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Personnel Neutron Monitoring at AB Atomenergi

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Abstract:

The routine personnel monitoring of fast neutrons is carried out by the counting of tracks in a nuclear emulsion. The tracks are counted in a microscope on a projection screen. This is a very tedious job and is only done on irradiated films which are counted over 6 mm^2. The irradiated films are selected according to the recorded dose on the gamma film.

It is often difficult to tell how much the visible tracks have faded during a two-weeks period. Fortunately the fading does not often exceed 20 % for this period.

If the dosimeter has been gamma-irradiated, it may be difficult to recognize the proton tracks. If the film is stored for some time before being developed, this gamma fog will to some extent fade away.

For large neutron doses a foil activation dosimeter is used. This dosimeter consists of a cadmium-shielded phosphorus foil, a cadmium-shielded gold foil and an unshielded gold foil. The phosphorus foil has to be counted shortly after exposure.

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1. 1 Introduction

For dosimetry of fast neutrons, persons working at reactors and other neutron producing objects wear a Kodak Personnel Neutron Monitoring Film Type A (1).

The Film is placed between two sheets of 0. 5 mm cadmium in a dosimeter holder of plastic.

1. 2 Composition of the film packet

Table 1. Composition of Kodak Personnel Neutron Monitoring Film Type A.

Material	Density $mg \cdot cm^{-2}$	Hydrogen content $mg \cdot cm^{-2}$
Paper wrapping	23. 5	1. 5
Emulsion NTA	30 μ	1. 7
Film base		
$C_6H_7O_2(OOCCH_3)_3$	26	1. 5
Paper wrapping	29	1. 8

These values are calculated for 20 °C and 50 % relative humidity.

1. 3 Processing

The films are developed in Du Pont X-ray developer for 4 minutes (20 °C). The bath with developer is agitated by a stream of nitrogen gas. After that the films are fixed in Du Pont X-ray fixer for half an hour, washed for one hour and dried in air.

1. 4 Evaluation microscope

The evaluation takes place in microscopes (Zeiss Standard microscope) with 100 X oil-immersion objectives. A microscope with accessories is shown in figure 1.

The microscopes are provided with projection head, Bausch & Lomb Euscope, which projects the image on a white screen. The enlargement is about 800 X. The microscopes are provided with Zeiss Hochleistung Mikroskopierleuchte with mercury lamp (HBO 75) and green filter.

The table of the microscope is driven by an electric motor. This motor moves the table at an adjustable speed in the X-direction. The X-movement is limited by end position switches to scan an area of 1.0 mm^2. The control of the X-movement is shown in figure 2. The Y-movement is adjusted manually. The depth is adjusted from top to bottom of the film by continuously oscillating agitation of the focusing knob.

1.5 Evaluation

It takes about 3 minutes to scan 1 mm^2 at a normal speed and with not too high a track density. An exposed film may be scanned over 6 mm^2.

The neutron dosimeter of a person working at a reactor is not considered to have been exposed if the corresponding gamma film is not exposed. Therefore, if there is no blackening of the gamma film, the neutron film will not be evaluated.

For persons working around other neutron producing objects and for persons at reactors with exposed gamma films, the neutron films are evaluated according to the points below.

1. If no track has been counted in the first path, the evaluation is terminated.
2. If not more than 2 tracks have been counted in the first two paths, the evaluation is terminated.
3. If not more than 4 tracks have been counted in the first three paths, the evaluation is terminated.

4. If more than 4 tracks have been counted in the first three paths, six paths will be evaluated in the film (equal to 6.0 mm^2).

The smallest dose which is taken into account is 20 mrem. By using the procedure mentioned above, the risk of films exposed to 20 mrem not being counted is only 3 %. At a dose of 30 mrem only 0.5 % of the films fail to be counted.

By these limitations of the evaluation a lot of work is saved, as it takes about 20 minutes to scan 6 mm^2 of a film.

1.6 The energy dependence of the neutron film dosimeter

The energy dependence was investigated at the Van de Graaff generator at Studsvik.

As neutron source the reaction

$$Li^7(p, n)Be^7 \qquad (2)$$

was used.

For energies below 1 MeV the sensitivity decreases very rapidly. Tracks from protons of energy below 0.3 MeV can hardly be recognized. In figure 3 the calibration constant, mrem $\cdot$ $track^{-1}$ $\cdot$ mm^2, is represented as a function of the neutron energy. The error of the experimental points was $\pm$ 20 %.

The dose is calculated using the calculations of SNYDER and NEUFELDT (3) and quality factors equal to the RBE factors in NBS Handbook 63. The dose curve is represented in figure 4.

The dosimeter film, Kodak Personnel Neutron Monitoring Film Type A, appeared to be almost as good as Kodak Personnel Monitoring Film Type B in the energy range concerned. For comparison see Appendix I.

Routine calibration and control of constancy are reported in Appendix II.

1.7 Latent image fading

Under severe conditions the fading of the latent image causes a gradual reduction of the track width. After some reduction of track width the tracks are so thin that continuous tracks cannot be recognized. The tracks therefore will not be counted.

The fading is especially severe in emulsions with fine grains. The phenomenon has been investigated in detail by LEIDE (4, 5). For Ilford G 5 emulsion he recommends a storage in air at a temperature and humidity below the curve in figure 5.

Usually these conditions are met. Films for personnel monitoring are usually kept throughout the time of exposure in centrally heated rooms, in which the relative humidity seldom exceeds 50 % and the temperature is about 20 °C. Dosimeters used for surrounding and plant monitoring are kept in plastic bags together with a drying agent.

In spite of ideal conditions a small fading has been noticed when the films are stored in room atmosphere at 50 % relative humidity.

When the films are stored at 60 % relative humidity, the fading is much more severe than at 50 %. At 80 % relative humidity all tracks have disappeared within 3 days.

The fading at different temperatures and humidities is shown in figure 6. The error in the relative track number of the experimental points was 0.1. In summe time when the humidity is high, it is inadvisable to use films for periods longer than one month.

Normally films are changed every fortnight, so that the fading amounts to max. 20 %.

1.8 Gamma fog

Gamma irradiation is bad for the neutron film. The gamma fog will cause difficulties in distinguishing the proton tracks from the fog. The film is good up to a dose of 1 r Co60 gamma. For higher doses the recognizable tracks are strongly reduced. In figure 7 the effect of gamma doses up to 10 r on the counted number of tracks is shown. The error in the relative number of tracks of the experimental points was 0.1. The films were irradiated by neutrons from a RaBe source and by gamma from Co60. They were thereafter immediately processed. For doses above 10 r Co60 gamma it is almost impossible to recognize any tracks. The situation is only slightly changed if the development time is changed.

Here the fading may be of some help. In figure 8 the number of tracks is shown after storage in room atmosphere (20 °C and 50 % relative humidity). The films were irradiated by neutrons from a RaBe source and after that by 8 r Co60 gamma. The gamma fog very rapidly decreases due to the fading, which agrees very well with the results of LEIDE (5). At increased restricted-energy-loss the latent image is less sensitive to fading. This fading process can be speeded up by using a chemical reducer. In this way most of the severe gamma irradiated neutron films can be saved.

1.9 Useful energy range

With normal evaluation technique without using fading of the latent image of the gamma radiation, the neutron film dosimeter is useful for measuring doses between 10 mrem and 10 rem ($E_n < 0.5$ MeV) for gamma doses less than 1 r. Using fading technique the dosimeter is useful with gamma doses up to 10 r.

2. 1 Foil dosimeter

Higher neutron doses are measured on a foil dosimeter. This was constructed by BRAUN and NILSSON (6) and consists of a phosphorus foil, a cadmium shielded gold foil and an unshielded gold foil. The dosimeter gives the neutron dose in three components of the neutron spectrum.

With this dosimeter doses above

10 rem for fast neutrons

5 rem for epithermal neutrons and

1 rem for thermal neutrons

can be measured.

The dosimeter is fastened on the back of the usual gamma film badge. One difficulty with this foil dosimeter is that it has to be evaluated very soon after irradiation. In order to keep the relative error within 10 %, it has to be evaluated within 10 hours.

Appendix I

Energy dependence of a neutron dosimeter with Kodak personnel monitoring film Type B (1).

The energy dependence of Kodak personnel monitoring film Type B has been investigated at different accelerators in Studsvik, Stockholm and Lund.

3. 1 The composition of the film packet

Table 2. Composition of Kodak personnel neutron monitoring film Type B.

Material	Density $mg \cdot cm^{-2}$	Hydrogen content $mg \cdot cm^{-2}$
Paper wrapping	10. 3	0. 7
Aluminium	27. 0	0
Film base	28. 5	1. 6
Emulsion NTA	30 μ	1. 7
Film base	28. 5	1. 6
Aluminium	27. 0	0
Paper wrapping	10. 3	0. 7

The values are calculated for 20 °C and 50 % relative humidity.

3. 2 Calibration

As neutron source the reactions

$T(d, n)He^4$, $D(d, n)He^3$ and $T(p, n)He^3$

were used. From these reactions neutrons from 0. 3 MeV to 16. 4 MeV were released (7).

The energy dependence (figure 9) above 0. 5 MeV is very good. The smallest neutron energy for which the dosimeter is useful is 0. 3 MeV. But at this low energy the sensitivity is low, since very short tracks are easy to miss in counting. The error of the experimental points was 20 %. The energy dependence of Kodak personnel neutron monitoring film Type A is also shown in figure 9 for comparison.

Kodak personnel neutron monitoring film Type B did not appear to be much better than Kodak personnel neutron monitoring film Type A. Therefore Type A was chosen for routine dosimetry. Another reason for the choice of the Type A was that this film is much more readily available in Sweden than Type B and is also considerably cheaper.

Appendix II

Routine calibration and control of constancy of neutron films

4.1 Introduction

The sensitivity of films may vary in different batches. According to LEHMAN (8) the thickness of the emulsion may vary between 24 μ and 33 μ from one batch to another. A variation of this order has not been observed by us. In seven examined batches the thickness was $30 \pm 0.6\,\mu$.

4.2 Calibration

In order to control the constancy of the films, some films from every new batch are irradiated by neutrons from a PuBe source.

The films are placed in dosimeter holders on an aluminium ring of radius 93.5 cm. The source consists of 2 C (31.7 g) plutonium mixed with beryllium. The neutron flux at right angles to the source and at this distance is $34\ n \cdot s^{-1} \cdot cm^{-2}$. The calibration apparatus is shown in figure 10.

By using the neutron spectrum given by STEWART (9) and the dose curve from figure 4, a dose rate of $4.6\ mrem \cdot h^{-1}$ has been calculatedfor this distance. The films are irradiated by about 300 mrem, at which dose they are easy to evaluate. This dose also reveals sufficient tracks for good statistical significance.

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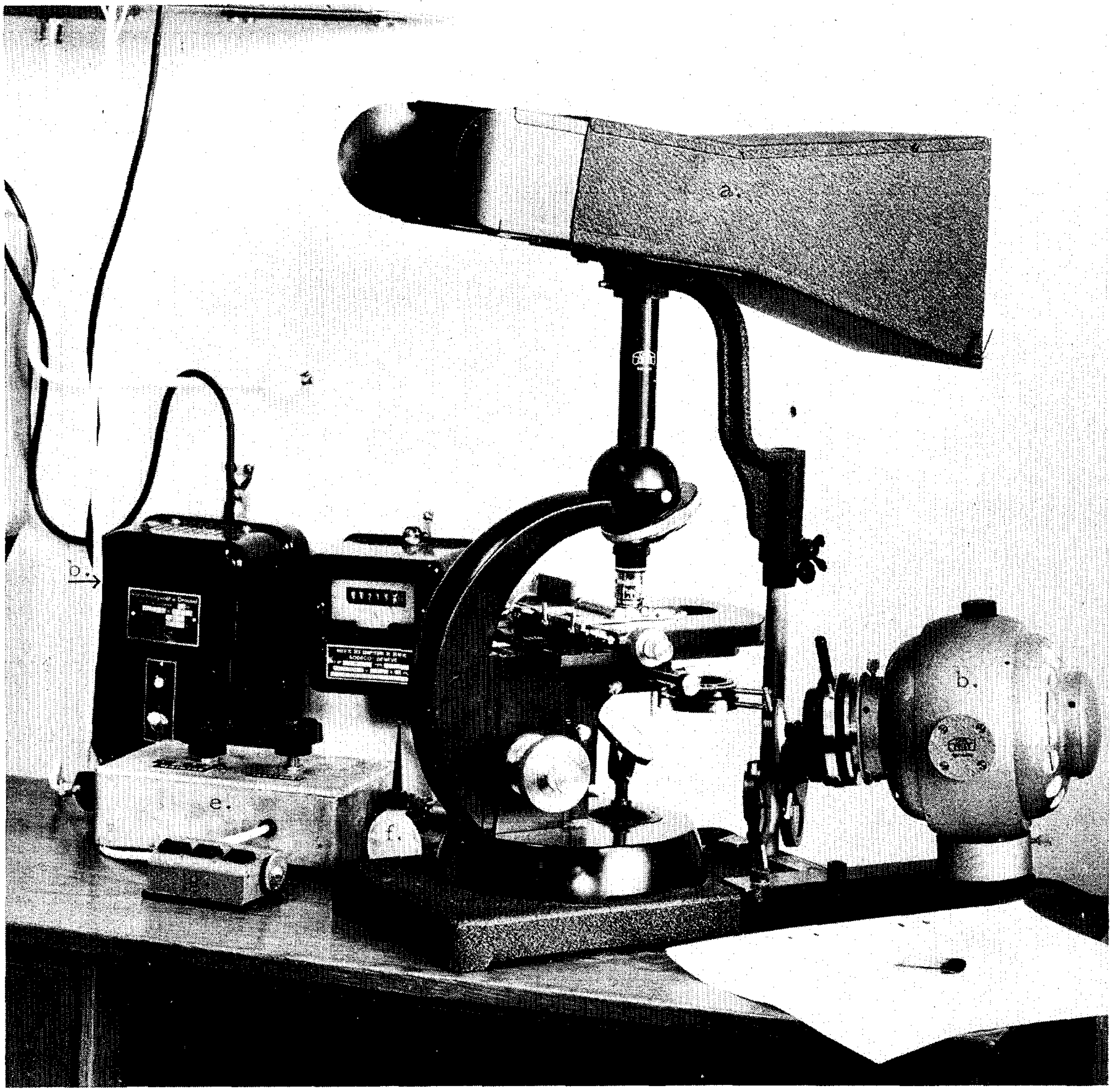

Figure 1.

Microscope for Evaluation of Neutron Dosimeter Films.

a. Projection head, Bausch & Lomb Euscope.

b. Zeiss Hochleistung Mikroskopierleuchte with mercury lamp.

c. Film holder.

d. Zeiss Standard Microscope with 100X oil-immersion objective.

e. Control-box for the movement of the table.

f. Immersion-oil.

g. Manual track-counter

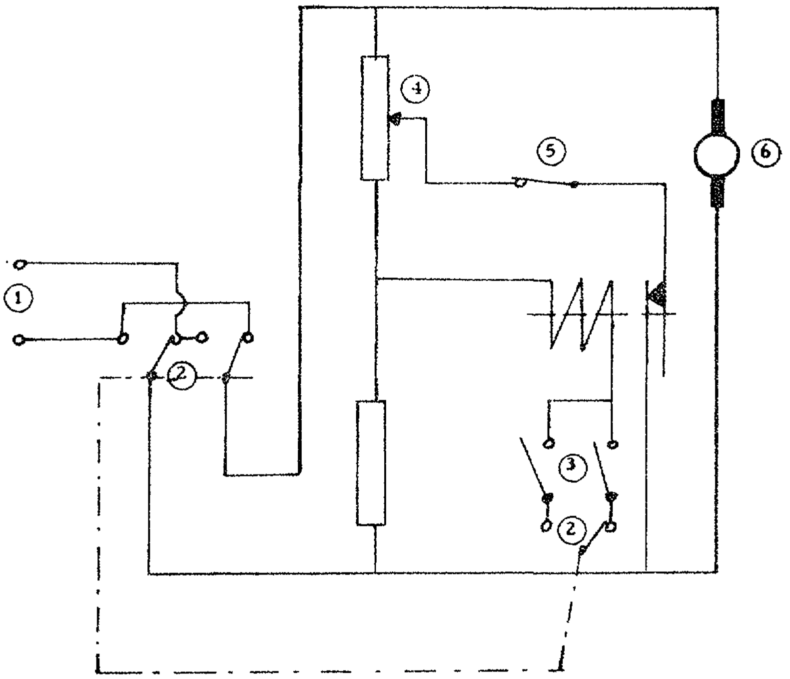

Figure 2. Control of table movement.

1. Input 48 V =
2. Direction switches
3. End position switches
4. Speed adjustment
5. Foot switch
6. Driving direct current motor

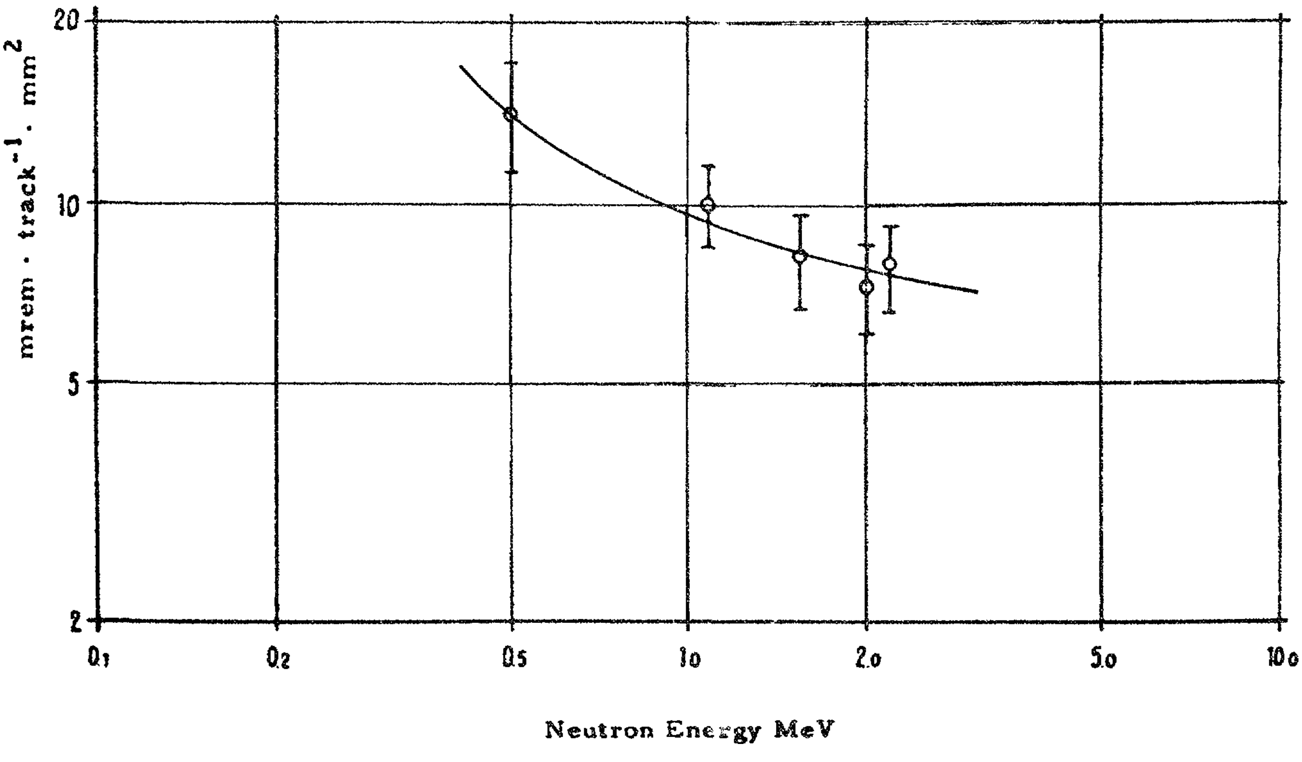

Figure 3. Energy dependence of the neutron dosimeter.

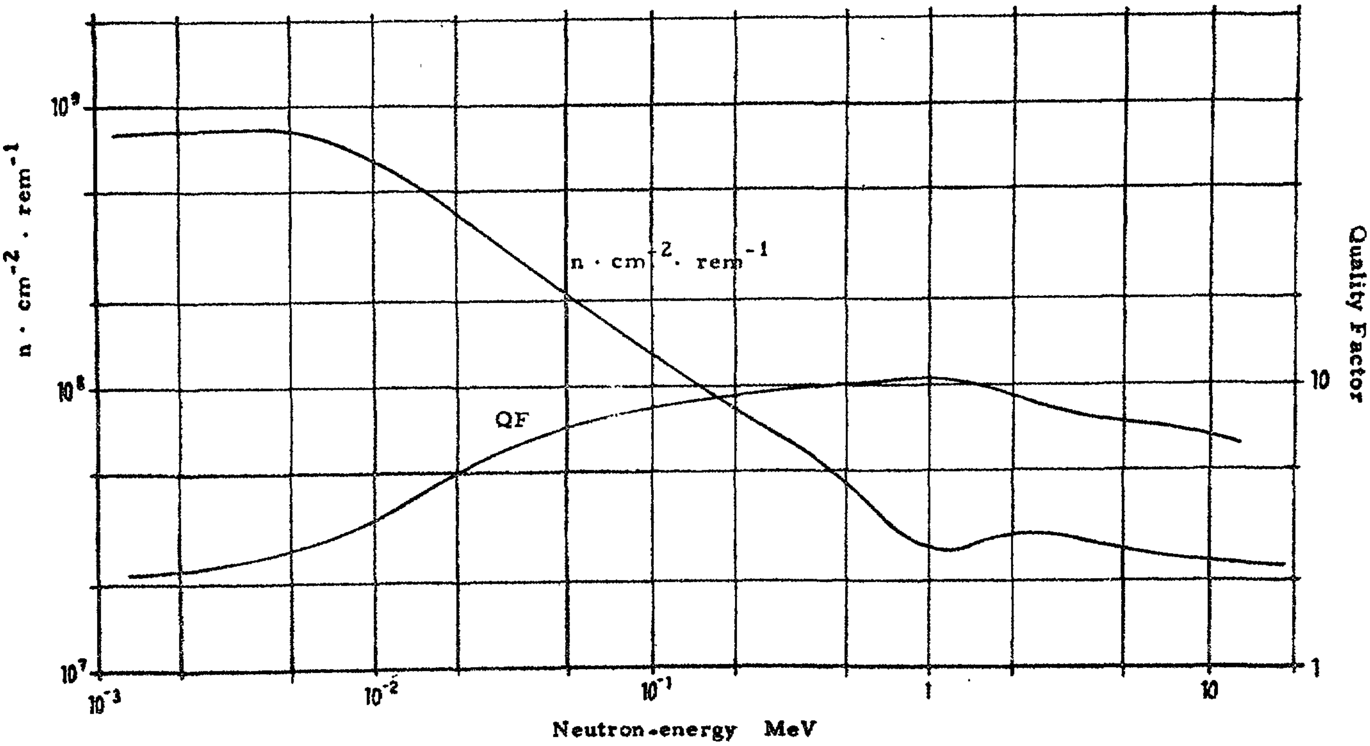

Figure 4. Dose curve for neutrons.

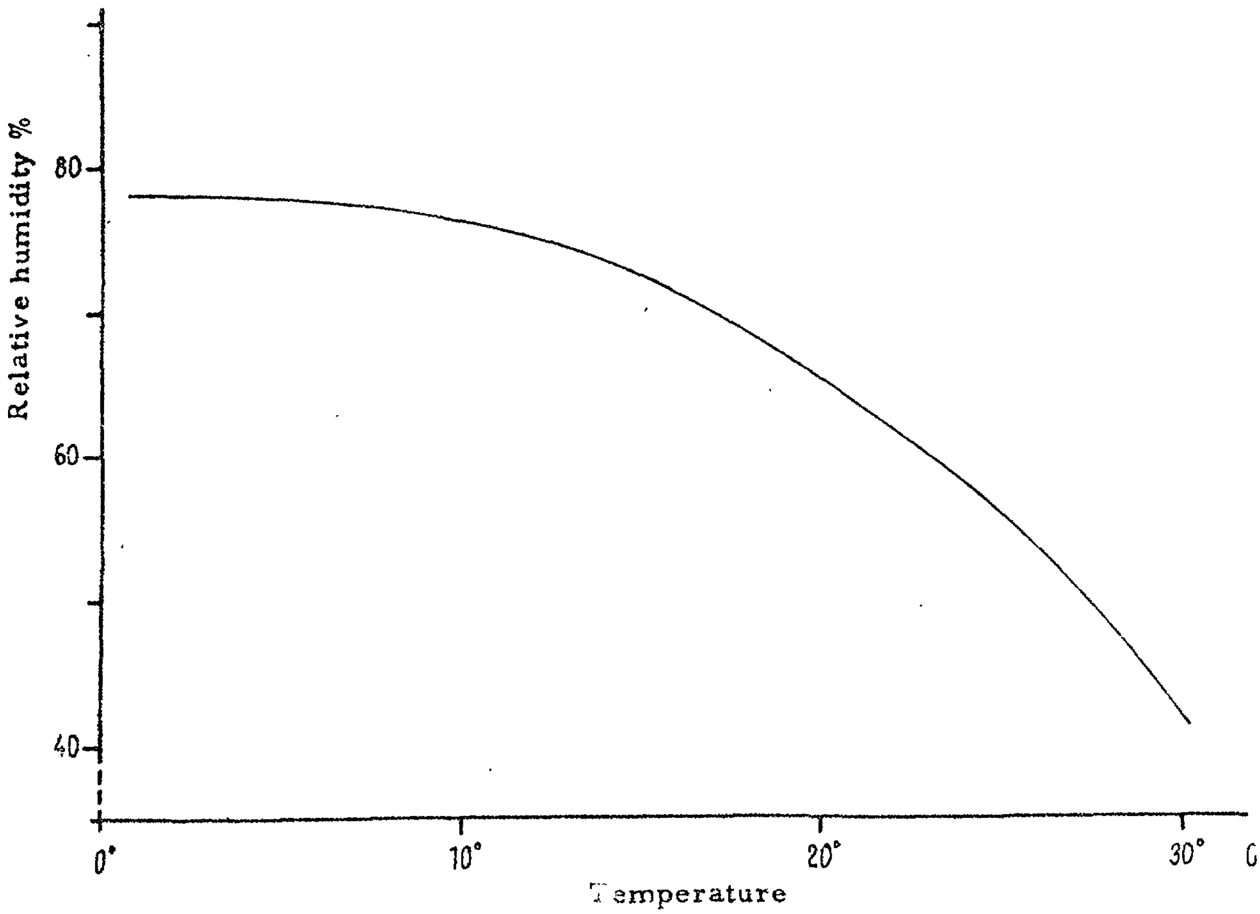

Figure 5. Preferable storage conditions for nuclear emulsions below the curve (from LEIDE (4)).

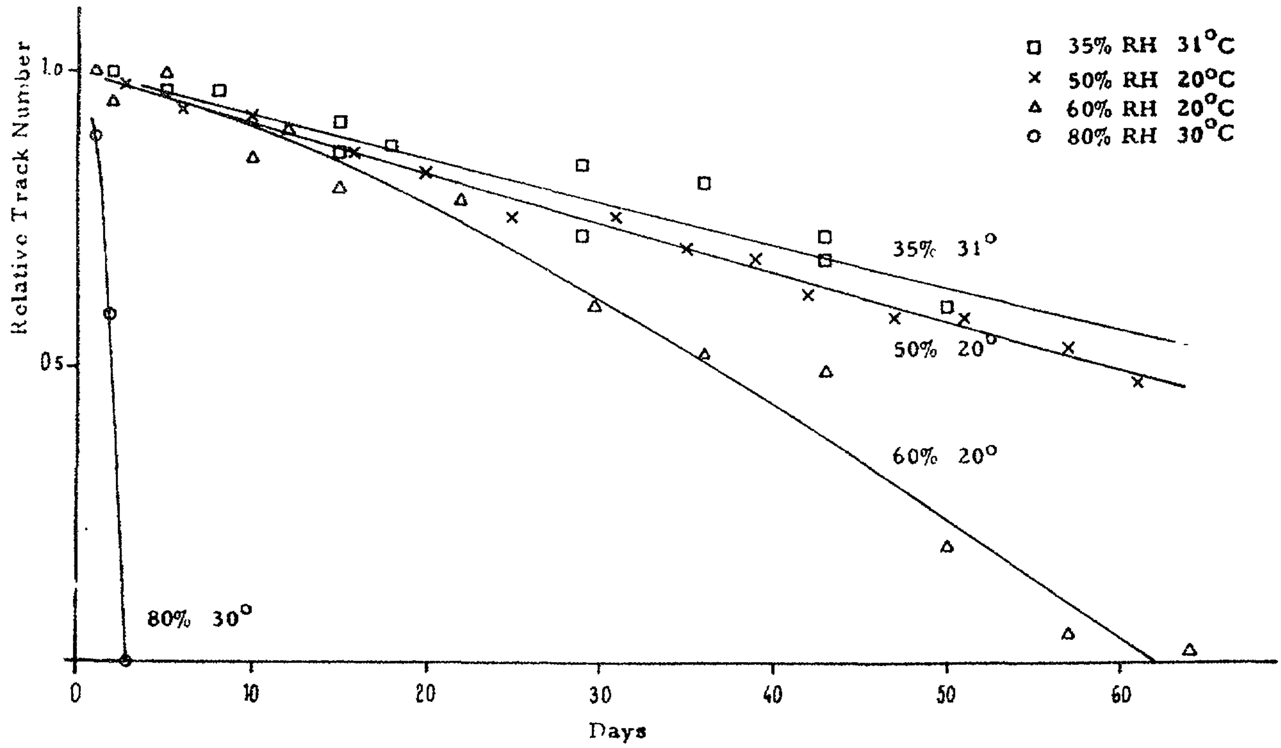

Figure 6. Fading of neutron dosimeter films.

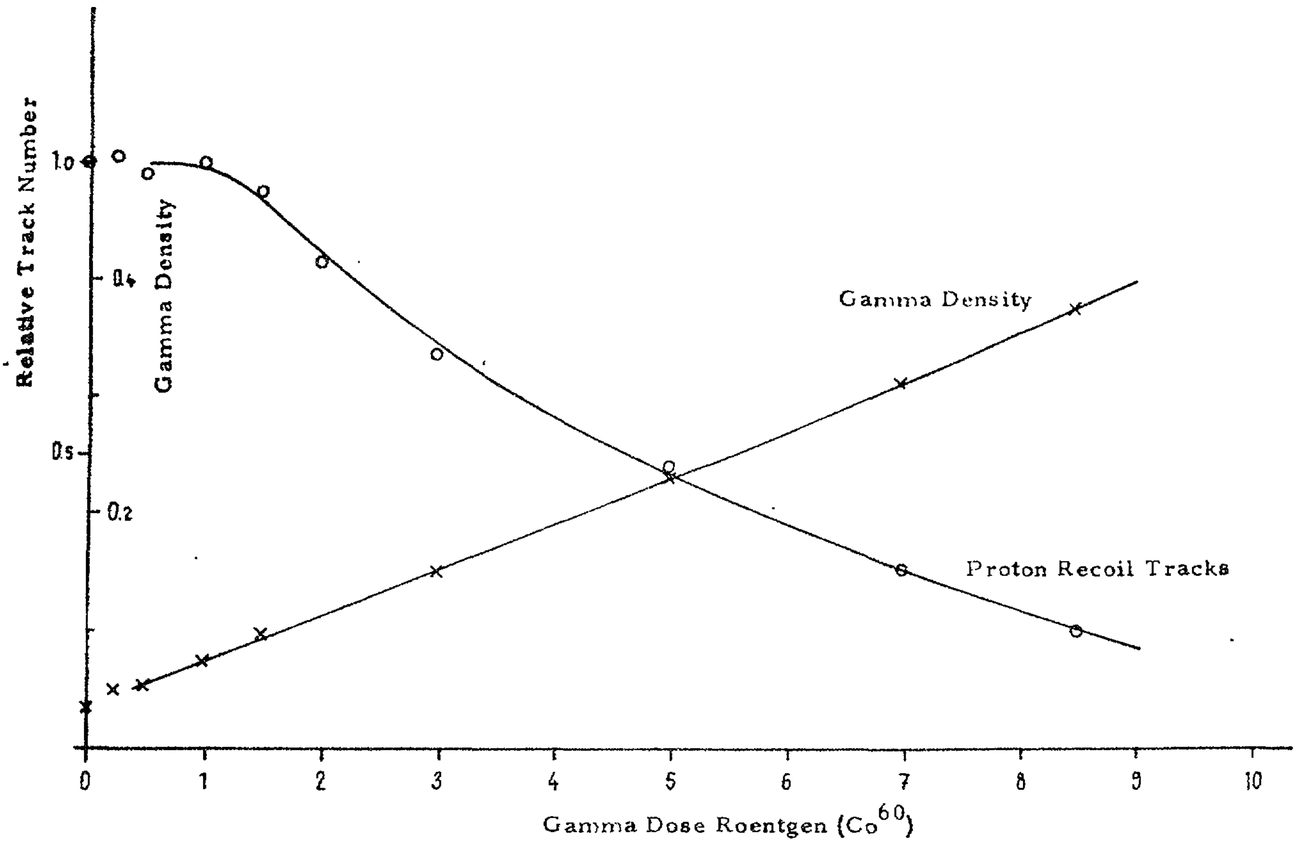

Figure 7. Visibility of proton recoils in gamma fogged neutron dosimeter films.

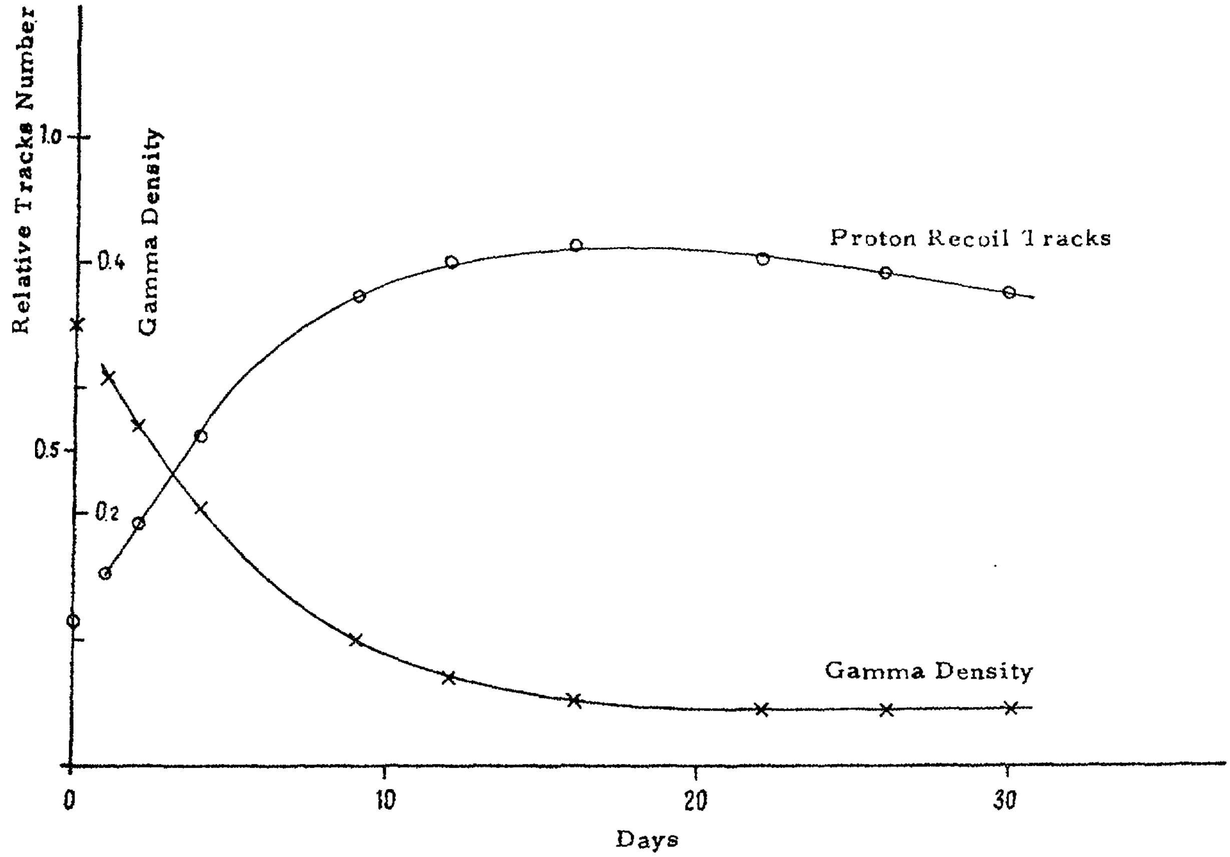

Figure 8. Visibility of proton recoils in gamma fogged (8r) neutron dosimeter films stored at 20 °C, 50 % RH.

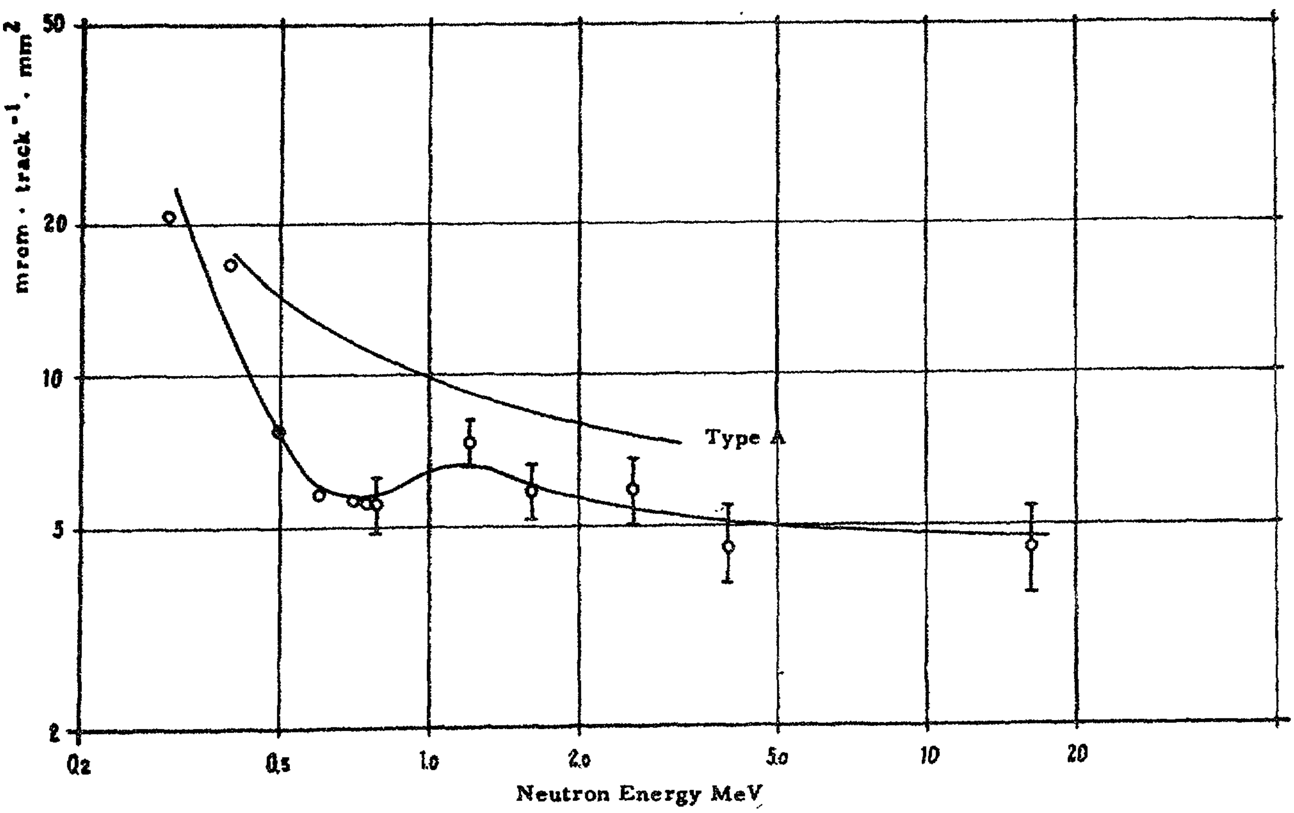

Figure 9. Energy dependence of neutron dosimeter with Kodak Personnel Neutron Monitoring Film Type B.

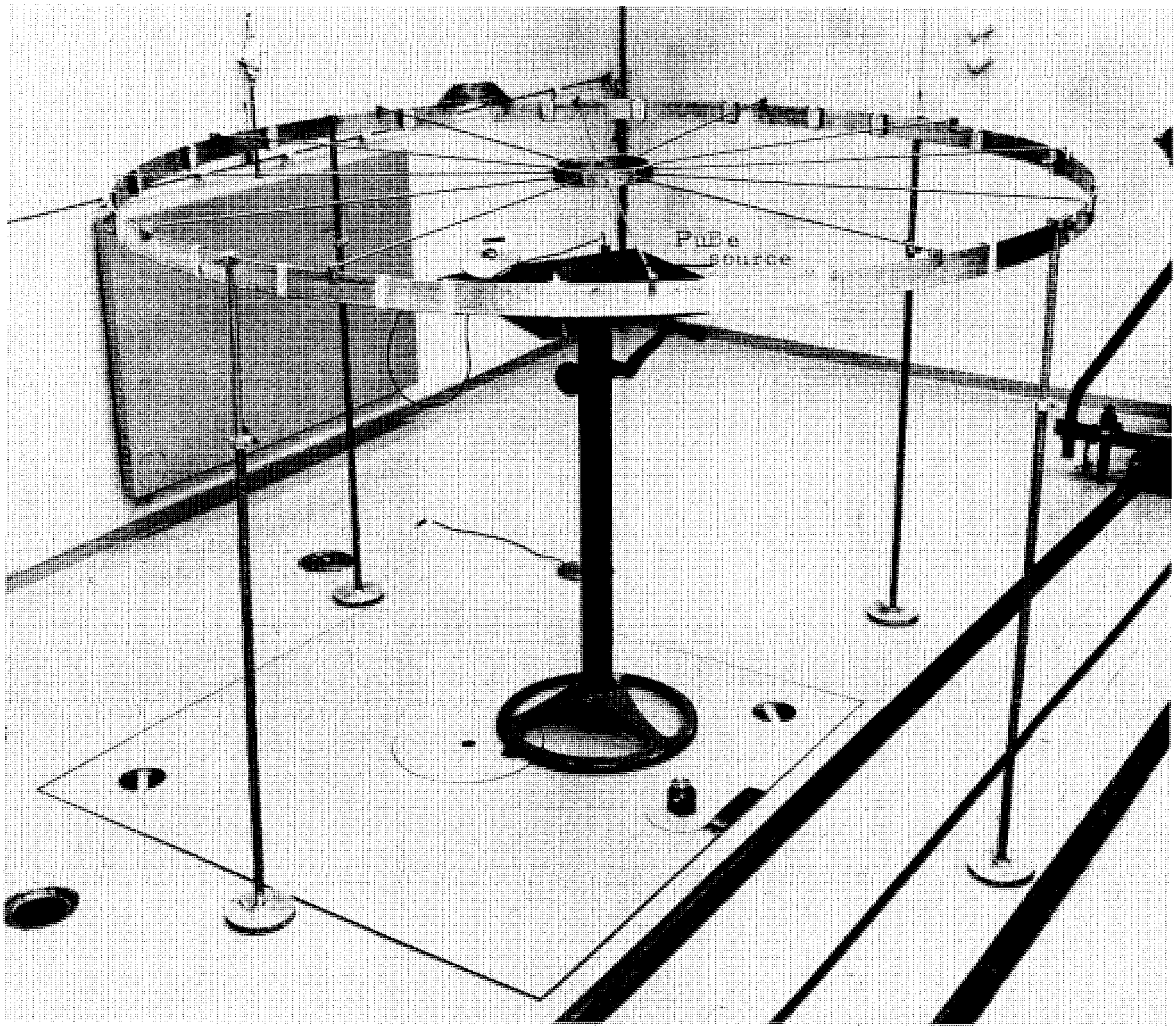

Figure 10.

Arrangement for Calibration and Control of Constancy

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