**EUR 538.e**

EUROPEAN ATOMIC ENERGY COMMUNITY — EURATOM

# THE MAGNETIC MIRROR NEUTRON POLARIZER AT THE REACTOR "ISPRA I"

by

M. FORTE

**1964**

**Joint Nuclear Research Center**
**Ispra Establishment - Italy**

**Reactor Physics Department - Neutron Physics**

**Paper presented at the International Conference on Nuclear Physics**
**with Reactor Neutrons**
**Argonne (Ill.) USA, 15-17 October 1963**

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shielding permit a reasonably low fast neutron and gamma-ray background (a gamma dose of $\sim$ 50 mr/hr in the beam). The spin of neutrons, guided in a special magnetic box where the field is gradually turned at 90°, can be reversed at the target position by reversing the box magnetizing current.

With moderate magnetic shielding, the reversal of the box field produced no systematic variation larger than $10^{-5}$ in the gain of conventional type scintillation counters placed close to the target.

The paper includes a description of the whole apparatus and some details of the mirror fabrication and mounting as well as measuring instrumentation and methods.

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## KEY TO THE FIGURES

# THE MAGNETIC MIRROR NEUTRON POLARIZER AT THE REACTOR "ISPRA I"

## INTRODUCTION

An apparatus producing a beam of polarized neutrons has been installed at the reactor Ispra 1.

The polarization is obtained by the method of reflecting a slow neutron beam on a magnetized Co-Fe mirror.

The beam is to be used, mainly, for capture gamma-ray experiments. The chosen method of polarization permits to combine a high neutron intensity with a very small beam width, so that narrow targets can be conveniently used. This is specially important in some experiments with polarized neutrons in order to avoid target scattering effects which would result to depolarization.

To facilitate the investigation of nuclei with low capture cross section, care has been taken for obtaining good beam purity and low background.

## 1 — MIRROR MATERIAL AND FABRICATION METHOD

At the surface of the magnetized mirror the refraction index must be larger or smaller than unity, according to the neutron spin state, so that total reflection of neutrons of one spin state can never take place. This condition is expressed, in terms of the average magnetic and nuclear coherent scattering amplitudes, by $| a_n | \leqslant a_m$, where $a_m$ will be proportional to the effective magnetic induction, taking into account that only a fraction of the atoms are oriented along the field.

Essentially, the only suitable magnetic materials are pure Co ($a_n = 0.28\ 10^{-12}$ cm, $a_m \simeq 2.5\ 10^{-17} B$ cm, $B$ in gauss) and Co alloys with some % Fe.

Using pure Co involves some practical difficulties. Indeed, to have satisfactory magnetic properties (not available with the normal exagonal structure of Co) it is necessary to use cubic structure Co, which can be formed by electroplating a thin layer on a copper backing (1).

The fabrication procedure is not quite straightforward and the layer may be easily damaged by the polishing work.

Therefore, we preferred to use, as a start material, a Co-Fe (Fe 6 %) alloy, as it was successfully employed at A.N.L. (2).

With this material ($a_n = 0.32\ 10^{-12}$ cm, $a_m \simeq 2.5\ 10^{-17} B$ cm), a magnetization (B-H) $\geqslant$ 13,000 gauss will fulfill the before stated condition.

We had available a hot rolled sheet 0.6 mm thick and 11 cm high. In preliminary magnetic measurements we found (B-H) $\simeq$ 15,700 to 17,000, at H = 100 to 350 gauss, in good agreement with the literature. (3).

The polarizing mirror, 110 cm long and 11 cm high, has been assemblied by aligning ten square mirrors. Each piece was made of a 11 × 11 cm$^2$ square of Co-Fe sheet, glued to a 2.5 cm thick copper backing by means of type I "Araldite". The sheet surface to be glued was first prepared by sand blasting. Care was taken for obtaining, as much as possible, a flat surface, so that, after working the same to an optical plane the sheet thickness remained sufficiently uniform to permit a regular magnetization.

The optical work was performed by conventional techniques (grinding with abrasives and polishing with oxides, by means of a pitch lap). Each mirror was obtained flat within few fringes. The polishing was not always satisfactory, indeed in almost all samples very fine scratches were visible under intense illumination, and sometimes slightly oxidized or opaque regions appeared.

The ten mirror segments are mounted on a single aluminum bar, as shown in fig. 1, 2, 3, so to expose to neutrons a 8 cm wide band of the mirror, where the magnetization is expected very high and regular (as previously measured with the separate Co-Fe sheets).

The precise alignement of the ten segments was obtained with reference to three thin (50 micron diam.) wires stretched along the mirror very close to its surface. By observing the distance between each wire and its image, with the help of an optical micrometer, the position of each segment could be set with an accuracy probably better than 5 ~ 10 microns.

## 2 — DESCRIPTION OF THE APPARATUS

The general lay out is shown in fig. 4.

A narrow thermal neutron beam is obtained through a first stainless steel collimator plugged into the beamhole. The collimating slit has the following dimensions : length 150 cm, height 10 cm, input width 0.9 cm, output width 0.5 cm.

The slit, which is closed at both ends by a 0.25 mm stainless steel window, can be filled with water to shut the beam.

After passing through the 8 cm high slit of a mechanical shutter, the beam is furtherly collimated by a lead-bronze plate fronting the first half of the mirror length. This latter collimation permits a minimum beam width, near the mirror center, of ~ 1.5 mm.

The separation between primary and reflected beam is finally accomplished by the output collimator made of a pair of lead-bronze plates fixed at the mirror end.

The mirror mounting bar, to which the collimating plates are fixed, is positioned in the gap of the electromagnet by means of micrometric screws. At the nominal 0° inclination, the mirror is aligned with one side of the collimating slit.

The electromagnet is made of two parallel Armco iron plates (poles) separated by six iron columns wound by coils. At the maximum supply power, of 300 W, the mirror is under a magnetizing field of about 350 gauss.

The apparatus is mounted on a heavy concrete basement and protected by a shielding tunnel consisting of a 10 cm inner lead wall and a 20 cm boron-paraffin (20 % boron oxide) wall. The inner surface of the tunnel is lined with 0.5 cm boron-plastic sheet.

Such a shielding was designed in order to provide a sufficient attenuation of both gamma and fast neutron doses, with a least encombrement. The outer dose levels, at 5 *MW* reactor power, are well below the M.P.L.'s adopted at Ispra, of 2.5 mrem/hr.

Some care was taken for reducing the stray radiations in the direction of the outgoing polarized neutron beam. Mainly, the walls of the slit of the mechanical shutter and the other collimating plates are made of a material (70 % Cu and 30 % Pb) having very high cross section both for fast neutrons and gamma-rays. Moreover, on their surfaces, thin coatings of boron and lithium compounds were suitably employed to prevent the production of high energy capture gamma-rays.

## 3 — BEAM MEASUREMENTS

The following characteristics of the outgoing beam have been experimentally studied:

— Intensity

— Polarization

— Collimation and flux distribution

— Ratio of fast to slow neutrons

— Gamma background

The measuring methods will first be described.

A detection efficiency of slow neutrons independent of the neutron spectrum (which varied with the mirror inclination, f.i.) was needed. The absolute slow neutron intensity was determined by detecting the 0.44 MeV gamma-rays from a thick *B* target exposed to the beam.

In connection with the polarization measurements we have mainly used a $BF_3$ counter placed in a 20 cm diam. paraffin cylinder enclosed in a Cd sheet. The detector was placed with its axis parallel to the beam height. The whole beam was admitted through a window in the Cd sheet.

The beam polarization was measured by means of a double reflection experiment, using the so called "shim method".

The polarized beam reflected from the firts mirror was made to reflect on a second mirror of the same kind and magnetized in a field of the same intensity and orientation (but, for practical reasons the analyzing mirror was only 55 cm long). The intensity after the second reflection was measured.

The beam impinging on the second mirror was then depolarized completely by inserting a 0.25 mm thick Fe shim. The intensity ratio with and without shim is related to the intrinsic polarization of the two mirrors, by $R = P_1.P_2 + 1$.

An accurate determination of the shim ratio was obtained after correcting for the secondary effects of the shim, such as absorption and small angle scattering. The correction, directly measured by inserting a second identical shim across the beam already depolarized by the first shim, was of the order of 3 ~ 4 %.

## 4 — MEASUREMENTS RESULTS

The polarization was measured at the same time as the total intensity and the fast neutrons and gamma background, while the beam collimation and the mirror inclination were variously adjusted.

The best compromise between neutron intensity and polarization, from a purely statistical point of view, corresponds to a maximum product $P\sqrt{I}$, which means a minimum measuring time of a polarization dependent effect, to have a given statistical accuracy.

From a practical point of view, however, the most stringent requirement is often to keep the background of fast neutrons and gamma-rays at a reasonably low level.

We observed first that, while the inclination of the polarizing mirror varied between 8' and 13', the intensity changed by a factor of the order of 2, but the polarization was not significantly affected. The corrected shim ratio ranged between ~ 1.55 and 1.65, indicating a "probable" polarization, given as $\sqrt{P_1P_2}$, from ~ 75 to 80 %.

At the inclination of 7', below which the background was catastrophically increased, due to direct transmission, the intensity was larger than 5. $10^7$ n/sec.

For the next experiments on capture gamma-rays the following conditions have been fixed :

| | |
|---|---|
| — Mirror inclination | 12' |
| — Polarization | 80 % |
| — Intensity | ~ $3.10^7$ n/sec |
| — Ratio of fast to slow neutrons | ~ $10^{-2}$ |

As previously observed, the polarization is not uniquely determined by the shim ratio. In our case the value found for the latter permits the extreme limits 65 % and 100 % for the polarization that each of the two mirrors may be able to produce.

Actually we presume that the imperfections, to which the lack of complete polarization is due, are rather equally shared by the two mirrors. To prove this, segments of polarizing and analyzing mirror were variously interchanged, with no practical effects.

Also the analyzing mirror was shifted to explore different beam sections, and its inclination was slightly varied : no change of the shim ratio larger than 5 ~ 6 % was observed.

To search for a possible unequal magnetization of the mirrors, the magnetic fields on the polarizing and the analyzing mirrors were independently varied. For instance, increasing the field from 230 to 350 gauss had the only effect to rise the reflected intensity by several percent.

According to the previous results we estimate rather safe to assume a polarization of 80 % with an uncertainty of ± 10 %.

The ratio of fast to slow neutrons reported above is the Cd ratio measured when using the $BF_3$ counter with parraffin moderator. When measured with a bare $BF_3$ counter, having about a 10 % efficiency to thermal neutrons, the Cd ratio was ~ $10^{-4}$.

Measurements of the gamma dose taken while the slow neutrons were stopped by a Cd shim, indicated a dose of the order of 50 mr/hr in the beam path.

A qualitative picture of the neutron flux distribution over the beam cross section was taken by exposing a normal photografic plate we coated with a LiF layer (fig. 5). As expected the neutron flux is highly concentrated at small reflecting angles.

In some experiments it is very important to have a very narrow target from which neutrons may easily escape after a first scattering event that may cause depolarization. Therefore it was interesting to have a measurement of the total neutron intensity still available with a reduced width of the output collimator slit, including only smaller reflection angles. The results (fig. 6) indicate that a beam of 1.5 ~ 2 mm width may be conveniently used without serious loss of intensity.

## 5 — METHODS OF REVERSING THE SPIN ORIENTATION

In order to measure polarization-dependent effects, as we plan to do with capture gamma-rays, the most convenient method is to reverse the spin orientation, while the detection system is left unchanged. Among possible methods of changing the spin orientation (4), we have chosen the one of gradually turning a magnetic guide field along the beam, as shown in fig. 7.

A neutron traveling through such a field, will see, in its own center-of-mass system, a rotating magnetic field. Provided that the field rotates slowly compared to the frequency of the Larmor precession, the spin will maintain the same orientation with respect to the turning field. More precisely, the neutron polarization will periodically vary like

$$1 - \tfrac{1}{2} \left[\omega^2/(\omega^2/4 + \Omega^2)\right] \mathrm{Sin}^2 \, (\omega^2/4 + \Omega^2)^{1/2} \, t,$$

where $\omega$ is the field frequency and $\Omega$ the Larmor frequency.

In our case, guide fields of the order of a few gausses are turned over a distance of a few tens of cm. Negligible depolarization ($< 1\ \%$) is expected at neutron velocities of, say, 3,000 m/sec or lower.

In the experimental device, schematically illustrated in fig. 7, the field along the beam path is the composition of the stray vertical field of the electromagnet of the polarizer with the horizontal field generated by a current in a magnetic box.

Neutrons traveling to the center of the box (target place), will undergo a gradual 90° field turning. Reversing the magnetizing current of the box will effect a 180° reversal of the spin at the target position.

The proposed method has the following main advantages. The current to maintain the field in the magnetic box, which in our case is of 5 ~ 10 gauss, can be conveniently low to be handled without difficulties by an electronic programming device.

It easy to prevent that reversing the box field may influence the detectors. Indeed, when the box was magnetically shielded by two layers of 0.35 mm mumetal sheet, the outside field variation was only a few $10^{-2}$ gauss.

It was verified that such a variation had very little influence on a standard scintillation counter, a 3" . 3" NaI (Tl) crystal directly coupled to a 3" Dumont 6363 photomultiplier, provided with a moderate magnetic shielding.

The crystal window was very close to the side wall of the box. $Co^{60}$ gamma-rays were detected with the discriminator bias set at the center of the 1.33 Mev line, so that the counting rate was extremely sensitive to changes of the photomultiplier gain. However, the relative counting rate variations corresponding to periodic field reversals were within the statistical counting error, of $\pm\ 2\ 10^{-4}$. This corresponded to a gain stability better than $10^{-5}$.

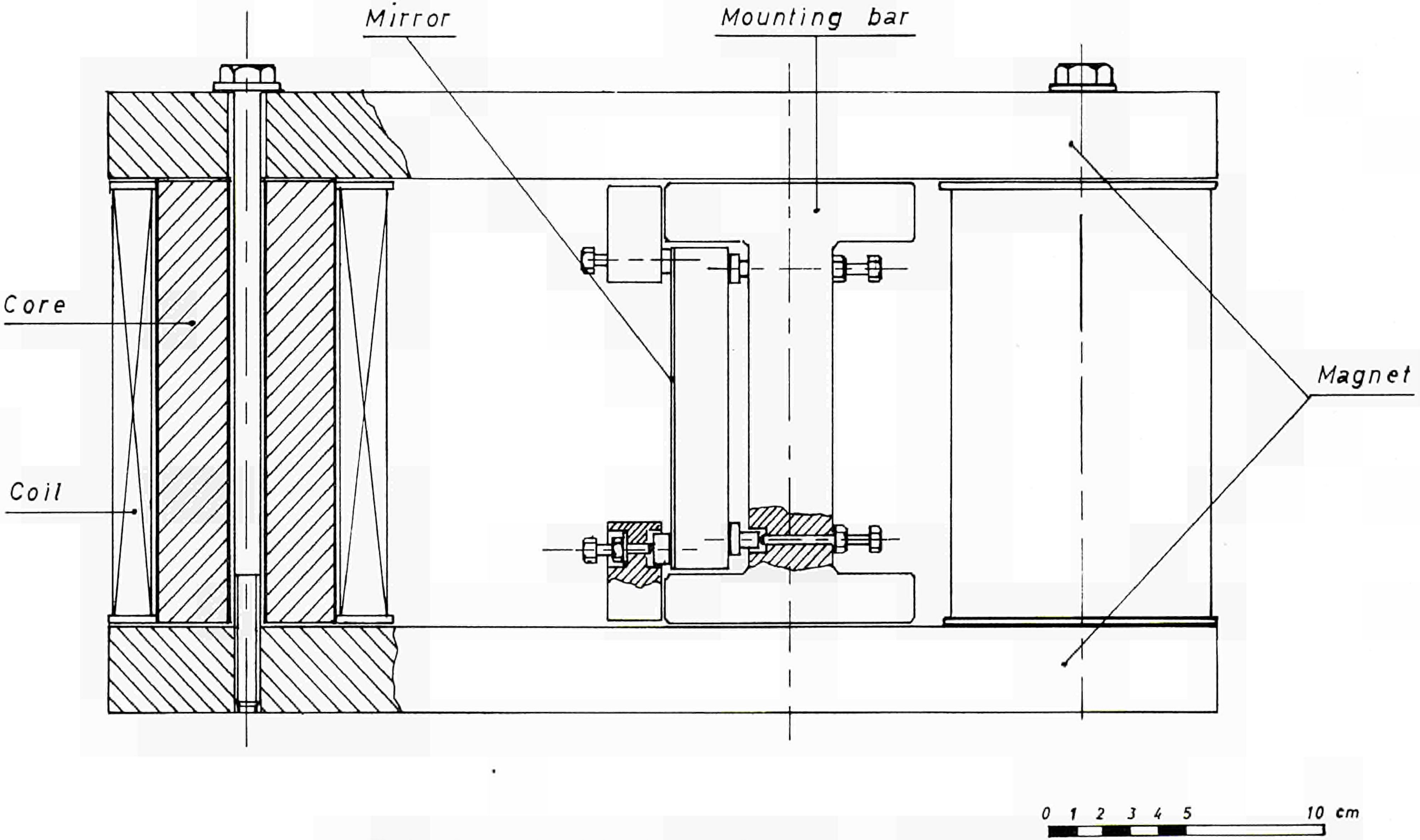

Fig. 1 — Cross section of the mirror mounting system, and of the electromagnet

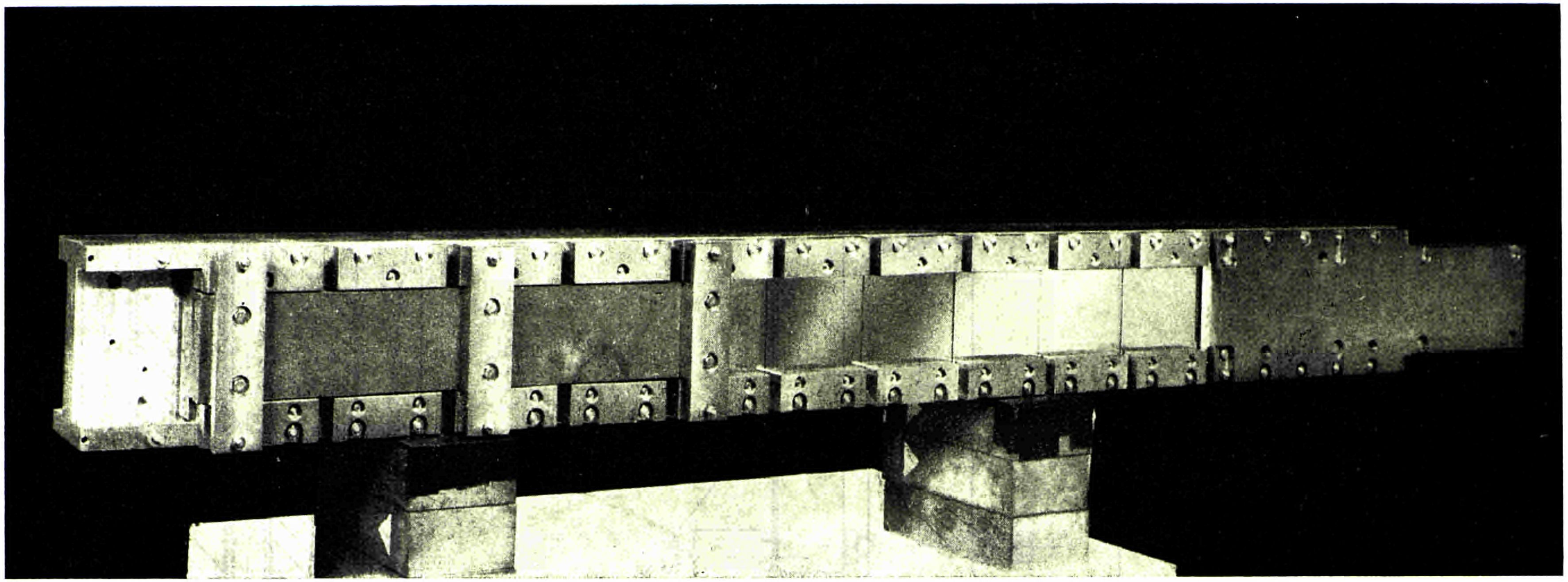

Fig. 2 — Photograph of the mirror with collimators

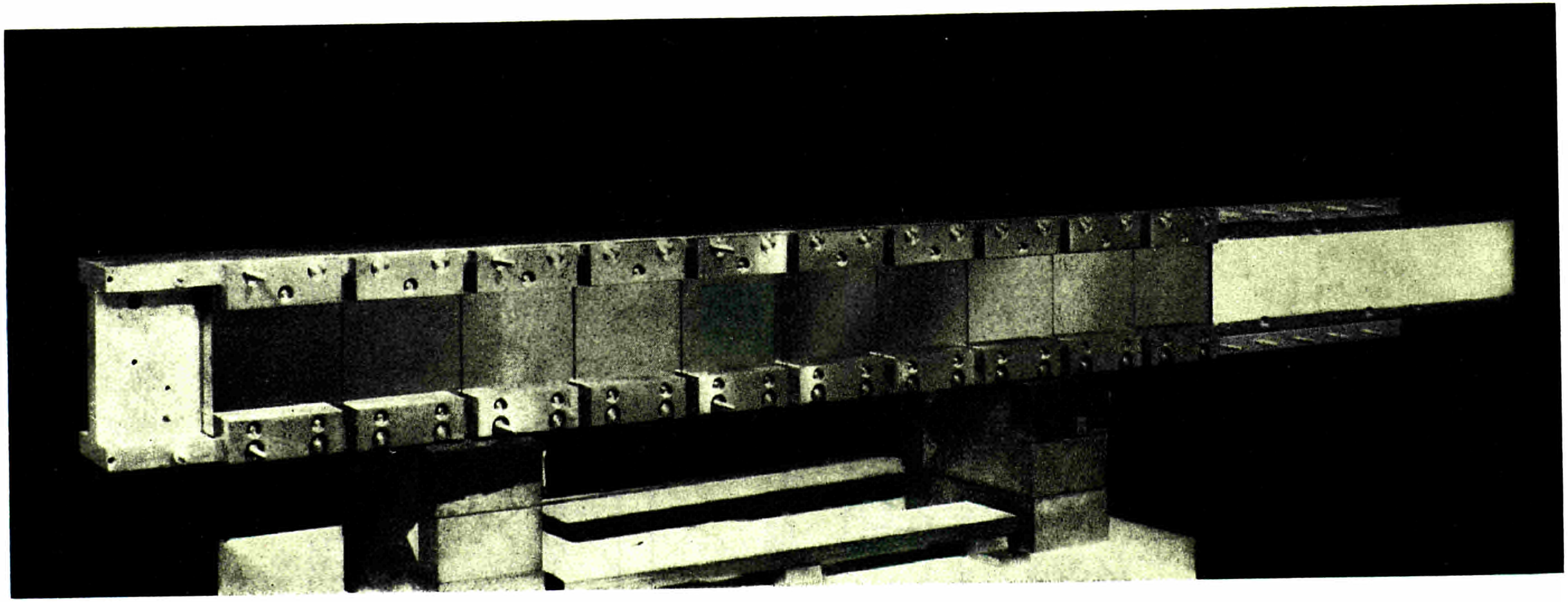

Fig. 3 — See fig. 2 : the front collimating plates have been removed.

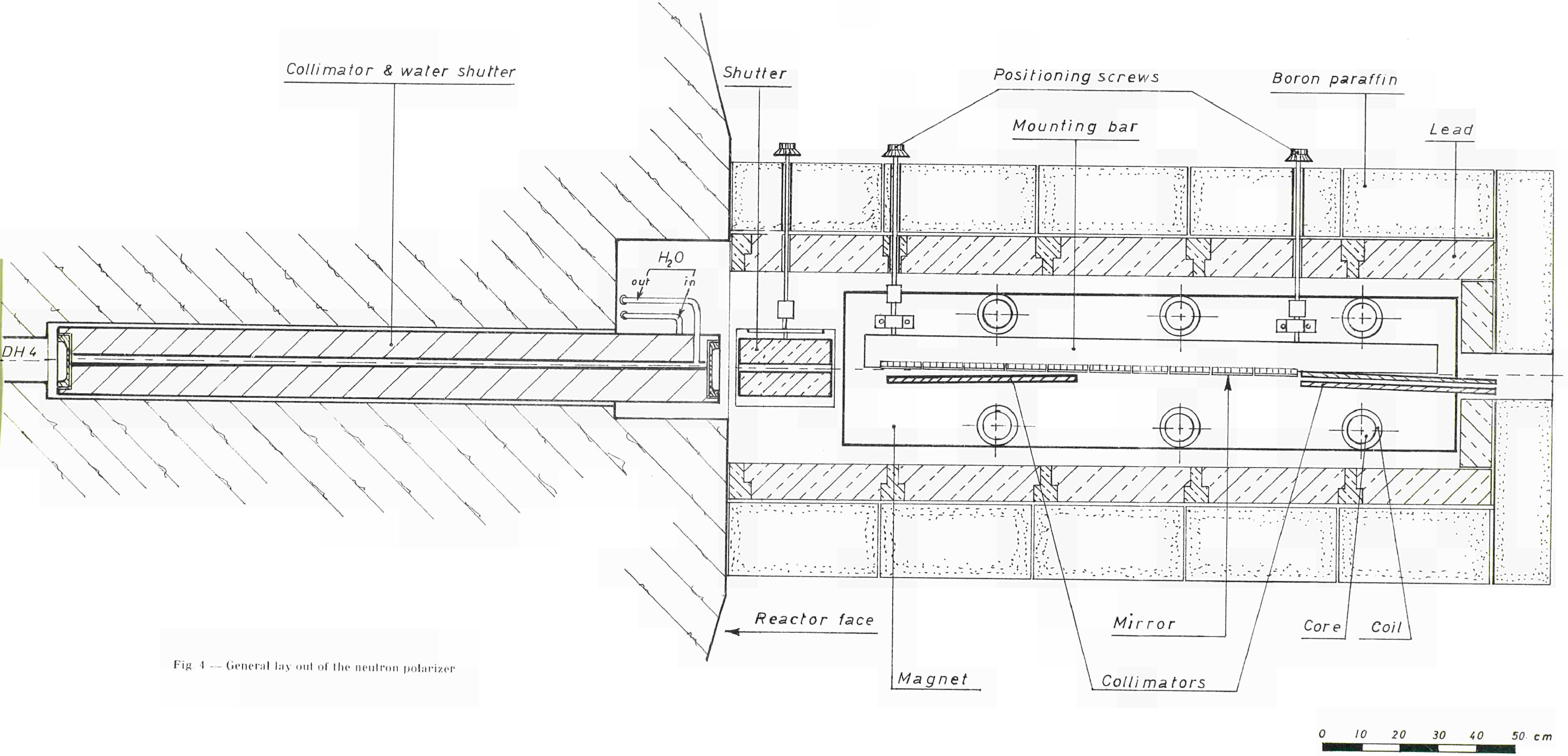

Fig. 4 — General lay out of the neutron polarizer

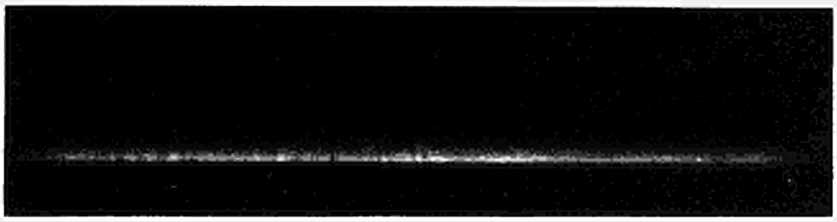

Fig. 5 — A "radiography" of the beam cross section

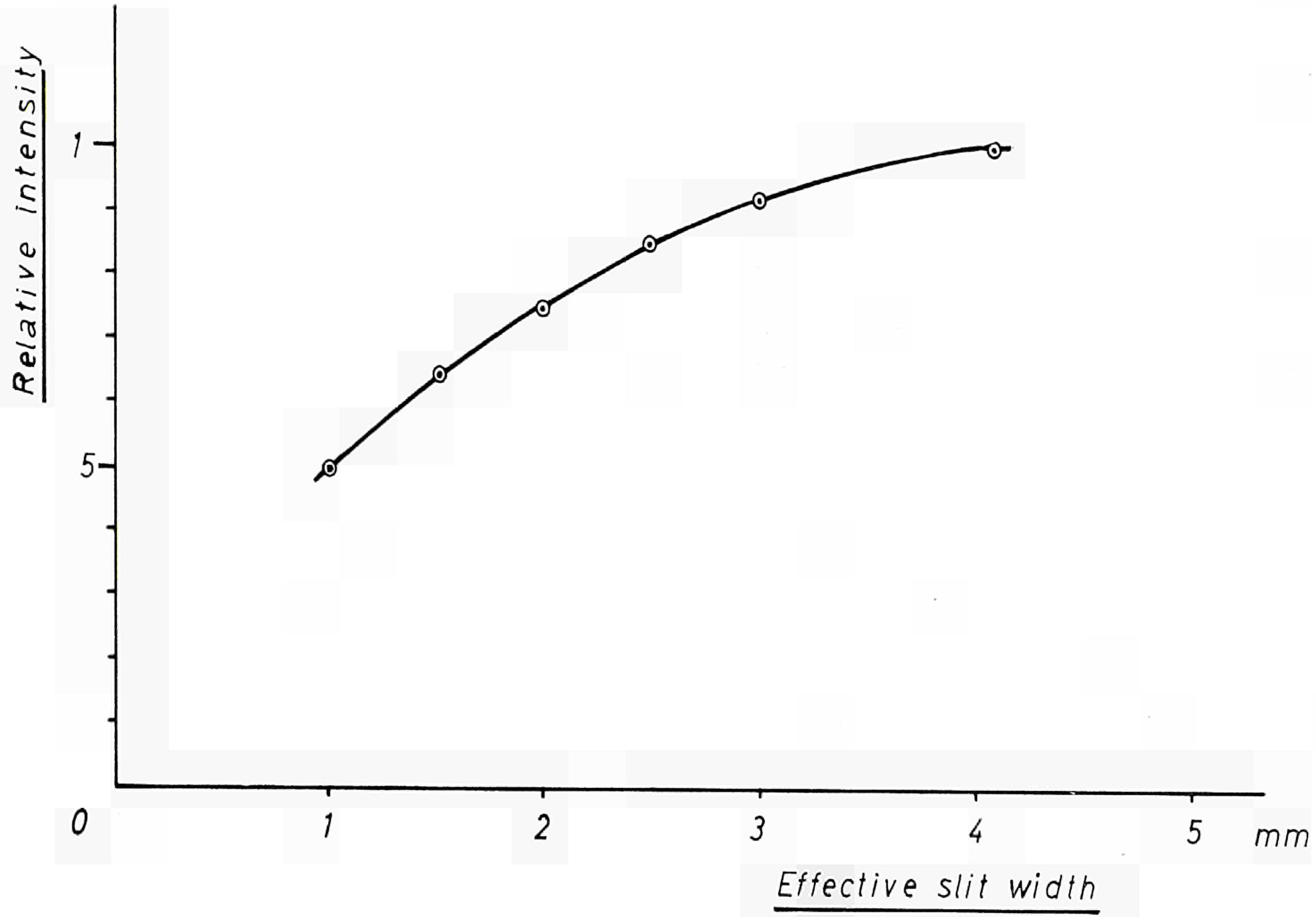

Fig. 6 — Beam intensity versus collimation width

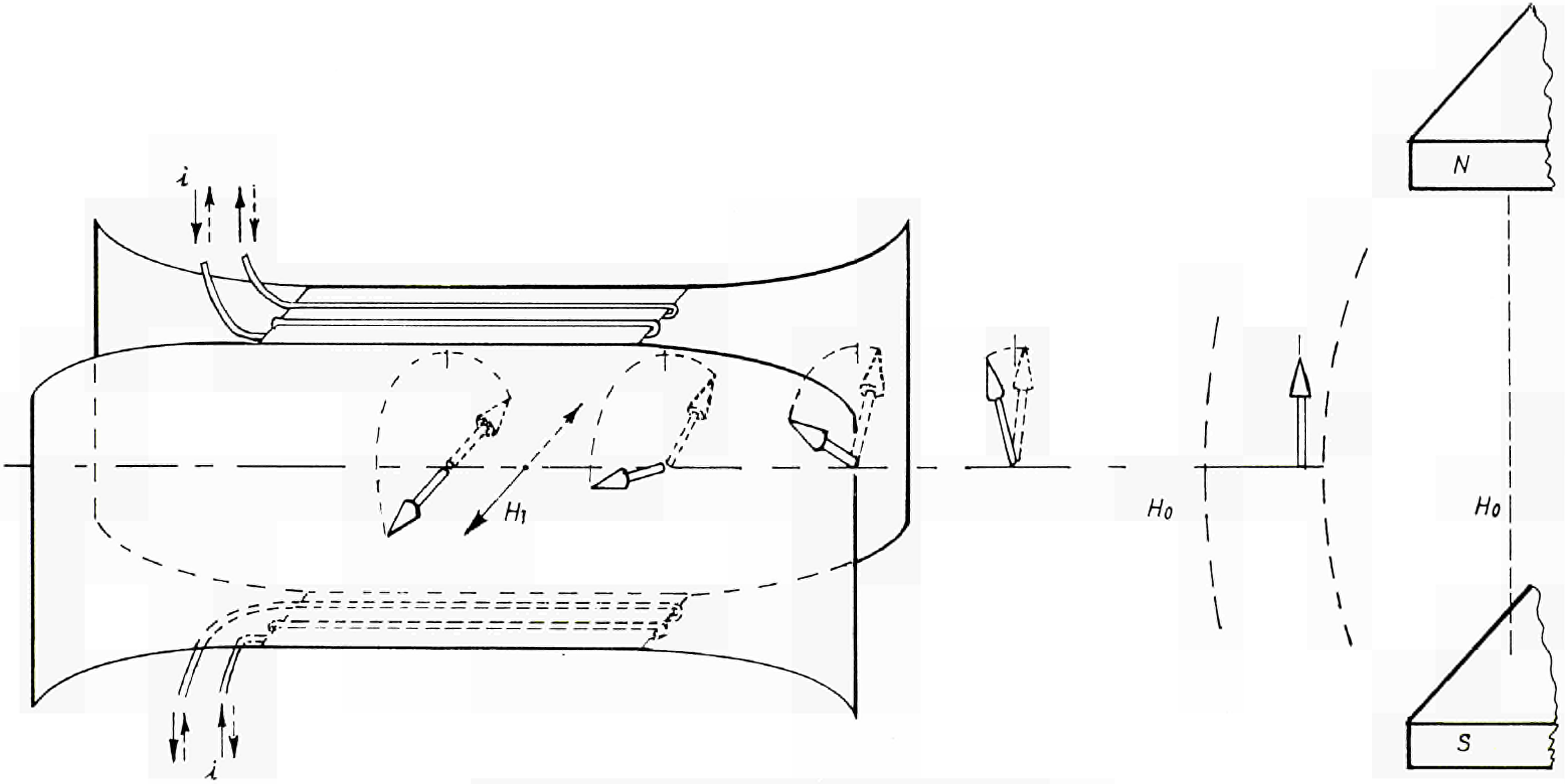

Fig. 7 — Scheme of the device for the neutron spin reversal

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