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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

PROPOSAL OF A NEW COLD NEUTRON FACILITY

by

H. MEISTER

Appendix: DESIGN STUDY OF A CROSS CHOPPER

by

H. GEIST

1966

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Departement
Experimental Neutron Physics

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With these input data our proposed facility, which we install for a thought experiment at the largest beam hole of the reactor Ispra-I (12" ø at the reactor core), supplies us with a mean neutron current through the sample (duty cycle included) of about 2.10^7 neutrons per minute. This number lies very close to the corresponding intensity value, which is attained by the "Three Phased Rotor Unit" installed at the H.F.B.R.-Reactor in Brookhaven.

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SUMMARY

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Proposal of a New Cold Neutron Facility

by

H. MEISTER

APPENDIX : Design Study of a Cross Chopper

by
H. GEIST

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C O N T E N T S

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Page

S U M M A R Y

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A - INTRODUCTION

The investigations on elastic and quasi-elastic scattering of neutrons by water have become very interesting for a couple of years. Just to bring one example we would like to refer to the intense activities in the study of structure and dynamics of water (1 to 11) by means of neutron scattering.

One of the most powerful experimental methods in this field is the time of flight technique, to which we shall restrict our considerations in the following. The main requirement for those measurements we have in mind is a very high resolution of the apparatus in order to separate the inelastic contributions from the elastic range and even to detect any structure in the elastic peak, which could be caused by those famous "quasi-elastic" scattering processes. This leads in connection with the nearly trivial claim of high intensity to the following characteristics of a good spectrometer for elastic work :

- Small and well defined energy of the monochromatic neutrons.
- Energy resolution of the analysing part of the instrument equal to the sharpness of the primary neutron energy.
- Angular divergencies of the beam with respect to sample and detector adjusted to the energy resolution of the system, in other words the effective areas of sample and counter should be as large as this limiting condition allows.
- High burst rate without overlaping neutrons from different bursts.

-/-

If we look at the cold neutron facilities which are operating up to now, we find that each type has at least one striking disadvantage with respect to our aim.

- Slow chopper with filter (12) : The energy resolution is too bad.
- Two or more phased rotors (13) : The area of the beam cross section is limited by reasons of mechanical stability to be relatively small
- Rotating crystal (14) : It is difficult to attain the desired energy resolution at low neutron energies and large beam areas because of the Doppler-effect. Moreover, the angular divergencies are much smaller than one could accept in regard to the corresponding energy resolution.
- Fixed crystal with chopper (15) : This arrangement is used with neutrons reflected out from the direct reactor beam by an angle of 90 degrees or even less. In this case the angular divergencies of the monochromatic neutron beam are again too small as already indicated above.

For the first moment our proposal seems to be only a simple modification of the latter type of cold neutron facility : The direct beam of the reactor is reflected by a single crystal under a large Bragg-angle and afterwards chopped by a slow chopper before impinging on the sample. Large Bragg-angles are necessary in order to get large angle divergencies (equivalent to high intensity) at a given value of the energy resolution. But this large Bragg angle perhaps was also the reason why people did not yet use this system, as the monochromatic neutrons are flying back towards the reactor block with an angle to the beam hole axis of 135 degrees (or 45 degrees if you like).

-/-

However, we believe that we can get rid of this drawback without loosing the principal advantage of this system by the method of double Bragg reflection under large Bragg angles. In the following we shall treat both methods of double and normal back-reflection as they might complete each other. While in the first case, where the direction of the monoenergetic neutron beam is perpendicular to the beam hole axis, only neutrons which are scattered in the sample by angles between 0 and 90 degrees can be observed, this range is extended in the second case to 135 degrees starting at 45 degrees.

The considerations written down in this report should finally give us an idea about efficiency, dimensions and costs of this new type of cold neutron facility.

B - PERFORMANCE DATA CLAIMED

The performance data stated here should fix quantitatively our ideas of a good spectrometer for investigations on elastic neutron scattering as described in the chapter before. These data are based on two assumptions which are more or less arbitrary :

1) We intend to use Al-single crystals orientated thus, that the neutrons are reflected by the (111)-planes with the Bragg-angle Θ equal to 67,5 degrees.

2) Our system seems to be predestinated for being installed at a very large beam hole. Therefore, as we have no better model, we do the lay out of the facility according to the dimensions of the largest beam hole of the Reactor Ispra I (internal nomenclature 12 SH 1).

By the assumption $\Theta = 67{,}5°$ and the interplanar distance of the Al (111)-planes, d = 2,3 A°, the neutron wave length is settled to be λ = 4,3 A°. (Corresponding values of neutron velocity v = 930 ms^{-1} and of neutron energy E = 4,4 meV). The half width of the neutron wave length spread should amount to $(\Delta\lambda/\lambda)_{\frac{1}{2}} = 0{,}01$. From this postulation consequently follows firstly that the resolution of the time of flight system should correspond to $\Delta\tau/T = 0{,}01$ (with $\Delta\tau \hat{=}$ half width in time of the neutron burst and $T \hat{=}$ time of flight for elastically scattered neutrons) and secondly that the angular divergency of the chopped beam in the plane, which is built up by the beam axes (the axes of beam hole and reflected beam and the lines sample detectors should lie within one plane), should have a half width of $(\Delta\chi)_{\parallel} = 0{,}01 \approx 0{,}6$ degrees. The angular divergency perpendicular to this distinguished plane does not influence very strongly the spread of the finally detected momentum transfer. (This is valid at least for neutrons scattered in the sample by angles $30° \leq \varphi \leq 150°$). Therefore it could be $(\Delta\chi)_{\perp} = 0{,}10 \approx 6°$. In connection with the values of the angular divergencies, it is of some

$\Theta = 67{,}5°$

d = 2,3 A°

λ = 4,3 A°

v = 930 ms^{-1}

E = 4,4 meV

$(\Delta\lambda/\lambda)_{\frac{1}{2}} = 0{,}01$

$\Delta\tau/T = 0{,}01$

$(\Delta\chi)_{\parallel} = 0{,}01 \approx 0{,}6°$

$(\Delta\chi)_{\perp} = 0{,}10 \approx 6°$

importance to have an idea of the beam dimensions at the position of the sample. Those are limited by the chopper. We believe that a reasonable size of the chopper windcw will be 5 cm x 10 cm, where the small side should be parallel to the plane of the beam axes.

 = 5 x 10 cm^2

C - PRINCIPAL IDEAS OF THE SOLUTION

The detailed calculations, which will start in the next chapter, refer to the following general pictures of the facility :

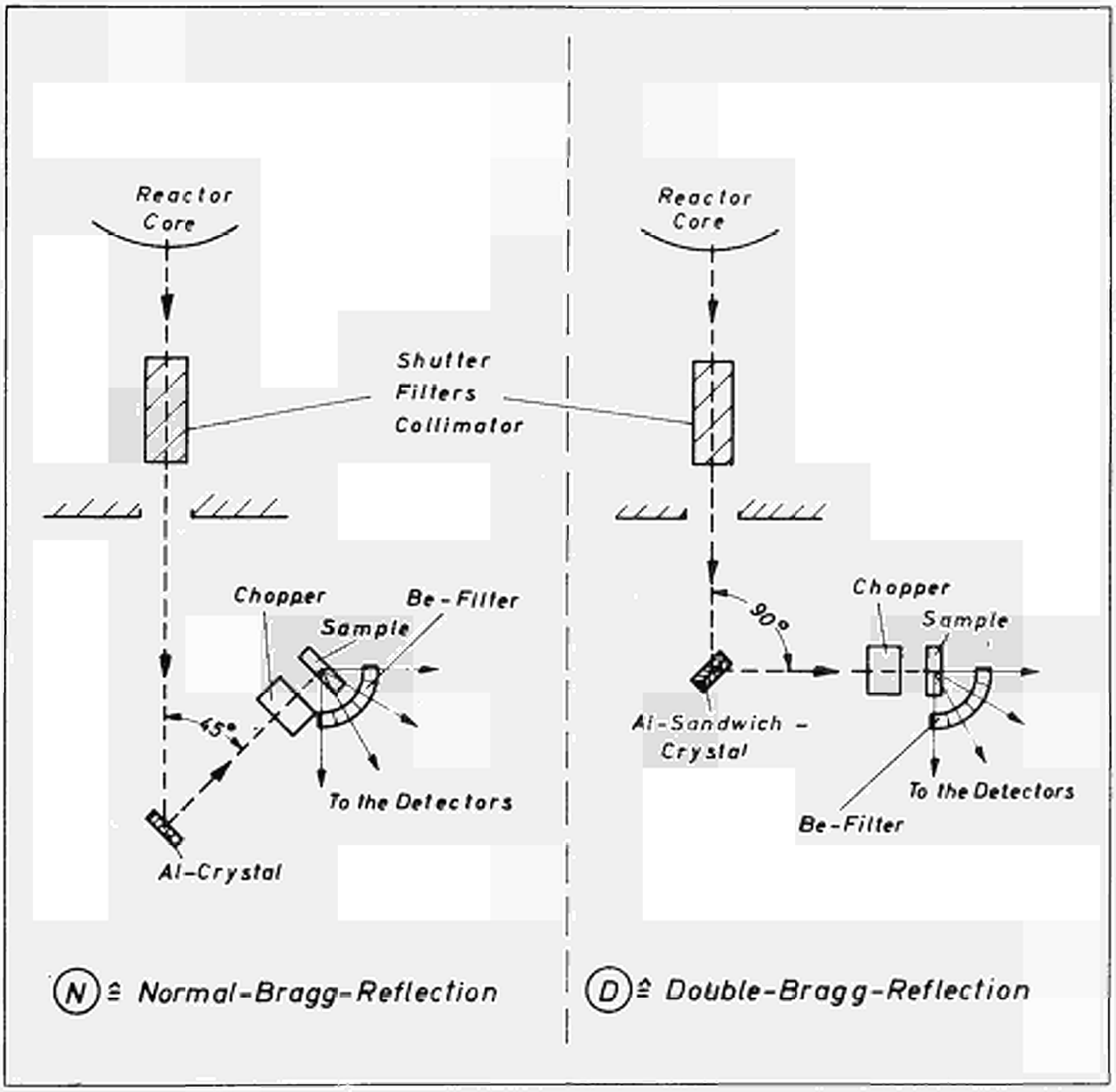

FIG. 1 - The general arrangements.

The arrangements N and D are in principle identical except the mode of monochromatization by the crystals. The neutrons which emerge from the surface of the reactor core should pass a Be- and Bi- filter before hitting the crystal. By using such filters the shielding problem will become less difficult. This is the only physical meaning of these filters here. The selection of the right neutron energy is done afterwards by a simple Al-crystal in the case N and by a sandwich like arrangement of differently orientated Al-crystals in the case D. Case N is very clear. The double reflection of case D is illustrated in Fig. 2.

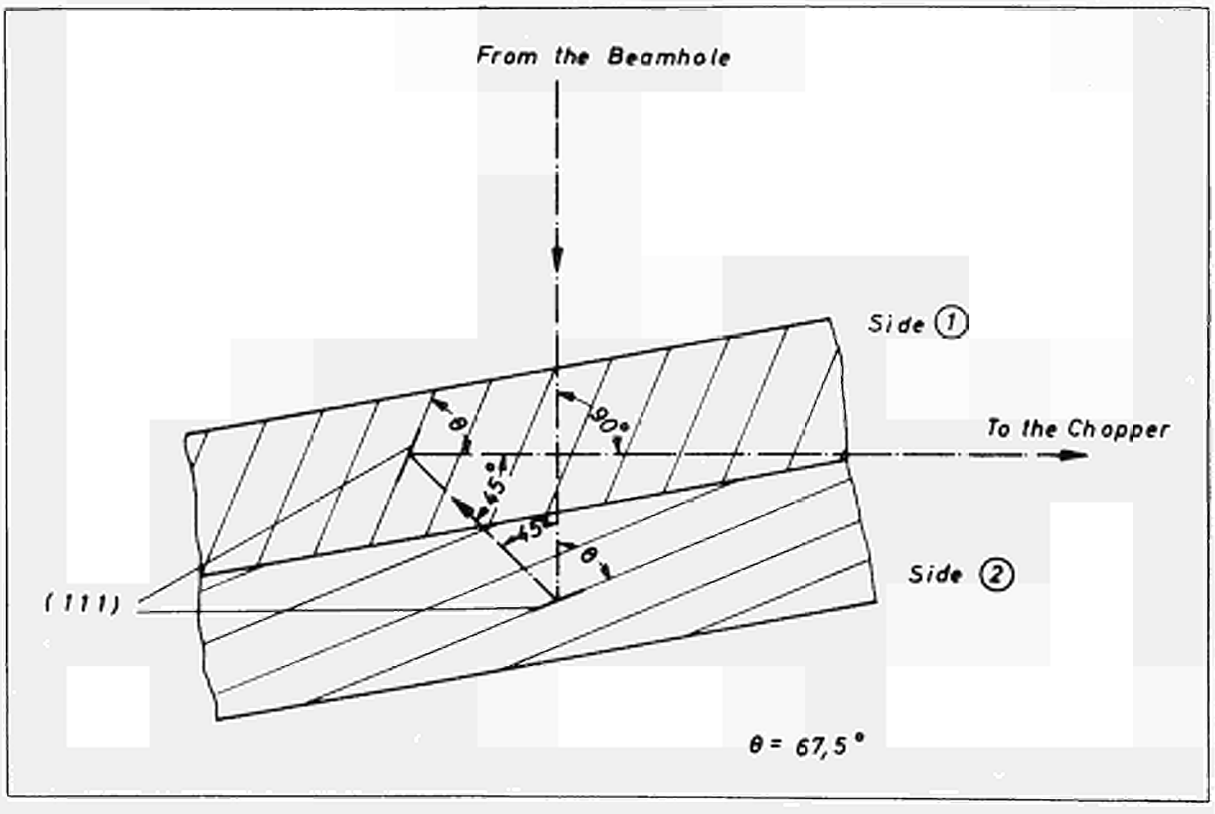

FIG. 2 - Sandwich - Crystal.

The incoming filtered beam passes the first side of the sandwich without being scattered coherently by the (111)-planes. The orientations of the (111)-planes in both parts of the sandwich are chosen thus that a maximum percentage of the neutrons with the wavelengths around the desired value of 4,3 A° are reflected back from the second side, undergo another reflection in side 1 and leave towards the chopper.

The chopper itself should be the same for both cases N and D. It is designed with respect to two facts : maximum transmission for 4,3 A° neutrons and very large duty cycle. Large duty cycle means high repetition rate and this creates the problem of overlaping neutrons from different bursts. In our case, as we are operating with very small primary neutron energies, this disturbance is caused especially by neutrons, which are scattered inelastically with energy gain. Those neutrons could catch up with the elastically scattered neutrons of the burst before.. A Be-filter, cooled by liquid nitrogen, should remove this difficulty.

It was also considered to put the chopper behind the sample and to cut off the "high energy"-neutrons by the chopper itself. But this arrangement has one weighty disadvantage : we can use only one counter bank. Because of the higher effectivity of the instrument, when operating with some more and independent counterbanks at the same time, we would prefer to install the Be-filter as indicated in Fig. 1.

D - SPECIAL CALCULATIONS

The calculations of this chapter do not pretend to a very profoundness. One should consider it to be an attempt of evaluating the characteristics of the facility by some simple estimations.

1) The Monochromatic Beam

Here we intend to deduce step by step the components of the intensity formula for the monochromatic beam before the chopper

$$I = \Phi(\lambda) \cdot \overline{\Delta\lambda} \cdot \int (\Omega/4\pi)\, dF \cdot R \tag{1}$$

where $\Phi(\lambda) \hat{=}$ flux of the filtered beam as a function of the neutron wave length

$\overline{\Delta\lambda} \hat{=}$ mean wave length interval for the neutrons selected by the crystal

$\int(\Omega/4\pi)\,dF \hat{=}$ emission probability by geometry

$R \hat{=}$ reflectivity of the crystal

This intensity I represents the monochromatic neutron flux integrated over the area of the chopper window, it is a beam current with the dimension neutrons per time unit.

In the following the calculations for normal (N) and double (D) Bragg-reflection are dealt in parallel.

a) Scattering Angle φ and Bragg-Angle Θ

The relation between the scattering angle φ and the Bragg-angle Θ , as illustrated in Fig. 3, is

N

$\varphi = 2\Theta$ (2n)

and consequently

$\Delta\Theta = \Delta\varphi/2$ (3n)

D

$\varphi = 2\pi - 4\Theta$ (2d)

$\Delta\Theta = \Delta\varphi/4$

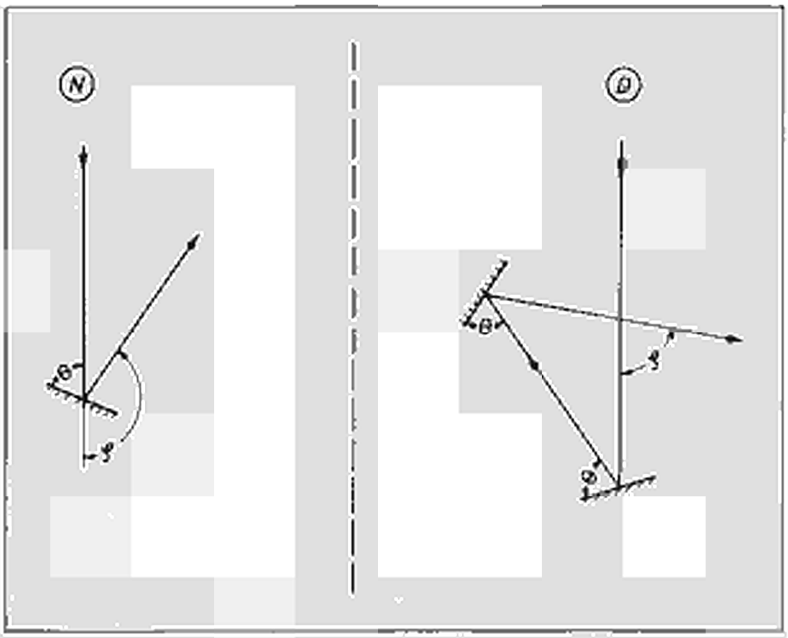

FIG. 3 - Geometry of Normal and Double Reflection.

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The spread $\Delta\varphi$ of the scattering angle is determined by the two collimators before and after the crystal.

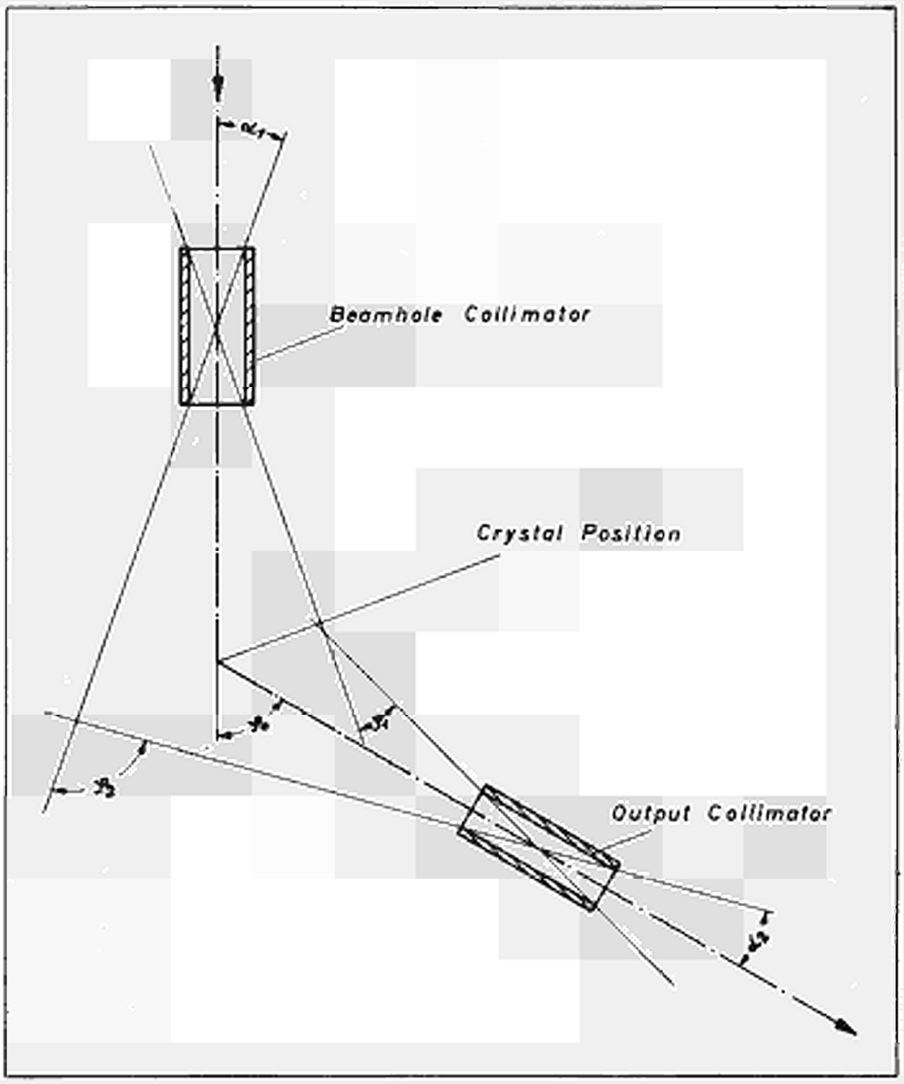

FIG. 4 - Collimation.

The maximum spread $(\Delta\varphi)_{max}$ is given by the difference of the extreme values φ_1 and φ_2 which belong to the border rays. $(\Delta\varphi)_{max} = \varphi_2 - \varphi_1 = 2\alpha_1 + 2\alpha_2$. α_1 and α_2 are the angles between border ray and axis of the collimator before and behind the crystal. (see Fig. 4).

If we assume the population of φ to have the idealized shape of a triangle distribution around φ_0 we get for the half width a value of

$$(\Delta\varphi)_{\frac{1}{2}} = (\varphi_2 - \varphi_1)/2 = \alpha_1 + \alpha_2 \qquad (5)$$

By this expression together with equation (3n) and (3d), we obtain the relation between the main spread of the Bragg-angle $(\Delta\Theta)_{\frac{1}{2}}$ and the collimations.

N	D
$(\Delta\Theta)_{\frac{1}{2}} = (\alpha_1 + \alpha_2)/2 \quad (6n)$	$(\Delta\Theta)_{\frac{1}{2}} = (\alpha_1 + \alpha_2)/4 \quad (6d)$

b) Wave Length Spread $(\Delta\lambda/\lambda)_{\frac{1}{2}}$

A combination of the results above with the Bragg-law leads straight forward to the value of the mean wave length spread $(\Delta\lambda/\lambda)_{\frac{1}{2}}$ we are interested in.

The Bragg law $\quad n\cdot\lambda = 2d\sin\Theta\ , \quad n = 1,2,3\cdots \qquad (7)$

gives by differentiation $\quad n\cdot\Delta\lambda = 2d\cos\Theta\cdot\Delta\Theta \qquad (8)$

Now we devide equ. (8) by equ. (7) and get

$$(\Delta\lambda/\lambda) = \mathrm{ctg}\,\Theta\cdot\Delta\Theta \qquad (9)$$

-/-

The halfwith of the wave length distribution in the reflected beam corresponds to $(\Delta\Theta)_{\frac{1}{2}}$ of equ. (6n) and (6d) respectively

N	D
$(\Delta\lambda/\lambda)_{\frac{1}{2}} = \mathrm{ctg}\,\Theta\cdot(\alpha_1+\alpha_2)/2$ (10n)	$(\Delta\lambda/\lambda)_{\frac{1}{2}} = \mathrm{ctg}\,\Theta\cdot(\alpha_1+\alpha_2)/4$ (10d)

If we introduce now the values $(\Delta\lambda/\lambda)_{\frac{1}{2}} = 0{,}01$, $\Theta = 67{,}5°$ and $\alpha_2 = (\Delta\chi)_{\parallel} = 0{,}01$ of chapter B, we get the determination of the beam hole collimation α_1 . ($\alpha_2 = (\Delta\chi)_{\parallel}$ is correct if we assume again a triangle distribution in χ).

N	D
$\alpha_1 = 2\cdot\mathrm{tg}\,\Theta\cdot(\Delta\lambda/\lambda)_{\frac{1}{2}} - \alpha_2$	$\alpha_1 = 4\cdot\mathrm{tg}\,\Theta\cdot(\Delta\lambda/\lambda)_{\frac{1}{2}} - \alpha_2$
$= 0{,}0384$	$= 0{,}0868$

c) Input Flux $\Phi(\lambda)\cdot\overline{\Delta\lambda}$

From other facilities with liquid nitrogen cooled Be-filters inside the beam hole one knows that about 1 % of the thermal flux (here $2.10^{13}\,cm^{-2}s^{-1}$) passes a 30 cm filter unit. The shape of the wavelength distribution is assumed to be zero for wave lengths smaller than the cut off value of 3,96 A° and to follow the low energy tail of the thermal equilibrium distribution beyond this limit (see Fig. 5).

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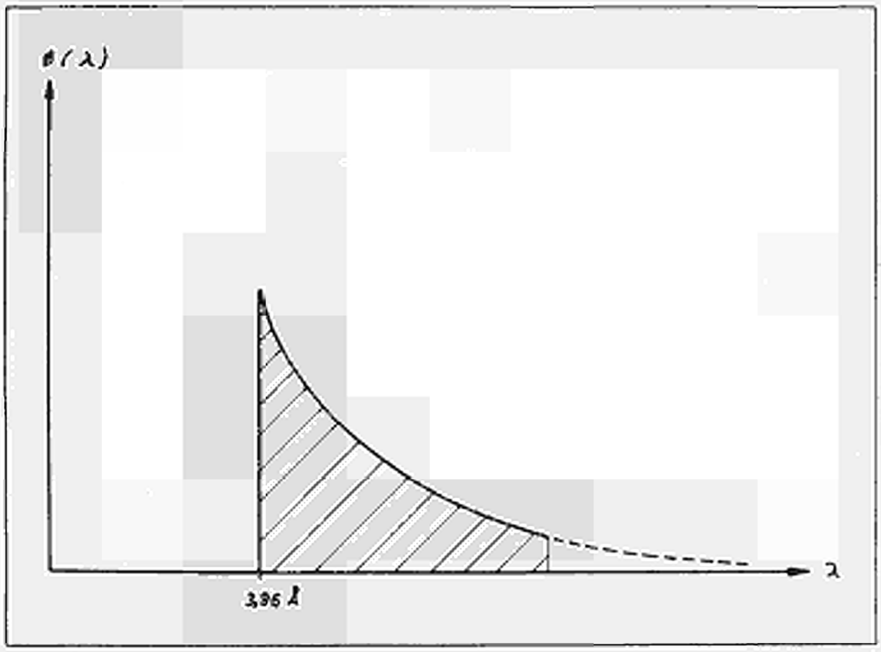

FIG. 5 - Filtered Neutron Flux.

$$\Phi(\lambda) = 0 \qquad \text{for } \lambda < 3{,}96\ \text{A}^\circ \tag{11}$$

$$\Phi(\lambda) = A / \lambda^5 \qquad \text{for } \lambda \geq 3{,}96\ \text{A}^\circ \tag{12}$$

The constant factor A is determined by the integrated flux,

$$\int_{3,96\text{A}^\circ}^{\infty} \Phi(\lambda) \cdot d\lambda = 0{,}01\ \Phi_{th} = 2 \cdot 10^{11}\ cm^{-2}\ s^{-1}$$

to be $A = 1{,}9 \cdot 10^{14}\ cm^{-2}\ s^{-1}\ A^{\circ 4}$

-/-

The mean value of the wavelength interval $\overline{\Delta\lambda}$ which enters directly to the intensity formula is not equivalent to the $\Delta\lambda$ of the final wavelength spread $(\Delta\lambda/\lambda)_2$. It is much smaller and given only by the output-collimation α_2: Let us consider one arbitrary direction in the filtered beam which includes together with the axis of the output collimator the angle φ. Then we see that neutrons deflected by angles between $\varphi - \alpha_2/2$ and $\varphi + \alpha_2/2$ can pass the output collimator. The interval $\Delta\varphi = \alpha_2$ is independent on the primary direction.

With equ. (3n, d), (9) and our input data we get :

N	D
$\overline{\Delta\lambda} = ctg\,\theta \cdot \lambda \cdot \alpha_2/2 \quad (14n)$	$\overline{\Delta\lambda} = ctg\,\theta \cdot \lambda \cdot \alpha_2/4 \quad (14d)$
$= 8{,}90 \cdot 10^{-3}$ A°	$= 4{,}45 \cdot 10^{-3}$ A°
and	
$\Phi(\lambda) \cdot \overline{\Delta\lambda} = (1{,}9 \cdot 10^{14} \cdot 8{,}90 \cdot 10^{-3})/(4{,}3)^5$	$\Phi(\lambda) \cdot \overline{\Delta\lambda} = (1{,}9 \cdot 10^{14} \cdot 4{,}45 \cdot 10^{-3})/(4{,}3)^5$
$= 1{,}15 \cdot 10^9\ cm^{-2}\ s^{-1}$	$= 5{,}75 \cdot 10^8\ cm^{-2}\ s^{-1}$

d) Crystal Mosaic Spread

The statement above, that $\Delta\varphi=\alpha_2$ is valid for all neutron directions preselected by the beam hole collimator, is based on two assumptions :

- Firstly all the range to which the wave lengths of the reflected beam extend, should be equally populated in the reactor beam, and

- Secondly the structure of the crystal should provide that all neutrons which finally pass the output collimator are reflected in saturation.

It can be easily understood that the first point is fulfilled very well as the chosen value of the neutron wave length is away far enough from the Be-cut off. The second point however should be explained more deeply. Here we have the impression that we touch the main problem of the facility proposed in this report and it will be investigated experimentally as soon as possible.

As the outgoing collimation is rather sharp compared with the collimation inside the beam hole, we neglect α_2 and consider only α_1 when discussing the crystal structure. We demand that all neutrons of flight directions within a range of $\pm\alpha_1$ around the main direction should be reflected in saturation. This means that the value of the mosaic spread of the crystal should be of the order of magnitude of $(\Delta\psi)_{\frac{1}{2}} \approx 2\alpha_1$. (In the arrangement D this is valid only for side 2 (see Fig. 2), whereas for side 1, the value of $(\Delta\psi)_{\frac{1}{2}}$ could be much smaller. Here we have $(\Delta\psi)_{\frac{1}{2}} \approx (\Delta\theta)_{\frac{1}{2}} = 0,024)$.

Moreover this spread should not be of an isotopic character but of cylindrical symmetry as follows :

the normals to the (111)-planes are all rather exactly (spread about 30') lying parallel to the plane of the beam axes, but have an angular distribution within this plane of half width $(\Delta\psi)_{\frac{1}{2}} \approx 2\alpha_1$
This definition of the anisotropic spread is exactly valid in the case of a plane non focusing crystal (see below) and should be modified a little bit concerning the plane built up by the normals if we consider a "bent mirror".
In any case it is obvious why this kind of anisotropy is desirable : it should avoid primary extinction by reflections in other direction but towards the output collimator. In general it should be possible to attain this type of structure by rolling plates of well oriented single crystal material.

e) Geometry Factor $\int(\Omega/4\pi)\cdot dF$

The expression $\int(\Omega/4\pi)\cdot dF$ comprehends the influence of the beam hole geometry on the current at the reference plane. In our case the reference plane is the chopper window, or better the sample, if we include already the chopper to our considerations. With the assumption of the crystal reflectivity equal to unity, the term $\int(\Omega/4\pi) dF$ indicates the neutron current through the sample corresponding to the flux unity at the emitting plane next the reactor core.

An exact solution of this integral is rather difficult, as there should be taken into account the variation of Ω over the emitting plane but also another importance function affected to dF, which is caused by the geometrical flux distribution.

-/-

Therefore we do the following simplifying transformation :

$$\int (\Omega/4\pi)\, dF = F \cdot \alpha_1 \cdot \beta \,/4\pi \qquad (15)$$

with $F \hat{=}$ area of the neutron emitting plane

$\left.\begin{matrix}\alpha_1 \\ \beta\end{matrix}\right\} \hat{=}$ angular collimation in the two planes of symmetry (horizontal and vertical).

We decided F to be 20 cm x 20 cm (see sketch of the final lay out Fig. 12). Moreover we have already determined α_1 for the two arrangements N and D.
The only missing number is β. It is easily evaluated for the case of a plane non focusing crystal.
There we get :

$$\beta_{non} = \ell_{CH} \,/ (D_{RC} + D_{CS}) \qquad (16)$$

where $\ell_{CH} \hat{=}$ long side of the chopper window

$D_{RC} \hat{=}$ distance reactor-crystal

$D_{CS} \hat{=}$ distance crystal-sample

There is a possibility of increasing this value by at least a factor of two if we go to some expense in the construction of the crystal. By bending the crystal (in the arrangement D only one of the two sides) or composing it of a few stripes with an adjusted orientation of the (111) planes one should be successful in obtaining a focusing effect as demonstrated in Fig. 6 (axes of primary and reflected beam turned into one plane).

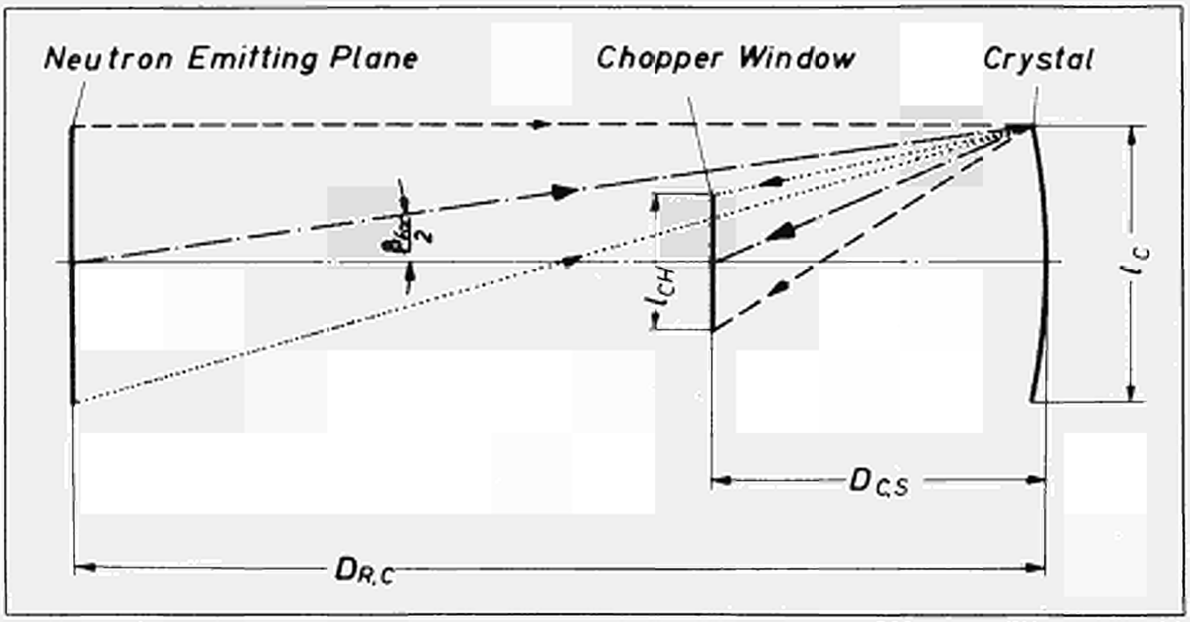

FIG. 6 - Focusing Effect of a curved Crystal.

From Fig. 6 we can read the value of β_{foc} directly

$$\beta_{foc} = l_C / D_{RC} \qquad (17)$$

For calculating the numbers of $\int(\Omega/4\pi)\,dF$ we must take the dimensions of the final lay out (see Fig. 12 and 13).

N

$$\int(\Omega/4\pi)\,dF = F \cdot \alpha_1 \cdot \beta_{foc} / 4\pi = \frac{400 \cdot 0{,}0384 \cdot 20}{450 \cdot 4\pi} = 5{,}44 \cdot 10^{-2}\ \mathrm{cm}^2$$

D

$$\int(\Omega/4\pi)\,dF = F \cdot \alpha_1 \cdot \beta_{foc} / 4\pi = \frac{400 \cdot 0{,}0868 \cdot 20}{300 \cdot 4\pi} = 18{,}4 \cdot 10^{-2}\ \mathrm{cm}^2$$

f) Crystal Reflectivity R

In both arrangements N and D the crystals will be cut in a way that the (111)-planes do not lie parallel to the crystal surface. This is caused by the fact that the broad beam of reactor neutrons should turn to a relatively narrow beam of monochromatic neutrons impinging on the chopper. The situation of normal Bragg reflection is illustred in Fig. 7.

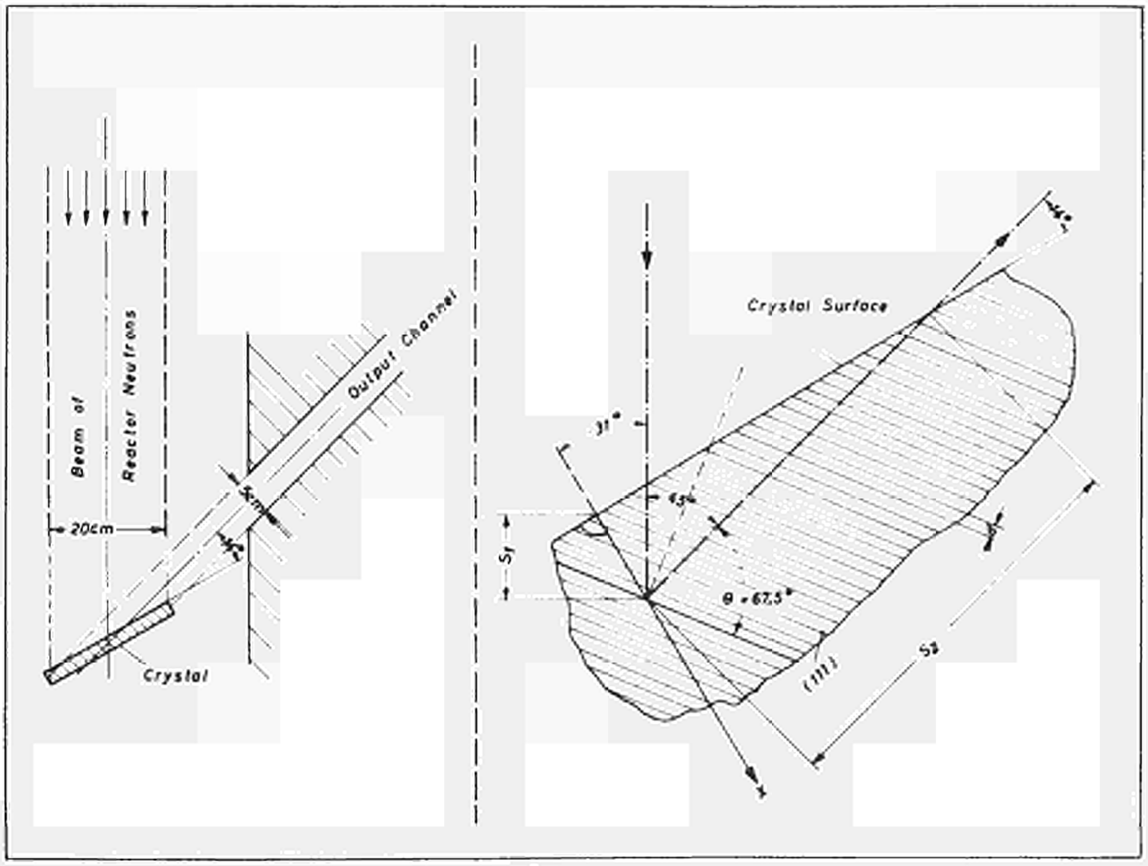

FIG. 7 - Geometrical Arrangement of Crystal N.

We consider the special event that a neutron penetrates the crystal to a depth x along the flight path s_1 . There it is Bragg-scattered and leaves the crystal along s_2 without being reflected again. The corresponding numbers of (111)-planes, which were traversed along s_1 and s_2 respectively are :

$$n_1 = (s_1 \sin\theta)/d = (x \cdot \sin 67{,}5°)/(d \cdot \cos 31°) \tag{18}$$

and

$$n_2 = (s_2 \sin\theta)/d = (x \cdot \sin 67{,}5°)/(d \cdot \cos 76°) \tag{19}$$

If we neglect absorption and assume w to be the probability for Bragg reflection per plane and $\bar{d}$ to be the mean distance of equally orientated planes (taking into account the mosaic structure), we get for the probability that a neutron of the right energy is scattered in the space between x and x + dx, but no more when it goes out of the crystal, the expression

$$\begin{aligned} r(x)dx &= \exp\{-wn_1\} \cdot w \cdot dn_1 \cdot \exp\{-wn_2\} \\ &= \exp\{(-wx)(\sin 67{,}5°/\cos 31° + \sin 67{,}5°/\cos 76°)/\bar{d}\} \cdot \\ &\quad \cdot (w \cdot \sin 67{,}5° \cdot dx)/(\bar{d} \cos 31°) \end{aligned} \tag{20}$$

For the case of a crystal in saturation (we mean saturation for all neutron energies, which could be reflected into the output channel), we get the reflectivity R (including only single reflections) by summing up the differential contributions from $x = 0$ to $x = \infty$

$$\begin{aligned} R_N = \int_0^\infty r(x)\,dx &= 1/(1 + \cos 31°/\cos 76°) \\ &= 0{,}22 \end{aligned} \tag{21}$$

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The reflectivity of the sandwich-crystal is the product of the single reflectivities R_1 and R_2 of both sides. Those are evaluated in the same way as described above, but with respect to the geometry of Fig. 8a.

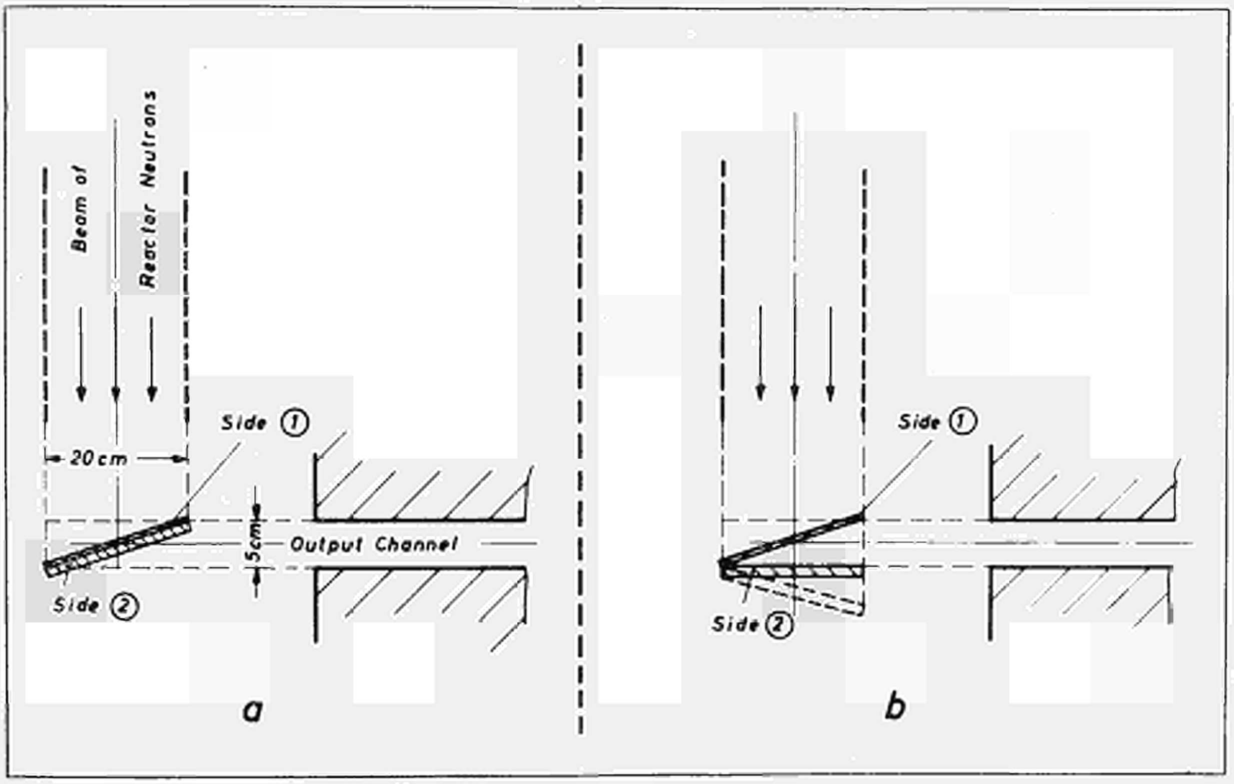

FIG. 8a and 8b - Two Possibilities of positioning the Crystal D.

The partial reflectivity R_1 is of course equal to R_N, as the geometrical situation is the same. But for side 2, we find that the traces of incoming and leaving neutrons have nearly the same length. Therefore the reflectivity is increased to $R_2 = 0,47$. With these numbers we obtain

$$R_D = R_1 \cdot R_2 = 0,22 \cdot 0,47 = 0,10$$

In order to demonstrate that these numbers will be realistic, we would like to remark that the Swedish workers Dahlborg, Sköld and Larsson (15) report about a measured reflectivity value of 27 % for an Al-single crystal but 1,08 Å neutron wave length. Also in this case the angular divergency of the primary beam is rather large.

For the experiment it could perhaps be favourable to use an arrangement like this of Fig. 8b. The main advantage there will be that the outgoing neutrons are not forced to penetrate again side 2 which will have a thickness of a few centimeters because of the large mosaic spread requested. The position of side 1, the curved crystal, should not be changed (althought one could increase the angle between the crystal surface and the axis of the reflected beam, as the neutrons are reflected back from side 2 under an angle of 45 degrees), as otherwise one could not use side 1 in the case of normal Bragg-reflection N. The overall reflectivity R_D calculated for the arrangement of Fig. 8a is practically not changed if we go over to the arrangement of Fig. 8b.

g) Monoenergetic Beam Current I

Now it is a small step to the beam current, we can expect before the chopper. We should only collect the numbers we have already prepared above, and put them into the intensity formula

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$$I = \Phi(\lambda)\cdot\overline{\Delta\lambda}\cdot\int(\Omega/4\pi)dF\cdot R \qquad (1)$$

The results are :

N	D
$I = 1{,}15.10^{9}.5{,}44.10^{-2}.0{,}22$	$I = 5{,}75.10^{8}.18{,}4.10^{-2}.0{,}10$
$1{,}4.10^{7}\ s^{-1}$	$1{,}1.10^{7}\ s^{-1}$

2) The Chopper

a) Duty Cycle ε

It must be the aim of our calculations about the chopper lay out to maximize the value of the duty cycle ε with a burst time $\Delta\tau$ which fits to a time resolution $\Delta\tau/T = 0{,}01$ of the time of flight system. According to the definitions we get :

$$\varepsilon = \Delta\tau\cdot a\cdot\nu = 0{,}01\cdot T\cdot a\cdot\nu = (0{,}01\cdot L\cdot a\cdot\nu)/v \qquad (22)$$

where $\Delta\tau \mathrel{\hat=}$ half width in time of the neutron burst (s)
$a \mathrel{\hat=}$ number of neutron bursts per chopper revolution
$\nu \mathrel{\hat=}$ chopper frequency (revolutions per second)
$T \mathrel{\hat=}$ neutron time of flight (s) corresponding to $\lambda = 4{,}3$ A°
$v \mathrel{\hat=}$ neutron velocity ($930 ms^{-1}$) corresponding $\lambda = 4{,}3$ A°
$L \mathrel{\hat=}$ length of the neutron flight path (m)

From equ. (22) we see that we are forced to find a compromise with respect to the mechanical construction. This is valid especially for the length of the neutron flight channel, as in our case with angular divergencies of 0,01 and 0,1 respectively, the dimensions of the

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counter bank give no reasonable limitation. We feel that L = 5 m is a value which could still be accepted.

For the product $(a \cdot v)$, which indicates the burst repetition rate, there exists an upper limit by the overlap problem. Even if we use the Be-filter behind the sample container (see chapter C and E), we must consider neutron velocities up to 1020 ms^{-1} corresponding to the Be-cut off. By this reason we believe that the value of $(a \cdot v)$ should not exceed 1000 bursts per second.

With a = 1, that means using a chopper with curved slits through the centre of the rotor, it is technically impossible (60 000 r.p.m.) to reach the limit above. A straight slit chopper (a = 2) at 30 000 r.p.m. is also out of discussion. Therefore we propose to use a "cross chopper" with the rotor axis besides the monochromatic beam as sketched below.

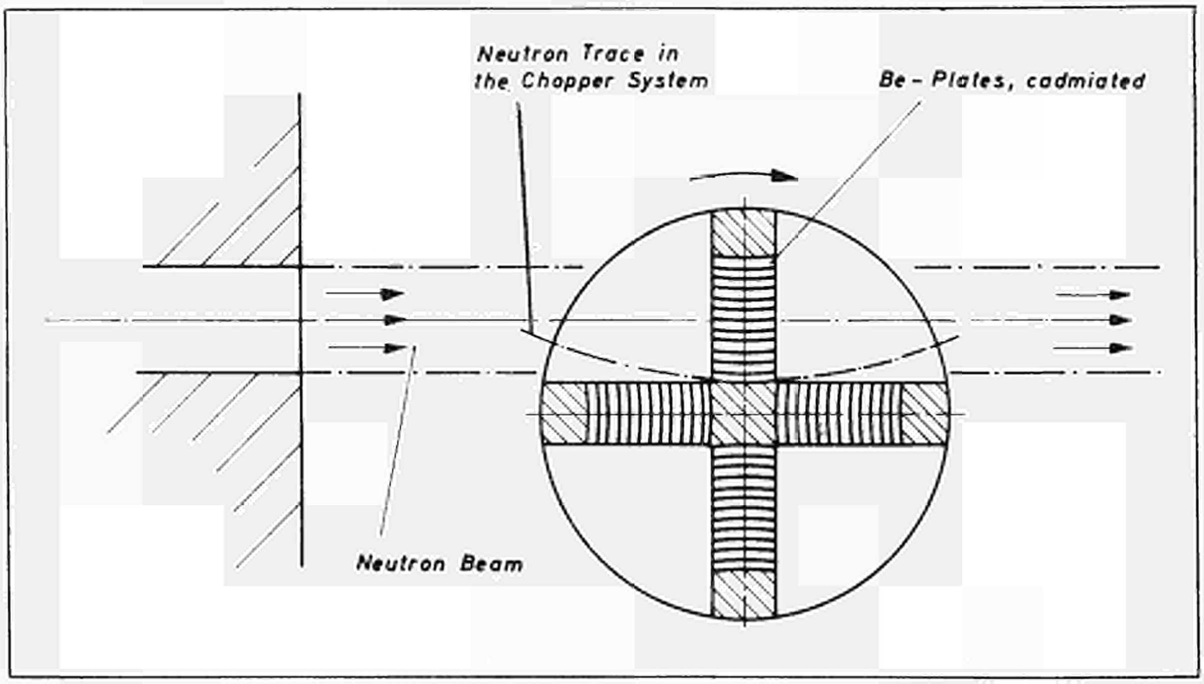

FIG. 9 - Cross Chopper Arrangement.

This type of chopper supplies us with four neutrons bursts per revolution. Therefore we already arrive at the value ($a \cdot v$) = 1000 with a chopper speed of 15 000 r.p.m.

The sense of rotation should be chosen in such a way that the arm in the region of the beam moves with the neutrons. By this method we avoid any interference of the chopper arms with the neutron burst, which is just cut. As we see in the system of the rotating chopper, the traces of the neutrons, which can pass one arm, tend away from those two arms perpendicular. Moreover the chopper will be relatively light. According to the picture we have in mind, the chopper should be composed mainly of Al and Be. Therefore we believe that one should not have troubles with the chopper speed of 15 000 r.p.m. With these data of the general chopper lay out we obtain for the value of the duty cycle

$$\varepsilon = (0{,}01 \ . \ 5 \ . \ 1000) \ / \ 930 \ = \ 0{,}054$$

b) Dimensions of the Slits

For the first calculations about the dimensions of the chopper slits we treat this chopper like a straight slit chopper, as the curvature of the slits will finally - if at all - be adjusted to the (sharp) neutron energy.

As already indicated above we drive at a solution with four arms, each composed by a packet of Be-plates, which are cadmiated at the surfaces where they touch each other. The neutrons should pass the beryllium and be absorbed, when hitting the Cd-layer between

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the Be-plates. The length of these plates is already predetermined by the dimensions of the beam to be about 110 mm (minimum 100 mm). Further we have to evaluate the numbers for the width, thickness and curvature of the plates.

We start with the width s_{Be} and thickness δ_{Be}, which are coupled by the neutron burst time $\Delta\tau$

$$\Delta\tau = \alpha_{CH} / 2\pi\nu = \delta_{Be} / s_{Be} \cdot 2\pi\nu \qquad (23)$$

This equation is based on the assumption that the angular divergency of the chopper slits α_{CH}, equivalent to the angle between border ray and cadmiated surface (see Fig. 10), is much larger than the angular divergency $(\Delta\chi)_{\parallel} = 0{,}01$ of the monochromatic neutron beam. We see below that this postulation is very well fulfilled.

From Equ. (23) we get with $\Delta\tau = (0{,}01 \cdot L)/v$

$$\alpha_{CH} \approx \delta_{Be} / s_{Be} = (2\pi\nu \cdot 0{,}01 \cdot L)/v = 0{,}085$$

The exact method of deducing from this ratio the absolute values of δ_{Be} and s_{Be} is a maximizing calculation for the chopper transmission, taking into account the inelastic scattering in Be and the decrease of the effective beam cross section by the Cd-layers of thickness δ_{Cd}.

For this purpose we first have to determine δ_{Cd}. We claim that the transmission through one Cd-zone should not exceed the value of 10^{-3}. The most unfavourable beam geometry with respect to the length of the neutron traces inside Cd is demonstrated in Fig. 10.

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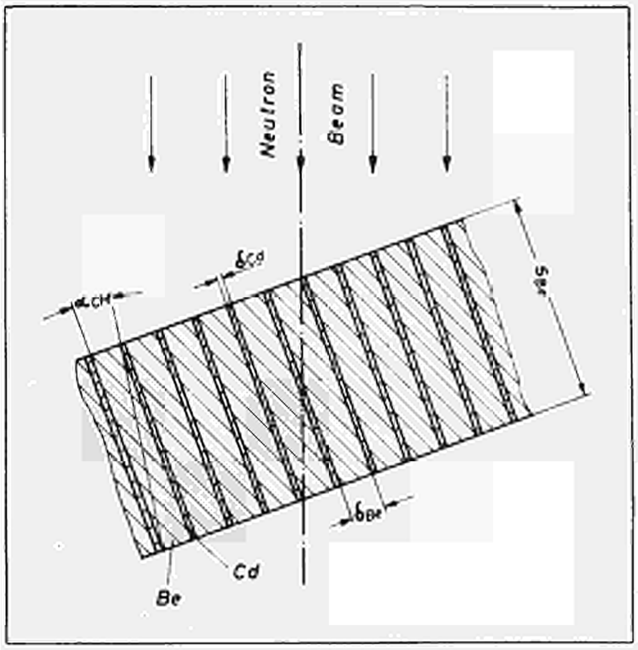

FIG. 10 - Geometry of minimum Neutron Absorption in Cd.

Simple geometrical considerations lead to

$$10^{-3} = \exp\{(-\Sigma_{Cd}\cdot\delta_{Cd}\cdot s_{Be})/2\delta_{Be}\}$$

and with the values

$$\delta_{Be}/s_{Be} = 0{,}085$$

and $\Sigma_{Cd} = 113\ cm^{-1}$ we find $\delta_{Cd} = 0{,}010\ cm$

(Resulting thickness of the Cd-cover per plate surface 0,005 cm).

When optimizing the chopper transmission we calculate with a total macroscopic cross section of Be at

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room temperature of $\Sigma_{Be} = 0{,}06\ cm^{-1}$. The term Tr, which is of interest here, represents the maximum value of the (triangular) chopper transmission function in time. By this value the intensities of chopped and unchopped beam are connected in the following way :

$$n = I.\ Tr.\ \Delta\tau$$

where n $\hat{=}$ number of neutrons per burst

(I $\hat{=}$ beam current before the chopper, dimension neutrons per time unit).

According to the general lay out of the chopper, the value Tr itself is determined by the product of two terms :

- the ratio of effective chopper cross section to the overall area of the chopper window
- and the attenuation of the neutron intensity by the beryllium

$$Tr = (\delta_{Be} \cdot exp\{-\Sigma_{Be} \cdot s_{Be}\}) / (\delta_{Be} + \delta_{Cd}) \qquad (25)$$

With the data $\delta_{Be} / s_{Be} = 0{,}085$, $\delta_{Cd} = 0{,}01$ cm and $\Sigma_{Be} = 0{,}06\ cm^{-1}$.

we already know : $Tr = (\delta_{Be} \cdot exp\{-0{,}705 \cdot \delta_{Be}\}) / (\delta_{Be} + 0{,}01)$

For optimizing the thickness δ_{Be} of the Be-plates we look for the value corresponding to $dTr/d\delta_{Be} = 0$.

$$dTr/d\delta_{Be} = 0 = exp\{-0{,}705\,\delta_{Be}\}\,[1/(\delta_{Be} + 0{,}01) - \\ - \delta_{Be}/(\delta_{Be} + 0{,}01)^2 - 0{,}705\,\delta_{Be}/(\delta_{Be} + 0{,}01)] \qquad (26)$$

There from

$$(1 - 0{,}705\,\delta_{Be})/(\delta_{Be} + 0{,}01) - \delta_{Be}/(\delta_{Be} + 0{,}01)^2 = 0 \qquad (27)$$

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The results are

$$\left.\begin{aligned} (\delta_{Be})_{optim.} &= 0{,}11 \text{ cm} \\ \text{and } (s_{Be})_{optim.} &= 1{,}30 \text{ cm} \end{aligned}\right\} \quad T_{\gamma\,optim.} = 0{,}85$$

This optimization is valid only if the plates will be curved. Otherwise, that means if one takes straight Be-plates by reasons of simple manufacturing, the value of the theoretically demanded plate deflection Δx_0 (see Fig. 11) is introduced to the calculations as an additive term to the thickness δ_{Cd} of the Cd-layer. Concerning the curvature of the Be-plates we are interested only in the quantity Δx_0 of the deflection, as the form of the slits is in a first approach assumed to be circular. We start our considerations with Fig. 11 and observe a representative neutron when traversing one chopper arm symmetrically at a distance x_0 from the chopper axis. The neutron leaves the chopper at a point B. While travelling from the point A (on the symmetry plane of the chopper arm) to B, the time t elapses and the chopper turns forward by the angle γ

$$\gamma = 2\pi\nu \cdot t \tag{28}$$

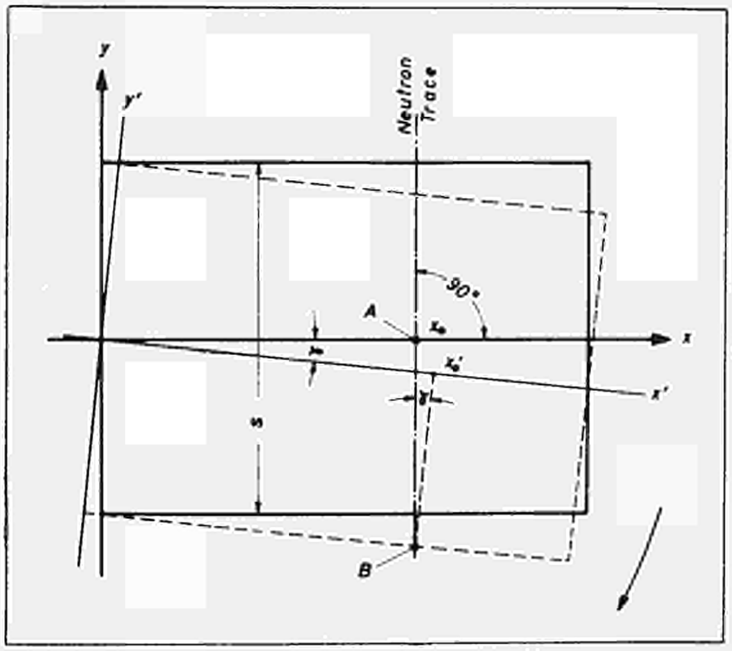

FIG. 11 - Orientation of one Chopper Arm with neutron at point A and B respectively.

With the simplifying assumptions
$\sin\gamma = \gamma$ and $\cos\gamma = 1$
we find the following relations :

$$t = (s/2 + x \cdot \gamma)/v \tag{29}$$

and $$(x_0' - x_0) = \Delta x_0 = (s \cdot \gamma)/2 \tag{30}$$

By these equations we come to :

$$(x_0' - x_0) = \Delta x_0 = (s/2)^2/(v/2\pi\nu - x_0) \tag{31}$$

Using the results of the optimizing calculations above, we calculate Δx_0 for $x_0 = 3$ cm and $x_0 = 8$ cm

$$(\Delta x_0)_3 = 0{,}0075 \text{ cm}$$
$$(\Delta x_0)_8 = 0{,}0083$$

These numbers indicate that it is suitable to work with an uniform curvature corresponding to $\Delta x_0 = 0{,}0080$ cm Even if the curvature of the Be-plates is completely neglected, the optimized value of the chopper transmission $(T_\gamma)_{optim.} = 0{,}85$ is decreased by only

$$\Delta x_0/(\delta_{Be})_{optim.} = 0{,}008 / 0{,}11 \approx 7 \%$$

3) The Efficiency of the Facility

There is only a small step now to the numbers, indicating the efficiency of the whole facility. We at least have to connect a few data evaluated by the previous calculations.

a) Beam Current at the Sample N

The main number of neutrons N arriving at the sample per time unit is built up by the product of

- the neutron beam current I before the chopper
- the duty cycle ε of the chopper
- the chopper transmission T_γ

- and a factor η, which takes into account the attenuation by scattering and absorption of neutrons in the filters, in air and a few window plates. We estimate η to amount about 70 % .

$$N = I. \varepsilon . Tr \cdot \eta$$

Now we have to split up our considerations according to the two distinct arrangements with normal and double Bragg-reflecting crystals.

N	D
$N = 1{,}4.10^7.0{,}54.0{,}85.0{,}70$	$N = 1{,}1.10^7.0{,}054.0{,}85.0{,}70$
$= 4{,}5 \;.\; 10^5 \;\; s^{-1}$	$= 3{,}5 \;.\; 10^5 \;\; s^{-1}$
$= 2{,}7 \;.\; 10^7 \; min^{-1}$	$= 2{,}1 \;.\; 10^7 \; min^{-1}$

b) Detector Count Rate c

We calculate the count rate c of one counter bank with the following assumptions about the neutron scattering experiment itself :

- One percent of the neutrons striking the sample are scattered isotropically. The rest is transmitted and will completely be absorbed afterwards.
- The angular divergencies of the neutron traces reaching the detector amount to the value of $(\Delta\chi)_{\parallel} = 0{,}01$ and $(\Delta\chi)_{\perp} = 0{,}1$ respectively. (Corresponding area of the detector about 5 cm x 50 cm).
- The detector efficiency is supposed to be e = 0,5 .
- The neutron flight channel is filled by helium gas. (No attenuation of neutron intensities, see chapter E).

We get : $c = 0{,}01 \cdot N \cdot (\Delta\chi)_{\parallel} \cdot (\Delta\chi)_{\perp} \cdot e / 4\pi$

and with the numbers of those two arrangements N and D

N	D
$c = 0{,}18 \;\; s^{-1}$	$c = 0{,}14 \;\; s^{-1}$
$\approx 10 \; min^{-1}$	$\approx 8 \; min^{-1}$

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These numbers of the integrated count rate will be confronted with a background (without sample) of about 5 counts/min. If one looks however only to the region of the elastic peak in the time of flight spectrum (range about 100 μs), one should find that the background component, which does not arise from the sample or sample container is negligible, as the corresponding ratio of signal to background will be in the order of magnitude of some 10^4 .

4) The Costs

For a judgement of the facility especially with respect to the chance of realisation, it will be of some importance to have an idea of the price. Therefore we present below a list with the costs of the main components of the spectrometer. Those costs - this should be stated very clearly - result from very rough estimations.

- Be-filter material	$	5 000 -
- Bi-filter material		4 000 -
- Mechanics of the beam hole plugs (including lead plugs, pumps, cooling system)		3 000 -
- Shielding waggon with crystal supports		5 000 -
- Sandwich crystal (normal crystal included, see chapter D,1,f)		6 000 -
- Cross chopper with driving system		3 000 -
- Be-filter near the sample container		3 000 -
		29 000 -

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		$	29 000 -
- Mechanics of the time of flight section (shield, He-container, sledges for the detectors)	10 000 -		
- Four counter banks, each 5 cm x 50 cm (voltage supply and amplifiers included)	4 000 -		
- Monitors (with power supply and counting device)	2 000 -		
- Spectrometer without time of flight analyser		$	45 000 -
- Time of flight analyser			25 000 -
T o t a l :		$	70 000 -

The costs of sample containers are not taken into account, as those vary over a large range depending on the type of measurement one intends to perform. With this small restriction one can say that the total costs of the spectrometer will finally amount to US. $ 70 000 -
We believe that one could start the work in the first year with a budget of US. $ 40 000 -

E - SKETCH OF THE FINAL LAY OUT

We describe the final lay out of the spectrometer by means of the Fig. 12 and 13 respectively following the way of the neutrons from the reactor core to the detectors.

The inner part of the beam hole is nearly empty. Only a diaphragm of boron-aluminium with a quadratic gap 20 cm x 20 cm is placed there. The space of the shutter shaft remains free also, as it will be useful to cut the beam by the shutter when operating in front of the beam hole. Next to the shutter shaft in the exterior part of the beam hole there is placed a plug composed of lead (20 cm length) and paraffin (30 cm length) with a concentric channel of 20 cm x 20 cm. The liquid nitrogen cooled filter unit with a polycrystalline Be-block of 30 cm length and 20 cm long Bi-single crystals (this sequence) joins the inner plug. These filters do not influence the characteristics of the spectrometer directly, but they simplify the shielding problem and improve the background. The rectangular hollow in front of the cylindric beam tube is filled again by a lead plug with a concentric channel of 20 cm x 20 cm cross section (perhaps conical).

In the following part between output of the beam hole and sample container there are differences between the two arrangements N and D. The positions of the crystals (distance from the wall of the reactor block 2,10 m and 0,6 m respectively) result from the different geometry of the Bragg-reflection and from the constructional feature, that the output channels through the shielding waggon tend to one fixed sample position, As a consequence of the latter point of view, it is necessary

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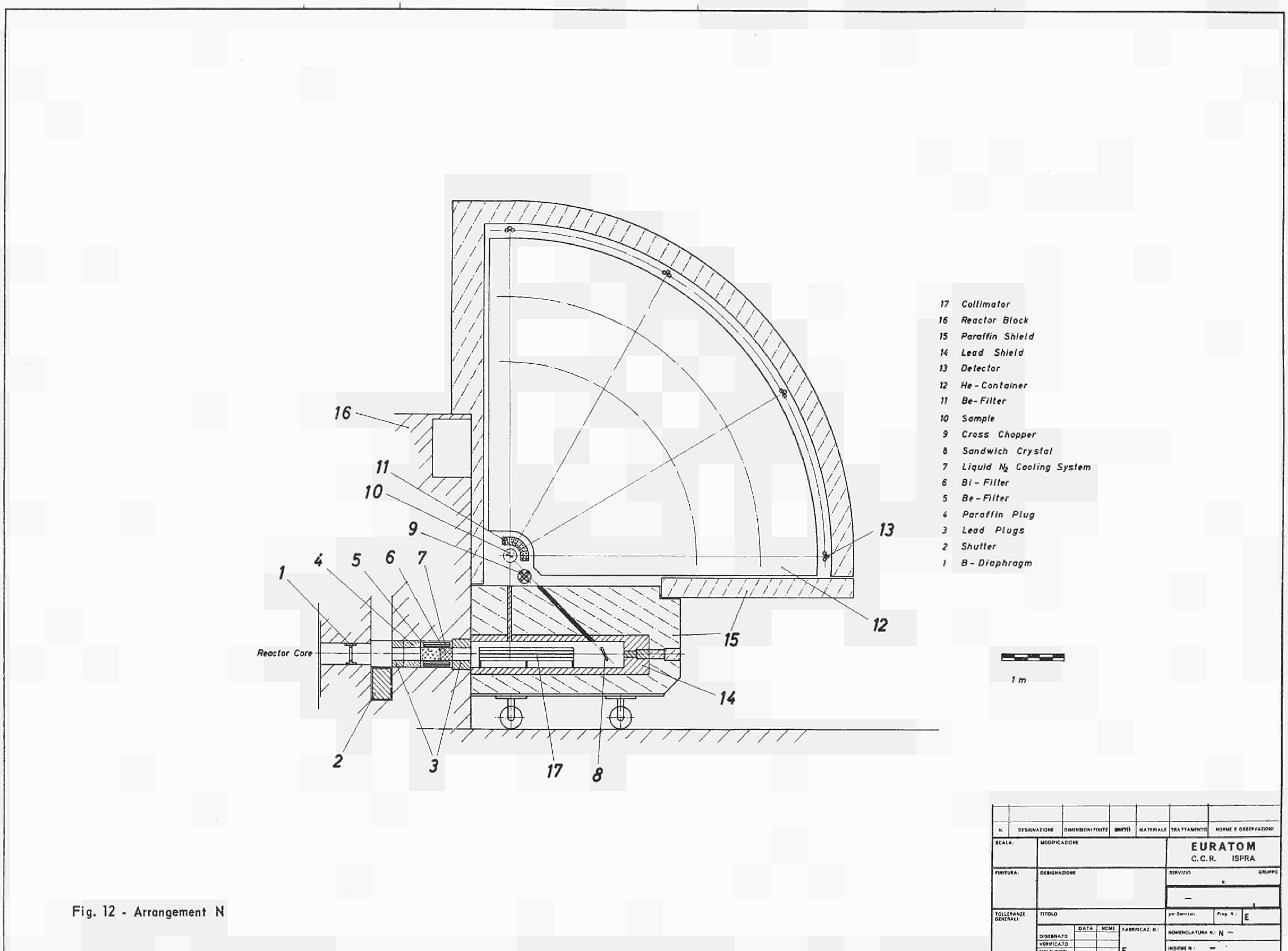
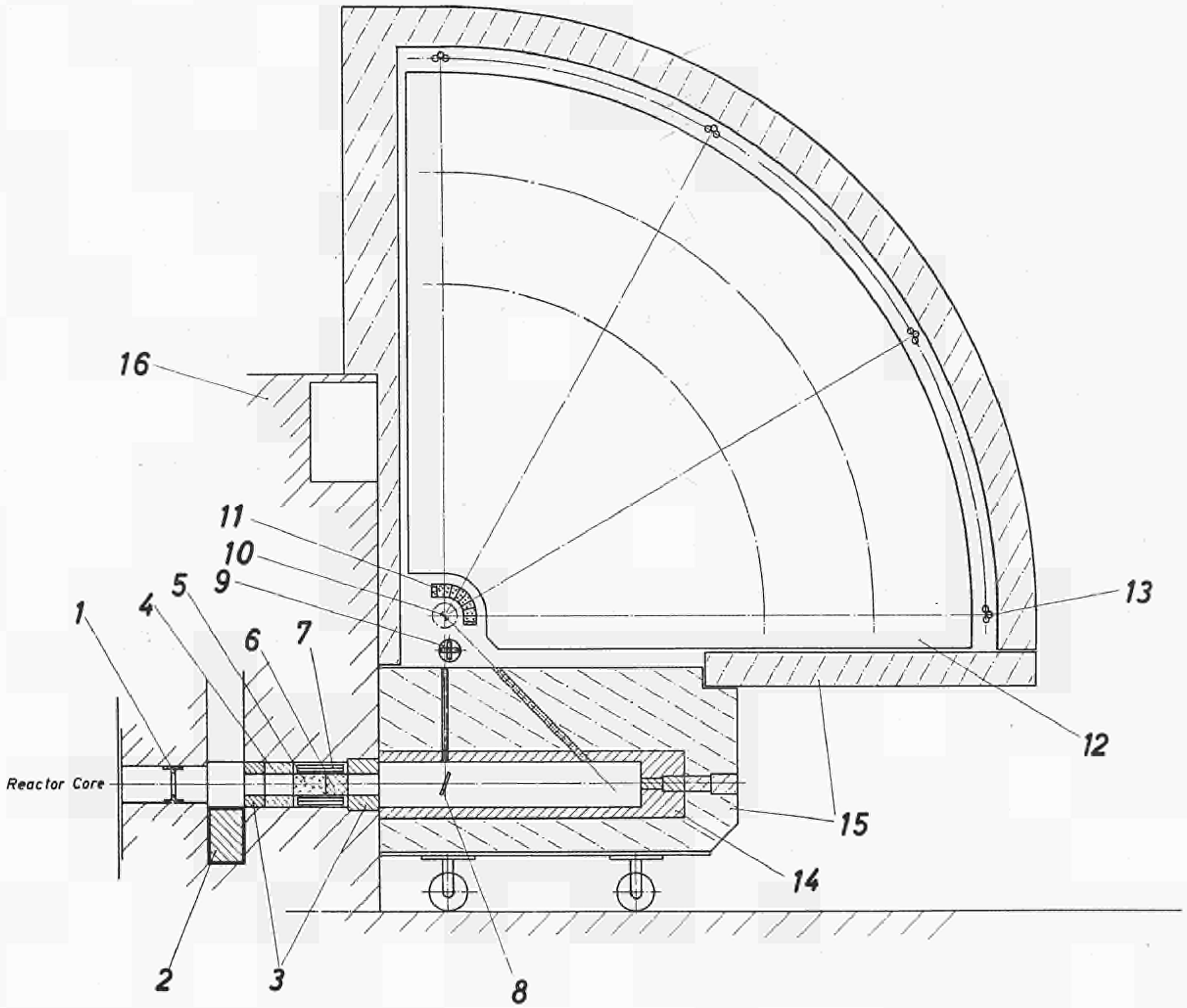


Fig. 12 - Arrangement N



16 Reactor Block
15 Paraffin Shield
14 Lead Shield
13 Detector
12 He-Container
11 Be-Filter
10 Sample
9 Cross Chopper
8 Sandwich Crystal
7 Liquid N_2 Cooling System
6 Bi-Filter
5 Be-Filter
4 Paraffin Plug
3 Lead Plugs
2 Shutter
1 B-Diaphragm

1m

Fig. 13 - Arrangement D

N.	DESIGNAZIONE	DIMENSIONI FINITE	QUANTITÀ	MATERIALE	TRATTAMENTO	NORME E OSSERVAZIONI

SCALA: MODIFICAZIONE — EURATOM C.C.R. ISPRA

FINITURA: DESIGNAZIONE — SERVIZIO GRUPPO

TOLLERANZE GENERALI: TITOLO — per Servizio: Prog. N.: E

DISEGNATO / VERIFICATO / CAPO DI GRUPPO — DATA — NOME — FABBRICAZ. N.: F — NOMENCLATURA N.: N — INSIEME N.: —

to change the cross chopper position when varying the type of crystals used.

But there appear some more differences between the two distinct arrangements. While the collimators of the output channels refer both to the same values of angular divergencies according to the performance data claimed, the collimation of the primary neutron beam is different. In the case of double Bragg-reflection with $\alpha_1 = 0{,}087$, the diaphragm in the inner beam tube serves in connection with the dimensions of the sandwich crystal itself (about 20 cm x 20 cm) for the right collimation, whereas it is necessary to insert a simple Soller collimator ($\alpha_1 = 0{,}038$) to the hole of the shielding waggon, when operating with normal Bragg-reflections.

A few remarks on the shielding waggon itself.
The thickness of the neutron shield in the upper part is chosen relatively large, as by this means there is caused no intensity loss because of the artificial collimation in the output channels but an improvement with respect to the background. Moreover it will be useful to close the whole shielding waggon gas tight and to fill it with helium gas in order to avoid the attenuation of neutron intensity by air scattering.

The latter aspect counts even more in the time of flight analysing division. There we intend to install inside the shielding housing, which encloses the whole section of neutron flight channels (shielding material water, walls 30 cm thick on the average), a light container for helium gas, which extends to the space between the liquid nitrogen cooled Be-filter near the sample and the counter banks. This container as well as the shielding waggon could permanently be attached to a helium bottle by a pressure reduction valve, which provides an overpressure of a few centimeters of H_2O.

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The neutron detectors, which operate in normal atmosphere, are mounted on sledges. Those will move within a range of little more than 90 degrees on a sector of 5 m/radius around the sample container.

We believe that a more detailed constructional study would not be well timed but would blow up this report.

F - COMPARISON WITH OTHER FACILITIES AND DISCUSSION OF THE RESULTS

The comparison with other cold neutron facilities already working is done on the basis of a paper by R.M. Brugger and Y.D. Harker [16], which deals with resolution and intensity compilations of time of flight neutron spectrometers. But our comparison refers only to spectrometers with rather good energy resolution and neutron energies of about 5 meV.

In column 1 of the Table below, we introduce those distinct facilities. In column 2, the integrated thermal neutron flux Φ_{th} of the proper reactor and in column 3 the value of the wave length spread $(\Delta\lambda/\lambda)_{\frac{1}{2}}$ of each facility are given. In column 4 and 5, we find the intensity data reported by Brugger and Harker and at the end the numbers calculated for the facility proposed in this paper.

The quantity N represents the neutron current through the sample (dimension min^{-1}) whereas φ_{cold} gives the mean value of the current density, called neutron flux (dimension $cm^{-2}min^{-1}$). The latter numbers are listed by reasons of fair play. Regarding the neutron <u>flux</u> the advantage of our facility seems not to be so striking. However one can figure out that this quantity (flux) does not count for the type of measurements we have in mind as long as the upper limit of the angular divergencies is not surpassed. And this is valid here.

In the last column we tabulate a figure of merit m, which gives a classification of the facilities with respect to the special use for elastic and quasielastic measurements. We are far away from maintaining that those facilities, which fare badly in this presentation, are bad constructions in general.

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Type and Location of the Facility	Φ_{th} $\left[\frac{1}{cm^2\,sec}\right]$	$\left(\frac{\Delta\lambda}{\lambda}\right)_{\frac{1}{2}}$ $[\%]$	N $\left[\frac{1}{min}\right]$	φ_{cold} $\left[\frac{1}{cm^2\,min}\right]$	m $\left[\frac{1}{min}\right]$
Cold Neutron Chopper Dido-Reactor, Harwell	$5 \cdot 10^{13}$	2.7	$2.4 \cdot 10^{6}$	$1.9 \cdot 10^{5}$	$1.3 \cdot 10^{5}$
Three Phased Rotors HFBR, Brookhaven	$5 \cdot 10^{14}$	1.5	$3.0 \cdot 10^{7}$	$4.8 \cdot 10^{6}$	$5.3 \cdot 10^{5}$
Double Chopper Reactor Ispra I	$2 \cdot 10^{13}$	2.5	$3.6 \cdot 10^{5}$	$1.5 \cdot 10^{5}$	$5.8 \cdot 10^{4}$
Rotating Crystal Reactor Ispra I	$2 \cdot 10^{13}$	1.0	$2.5 \cdot 10^{4}$	$7.0 \cdot 10^{2}$	$2.5 \cdot 10^{4}$
Rotating Crystal NRU-Reactor, Chalk River	$2 \cdot 10^{14}$	1.0	$2.5 \cdot 10^{5}$	$2.0 \cdot 10^{4}$	$2.5 \cdot 10^{4}$
Facility Proposed (Reactor Ispra I) Arrangement N	$2 \cdot 10^{13}$	1.0	$2.7 \cdot 10^{7}$	$5.4 \cdot 10^{5}$	$2.7 \cdot 10^{7}$
Arrangement D	$2 \cdot 10^{13}$	1.0	$2.1 \cdot 10^{7}$	$4.2 \cdot 10^{5}$	$2.1 \cdot 10^{7}$

TABLE 1 - Comparison with other Facilities.

We start the calculations on the figure of merit m with the numbers of the beam current N and normalize those to a value of the thermal neutron flux Φ_{th} equal to $2.10^{13} cm^{-2} s^{-1}$ (equivalent to the flux of the reactor Ispra-I) and to a wave length spread $(\Delta\lambda/\lambda)_{\frac{1}{2}}$ equal to 1 % supposing that a variation of the resolution is inserted by the square of $(\Delta\lambda/\lambda)_{\frac{1}{2}}$ to the intensity formula.

$$m = N \cdot 2 \cdot 10^{13} \cdot \Phi_{th}^{-1} \cdot (\Delta\lambda/\lambda)_{\frac{1}{2}}^{-2}$$

The time resolution $\Delta\tau/T$ does not enter into this figure of merit if we assume that this value could be adapted to the accuracy claimed by varying the length of the neutron flight path. Moreover there are not taken into account the different angular divergencies of the chopped beam (those might be small enough in any case) and corrections for the different energy spectra of the reactor fluxes.

From the numbers of Table 1, we may conclude the following : Both arrangements N and D of the facility proposed in this report are equivalent concerning the beam intensity. The difference of 20 % lies within the uncertainty of the calculations. But both arrangements, which are supposed to be installed at the largest beam hole of the Reactor Ispra-I, could supply us with neutron intensities, which might compete with those of the three phased rotor unit at the high flux reactor in Brookhaven. Further it seems to us that there still exists no facility, which is designed especially for investigations on elastic and quasielastic neutron scattering, as in the figure of merit there is a difference of a factor 50 between our facility and the second placed equipment, which is again the famous three rotor instrument in Brookhaven.

The intensity numbers of some 10^7 neutrons per minute

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discussed above cannot be applied directly to inelastic scattering work. For instance one cannot use our cross chopper, which gives the large value of the duty cycle (0,054), but a normal curved slit chopper. On the other hand it is not necessary for inelastic experiments with energy gain of the neutrons (energy loss processes are negligible as the neutron wave length is fixed to 4,3 A°) to have such small angular divergencies as we claim now. But if we take out the Soller collimator from the output channel of the shielding waggon, this means that we increase the angular divergency in the plane of the beam axes from 0,01 to 0,05 and the wave length spread from 0,01 to less than 0,02, we get the intensity of the non chopped monochromatic beam enhanced by a factor of 5. These remarks should indicate only that the facility proposed could perhaps become interesting also for inelastic scattering work if some modifications are applied.

Finally we would like to demonstrate by the measuring time one should expect that it is worthwhile to fight for those very high neutron intensities. (This all the more as in our case the total price of the facility which is estimated to amount to about US. $ 70 000 - seems to be relatively low). We may return to the example regarded in the introduction of this report : investigations on structure and dynamics of liquids by means of a shape analysis of the elastic peak in the time of flight spectrum of the scattered neutrons. Normally, in order to keep the correction terms samll, one uses samples, which correspond to a neutron scattering probability p of about 2 % . Besides this the total number of counts C in the elastic peak should fit to the accuracy of the measurement. We consider $C = 10^5$ to be suitable. With these data and the value of the standard count rate c of chapter D,3,b

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(c = count rate at the detector for scattering probability equal to 1 %, $c \approx 10\ \mathrm{min}^{-1}$) we obtain the measuring time t as follows :

$$t = \frac{C}{p.100.c} \approx \frac{10^5}{20} = 5\,000\ \mathrm{min} = 83\ \mathrm{h} = 3{,}5\ \mathrm{days}$$

We believe that a measuring time of a few days is the upper limit one could accept for high precision measurements with very delicate samples. In other words it seems to us that many cold neutron experiments, which could spend new knowledge on the features of liquids and solids, will become realizable with neutron intensities, which could just be attained by this new facility proposed.

G - ACKNOWLEDGEMENTS

I am greatly indebted to Mr. W. Kley, Chief of the Experimental Neutron Physics Division at the Euratom Research Centre in Ispra, for his dynamic support and many valuable suggestions to this work.

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H. MEISTER.

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A P P E N D I X

DESIGN STUDY OF A CROSS CHOPPER

by H. Geist.

From the foregoing report result for the design of a cross chopper the following :

Neutron Physical Demands :

1) Apparatus with 4 chopping areas ;

2) Dimensions of each of these areas at least equal to the neutron beam section ; in our case at least 10 x 5 cm^2 ;

3) Every area consists of a package of beryllium sheets, separated from each other by a thin Cd-layer. The width of the Be-sheets is 1,3 cm . They may be straight or slightly curved in direction of their width ;

4) When the chopper is in the position "open", no other material than aluminium may be before or behind the chopping areas. The total thickness of aluminium in the beam should be as low as possible ;

5) The operation speed of the apparatus is 15 000 r.p.m..

Design Principles Adopted for the Apparatus :

1) Since a test run at 1.3 times operational speed is necessary, 20 000 r.p.m. are fixed as design speed ;

2) At design speed, a safety factor of 2 is fixed. As safety factor, the quotient of yield strength over overall stresses (not local stress concentrations) is defined ;

3) Stresses on the beryllium sheets must be avoided ;

4) The apparatus runs in air. In order to have a power consumption as low as possible, all surfaces must be smooth ;

5) The apparatus must be so rigid that the first critical speed of the shaft is above design speed ;

6) As motor, a high frequency motor directly mounted on the shaft is used ;

7) As bearings, oil mist lubricated ball-bearings for grinding spindles are chosen ;

8) It must be possible to balance dynamically with great precision the rotating part (wholly mounted) of the apparatus.

Description of the Apparatus :

On the above principles, the design study shown in Fig. 1 and Fig. 2 of the Appendix is based.

The beryllium sheets of a chopping area are fixed by wedges in a box girder. According to the shape of the faces of the wedge and the upper filler towards the sheet package, curved or straight sheets may be inserted.
The box girders are made of aluminium. Their sides have a relatively small thickness. Their ends are clamped to the shaft by a four-armed, star shaped piece. They can be considered as beams with uniformly distributed load, freely supported at their ends. The beryllium sheets are only subject to compressive forces. On the sides of the upper beams of the girders, o,5 mm thick Cd-foils are glued in order to absorb those neutrons that otherwise would pass above the chopping areas.

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The arms of the star shaped pieces are subject to tension stresses due to the applied load, the centrifugal force, and bending. They are machined in such a way that the maximum tension stresses in every section parallel to the shaft are in first approximation uniform.

The dimensions of the shaft are thus that its first critical velocity is above design speed. On the side towards the motor, it is supported by a group of two ball-bearings which take besides of the radial forces, all axial forces to which it is subject. A third ball bearing is located at its other end. It is pre-stressed in axial direction by a helical spring to eliminate the radial play.

The temperatures of the outer races of all bearings are measured by thermocouples and monitored if they exceed a pre-set value.

The bearings are housed in parted supports. Thus, dynamic balancing on an adequate machine with the bearings mounted on the shaft is possible. The parted supports also facilitate mounting and dismounting.

Behind the pre-stressed bearing, a pick-up device is placed. It gives the trigger pulses for the time-of-flight installation and consists of a commercially available, stationary magnetic pick-up and of a rotating disc of unmagnetic material that has at one point of its circumference a pin of soft iron.

Smooth surfaces of the rotating parts are obtained by putting an aluminium tube around the two star shaped pieces. The end surfaces of the cylinder are closed by two Al-discs screwed to the different arms.

-/-

Some Design Data

1) Box Girder

Material	: high strength Al-alloy
Yield Strength	: ca. 32 kg/mm^2
Weight with all inserts	: 0,5 kg
Centrifugal force with all inserts at design speed	: 13 000 kg
Maximal Deflection under this uniformly distributed load	: 5.10^{-3} cm
Unbalance caused by a displacement of the centre of gravity of 10.10^{-3} cm	: 25 kg
Maximal bending tension stress	: 900 kg
Maximal bending compressive stress	: 1 200 kg/cm^2
Maximal shear stress	: 910 kg/cm^2
Centrifugal force of a Cd-foil glued to the upper beam	: 550 kg
Shear stress on the glued connection	: 20 kg/cm^2
Shear strength of an araldite-type glue	: 250 kg/cm^2

2) Four Armed, Star Shaped Piece

Material	: high strength steel, heat treated, type maraging- or Cr Ni Mo - steel

-/-

Yield strength	: ca. 100 kg/mm^2
Centrifugal force of one arm	: ca. 17 000 kg
Maximum tension stress in every section parallel to the axis due to centrifugal forces, applied load and bending moment	: 5 000 kg/cm^2

3) Shaft

Material	: Steel, surface hardened, all seats and threads grinded
Stresses	: Negligible
Critical velocity	: Above design speed

4) Bearings

Type	: High precision grinding spindle ball-bearings with plastic cage
Lubrication	: Oil mist
Maximum allowable turning rate	: 25 000 r.p.m.

5) Motor

High frequency synchronous motor

Power	: at 15 000 r.p.m. 2,5 kW
	: at 20 000 r.p.m. ca. 3,5 kW
Maximum allowable speed	: 40 000 r.p.m.

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6) Cover - Tube

Material	: High strength Al-alloy
Yield strength	: ca. 32 kg/mm
Circumferential stress	: 1 600 kg/cm^2

7) Other Data of Interest

Weight of the rotating parts	: 15 kg
Circumferential velocity	: at 15 000 r.p.m. 190 m/sec
	: at 20 000 r.p.m. 250 m/sec
Kinetic energy	: at 15 000 r.p.m. ca. 5 600 mkg
	at 20 000 r.p.m. ca. 10 000 mkg

Power consumption due to friction :

- in air at 15 000 r.p.m.	ca. 1,4 kW
- at 20 000 r.p.m.	ca. 3,2 kW
- in helium, at 15 000 r.p.m.	ca. 0,3 kW
- at 20 000 r.p.m.	ca. 0,7 kW

Maximum power to overcome inertia of the rotating part during acceleration from 0 to 20 000 r.p.m. within 10 minutes:

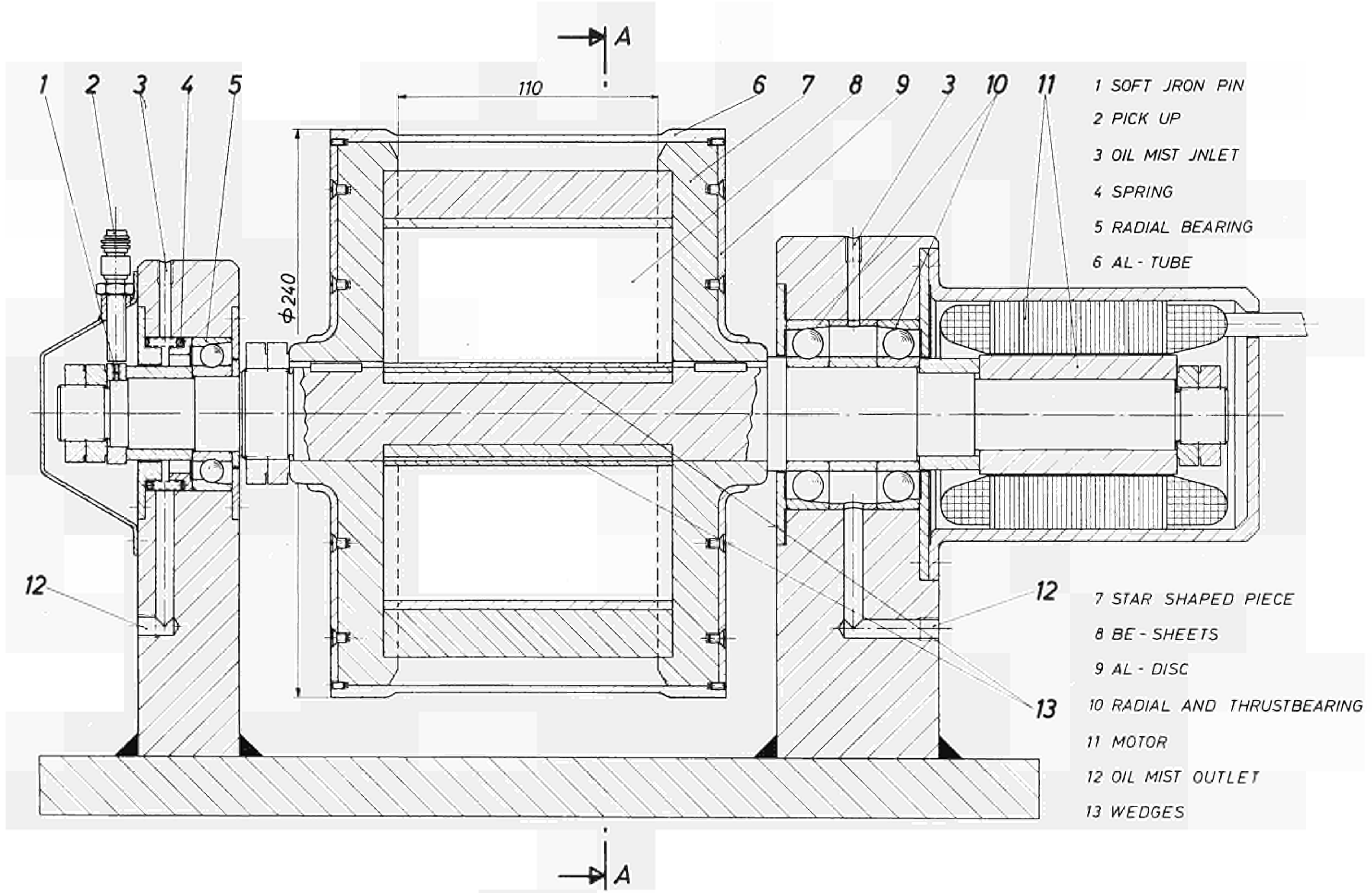
0,3 kW

C o n c l u s i o n

The foregoing demonstrates that a cross chopper fulfilling the mentioned demands of physicist can be built with rather common materials and techniques and without excessive expense. It shows also that such a device can be operated safely having the usual engineering safety factor.

It must be born in mind that this design study does not pretend to give already the final solution of the problem, but that it shall only show the feasibility of such a device.

Before a design is arrived at, some details will have to be changed and others must be optimized.



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1 2 3 4 5
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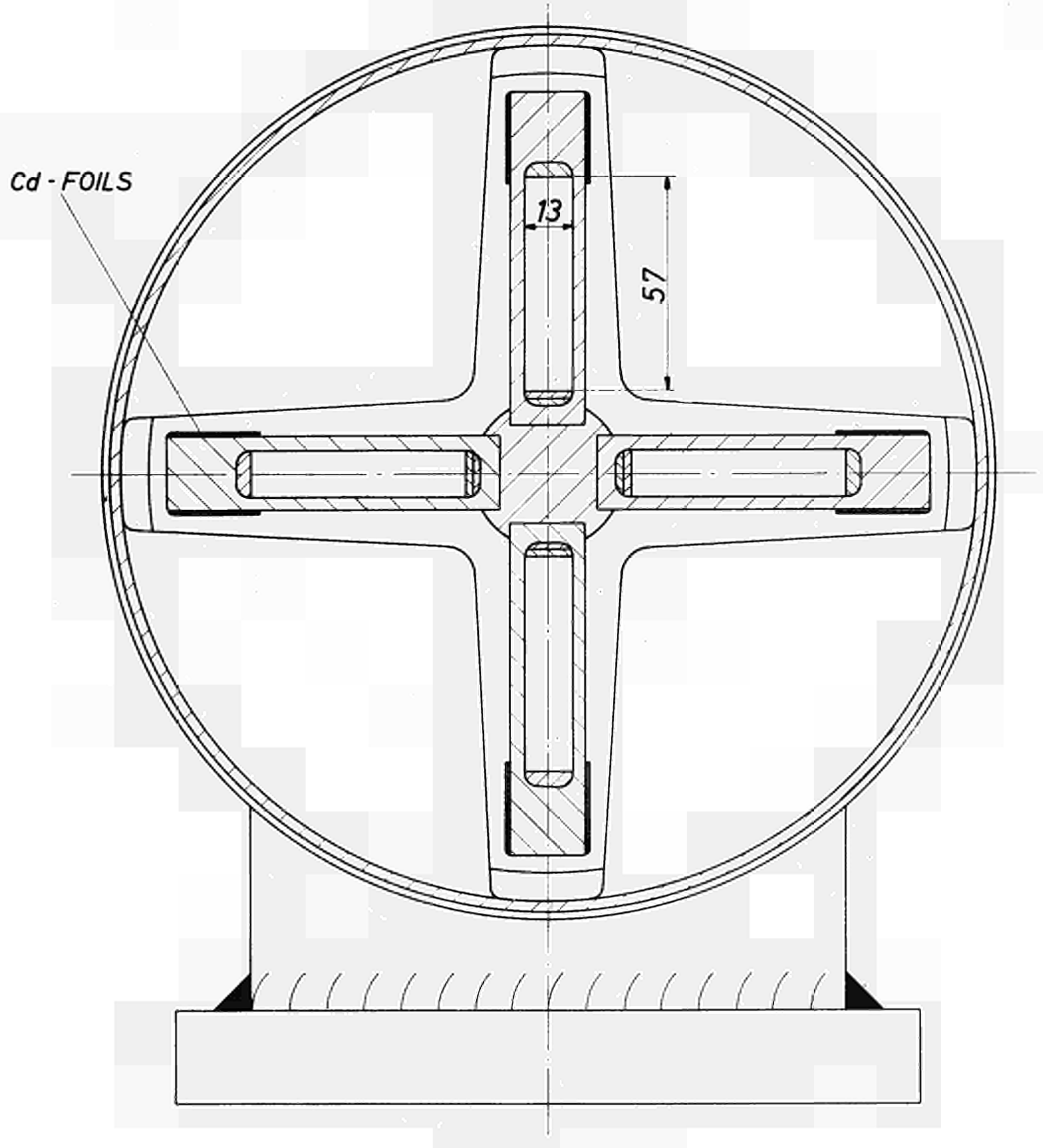
A
1 SOFT JRON PIN
2 PICK UP
3 OIL MIST JNLET
4 SPRING
5 RADIAL BEARING
6 AL - TUBE
7 STAR SHAPED PIECE
8 BE - SHEETS
9 AL - DISC
10 RADIAL AND THRUSTBEARING
11 MOTOR
12 OIL MIST OUTLET
13 WEDGES

Fig. 1



Section A-A

Fig. 2

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Alfred Nobel

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