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SURVEY MEASUREMENTS ON THE OPTIMALISATION OF THE SCATTERER SHAPE FOR A COLD NEUTRON SOURCE

by

L. OLIVI and R. MISENTA

1966

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Experimental Neutron Physics

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SUMMARY

The output of subthermal neutrons was measured for differently shaped lucite samples in a graphite stack which simulated a tangential beam hole of a reactor. The samples were cooled to liquid nitrogen temperature. The obtained values were normalized to the output of a circular slab by the introduction of a shape factor. The measurements show that an elliptical slab in the reflection position and a black body shaped scatterer have gain factors by 20 - 50 % higher than a circular scatterer of the same thickness. The usual gain factor, which is defined as the neutron output at high temperature to that at low temperature is for all shapes between 2.5 and 3.

I. Introduction

The dependance of the cold neutron output on the moderator shape has been mentioned by Webb in his survey article on cold neutron sources and Webb proposed some scatterer geometries which can lead to a higher output of cold neutrons /¯1_/ from a cold moderator in the reactor.

For the planned installation of a cold neutron source in a tangential beam hole of the Ispra-I reactor the question has been raised wether a substantial increase in the output of cold neutrons can be obtained by appropriately choosing the shape of the scatterer cell.

In order to answer this question survey measurements have been performed on differently shaped lucite samples*. The spatial flux distribution in a tangential beam hole of a reactor was mocked up by a graphite stack with a channel of large cross section and with americium-beryllium neutron sources.

The counting rate of a BF_3 counter with a beryllium filter in front of it was taken as measure for the cold neutron output. With this mock-up the cold neutron output of cylindrical and elliptical scatterers and a scatterer with a black body shape was measured at room temperature and at about 80°K.

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* The experimental investigation of this question was suggested by W.KLEY.

Manuscript received on March 15, 1966.

II. Experimental set-up and flux distribution

The neutron flux in a tangential beam hole is roughly mocked up in a graphite stack with a transversal channel (Fig. 1). Three Am-Be neutron sources with a total activity of 11 C and a total neutron output of 2.6×10^7 n/sec are placed in a distance of 28 cm from the channel. The neutrons are moderated by diffusing through the graphite and scattered by the scattering sample Sc into the collimator. The collimator has been chosen that only neutrons coming from the scatterer reach the counter. After having passed a beryllium filter with a length of 20 cm the neutrons are counted by a BF_3 counter. In the transversal channel is a vacuum insulated cryostat in which the samples are mounted and cooled. The heat from the samples is transferred to a copper box filled with liquid nitrogen by natural convection of helium gas.

Some measurements on the longitudinal, transversal and angular distributions of the thermal flux inside the channel have been made with a Cd-covered BF_3 counter with a length of 16 cm. The longitudinal flux distribution shows the expected cosine-like behaviour. The transversal flux decreases from the side of the neutron sources to the other side with a slope of approximately 0.85%/cm up to a distance of 16 cm and then with a slope of about 0.33%/cm[*]. The angular dependance of the flux has been measured in the central position of the transversal channel by rotating a BF_3 counter which had a Cd cover with a slit. By placing the slit in the direction of the source the counting rate was higher by 30% than the counting rate observed in the opposite sense. The Cd ratio is approximately 45 in the whole channel.

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[*] The distance is measured from the channel wall which is close to the neutron source.

III. Measurements

1. Method

For the measurements a scatterer sample * is mounted in a cryostat. Then the counting rate at room temperature is taken. The sample is cooled by natural convection of gaseous helium between a copper box which is filled with liquid nitrogen and the sample. As soon as the cooling starts the counting rates increases. After 8-10 hours the counting rate reaches a constant value, indicating that the scatterer has reached a steady state temperature. This value and the value of the counting rate taken at room temperature are the quantities of physical interest. For the evaluation of the results the background is subtracted from the measured counting rates. As background the counting rate measured without a scattering sample has been taken. All counting rates have been normalized to 10 min. From the corrected counting rates the gain factor is calculated. This factor is defined as the ratio of the corrected counting rate at low temperature to that at room temperature.

2. Circular slabs

The counting rates of circular lucite slabs with a diameter of 17.5 cm have been measured at room and at low temperature for thickness up to 6 cm. Fig. 2 shows the background corrected counting rates normalized to 10 min at the two temperatures and Fig. 5 the gain factors as function of the thickness. From the figures it is seen that the optimum thickness is between 3 and 4 cm and that there is no substantial increase in counting rate and gain factor for samples thicker than 2.5 cm.

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* All scatterers have been made from lucite, which has the sum formula $(C_5H_8O_2)_n$ a density of 1.2 g/cm^3 and 5.7x10^{22}h atoms/cm^3.

The arrows in Fig. 2 give the statistical error calculated from the total number of collected counts and by taking into account the statistical error of the background. In general the statistical error of the background corrected counting rates is between ±2 and ±7%.

The gain factors have been calculated by taking the counting rates from the curves from the Fig. 2 and calculating the ratios. For this reason no experimental points are indicated in Fig. 5. Based on the statistical errors of the counting rates at room and at low temperature an error of ±10% or less is estimated for the gain factors shown in Fig. 5.

3. Elliptical slabs

The counting rates of elliptical slabs with axis of about 42.5 cm and 17.5 cm and which were inclined by 26° against the channel wall have been measured in the two positions, reflection (Fig. 1b) and transmission (Fig. 1c) at room and at low temperature for thickness up to 5.2 cm. Fig. 3 shows the background corrected counting rates at the two temperatures and Fig. 5 the gain factors for elliptical lucite slabs in reflection and in transmission as function of the thickness.

From the figures it is seen that the optimum thickness for elliptical slabs is with 3 to 4 cm the same as for circular slabs. An important difference is seen by comparing the counting rates and the gain factors measured in reflection and transmission. For a thickness of 3.5 cm the counting rate measured in reflection is 375 cts/10' and for transmission 246 cts/10' whereas the respective gain factors are 2.5 and 3.0.

4. Black-body scatterer

A black body shape has been approximated by a cylindrical shell with an outer diameter of 17.5 cm and a height of 23 cm which is closed at one end by a circular slab of lucite with a thickness of 3.5 cm and at the other end by a circular beryllium piece with a thickness of 5 cm and a diameter of 10 cm (see insert of Fig.4). The counting rates for the samples at room and at low temperature have been measured for three thickness of the shell. Fig.4 shows the background corrected counting rates at room and at low temperature for three different thickness of the shell. From the figure it is seen that the counting rate reaches a maximum with a shell thickness of about 12 mm.

IV. Discussion of the results

For the discussion of the results a gain factor is used. Furthermore a shape factor [x] is introduced which is defined by the ratio back-ground corrected counting rate for a given sample at a temperature T to background corrected counting rate for a cylindrical sample with the same thickness at the same temperature T.

In Fig.5 the gain factors and the shape factors for the circular and the elliptical slabs in reflection and in transmission are plotted as function of the thickness.

For a slab thickness of 3.5 cm the background corrected counting rates at room and low temperature, the gain factors and the shape factors for the different scatterer shapes have been compiled in Table 1.

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[x] The defined shape factor includes not only the shape of the scatterer but also the position of the scatterer to the direction of the neutron current and the counting tube, e.g. for the elliptical slabs measured in reflection and transmission the shape is the same only the orientation against the neutron current and the counting tube is different.

	background corrected counting rate (cts/10') at		gain factor	shape factor at	
	room temperature	low		room temperature	low
circular slab	122	322	2.64	1.0	1.0
elliptical slab in reflection	148	374	2.54	1.21	1.15
in transmission	82	246	3.00	0.67	0.76
blackbody scatterer d_2 = 12 mm, 1 = 23 cm	185	478	2.58	1.51	1.48

Table 1 : The background corrected counting rates in cts/10' at room and low temperature, the gain factors and the shape factors at room and low temperature for the different scatterer shapes with a thickness of 3.5 cm

The obtained shape factors of 1,2 for an elliptical slab in reflection and of 1,5 for a black body shaped scatterer show that the output of cold neutrons from a scatterer placed in a neutron flux with a gradient can be increased by 20% in comparison with a circular slab, by choosing an elliptical slab of the same thickness and working in reflection or by 50% by choosing a black body shaped scatterer. This increase in the output is already obtained with the scatterers at room temperature. For an elliptical slab the shape factor is about 0,7 in transmission and 1,2 in reflection. The difference in the shape factor for an elliptical slab in reflection and transmission can be qualitatively understood. Due to the flux gradient the number of neutrons scattered by the scatterer surface which is seen by the counter is larger in the reflection position than that number in the transmission position.

In order to consider the shape factor of 1,5 for the black body shaped scatterer it is important to take into account that the shape factor comprises two different effects :

- the difference in the number of neutrons which are scattered per sec into the collimator by the circular slab and by the black body shaped scatterer ;
- and the difference in the probability that a neutron is moderated in the circular slab and in the black body shaped scatterer.

Since these two effects have not been separated by the measurements it is difficult to say which effect causes the incrase in the cold neutron output of the black body scatterer [x]. Since the shape factor for each of the three scatterers is the same at room and at low temperature survey measurements on the optimalisation of the scatterer shape can be made with hydrogenous samples at room temperature.

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[x] The two effects could be separated by counting in addition the number of neutrons above the Cd cut off which are scattered into the collimator by a circular slab and by a black body shaped scatterer.

A difference between the gain factors for a circular slab, an elliptical slab in reflection and a black body shaped scatterer has not been found. The gain factors for all these geometries is 2.5 to 2.6. For an elliptical slab in transmission a gain factor of 3 has been measured which is higher by about 20% than the gain factors of the three other scatterers. However the neutron output at low temperature is still lower by about 30% than the output of a circular slab.

<u>Bibliography</u>

1) F.J. Webb
Reactor Science and Technology, 17, 187 (1963)

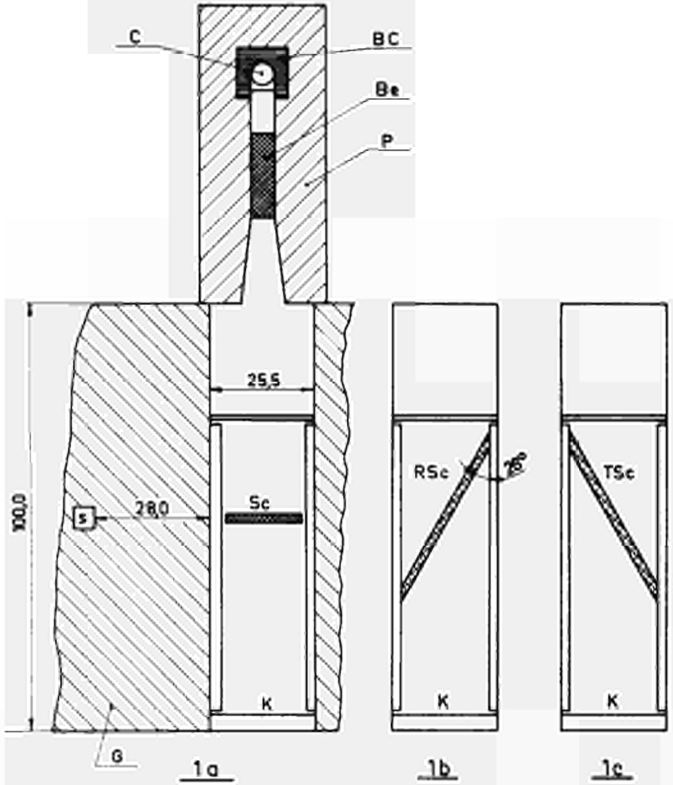

Fig.1 : Horisontal section of the experimental set-up

1a : Sc - Circular slab
1b : RSc- Elliptical slabs in reflection
1c : TSc- Elliptical slabs in transmission
C : Counter
Bc : Boron carbide
Be : Beryllium filter
P : Paraffine
S : Neutron source
G : Graphite
K : Cryostat

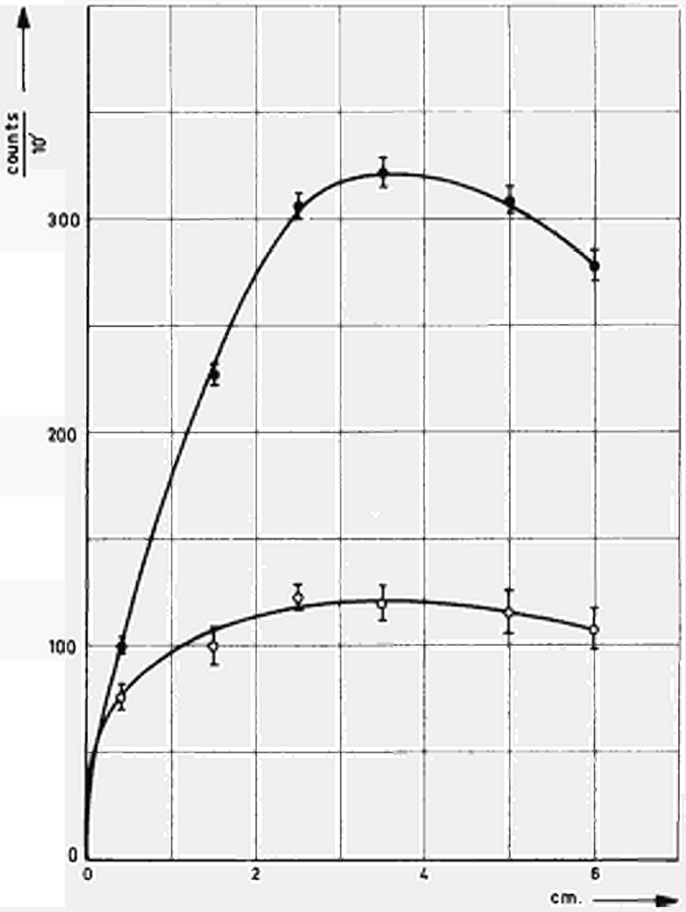

Fig.2 : The background corrected counting rates for circular lucite slabs as function of the thickness

Diameter of the slabs : 175 mm

Ŏ counting rates at room temperature

● counting rates obtained with the cooled samples

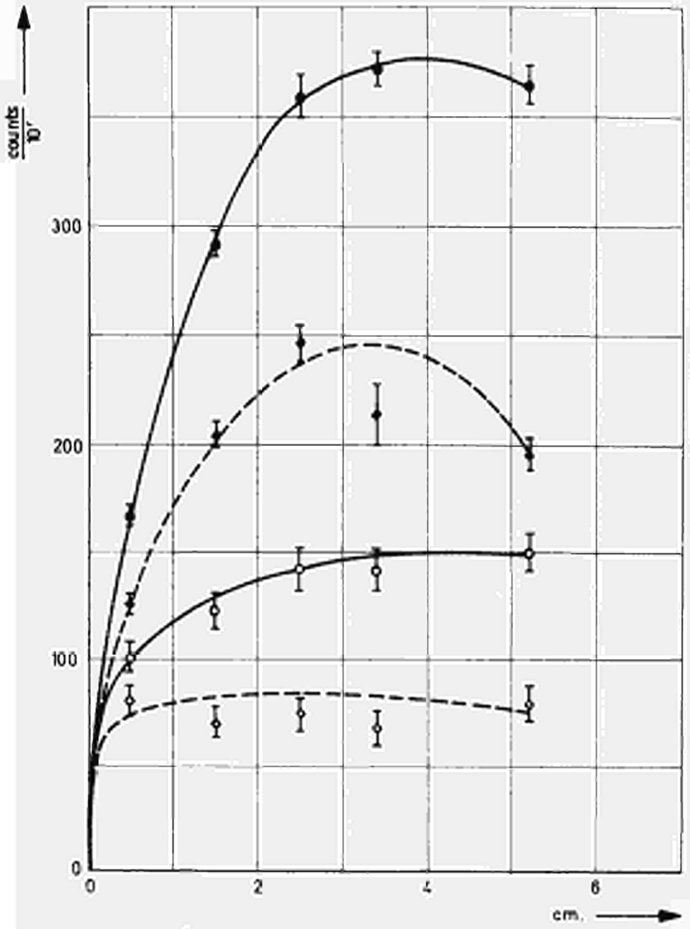

Fig.3 : The background corrected counting rates for circular lucite slabs measured in reflection and in transmission as function of the thickness

○ ○ counting rates at room temperature

○ ● counting rates obtained with the cooled samples

——— measured in reflection

- - - - - measured in transmission

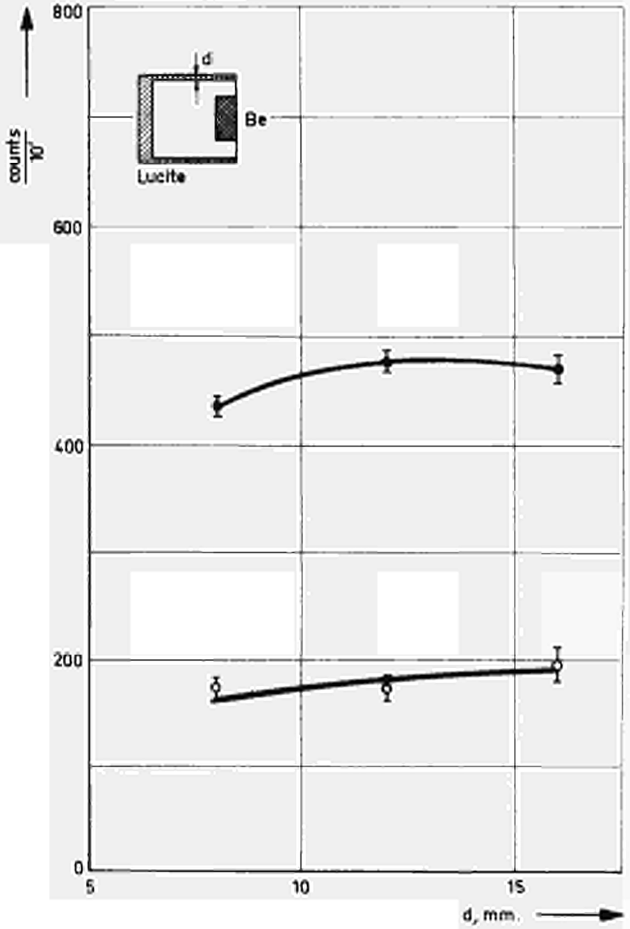

Fig.4 : The background corrected counting rates for a black body scatterer as function of the shell thickness d.

Be : circular beryllium piece with a diameter of 10 cm and a thickness of 5 cm

d : thickness of the shell

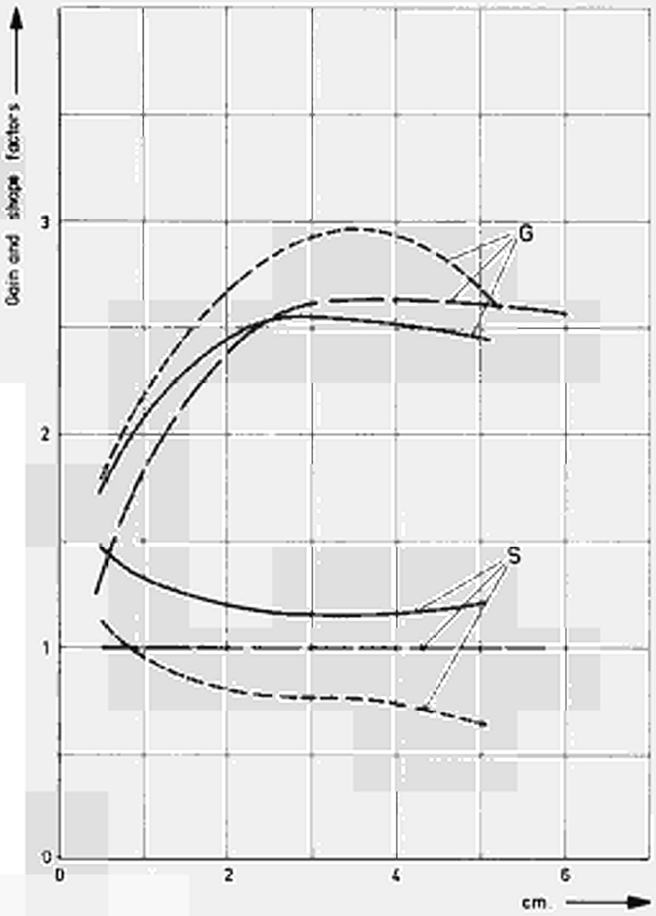

Fig.5 : The gain and shape factors for circular and elliptical slabs as function of the thickness

——— —— circular slab

———— elliptical slab in reflection

– – – – elliptical slab in transmission

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> To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.
>
> **Alfred Nobel**

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