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REFLECTOR STUDIES FOR PULSED NEUTRON MODERATORS

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ABSTRACT

The time independent thermal neutron flux emitted from a thin moderator surrounded by various configurations of reflector material has been measured using a small laboratory source. Significant gains over an unreflected moderator have been observed.

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INTRODUCTION

In the proposal documentation for the Rutherford Laboratory pulsed spallation neutron source[1], neutron intensity estimates were based on a conceptual design which incorporated neutron reflecting materials around the moderators. A reflector can increase the efficiency of a moderator by

(a) scattering into the moderator primary fast neutrons which would not otherwise enter it

(b) reflecting neutrons which have left the moderator in unfavourable directions after only a few collisions.

Materials suitable for use as reflectors on pulsed sources should have the following properties:

(a) High atomic number density
(b) High scattering cross-section in the energy range 200 eV - 1 MeV
(c) Low absorption in the energy range 200 eV - 1 MeV
(d) High (but not too high) logarithmic energy decrement per collision.

Common materials exhibiting these properties are Be, D_2O and graphite.

The literature on reflectors for pulsed thermal neutron systems is sparse (see for example [2 - 5]). For optimising the Rutherford Laboratory spallation neutron source target/moderator assembly benchmark data were obtained in a series of experiments during the summer 1977. In these experiments (referred to as MUSTA - Mock-Up Spallation Target Assembly), the Nimrod proton accelerator was operated with short pulses ($\sim$ 5 μs) at $\sim$ 800 MeV to simulate as far as possible the proposed source, and thermal neutron yields and pulsed widths were determined for a variety of target assembly configurations.

The present experiments provide basic data for reflectors *per se*. Measurements have been made of the time-independent thermal neutron fluxes emitted from the surface of a polyethylene moderator with a small Ac-Be source placed close to one edge. The moderator and reflector are neutronically 'decoupled' by means of an absorbing layer of cadmium or boron. (On a pulsed source this reduces pulse broadening due to the long time return of

slow neutrons from the reflector). Beryllium and graphite have been studied as reflecting materials, in 'close-packed' configurations, and in simulated MUSTA geometries using the actual MUSTA reflectors. The mean thermal vector flux at the surface of the moderator was calculated from a knowledge of the detector geometry and efficiency, and was related to the epithermal flux for comparison with the estimates for the new spallation neutron source.

EXPERIMENT

The configurations studied were:-

A Close packed beryllium reflector, 10 cm thick, Cd decoupled
B Close packed graphite reflector, 12 cm thick, Cd decoupled
C MUSTA beryllium reflector, Cd decoupled
D MUSTA small graphite reflector, Cd decoupled
E MUSTA small graphite reflector, B_4C decoupled
F MUSTA beryllium reflector, B_4C decoupled

The experimental arrangement for the 'close-packed' case is illustrated in figure 2. A 10 cm x 10 cm x 4 cm polyethylene moderator (ρ = 0.92 g cm^{-3}) surrounded on five sides by 1 mm thick cadmium sheet was viewed by a BF_3 counter placed at 86 cm from the uncovered 10 cm x 10 cm face. The moderator-counter path was surrounded by cadmium so that the counter could see nothing but polyethylene and cadmium. A small Ac-Be source ($\sim$ 1 cm^3) was placed close to one edge of the moderator and a large amount of borated resin shielding placed around the detector and cadmium tube. The Ac-Be source spectrum is shown in figure 1; the source strength was 6 x 10^7 n_f/min. A cadmium shutter was arranged in front of the BF_3 counter so that measurements could be made with and without cadmium covering the detector. The difference between these two measurements gives the number of neutrons arriving at the detector with energies less than 0.5 eV which for the present purpose we define as thermal neutrons. In each experiment the reflector was removed and a comparison made with the resulting 'bare' moderator. The cross-sectional area of the BF_3 was 4 cm^2, and a mean efficiency η = 0.5 was used in all cases.

In the MUSTA geometries, the Ac-Be source was located in the centre of a relatively large void ($\sim$ 10 cm high) corresponding to a realistic spallation target and there was a wide viewing port on one side of the moderator. A typical configuration is shown in figure 3. For measurements with the moderator decoupled from the reflector at an energy of 170 eV by B_4C, the moderator-detector distance was 103 cm, see figure 4.

RESULTS

A summary of the results is given in Table 1. A reflector 'gain' factor may be estimated from the ratio of the sub-cadmium count rate with reflector present to that with the reflector removed, ie for case A $\frac{83.7}{10.6} = 7.9$. The calculation of Φ_{th}, the thermal vector flux per source neutron at the surface of the moderator, and the estimation of the flux per unit lethargy at 1 eV, $E\,\Phi(E)\big|_{1eV}$, are detailed in the following example (case A):

For the detector of area 4 cm^2 at distance 86 cm from the moderator the solid angle factor $\frac{A}{L^2}$ is $\frac{4}{(86)^2}$. Thus, I_{th}, the thermal intensity emitted from the 100 cm^2 moderator face is given by

$$I_{th} = \frac{NL^2}{\eta A} = \frac{83.7 \times (86)^2}{0.5 \times 4} = 3.1\ 10^5 \text{ n ster}^{-1} \text{ min}^{-1}$$

Normalising to source neutrons

$$\Phi_{th} = \frac{I_{th}}{S} = \frac{3.1\ 10^5}{6\ 10^7} = 5.2\ 10^{-3} \text{ n ster}^{-1}\ n_f^{-1}$$

It has been shown experimentally that the ratio

$$\frac{\Phi_{th}}{E\Phi(E)\big|_{1eV}} = 4.5 \text{ for a } 10 \text{ cm} \times 10 \text{ cm} \times 4 \text{ cm } (CH_2)_n \text{ moderator [5],}$$

and this figure agrees to within 10% with the theoretical value calculated from Fermi age theory.

Thus for this configuration (case A), we have

$$E\Phi(E)\big|_{1eV} = \frac{\Phi_{th}}{4.5} = 1.2\ 10^{-3} \text{ n ster}^{-1}\ n_f^{-1}$$

SUMMARY

Table 1 summarises the experimental data and calculated intensities. It should be emphasised that these figures refer specifically to the geometries studied; for example, in some of the present experiments the primary neutron source was located in a void, decreasing the source-moderator coupling efficiency, and the reflector below the source region was ill-defined. In addition the coupling efficiency is low due to the relatively hard neutron spectrum from the Ac-Be source [6]. These factors all operate to reduce the reflector efficacy.

The results are consistent with the arguments used in estimating the spallation neutron source fluxes. (The SNS Proposal uses the figure $E\Phi(E)\big|_{1eV} = 2.5\ 10^{-4}$ n/ster.n_f). A Monte-Carlo simulation [6] of case F is also in good agreement with the observed value of the source-moderator-reflector coupling.

TABLE I

SUMMARY OF RESULTS

	Configuration	Solid Angle A/L^2	Sub-Cd Count Rate (Reflected) ct/min	Sub-Cd Count Rate (Reflector Removed) ct/min	I_{th} n_{th}/ster. min	Φ_{th} n_{th}/ster. n_f	$E\Phi(E)\rvert_{1eV}$ n/ster.n_f
A	Close packed beryllium, moderator in Cd trumpet	$\frac{4}{86^2}$	83.7	10.6	$3.1\ 10^5$	$5.2\ 10^{-3}$	$1.2\ 10^{-3}$
B	Close packed graphite, moderator in Cd trumpet	$\frac{4}{86^2}$	43.3	10.6	$1.6\ 10^5$	$2.7\ 10^{-3}$	$5.9\ 10^{-4}$
C	MUSTA beryllium, moderator in Cd trumpet	$\frac{4}{86^2}$	19.8	4.5	$7.3\ 10^4$	$1.2\ 10^{-3}$	$2.7\ 10^{-4}$
D	MUSTA small graphite, moderator in Cd trumpet	$\frac{4}{86^2}$	13.1	4.2	$4.8\ 10^4$	$8.1\ 10^4$	$1.8\ 10^{-4}$
E	MUSTA beryllium, moderator in MUSTA B_4C trumpet	$\frac{4}{103^2}$	5.8	2.6	$3.1\ 10^4$	$5.1\ 10^{-4}$	$1.1\ 10^{-4}$
F	MUSTA small graphite, moderator in MUSTA B_4C trumpet	$\frac{4}{103^2}$	5.2	2.9	$2.8\ 10^4$	$4.6\ 10^{-4}$	$1.0\ 10^{-4}$

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7. K W Geiger and L van der Zwan, 'Radioactive Neutron Source Spectra from ^{9}Be (α , n) Cross Section Data', Nucl. Instrum. Meth. 131, 315 (1975).

FIGURE CAPTIONS

1. The fast neutron spectrum produced by the Ac-α-Be reaction *[7]*.

2. 32 cm x 28 cm x 30 cm arrangement of graphite in the 'close-packed' configuration showing the location of the Ac-Be source relative to the 10 x 10 x 4 cm^3 moderator, cadmium tube, shielding and BF_3 detector. The reflector was located on a concrete base.

3a Source-moderator-reflector configuration for the MUSTA small graphite assembly.

3b Isometric view of the source-moderator-reflector configuration for the MUSTA small graphite assembly.

4. MUSTA beryllium assembly with the MUSTA B_4C decoupler trumpet in position. For clarity the cadmium tube used in the experiment has been removed.

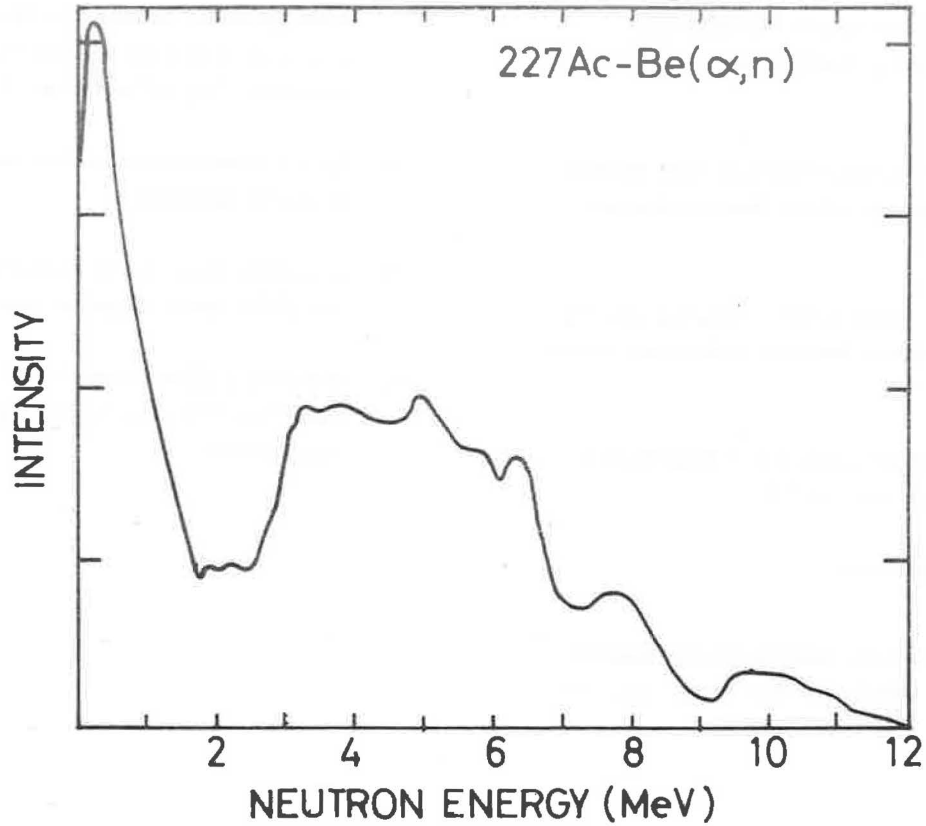


Fig.1.

CLOSE PACKED GRAPHITE REFLECTOR GEOMETRY

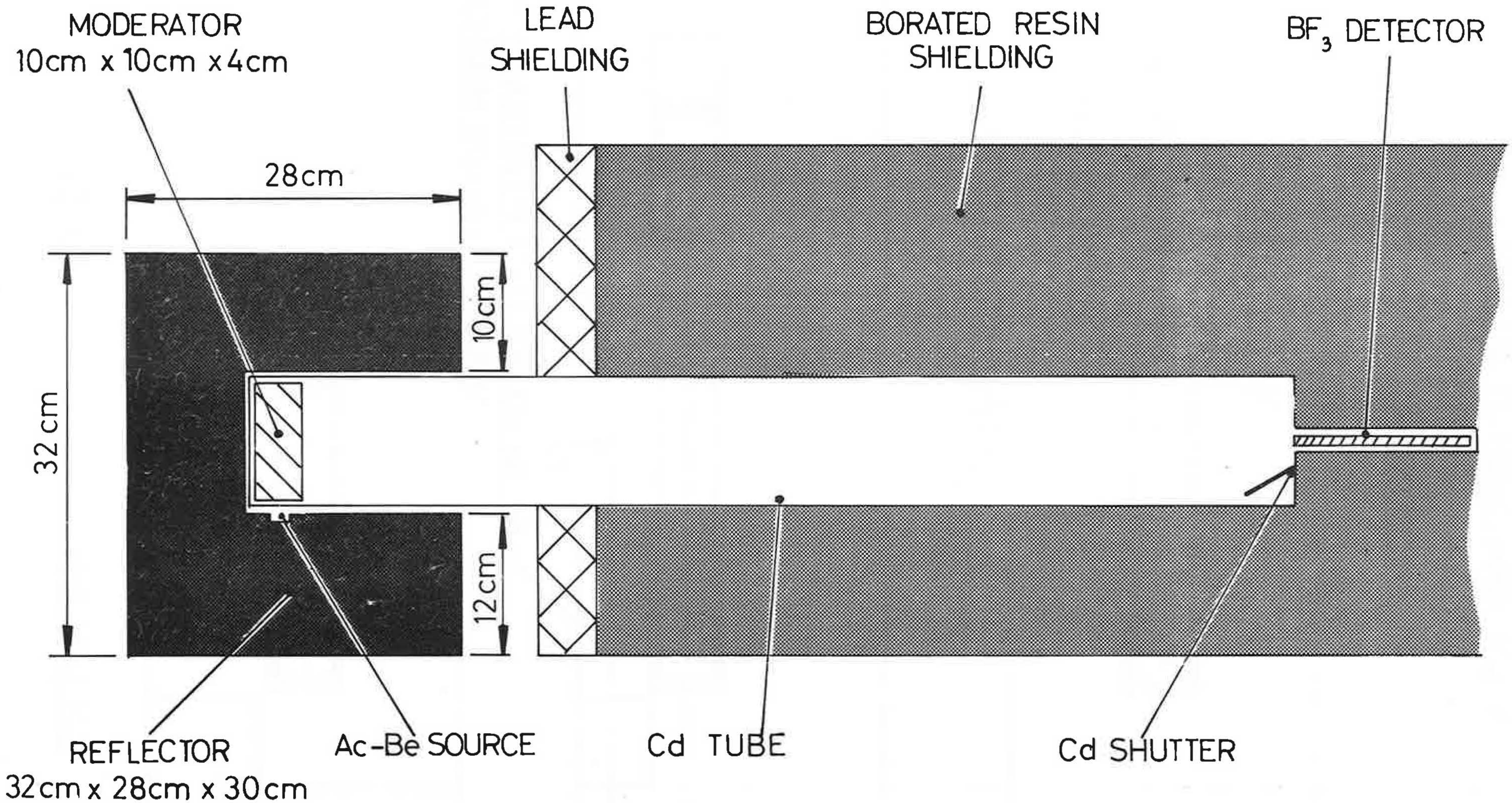
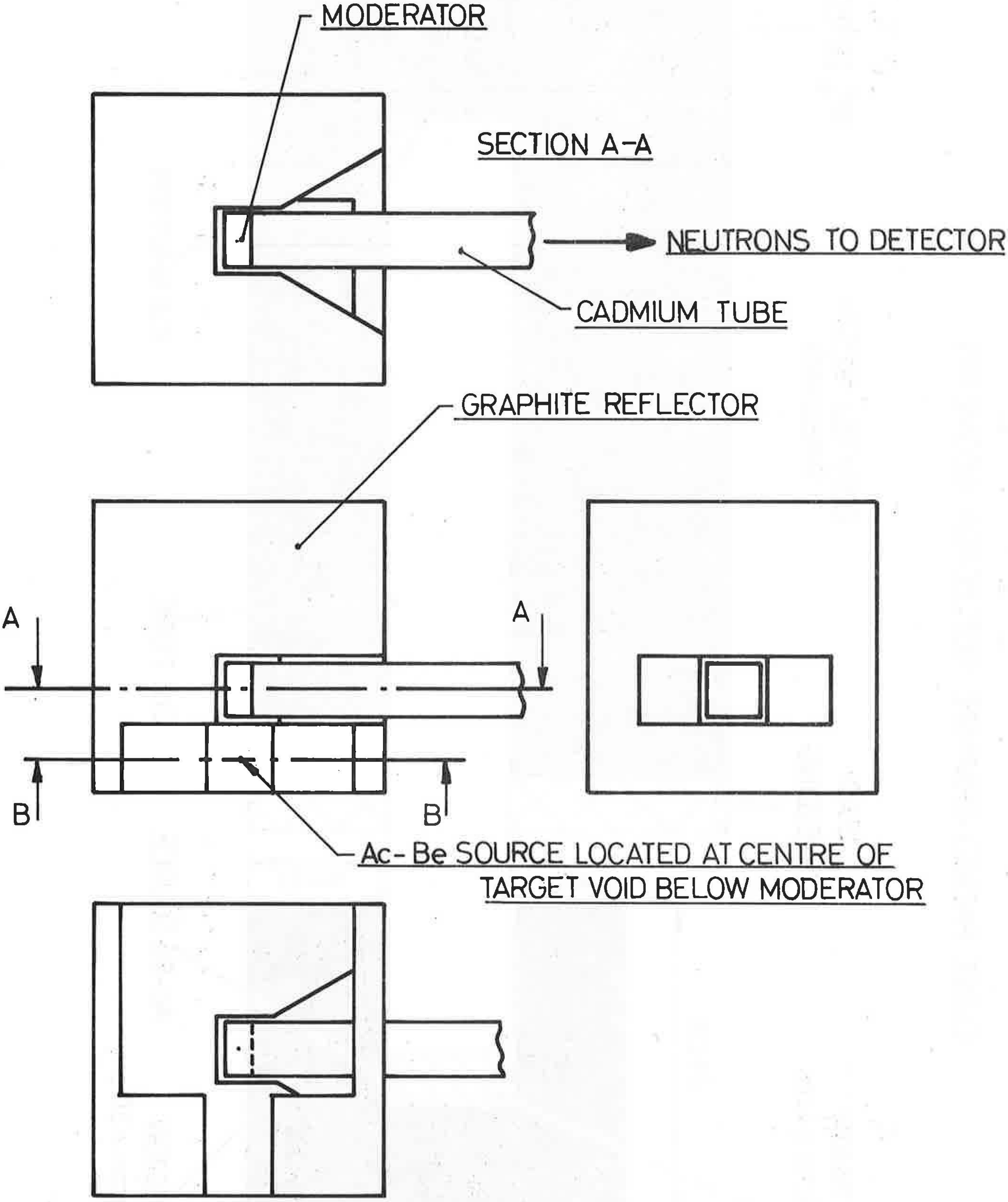


FIG 2

MUSTA SMALL GRAPHITE ASSEMBLY



SECTION B-B

FIG.3a.

MUSTA SMALL GRAPHITE ASSEMBLY

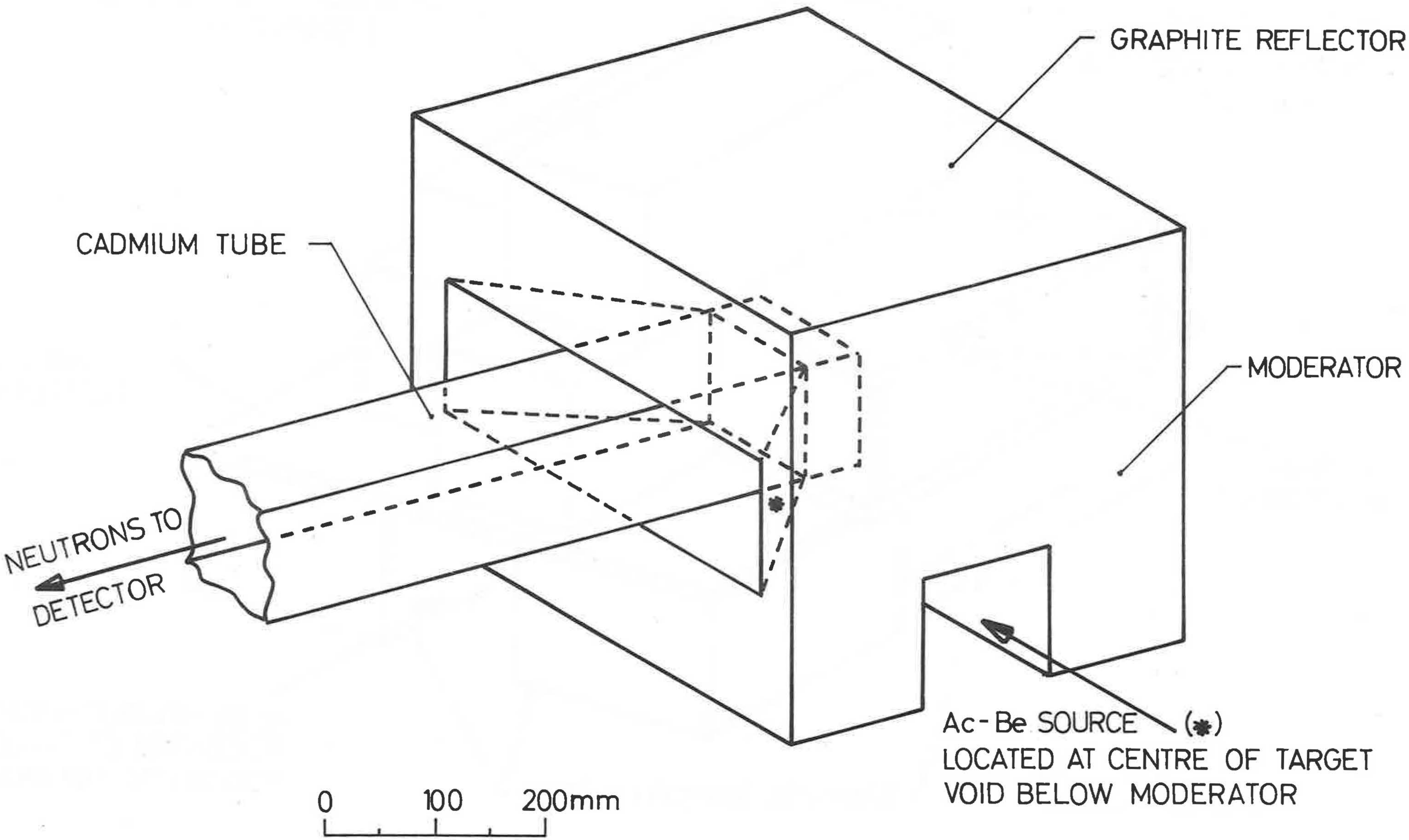
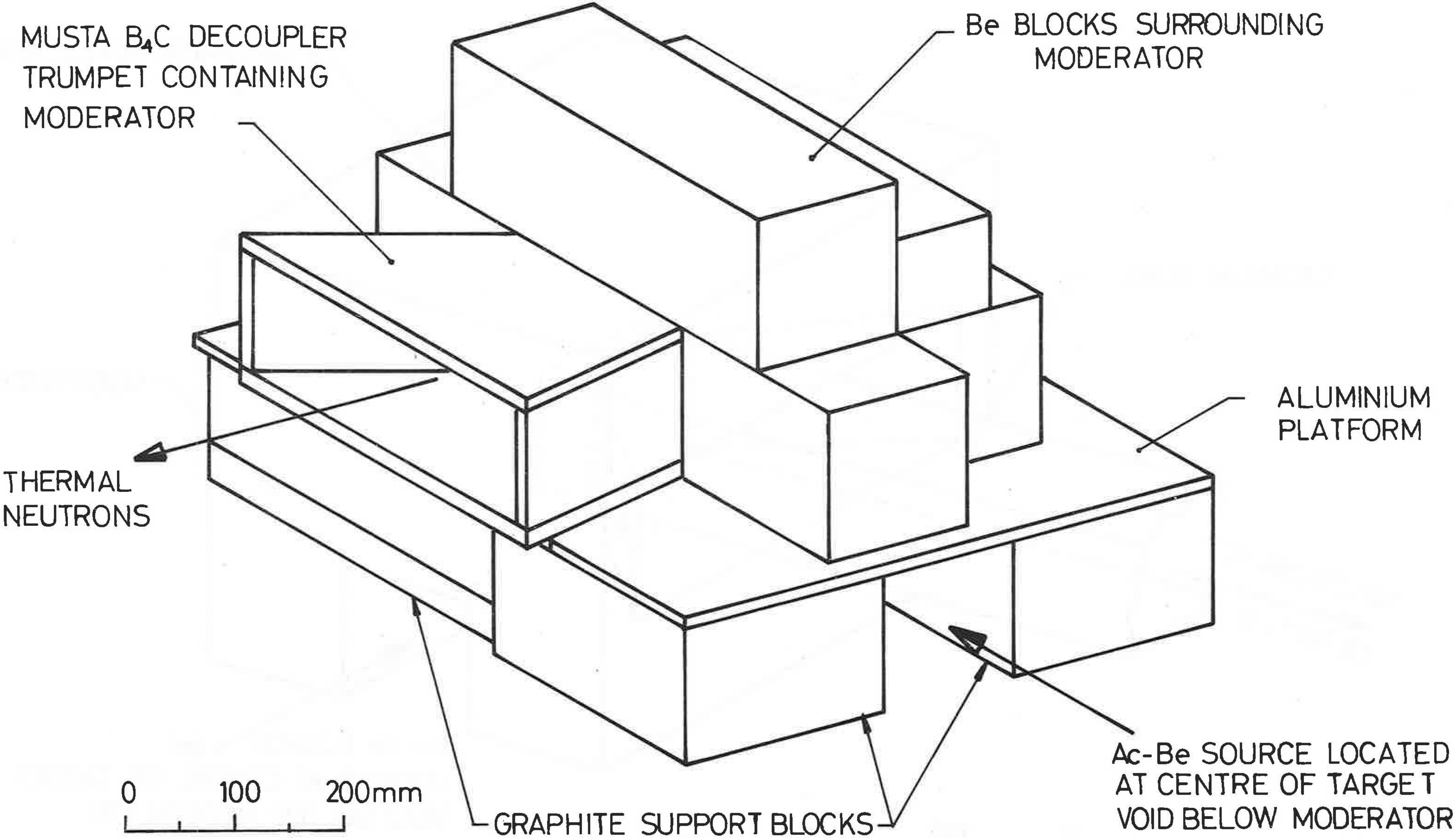


FIG.3b.



MUSTA BERYLLIUM ASSEMBLY

FIG. 4.