negligible spread of dose equivalent rates for measurements reproduced at different dates. We cannot tell whether this is attributable to the:

- positioning of the chamber;
- power level of ZOE with regard to the 100kW rating;
- PM power supply.

Distance X in cm	**In115/Cd**	**Au197/Cd**
	Flux by unit of lethargy at 1.46eV	**Flux by unit of lethargy at 4.91eV**
	13/4/65	**5-6/4/65**
0.0	**9.20E5**	**9.66E5**
0.5	**9.95E5**	**9.71E5**
3.0	**9.53E5**	**9.45E5**
3.5	**1.00E6**	**8.47E5**
6.0	**6.37E5**	**5.32E5**
10.	**2.77E5**	**2.00E5**
15.	**8.47E4**	**5.95E4**
20.	**2.57E4**	**2.18E4**
25.	**1.11E4**	**9.10E3**
30.	**4.14E3**	**3.70E3**
35.		**1.43E3**
40.	**8.30E2**	
45.		**3.55E2**
50.		**1.04E2**
60.		**3.12E1**

Table G-6

This Table lists measurements of epithermal flux densities per unit of lethargy from In115 (n,γ)/Cd (and not In115(n,n') as at present) and Au197 (n,γ)/Cd dosimeters.

Distance X in cm	Equivalent flux density at 2200m/s BF3/Cd counter
	25/5/60
5.5	4.97E5
7.5	3.52E5
10.	2.02E5
15.	6.30E4
20.	2.08E4
30.	3.13E3
40.	6.14E2
50.	1.28E2
60.	3.05E1

Table G-7

This series of measurements predates the 1965 measurements.

Distance X in cm	**Equivalent thermal flux at 2200m/s Mn/Cd**	
	12/4/65	**5/7/65**
0.0		**7.70E5**
1.0		**1.00E6**
2.40		**1.02E6**
3.5		**8.50E5**
4.0		**7.88E5**
5.0		**6.98E5**
10.		**2.46E5**
15.		**7.50E4**
20.	**3.05E4**	
25.	**9.73E3**	
30.	**4.12E3**	
35.	**1.44E3**	
40.	**7.02E2**	
45.	**3.23E2**	
50.	**1.37E2**	

Table G-8

Distance X in cm	**Equivalent thermal flux at 2200m/s** **Bare BF3 counter**		
	May 57	**8/2/58**	**10/5/60**
0.0			**8.87E6**
1.0			**2.42E7**
2.0			**3.30E7**
4.0			**3.46E7**
5.0			**3.55E7**
7.5			**2.66E7**
10.			**1.50E7**
15.	**7.10E6**		
20.	**2.44E6**		**2.44E6**
23.	**1.29E6**		
27.	**5.76E5**		
30.	**3.10E5**		**3.43E5**
37.	**1.15E5**		
40.	**7.27E4**		**6.24E4**
43.	**4.70E4**		
45.	**3.28E4**		
50.	**1.33E4**		**1.23E4**
55.	**4.43E3**		
60.	**2.75E3**		**2.62E3**
70.			**6.43E2**
72.	**4.88E2**		

Table G-9 (beginning)

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare BF3 counter (cont'd)**		
	May 57	**8/2/58**	**10/5/60**
77.	**1.95E2**		
80.	**1.06E2**		**1.70E2**
85.	**6.65E1**		
90.	**4.00E1**		**4.55E1**
97.	**1.55E1**		
100.			**1.31E1**
107.	**5.32**		
110.			**4.03**
112.	**2.84**		
117.	**1.33**		
120.		**1.46**	**1.32**
130.			**4.31E-1**
132.	**3.10E-1**		
140.		**2.13E-1**	**1.54E-1**
147.	**7.18E-2**		
150.			**5.72E-2**
157.	**3.46E-2**		
160.		**4.42E-2**	
167.	**1.29E-2**		
175.	**6.21E-3**		
180.		**1.33E-2**	

Table G-9 (cont'd and end)

Like the measurements made with a BF3/Cd counter, these measurements are older than those made with activation dosimeters (1965). Up to the 70 cm abscissa, the scattering varies from 5 to 15% for repeated measurements and appears to increase beyond that point. The X=180cm value seems to be incorrect when compared with the X=160, 167, 175 cm values. Note that the light water mass was 250 cm thick.

Distance X in cm	Equivalent thermal flux at 2200m/s for bare Mn			
	Mai 57	5/4/65	7/4/65	26/4/65
0.0	5.50E6			1.04E7
3.0			4.23E7	3.75E7
4.5			4.19E7	
5.0	3.75E7			
6.0			3.37E7	3.38E7
7.5			3.37E7	
9.0			2.23E7	
10.	1.90E7			2.10E7
10.5			1.88E7	
12.			1.42E7	
13.5			9.07E6	
14.	6.90E6			
15.			7.90E6	7.72E6
20.	2.25E6		2.66E6	2.50E6
25.			8.40E5	
30.			3.40E5	
35.	1.60E5		1.50E5	
40.	5.90E4	6.50E4	5.60E4	
45.	3.10E4	2.96E4	2.94E4	
50.		1.22E4		
55.		6.18E3		
60.		2.45E3		
65.		1.30E3		
70.		6.53E2		
75.		3.76E2		
78.2		2.17E2		

Table G-10

IV Comparison of the readjusted experimental results with the results of calculation by the TRIPOLI4 program

This paragraph provides for each dosimeter the results of calculations made with the three-dimensional TRIPOLI4 Monte-Carlo program [5] as well as the ratios between calculated and experimental values (C/E) **after adjustment** of the experimental values by the multipliers explained in part B of reference [2] (paragraph V). These multipliers are listed in Table G-11 below.

Equivalent Mn and Mn/Cd (n,γ) thermal fluxes	**1.00**
Epithermal Au/Cd and In/Cd (n,γ) fluxes per unit of lethargy	**1.016**
Equivalent Rh103(n,n') fission fluxes	**0.815±0.04**
Equivalent S32 (n,p) fission fluxes	**0.815±0.03**
Equivalent P31(n,p) fission fluxes	**0.815±0.01**
Equivalent WIGNER Si fission fluxes	**1.015±0.02**

Table G-11

The interpretation of the light water experiment with the TRIPOLI4 program used the data file entitled "naiadeeau_60_fission_tripoli.data" distributed with SINBAD-NAIADE-H2O-60. The number of the results list was 05-010. The calculation included 360 batches of 7600 thermal neutrons and took 1601960 seconds on a PC sequenced at 2.7GHz. This simulation time included calculation of the power of the fission plate and calculation of propagation in 2.50 m of water. It was increased with regard to that of an ordinary calculation as a result of a deliberate over-biasing to ensure satisfactory simulation of fast neutrons at a very large distance.

The propagation of fast neutrons through a block of light water does not pose any problems regarding the choice of biasing parameters. Furthermore, with light water it is possible to use the MONITORING 0 option in TRIPLOI4 in conjunction with the FIXED_SOURCE_CRITICALITY option (sub-critical problem with an imposed source). We have therefore chosen these options. Accordingly, it was possible to define a beam of thermalised neutrons with a Maxwell distribution at the temperature of the NAÏADE hall as the source term. These neutrons induce first generation fast fission neutrons in the U235 of the converter. The neutrons generated in this way scatter into the (thick) converter and surrounding structures. A very small proportion is back-scattered by the water present in the experimental area. In turn, all these scattered neutrons produce fissions that are taken into account in the TRIPOLI4 calculation (around 12%) without any approximation regarding their spatial and energy distribution. This procedure, described in parts C and D of the report (reference [2]), requires optimised adjustment of the weighting (biasing) without there being any possibility of correction and adjustment by the TRIPOLI4 program itself. Our biasing parameters for fission neutrons were deliberately increased slightly more than usual in order to have a sufficient number of very fast neutrons with very high penetration (250 cm). In light water, a monitor group forms and supplies the neutron spectrum with epithermal neutrons at every distance. This slight increase in biasing, as we stated earlier, is what takes up the calculation time.

The cross sections and fission spectra for U235 and U238 used to interpret the experiment with the TRIPOLI4 program were all taken from the ENDF/B-VI R4 evaluation. To calculate conventional fluxes from reaction rates we used the average values on the fission spectrum σ_f, the resonance integrals I and the cross-sections at 2200m/s σ_0 given below. **They are consistent with the point cross-section data used to calculate reaction rates during interpretation by the TRIPOLI4 program.** The microscopic reaction rates are therefore specified unambiguously.

P31(n,p)	IRDF_90	σ_f=0.02858b	recalculated
Mn55(n,γ)	ENDF/B-VI/R4	σ_0=13.45b	[6]
S32(n,p)	IRDF_90	σ_f=0.06524b	recalculated
Au197(n,γ)	IRDF_90	I=1565b	[6]
In115(n,γ)	ENDF/B-VI R4	I=3281b	[6]
Rh103(n,n')	IRDF_90	σ_f=0.7033b	recalculated
Np237(n,f)	ENDF/B-VI R4	σ_f=1.305b	[6]
Si WIGNER	[3]	« σ_f « =0.9970	[3] and recalculation
B10(n,α)	ENDF/B-VI R4	σ_0=3840b	[6]

The effective cadmium cut-off was set at 0.5eV. Note the following with regard to the significance of the value "σ_f"=0.9970 for the silicon diode: in reference [3], the response function had been normalised (1964-1965) at unity on the U235 fission spectrum known at the time. We have used this normalisation for the U235 fission spectrum given in ENDF/B-VI R4, which explains the very slight deviation from unity.

The geometrical description used in the TRIPOLI4 calculations was constructed as follows. We kept the description of NAÏADE 1 given in part A of reference [2], in which the vessel is filled with light water (a parallelepiped measuring 300 cm × 300 cm × 250 cm). In this parallelepipedic-shaped volume, we established orthocylinders along axis Ox (of the converter) whose abscissas for the boundary planes normal to Ox coincide with those of all dosimeter centres. The two radii used to describe the orthocylinders are respectively 5 cm for X below 100 cm and 10 cm for X above 100 cm. This provides the average values for conventional fluxes on disks of surface areas measuring 78.5398 cm2 and 314.159 cm2 respectively. No correction was made to change from these average values to the values measured by the dosimeters which are practically point.

The number of atoms per 10^{-24} cm3 adopted for water are 3.3373E-2 for O16 and 6.6746E-2 for bonded H in H2O.

Table G-12 below gives the number of neutrons emitted for all generations combined. The spatial and energy distribution of the incident beam of neutrons thermalised at 27°C is described in part D of reference [2] (paragraph II-2-1). Note that the integral of the number of thermal neutrons emitted and used to normalize the calculation is 2.17104E11n/s. In order to determine the power of the fissile plate in the presence of water, we have divided the natural uranium converter into two equal parts 1 cm thick.

1. volume 11 on the ZOE reactor side (V11)
2. volume 12 on the NAÏADE 1 pit side (V12)

U235 first centimetre Volume 11	**1.1582E11 n/s**	**±0.0059%**
U235 second centimetre Volume 12	**5.6358E10 n/s**	**±0.0091%**
U235 TOTAL	**1.7218E11 n/s**	
U238 first centimetre Volume 11	**1.0572E10 n/s**	**±0.15%**
U238 second centimetre Volume 12	**8.9246E09 n/s**	**±0.14%**
U238 TOTAL	**1.9497E10 n/s**	
GRAND TOTAL	**1.9168E11 n/s**	

Table G-12

The following Tables, numbered from G-13 to G-22, list the following in succession:

- Type (a) Tables: results of calculations made by the TRIPOLI4 Monte-Carlo program with random standard deviations (σ as a %) and conventional fluxes at different abscissas.
- Type (b) Tables: C/E ratios for each abscissa by separating measurement campaigns made at different dates.

Distance X in cm	**Equivalent P31/Cd fission flux**	
	σ as a %	**TRIPOLI4**
0.	**0.59**	**1.952E7**
1.5	**0.61**	**1.316E7**
2.25	**0.62**	**1.116E7**
6.0	**0.69**	**5.220E6**
10.	**0.75**	**2.485E6**
15.	**0.81**	**1.050E6**
20.5	**0.95**	**4.335E5**
25.5	**1.08**	**2.000E5**
30.5	**1.16**	**9.486E4**

Table G-13 (a)

Distance X in cm	**Equivalent P31/Cd fission flux**		
	C/E 12/4/65	**C/E 26/4/65**	**C/E 7/7/65**
0.		**1.08**	
1.5			**1.08**
2.25		**1.00**	
6.0		**0.99**	**1.00**
10.		**0.95**	
15.		**0.95**	
20.5	**0.88**		
25.5	**0.94**		
30.5	**0.93**		

Table G-13 (b)

The match between calculated and experimental data is relatively good in the case of equivalent P31 fission flux. Note, however, a slight decline in the C/E ratio according to distance, which after around 30 centimetres amounts to almost 10%.

Distance X in cm	**Equivalent Rh/Cd fission flux**	
	σ as a %	**TRIPOLI4**
0.	**0.30**	**2.822E7**
3.7	**0.33**	**9.696E6**
6.8	**0.37**	**4.826E6**
10.9	**0.40**	**2.090E6**
27.	**0.66**	**1.257E5**
32.	**0.73**	**5.676E4**
37.	**0.84**	**2.648E4**

Table G-14 (a)

Distance X in cm	**Equivalent Rh/Cd fission flux**	
	C/E 14/4/65	**C/E 26/4/65**
0.		**1.06**
3.7		**0.95**
6.8		**0.91**
10.9		**0.79**
27.	**0.69**	
32.	**0.68**	
37.	**0.68**	

Table G-14 (b)

Note the strong mismatch for equivalent Rh103 fission flux and the excessive attenuation calculated by the program according to penetration distance. This point can very clearly be seen in the equivalent P31 fission flux in which the neutrons have greater energy than the Rh103.

Distance X in cm	Equivalent Si Wigner/Cd fission flux	
	σ as a %	TRIPOLI 4
0.5	0.25	2.775E7
3.	0.27	1.340E7
3.5	0.28	1.179E7
6.0	0.30	6.463E6
10.	0.33	2.719E6
15.	0.37	1.023E6
20.	0.44	4.144E5
25.	0.52	1.762E5

Table G-15 (a)

Distance X in cm	Equivalent Si Wigner/Cd fission flux		
	C/E 6-7/4/65	C/E 5-6-7/7/65	C/E 7/7/65
0.5	0.88 & 0.90		0.88
3.	0.75	0.75	
3.5	0.87		
6.0	0.85	0.86	0.85
10.	0.71		
15.	0.61		
20.	0.55	0.55	
25.	0.48		

Table G-15 (b)

It is worth noting firstly the excellent consistency of repeated measurements and secondly the underestimation of equivalent silicon fission flux by the calculation. The mismatch observed in the presentation of measurements with Rh103 would appear to be borne out by the silicon diode measurements, whose sensitivity is fairly comparable. The Annexes to reference [2] present the response of these diodes as a function of neutron energy [3].

Distance X in cm	**Equivalent S/Cd fission flux density**	
	σ as a %	**TRIPOLI4**
0.	**0.63**	**1.921E7**
5.	**0.69**	**6.248E6**
10.	**0.77**	**2.457E6**
15.	**0.82**	**1.042E6**
20.	**0.96**	**4.664E5**
25.	**1.09**	**2.152E5**
30.	**1.18**	**1.018E5**
34.7	**1.23**	**5.107E4**
40.	**1.36**	**2.416E4**
44.8	**1.47**	**1.247E4**
53	**1.66**	**4.218E3**

Table G-16 (a)

Distance X in cm	**Equivalent S/Cd fission flux**	
	C/E 5-6-7/7/65	**C/E 12-13/7/65**
0.	**1.12**	**1.07**
5.	**1.02**	**0.96**
10.		**0.94**
15.		**0.94**
20.		**0.92**
25.		**1.00**
30.		**1.04**
34.7	**1.04**	
40.	**1.09**	
44.8	**1.11**	
53	**1.21**	

Table G-16 (b)

Measurements made with the S32 dosimeter confirm the measurements recorded by the P31 dosimeter up to 30 cm of penetration. The S32 response is fairly close in sensitivity to that of the P31 dosimeter, if a little harder. The spectrum index for the S32/P31 (ratio between two fission equivalent fluxes) is therefore very close to unity. Beyond 40 cm the results of the calculation appear to overestimate those of the experiment. (The maximum abscissa of measurements by Rh103 dosimeters was 30 cm).

Distance X in cm	**Dose equivalent rate (ANS77) in Rem/h**	
	σ as a %	**TRIPOLI4**
0.0	**0.24**	**4.251E3**
10.	**0.34**	**4.371E2**
15.5	**0.43**	**1.486E2**
20.	**0.47**	**6.422E1**
30.	**0.66**	**1.146E1**
35.55	**0.71**	**4.739**
40.	**0.80**	**2.372**
50.	**1.01**	**5.412E-1**
58.75	**1.41**	**1.637E-1**
70.	**1.56**	**3.711E-2**
80.	**1.92**	**1.067E-2**
90.	**2.29**	**3.148E-3**

Table G-17 (a)

Distance X in cm	**Dose equivalent rate (fast PM) in mRem/h**			
	C/E 11/2/58	**C/E 5/7/58**	**C/E 7/7/58**	**C/E 9/7/58**
0.0	**2.85**	**2.87**		
10.	**2.03**	**1.84**		**2.47**
15.5			**2.15**	
20.	**1.69**	**1.54**	**1.66**	**2.14**
30.	**1.34**	**1.31**	**1.48**	**1.75**
35.55			**1.43**	
40.	**1.28**	**1.14**		**1.62**
50.	**1.16**	**1.03**	**1.23**	
58.75	**1.28**			
70.	**1.16**	**1.01**		
80.	**1.22**	**1.12**		
90.	**1.03**	**1.04**		

Table G-17 (b)

It is difficult to compare calculation data with experimental data in that the response function used by the calculation to obtain dose equivalent rates is the ANS_77 standard which may be different to the response of photomultiplier counter (fast PM [4]). A calculation by the TRIPOLI4 program with a reduced number of neutrons (360 batches of 760 thermal source neutrons, calculation reference number 05-011) was carried out firstly with the ANS_77 response function and secondly the factor for converting flux rate into dose equivalent rate recommended in 1958 for protection calculations [4]. This response function is given below in Table G-17 (c). The comparison of the two equivalent flow rates according to the distance travelled in water in NAÏADE 1 is given in Table G-17 (d).

Energy MeV	Conversion mRem/h	Energy MeV	Conversion mRem/h
0.	0.	2.50	0.212
0.25	0.0585	2.75	0.221
0.50	0.0900	3.00	0.230
0.75	0.115	3.25	0.238
1.00	0.134	3.50	0.246
1.25	0.150	3.75	0.254
1.50	0.164	4.00	0.261
1.75	0.177	4.25	0.269
2.00	0.190	4.50	0.275
2.25	0.200	4.75	0.281
		5.00	0.287

Table G-17 (c)

Distance X in cm	ANS_77 (A) TRIPOLI4 Rem/h	σ %	1958 [4] (B) TRIPOLI4 mRem/h	σ %	A/B ratio
0.0	4.227E3	0.74	5.016E6	0.80	0.843
10.	4.459E2	1.07	4.125E5	1.02	1.081
15.5	1.503E2	1.29	1.416E5	1.12	1.061
20.0	6.537E1	1.50	6.217E4	1.22	1.051
30.0	1.133E1	2.07	1.145E4	1.67	0.990
35.55	4.786	2.30	4.633E3	1.67	1.033
40.0	2.379	2.42	2.316E3	1.82	1.027
50.0	5.394E-1	2.99	5.203E2	2.26	1.037
58.75	1.599E-1	3.84	1.509E2	2.84	1.060
70.0	3.536E-2	4.2	3.339E1	3.47	1.059
80.0	9.921E-3	5.01	8.951	3.61	1.108
90.0	2.982E-3	7.14	2.656	5.81	1.123

Table G-17 (d) (during the same calculation and therefore using the same spectra)

Distance X in cm	**Flux by unit of lethargy at 1.46eV (In115/Cd)**			
	σ as a % (a)	**TRIPOLI4 (a)**	**σ as a % (b)**	**TRIPOLI4 (b)**
0.	**7.97**	**6.169E5**	**2.84**	**5.640E5**
0.5	**7.10**	**8.247E5**	**2.87**	**8.408E5**
3.0	**48**	**2.409E6**	**7.93**	**1.262E6**
3.5	**5.46**	**1.090E6**	**2.33**	**1.177E6**
6.0	**6.48**	**8.836E5**	**2.26**	**8.281E5**
10.	**8.31**	**3.401E5**	**2.69**	**3.256E5**
15.	**9.12**	**1.117E5**	**3.60**	**1.029E5**
20.	**12.**	**3.249E4**	**4.42**	**3.664E4**
25.	**10.**	**1.085E4**	**4.15**	**1.497E4**
30.	**13.**	**5.230E3**	**5.97**	**5.123E3**
40.	**21.**	**8.805E2**	**6.10**	**9.413E2**
0. à 40.	**Product (a) →**	**7.279E55**	**Product (b) →**	**5.169E55**

Table G-18 (a)

The column with the heading TRIPOLI4 (a) gives the flux by unit of lethargy at 1.46eV obtained by dividing the microscopic reaction rate by the resonance integral of In115. This flux density value contains a major statistical error due to the presence of fine resonance In115 at 1.46eV (the scores are highly scattered by distance between the resonance energy and the neutron energy at the moment of impact). We propose another method to obtain the flux by unit of lethargy (see column b): we divide the flux integrated into an interval centred around 1.46eV [4.38eV, 0.4867eV] by the width of this interval in lethargy (1.099 corresponds to a factor 3 on either side of 1.46eV). To check that this latter method did not introduce a slight bias, we calculated the products of the 11 flux density values obtained in of the columns TRIPOLI4(a) and TRIPOLI4(b), then we calculated the ratio Q_{In} of these two products.

This gives us the magnitude of around 3% for bias in that $\sqrt[11]{Q_{In}} = 1.0316$. Note that this estimate is itself skewed by statistical uncertainty.

Distance X in cm	**Flux by unit of lethargy at 4.91eV (Au197/Cd)**			
	σ as a % (c)	**TRIPOLI4 (c)**	**σ as a % (d)**	**TRIPOLI4 (d)**
0.	**9.54**	**5.799E5**	**3.30**	**6.169E5**
0.5	**8.69**	**8.939E5**	**2.39**	**8.377E5**
3.0	**7.73**	**1.168E6**	**1.85**	**1.164E6**
3.5	**6.52**	**1.050E6**	**2.27**	**1.155E6**
6.0	**12.**	**8.863E5**	**2.63**	**7.788E5**
10.	**7.24**	**2.815E5**	**2.66**	**3.081E5**
15.	**12.**	**1.003E5**	**3.56**	**9.453E4**
20.	**16.**	**3.015E4**	**4.43**	**3.253E4**
25.	**15.**	**1.360E4**	**5.00**	**1.333E4**
30.	**19.**	**4.956E3**	**6.71**	**4.722E3**
35.	**20.**	**1.732E3**	**8.55**	**2.328E3**
45.	**27.**	**4.243E2**	**9.77**	**4.126E2**
50.	**25.**	**1.442E2**	**9.26**	**2.085E2**
55.	**27.**	**1.274E2**	**8.82**	**1.167E2**
60.	**25.**	**4.121E1**	**11.**	**4.772E1**
65.	**29.**	**2.949E1**	**11.**	**2.402E1**
0. à 65.	**Product (c) →**	**5.366E65**	**Product (d) →**	**8.716E65**

Table G-18 (a')

This process of analysis was also applied to the Au197 dosimeter (resonance at 4.91eV) in Table G-18 (a') which also produced a bias of around 3% : $\sqrt[16]{Q_{Au}} = 0.970$
The energy interval is still a factor of 3 around 4.91eV namely [14.73eV, 1.6367eV].

Distance X in cm	**In115/Cd**	**Au197/Cd**
	Flux by unit of lethargy at1.46eV	**Flux by unit of lethargy at 4.91eV**
	C/E 13/4/65	**C/E 5-6/4/65**
0.0	**0.60**	**0.63**
0.5	**0.83**	**0.85**
3.0	**1.30**	**1.21**
3.5	**1.16**	**1.34**
6.0	**1.28**	**1.44**
10.	**1.16**	**1.52**
15.	**1.20**	**1.56**
20.	**1.40**	**1.47**
25.	**1.33**	**1.44**
30.		**1.26**
35.		**1.60**
40.	**1.12**	
45.		**1.15**
50.		**1.97**
60.		**1.51**

Table G-18 (b)

This Table shows the calculated values to be underestimated with regard to the experimental data for very low abscissas and to be overestimated for values above 3 cm of penetration.

Distance X in cm	**Equivalent flux at 2200m/s BF3/Cd counter**	
	σ as a %	**TRIPOLI4**
5.5	**2.05**	**4.016E5**
7.5	**2.05**	**2.585E5**
10.	**2.05**	**1.434E5**
15.	**2.88**	**4.471E4**
20.	**3.48**	**1.595E4**
30.	**4.66**	**2.298E3**
40.	**4.84**	**4.234E2**
50.	**6.26**	**9.357E1**
60.	**8.84**	**2.161E1**

Table G-19 (a)

Distance X in cm	**Equivalent flux at 2200m/s BF3/Cd counter**
	C/E 25/5/60
5.5	**0.81**
7.5	**0.73**
10.	**0.71**
15.	**0.71**
20.	**0.77**
30.	**0.73**
40.	**0.69**
50.	**0.73**
60.	**0.71**

Table G-19 (b)

The underestimation in the calculation is constant in relation to the abscissa: the C/E factor is around 0.7 to 0.8. It would be interesting to see the effect of the cadmium cut-off which we took to be equal to 0.5eV and which has greater impact for a response at 1/v (such as that of the BF3 counter) than in does for a resonating dosimeter such as Au197 for example.

Distance X in cm	**Equivalent thermal flux at 2200m/s Mn/Cd**	
	σ as a %	**TRIPOLI4**
0.0	**3.58**	**7.056E5**
1.0	**3.12**	**1.059E6**
2.40	**2.65**	**1.126E6**
3.5	**2.91**	**1.055E6**
4.0	**2.39**	**9.331E5**
5.0	**3.02**	**8.305E5**
10.	**4.54**	**2.709E5**
15.	**3.72**	**8.967E4**
20.	**4.80**	**2.717E4**
25.	**5.08**	**1.063E4**
30.	**26.**	**5.679E3**
35.	**8.10**	**2.161E3**
40.	**6.62**	**7.442E2**
45.	**9.54**	**3.559E2**
50.	**8.95**	**1.662E2**

Table G-20 (a)

Distance X in cm	**Equivalent thermal flux at 2200m/s Mn/Cd**	
	C/E 12/4/65	**C/E 5/7/65**
0.0		**0.92**
1.0		**1.06**
2.40		**1.10**
3.5		**1.24**
4.0		**1.18**
5.0		**1.19**
10.		**1.10**
15.		**1.20**
20.	**0.89**	
25.	**1.09**	
30.	**1.38**	
35.	**1.50**	
40.	**1.06**	
45.	**1.10**	
50.	**1.21**	

Table G-20 (b)

The conclusions drawn with regard to the part of the neutron spectrum above the cadmium cut-off are perfectly consistent with those drawn from analyses of the In115 and Au 197 dosimeters. It should nonetheless be noted that the stochastic accuracy of our Monte-Carlo calculations is not particularly good in that σ varies (Table G-20 (a)) from 4% to 10% if the abscissa point X=30cm is eliminated.

Distance X in cm	**Equivalent thermal flux at 2200m/s BareBF3 counter**	
	σ as a %	**TRIPOLI4**
0.0	**2.29**	**5.654E6**
1.0	**1.19**	**2.109E7**
2.0	**1.02**	**3.216E7**
4.0	**0.91**	**4.096E7**
5.0	**0.91**	**4.081E7**
7.5	**1.01**	**3.190E7**
10.	**0.87**	**2.212E7**
15.	**1.35**	**8.320E6**
20.	**1.43**	**3.016E6**
23.	**1.63**	**1.644E6**
27.	**1.75**	**7.260E5**
30.	**2.36**	**4.318E5**
37.	**2.73**	**1.240E5**
40.	**2.10**	**7.714E4**
43.	**2.83**	**4.776E4**
45.	**3.52**	**3.331E4**
50.	**3.42**	**1.564E4**
55.	**3.23**	**7.375E3**
60.	**4.47**	**3.729E3**
70.	**3.70**	**9.068E2**
72.	**3.81**	**6.789E2**

Table G-21 (a) beginning

Distance X cm (cont'd)	**Equivalent thermal flux at 2200m/s Bare BF3 counter**	
	σ as a %	**TRIPOLI 4**
77.	**3.62**	**3.630E2**
80.	**3.62**	**2.630E2**
85.	**4.02**	**1.303E2**
90.	**5.54**	**6.904E1**
97.	**5.23**	**2.766E1**
100.	**4.46**	**2.009E1**
107.	**3.12**	**8.441**
110.	**8.21**	**5.898**
112.	**3.61**	**4.438**
117.	**3.68**	**2.440**
120.	**4.08**	**1.816**
130.	**3.93**	**5.802E-1**
132.	**4.03**	**4.674E-1**
140.	**4.05**	**2.019E-1**
147.	**5.11**	**9.227E-2**
150.	**5.30**	**6.982E-2**
157.	**7.00**	**3.435E-2**
160.	**6.19**	**2.375E-2**
167.	**6.61**	**1.178E-2**
175.	**7.90**	**5.070E-3**
180.	**8.39**	**2.964E-3**

Table G-21 (a) cont'd and end

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare BF3 counter**		
	C/E May 57	**C/E 8/2/58**	**C/E 10/5/60**
0.0			**0.64**
1.0			**0.87**
2.0			**0.97**
4.0			**1.18**
5.0			**1.15**
7.5			**1.20**
10.			**1.47**
15.	**1.17**		
20.	**1.24**		**1.24**
23.	**1.27**		
27.	**1.26**		
30.	**1.39**		**1.26**
37.	**1.08**		
40.	**1.06**		**1.24**
43.	**1.02**		
45.	**1.02**		
50.	**1.18**		**1.27**
55.	**1.66**		
60.	**1.36**		**1.42**
70.			**1.41**
72.	**1.39**		

Table G-21 (b) beginning

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare BF3 counter (cont'd)**		
	C/E May 57	**C/E 8/2/58**	**C/E 10/5/60**
77.	**1.86**		
80.	**2.48**		**1.55**
85.	**1.96**		
90.	**1.73**		**1.52**
97.	**1.28**		
100.			**1.53**
107.	**1.59**		
110.			**1.46**
112.	**1.56**		
117.	**1.83**		
120.		**1.24**	**1.38**
130.			**1.35**
132.	**1.51**		
140.		**0.95**	**1.31**
147.	**1.29**		
150.			**1.22**
157.	**0.99**		
160.		**0.54**	
167.	**0.91**		
175.	**0.82**		
180.		**0.22**	

Table G-21 (b) cont'd and end

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare Mn**	
	σ as a %	**TRIPOLI4**
0.0	**2.14**	**6.059E6**
3.0	**0.95**	**3.914E7**
4.5	**0.96**	**4.159E7**
5.0	**0.90**	**4.109E7**
6.0	**1.07**	**3.771E7**
7.5	**1.01**	**3.202E7**
9.0	**0.83**	**2.614E7**
10.	**0.86**	**2.219E7**
10.5	**0.83**	**2.017E7**
12.	**0.94**	**1.524E7**
13.5	**1.07**	**1.131E7**
14.		
15.	**1.35**	**8.335E6**
20.	**1.42**	**3.007E6**
25.	**1.60**	**1.081E6**
30.	**2.34**	**4.341E5**
35.	**2.35**	**1.776E5**
40.	**2.09**	**7.703E4**
45.	**3.51**	**3.339E4**
50.	**3.40**	**1.567E4**
55.	**3.24**	**7.419E3**
60.	**4.45**	**3.741E3**
65.	**4.11**	**1.894E3**
70.	**3.70**	**9.093E2**
75.	**4.95**	**4.963E2**
78.2	**4.39**	**3.167E2**

Table G-22 (a)

Distance X in cm	**Equivalent thermal flux at 2200m/s bare Mn**			
	C/E May 57	**C/E 5/4/65**	**C/E 7/4/65**	**C/E 26/4/65**
0.0	**1.10**			**0.58**
3.0			**0.93**	**1.04**
4.5			**0.99**	
5.0	**1.10**			
6.0			**1.12**	**1.12**
7.5			**0.95**	
9.0			**1.17**	
10.	**1.17**			**1.06**
10.5			**1.07**	
12.			**1.07**	
13.5			**1.25**	
14.				
15.			**1.06**	**1.08**
20.	**1.34**		**1.13**	**1.20**
25.			**1.29**	
30.			**1.28**	
35.	**1.11**		**1.18**	
40.	**1.31**	**1.19**	**1.38**	
45.	**1.08**	**1.13**	**1.14**	
50.		**1.28**		
55.		**1.20**		
60.		**1.53**		
65.		**1.46**		
70.		**1.39**		
75.		**1.32**		
78.2		**1.46**		

Table G-22 (b)

The comparisons of the values calculated by the TRIPOLI4 program with the thermal neutron measurements by the dosimeters (Table G-21 (b) for the bare BF3 counter and (b) for the bar Mn55 dosimeter) are perfectly consistent with the conclusions drawn with regard to epithermal dosimeters up to penetrations of around 80 cm. The calculation produced one underestimation for a very short distance and one overestimation after a few centimetres of propagation. Table G-21 (b) (bare BF3), shows a sharp decrease in the C/E ratio at penetration distances over 150 cm, perhaps due to background noise or the existence of photoneutrons at a very large distance.

V Influence of the origin of Rh103 response functions on calculation results

The comparison of the calculation and experimental results for equivalent Rhodium fission flux density poses a problem in that the attenuation calculated in the water is far higher than that observed during the experiment (see Table G-14 (b)). This mismatch appears to be borne out by the analysis of the C/E ratios for silicon diode measurements. We have nonetheless calculated the C/E ratios with other evaluations of the cross section Rh103 (n,n'):

• IRDF90	703.3mb	255 values
• RRDF98	707.7mb	201 values
• IRDF02	712.6mb	255 values

Table G-23 lists the values of C/E ratios for the various function response origins according to distance. Note that these ratios can be precisely compared with each other given that they were obtained from the same calculation (05_012) which means that the calculated spectrum is strictly the same.

Influence of the origin of Rh103(n,n') cross sections						
Distance X in cm	**IRDF90**		**RRDF98**		**IRDF02**	
	C/E	**σ %**	**C/E**	**σ %**	**C/E**	**σ %**
0.	**1.064**	**0.80**	**1.035**	**0.83**	**1.061**	**0.80**
3.7	**0.952**	**0.89**	**0.932**	**0.92**	**0.950**	**0.89**
6.8	**0.903**	**0.94**	**0.888**	**0.98**	**0.901**	**0.95**
10.9	**0.792**	**1.07**	**0.785**	**1.11**	**0.792**	**1.09**
27.0	**0.691**	**1.57**	**0.695**	**1.63**	**0.693**	**1.60**
32.0	**0.684**	**1.85**	**0.689**	**1.88**	**0.686**	**1.86**
37.0	**0.690**	**2.84**	**0.697**	**2.10**	**0.693**	**2.08**

Table G-23

VI Calculated estimate of background noise

The contribution to background noise by fast and epithermal neutrons (E>0.5eV) from the core of the ZOE reactor was calculated by the TRIPOLI4 program. The Maxwell neutrons from the ZOE reactor's reflector were attenuated by the uranium plate and then absorbed by the thick boral shield. The determination of the source of the neutrons generating the background noise is described in part D of reference [2] (§IV).

The experimental flux levels (see details in Table D-15 of reference [2]) were determined under the following conditions:

- No uranium plate to convert thermal neutrons into fission neutrons;
- No thick boral shield;
- 60 cm diaphragm;
- Aluminium vessel in place;
- ZOE power output reduced to 100kW;
- Measurements made along the axis of the converter on the inside face of the vessel (x=y=z=0.).

Under the above conditions the experimental flux values were as follows:

Equivalent fission flux at 2200m/s	6.4E7
Flux by unit of lethargy	1.e4 to 2.e4
Equivalent fission flux	4.0E4 to 5.0e4

It should also be noted that the magnitude of the equivalent fission flux at the same point with, this time, the presence of the fission plate (converter) and boral shield produced a result of 1.8E7, i.e. almost 0.3% as the noise/signal ratio.

The results given below were obtained with a background noise source which met the specification given in paragraph IV-2 of part D (reference [2]). The neutrons were only emitted within a cone along an axis Ox with a cone angle of arccos (0.95) to avoid expending calculation time on the concrete structures surrounding the ZOE reactor. The TRIPOLI4 calculation used the file “bruitdefond_eau_60_fission.data” distributed with SINBAD-NAIADE-H2O-60. It comprised 450 batches of 210000 neutrons and took 289399s.

The last column in the following Tables, relating to a given dosimeter, indicates the percentage background noise (TRIPOLI4 calculation 05-014) with regard to the direct signal, the latter being the value calculated by TRIPOLI4. The second column lists the random standard deviation in the background noise. This standard deviation is attributable solely to use of the Monte-Carlo method.

Distance X in cm	**Equivalent P31/Cd flux**	
	σ as a % (noise)	**Noise/signal TRIPOLI4 %**
0.	**0.64**	**0.217**
1.5	**0.52**	**0.237**
2.25	**0.71**	**0.249**
6.0	**0.62**	**0.298**
10.	**0.65**	**0.347**
15.	**0.83**	**0.410**
20.5	**0.93**	**0.475**
25.5	**0.92**	**0.533**
30.5	**1.04**	**0.586**

Table G-24

Distance X in cm	**Equivalent Rh/Cd fission flux**	
	σ as a % **(noise)**	**Noise/signal as a % TRIPOLI4**
0.	**0.48**	**0.200**
3.7	**0.40**	**0.251**
6.8	**0.47**	**0.290**
10.9	**0.59**	**0.338**
27.	**0.98**	**0.516**
32.	**0.95**	**0.567**
37.	**1.05**	**0.613**

Table G-25

Distance X in cm	**Equivalent Si Wigner/Cd fission flux**	
	σ as a % **(noise)**	**Noise/signal as a % TRIPOLI4**
0.5	**0.37**	**0.200**
3.	**0.39**	**0.233**
3.5	**0.48**	**0.241**
6.0	**0.43**	**0.272**
10.	**0.50**	**0.318**
15.	**1.45**	**0.381**
20.	**1.14**	**0.432**
25.	**0.82**	**0.482**

Table G-26

Distance X in cm	**Equivalent S/Cd fission flux**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
0.	**0.70**	**0.217**
5.	**0.65**	**0.287**
10.	**0.69**	**0.349**
15.	**0.88**	**0.412**
20.	**0.90**	**0.468**
25.	**0.92**	**0.528**
30.	**1.12**	**0.582**
34.7	**1.13**	**0.648**
40.	**1.27**	**0.698**
44.8	**1.38**	**0.783**
53	**1.99**	**0.884**

Table G-27

Distance X in cm	Dose equivalent rate (ANS77) in Rem/h	
	σ as a % (noise)	Noise/Signal as a % TRIPOLI4
0.0	0.43	0.208
10.	0.44	0.317
15.5	0.50	0.365
20.	0.99	0.414
30.	0.72	0.512
35.55	0.85	0.577
40.	1.26	0.632
50.	1.15	0.757
58.75	1.47	0.840
70.	1.47	0.990
80.	5.53	1.15
90.	3.05	1.24

Table G-28

Distance X in cm	**Flux per unit of lethargy (1.46eV In115/Cd)**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
0.	**1.55**	**0.838**
0.5	**1.52**	**0.848**
3.0	**1.38**	**0.497**
3.5	**1.03**	**0.458**
6.0	**1.86**	**0.322**
10.	**2.68**	**0.283**
15.	**2.21**	**0.309**
20.	**1.99**	**0.373**
25.	**2.46**	**0.392**
30.	**3.61**	**0.502**
40.	**3.87**	**0.659**

Table G-29

Distance X in cm	**Flux by unit of lethargy (4.91eV Au197/Cd)**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
0.	**1.82**	**0.917**
0.5	**1.32**	**0.965**
3.0	**1.46**	**0.508**
3.5	**1.09**	**0.432**
6.0	**2.02**	**0.307**
10.	**2.63**	**0.264**
15.	**2.25**	**0.308**
20.	**3.24**	**0.381**
25.	**2.68**	**0.400**
30.	**3.62**	**0.520**
35.	**2.71**	**0.500**
45.	**3.15**	**(0.715)***
50.	**4.48**	**(0.679)***
55.	**3.11**	**(0.644)***
60.	**3.93**	**(0.828)***
65.	**3.21**	**(0.862)***

Table G-30

* The useful signal comprises a significant stochastic inaccuracy.

Distance X in cm	**Equivalent flux at 2200m/s BF3/Cd counter**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
5.5	**1.15**	**0.321**
7.5	**1.34**	**0.277**
10.	**2.22**	**0.278**
15.	**1.72**	**0.312**
20.	**2.34**	**0.374**
30.	**2.77**	**0.511**
40.	**3.21**	**0.601**
50.	**2.85**	**0.698**
60.	**3.08**	**0.854**

Table G-31

Distance X in cm	**Equivalent thermal flux at 2200m/s Mn/Cd**	
	σ as a % **(noise)**	**Noise/Signal as a % TRIPOLI4**
0.0	**2.14**	**1.15**
1.0	**1.20**	**0.723**
2.40	**1.06**	**0.501**
3.5	**1.39**	**0.380**
4.0	**2.09**	**0.368**
5.0	**2.40**	**0.318**
10.	**3.62**	**0.266**
15.	**2.58**	**0.336**
20.	**2.85**	**0.385**
25.	**3.36**	**0.448**
30.	**3.76**	**(0.374)**
35.	**3.58**	**0.474**
40.	**4.82**	**0.647**
45.	**3.18**	**0.693**
50.	**6.47**	**(0.792)**

Table G-32

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare BF3 counter**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
0.0	**1.00**	**0.620**
1.0	**0.67**	**0.600**
2.0	**0.50**	**0.546**
4.0	**0.58**	**0.455**
5.0	**1.77**	**0.426**
7.5	**0.67**	**0.362**
10.	**0.88**	**0.326**
15.	**0.68**	**0.320**
20.	**0.99**	**0.345**
23.	**0.92**	**0.370**
27.	**1.00**	**0.438**
30.	**1.19**	**0.463**
37.	**1.04**	**0.525**
40.	**1.24**	**0.546**
43.	**1.33**	**0.576**
45.	**1.11**	**0.625**
50.	**1.40**	**0.662**
55.	**1.27**	**0.712**
60.	**1.34**	**0.733**
70.	**1.31**	**0.893**
72.	**1.58**	**0.951**

Table G-33 beginning

Distance X in cm (cont'd)	**Equivalent thermal flux at 2200m/s Bare BF3 counter**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
77.	**1.74**	**0.978**
80.	**2.92**	**0.957**
85.	**1.53**	**1.07**
90.	**1.53**	**1.11**
97.	**1.68**	**1.25**
100.	**1.82**	**1.24**
107.	**1.89**	**1.33**
110.	**2.04**	**1.36**
112.	**2.01**	**1.45**
117.	**2.22**	**1.50**
120.	**2.29**	**1.46**
130.	**2.51**	**1.55**
132.	**2.60**	**1.56**
140.	**2.82**	**1.54**
147.	**3.01**	**1.62**
150.	**3.04**	**1.57**
157.	**3.25**	**1.57**
160.	**3.26**	**1.66**
167.	**3.39**	**1.61**
175.	**3.55**	**1.62**
180.	**3.64**	**1.66**

Table G-33 cont'd and end

Distance X in cm	**Equivalent thermal flux at 2200m/s Bare Mn**	
	σ as a % (noise)	**Noise/Signal as a % TRIPOLI4**
0.0	**0.95**	**0.667**
3.0	**0.52**	**0.495**
4.5	**0.55**	**0.434**
5.0	**1.75**	**0.441**
6.0	**0.62**	**0.398**
7.5	**0.69**	**0.362**
9.0	**0.71**	**0.331**
10.	**0.88**	**0.326**
10.5	**0.88**	**0.324**
12.	**0.74**	**0.317**
13.5	**0.85**	**0.320**
14.		
15.	**0.68**	**0.320**
20.	**0.99**	**0.347**
25.	**1.78**	**0.406**
30.	**1.19**	**0.445**
35.	**0.99**	**0.506**
40.	**1.24**	**0.547**
45.	**1.11**	**0.625**
50.	**1.39**	**0.664**
55.	**1.26**	**0.711**
60.	**1.33**	**0.737**
65.	**1.26**	**0.785**
70.	**1.32**	**0.895**
75.	**1.45**	**0.885**
78.2	**1.37**	**0.970**

Table G-34

VII Conclusions

The dosimeters used to measure fast neutrons were as follows:

1. Sulphur (reaction S32(n,p)) and phosphorus (reaction P31(n,p)) for relatively close responses (threshold of around 2MeV). The spectrum index calculated in water from the two equivalent fission fluxes is practically equal to unity.
2. The rhodium (reaction Rh103(n,n')) and the silicon diode which integrate neutrons with slightly less energy than sulphur and phosphorus (integration threshold of the order of several hundred keV for the two dosimeters).

We observed a satisfactory match between the calculation data and experiment data with regard to S32 and P31. However, the results of the calculations tend to overestimate equivalent S32 fission fluxes over large distances (X>40 cm) and to underestimate equivalent P31 fission fluxes, which increase according to distance (C/E=0.93 to 30.5cm) and slightly anticipate the direction of the results calculated for equivalent Rhodium fission fluxes. (Measurements with the P31 dosimeter were only made over distances of less than 30.5 cm). Analysis of the C/E ratios with regard to the response of the Rh103 dosimeter and silicon diodes clearly poses a problem in that the calculated equivalent Rh103 fission flux is attenuated more quickly than the measurements indicate (C/E=0.68 to 37cm). The same was true for the equivalent fission flux values calculated for the diodes which, in addition, are lower in absolute values. It is worth noting the very good level of reproducibility of the measurements made with diodes at an interval of 3 months

We shall not draw any firm conclusions regarding the C/E ratios for equivalent biological dose rate values due to lack of more specific knowledge about the response function according to the energy of the counter used and its calibration. The sole trend that we can indicate is the stronger attenuation for calculated values than for those obtained experimentally.

Analysis of the C/E ratios of dosimeters measuring slow neutrons (epicadmic and thermal) prompts us to draw the conclusions set out below. If we disregard the measurements by BF3 under cadmium (the calculation uniformly underestimates the experimental data by 20 to 25%), the other C/E ratios are mutually consistent with regard to both measurements of epithermal (Mn55/Cd, Au197/Cd, In115/Cd) and measurements of thermal neutrons. There is underestimation over a very short distance (as in the case of other benchmarks such as iron and graphite) and a practically constant small overestimation afterwards. After 150 cm of penetration, a parasite signal appears which may be attributable to neutron background noise, perhaps due to photoneutrons which appear at large distances in light water (traces of deuterium). It should be noted that measurements of thermal neutrons in water have been made at very high penetration distances of up to 180 cm.

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