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ADVANCED NEUTRON SOURCES
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Status Report on the SIN Spallation Neutron Source

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Abstract

This status report describes the general layout of the planned SIN spallation neutron source. In the description of the technical concept we emphasize the version using natural convection of the liquid metal target. In the second part of the report we discuss the neutronics, based on results of mock-up experiments. Furthermore, beam tube arrangements and proposed spectrometers are presented.

Layout

Figure 1 shows the general layout of the SIN accelerator system and of the experimental hall with the two meson target stations. The injector II with its pre-injector (Cockcroft-Walton) can be seen at the north side of the hall. With this injector 2 mA beam currents of 590 MeV protons can finally be expected. The position of the planned spallation neutron source will be south-east of the main experimental hall, in the prolongation of the primary proton beam. This site is illustrated in Fig. 2 which also shows the extended experimental hall. The south-east hall is reserved for the neutron source and the experimental areas with thermal neutrons and the "guide-hall" for experiments with cold neutrons.

Technical Concept

The SIN spallation neutron source will use the principle of a liquid heavy-metal target (Pb/Bi-eutectics). Either of the two following cooling concepts may be applied:

1) forced convection - horizontal target

2) natural convection - tilted or vertical target (beam entering from below)

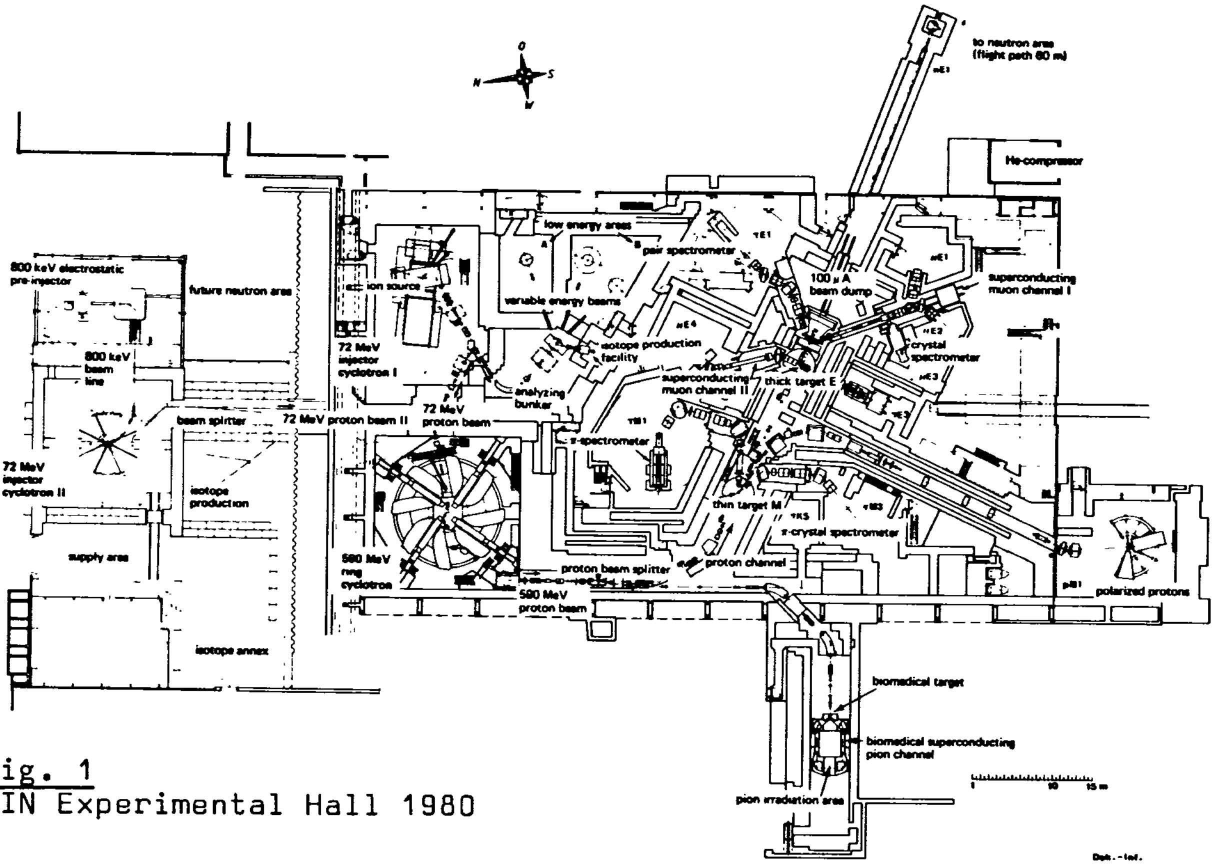

Fig. 1
SIN Experimental Hall 1980

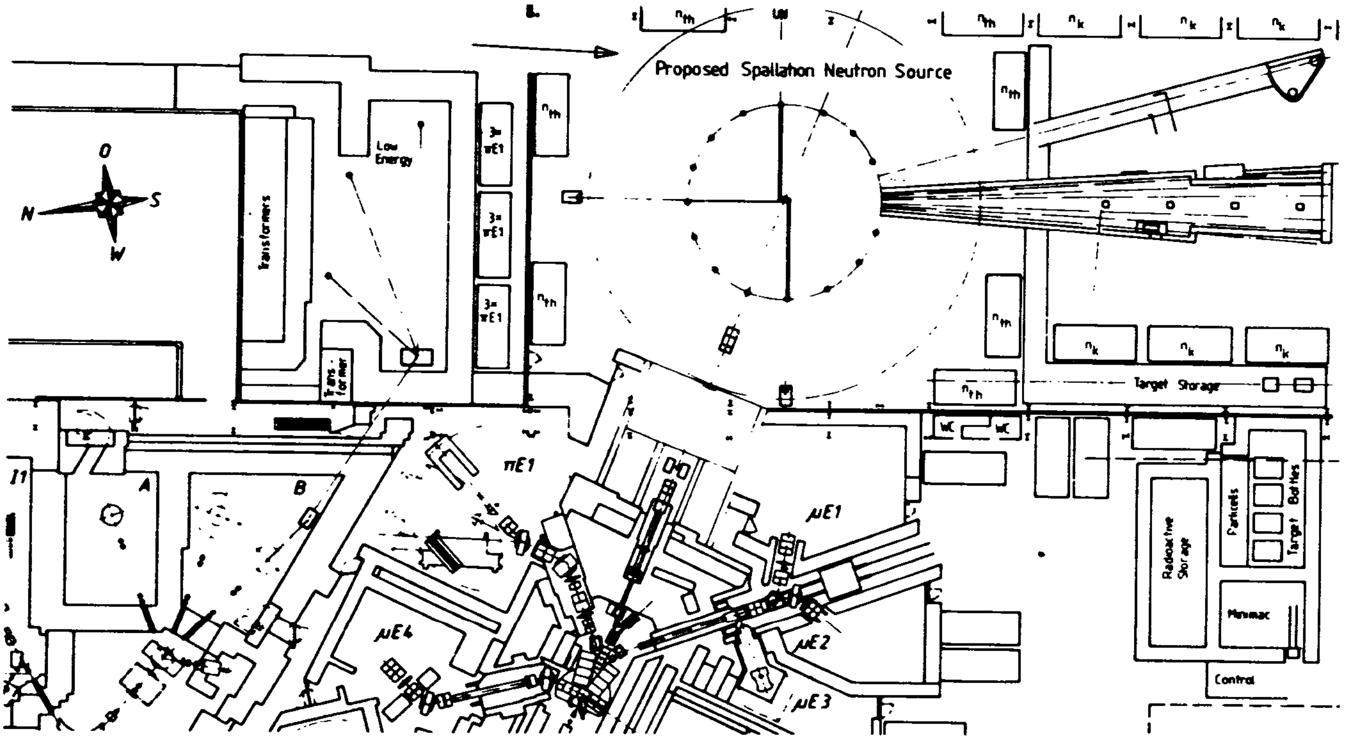

Fig. 2
Experimental Hall including the planned neutron hall

The first concept has been discussed at ICANS III and IV[1]. In this report we shall restrict the discussion to the second concept[2]. A somewhat schematical view of a vertical spallation source arrangement is shown in Fig. 3

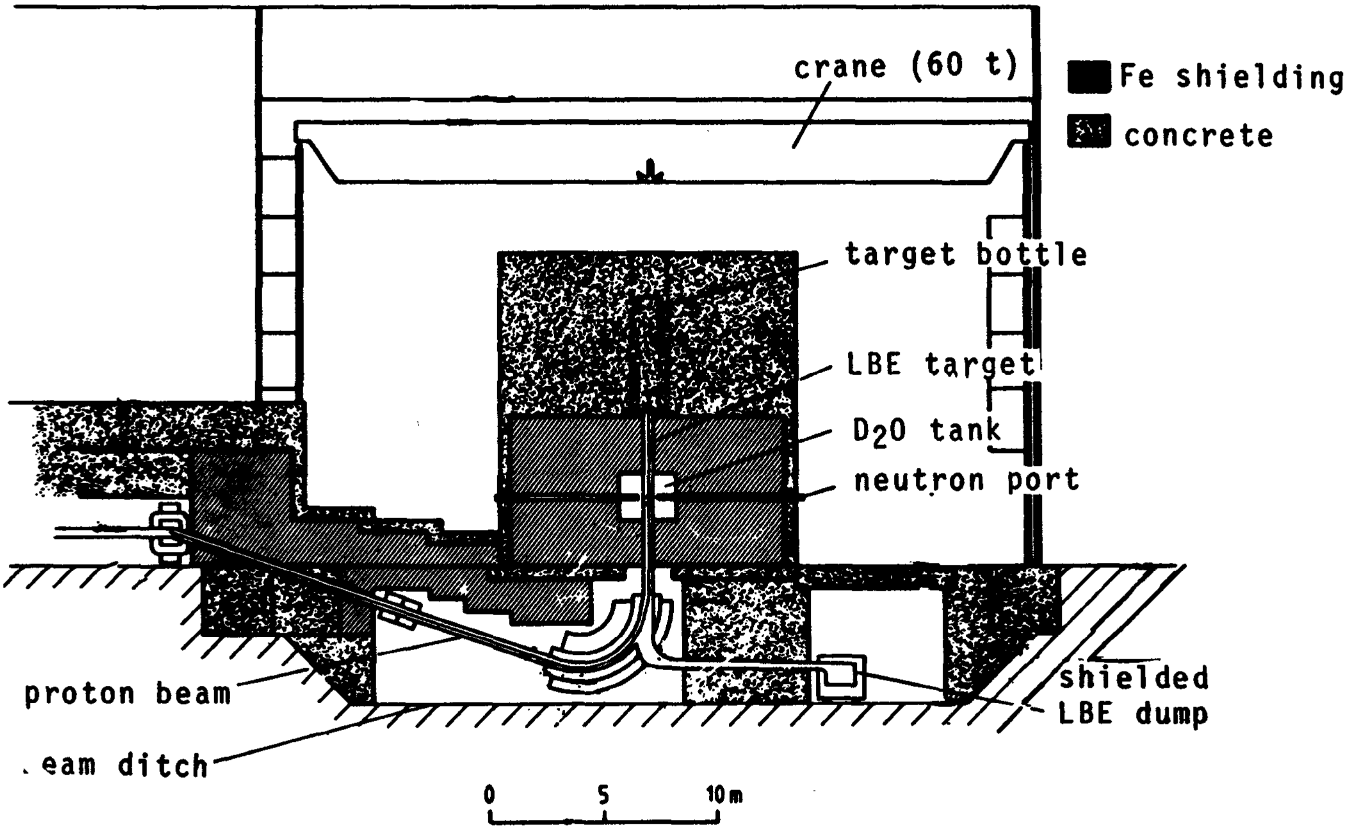

Fig. 3
Schematic view of the vertical version of the spallation neutron source

A critical component for both versions of a convective liquid metal target is the beam window. The power density dumped in the window can however be diluted up to a certain extent. Contrary to a pulsed spallation source with its small hydrogen moderators which require a high neutron source density in the target, the continuous source may accept a more spread beam without strong penalty. The coupling of the source to the moderator is always good. Furthermore, yield measurements at a cylindrical target with fixed diameter and variable cross section of the proton beam showed that up to a ratio of the beam target radius of 0.5 the decrease of the neutron yield is less than 20 %. Nevertheless, radiation damage tests at possible beam window materials are very essential. One of these tests is described below:

Window material Reactor - graphite
Thickness D = 3 mm
Diameter Ø = 2 cm

Beam current and size	100 µA (590 MeV protons) within 0.3 cm^2 corresponding to a current density of 333 $\mu A/cm^2$

This piece of graphite was exposed to the beam for 200 hrs. at a temperature of T ≈ 1200° C. After this load of 67 $mA \cdot h/cm^2$ no macroscopic damage was observed. This probe should now still be investigated microscopically and exposed to strength tests. If these tests turn out to be successful, such a window has a fair chance to survive longer than 1600 hrs. with a beam current of 2 mA and a beam diameter of 4 cm. Stronger radiation tests on graphite materials will be mentioned by Ch. Tschalär in his discussion contribution3). Further tests with the window material in contact with Pb/Bi of the target ought to be done.

Let us now discuss the conception of the liquid metal target with natural convection as a cooling mechanism. Figure 4 shows a schematic view of the target. The vertical target will be described in the contribution to this meeting by Ch. Tschalär. I restrict the discussion in this status report to the tilted version.

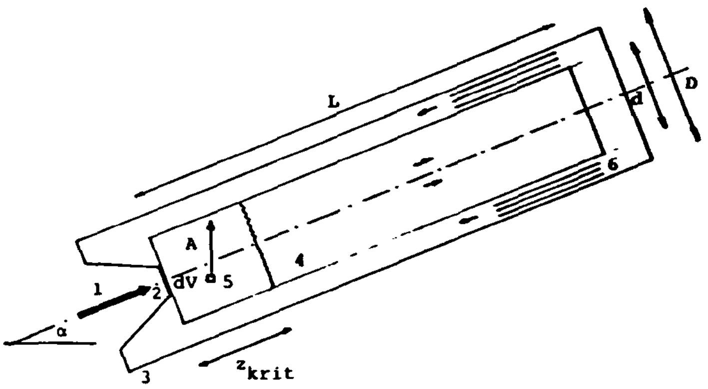

Fig. 4
Liquid metal target - tilted version - using natural convection

In the stationary case the flow of the liquid metal is dominated by the rise along the target axis towards the heat exchanger. This flow is driven by the buoyancy force

$$\rho g \beta \Delta T \cdot V \cdot \sin\alpha$$

ρ: density of Pb/Bi eutectics; $-1/\rho \cdot \delta\rho/\delta T = \beta$: thermal expansion coefficient; α: target tilt angle as indicated in Fig. 4; V: volume of the target.

A simple one-dimensional consideration for turbulent flow caused by a 1 MW proton beam leads for a head of 2 m to a flow rate of 4 l/sec. and a temperature rise of ∿ 200° C. This is indeed a very comfortable situation. However, the really critical situation appears during the start-up phase. A 1 MW beam drives the target temperature in the stopping region from 130° C up to the boiling point of 1670° C within 1 sec. if the liquid stays at rest. On the other hand, the 30 cm deep, heated region needs about 8 sec. to be moved out of the beam stopping area by the buoyancy force in the start-up situation. This demonstrates the rather large inertia of this system. In order to circumvent this difficulty, the beam power may be increased gradually - a procedure more adequate to certain parts of the accelerator system (rf-system) in any case.

A more thorough investigation of the fluid dynamics shows however that a target design is possible which does not even rely upon such a procedure. If outside the heated beam cross section there is ample target material available for a transversal convection during the starting phase, overheating can be avoided.

Figure 5 shows the time development of the temperature profiles in the vertical symmetry plane of the target. This and the following figures are the results of the solution of the Navier-Stoker- and Heat Conduction equations. The problem is treated in the Boussineq approximation i.e., incompressibility and constant density are assumed apart from the driving buoyancy force of course. For the code available, a quadratic cross section of the target containment (l = 19.2 cm) was more convenient. Furthermore a constant temperature (130° C) at the target boundary has been assumed. The case of an adiabatic boundary will be presented in another report.

The results for this case can be interpreted in the following manner. Two vertical vortices to the left and right side

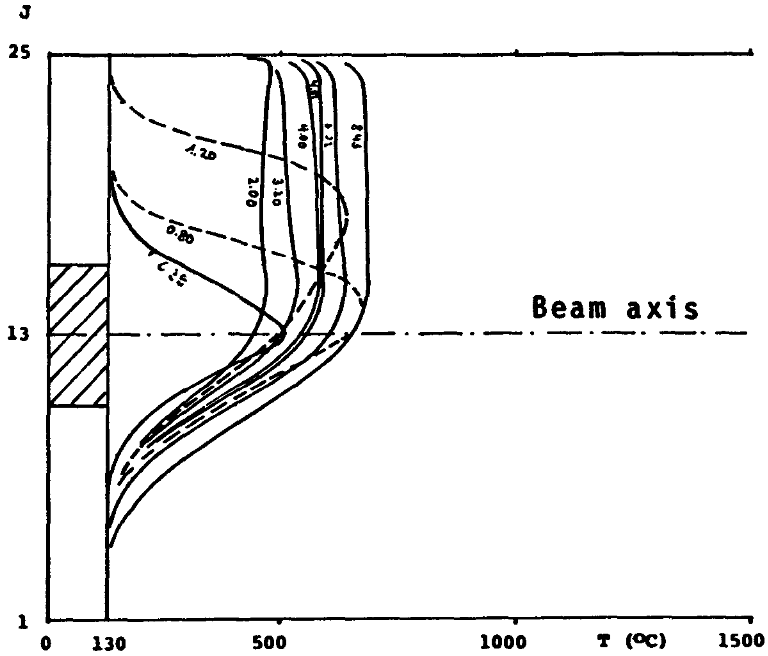

Fig. 5
Time development of the temperature profile in the vertical symmetry plane

of the beam axis transport the heated material to the upper cooled target boundary. The cooled material then flows down along the boundary and is drawn up again into the center. The isothermal field through a cross section of the target, shown in Fig. 6, may visualize the situation more clearly. At this very first moment the convection of the liquid metal along the target axis is not yet important. After about 8 sec., however, this motion has come into full action - the material has moved out of the heated region - and the flow and temperature pattern remains stationary. Figure 7 describes the time development of the maximal temperature in the system. This temperature remains far below the boiling point even during the start-up phase. After 7 sec. the spatial position of the point with maximal temperature remains fixed. At this time the up-drift along the target is activated and the heat exchanger stabilizes the temperature.

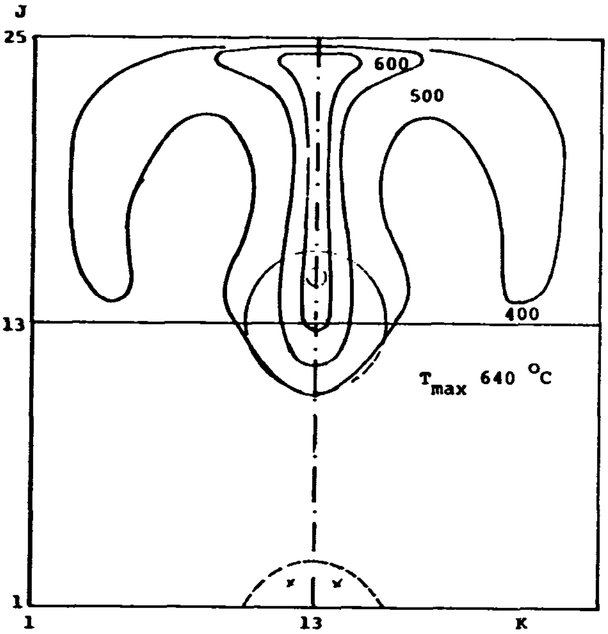

Fig. 6
Isothermal field after 8 sec.

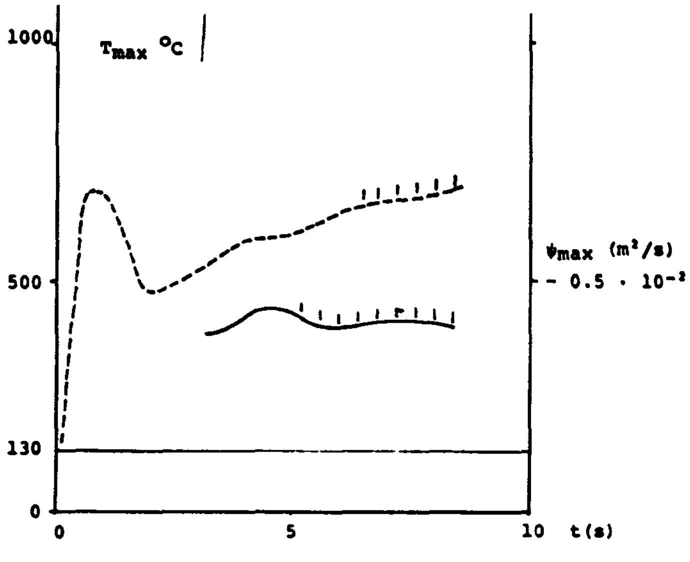

Fig. 7
Time development of the maximal temperature in the target. The lower curve is the time dependence of the maximal value of the streaming function.

Neutronics

Figure 8 shows three models of a neutron source which were considered in the mock-up experiment at SIN by the Jülich - Karlsruhe - SIN collaboration. The first two models have been investigated mainly in view of the German SNQ-project, and will not be discussed further in this report. The third model is relevant for the planned SIN source. The neutron flux in the D_2O was measured with Dy-foil activation and with BF_3-counters mounted inside snorkels. The two independent measurements are consistent. Through the beam tube, indicated in Fig. 8, a beam of thermal neutrons was extracted from the system. The counting rate from this beam, together with the proton beam monitors, served as one of the absolute calibrations of the neutron flux in the moderator. The results indicate that a thermal flux of $9 \cdot 10^{13}$ n/cm^2 sec. at the tube nose in the moderator can be realized for 1 mA primary proton beam current at 590 MeV. This calibration agrees with the gauge of the Dy-measurements with an uranium probe.

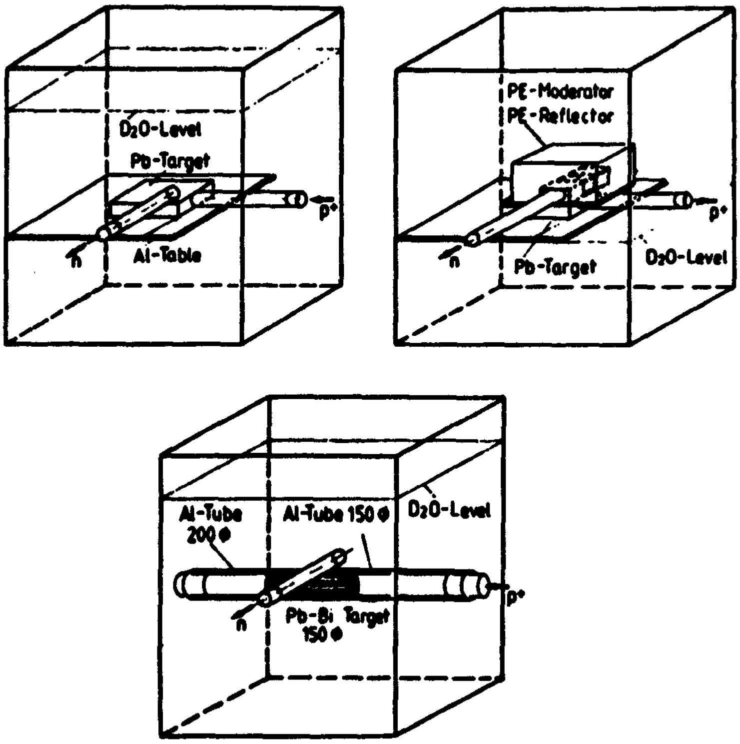

Fig. 8
Models considered in the mock-up experiment at SIN for neutronics investigations

The results of this flux measurements are represented in Fig. 9. The position of the target is below the z-axis with its

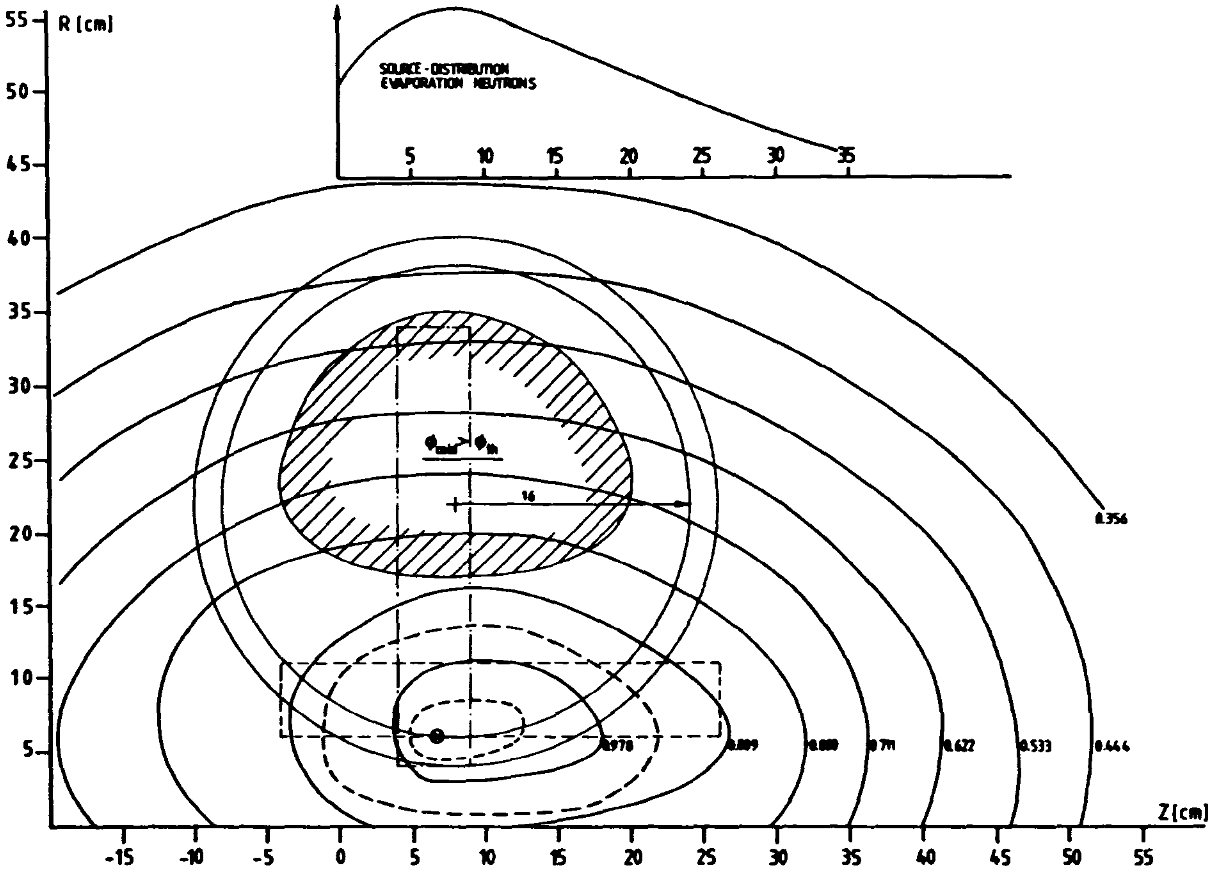

Fig. 9
Flux distribution for thermal neutrons in the D_2O-reflector

front end at z = 0 cm. The proton beam comes in from the left side below the z-axis. The whole system is cylindrically symmetric around the target center line which is 10 cm below the z-axis. In the (r, z) frame are drawn the lines of an equal flux for thermal neutrons.

The numbers at the equi-flux lines signify the thermal flux in units of maximal flux which is situated at the point (6 cm, 7 cm). In the upper small frame of Fig. 9 is indicated the source distribution of evaporation neutrons at the surface of the target, measured by activation of Rh-foils..

Using this flux distribution for thermal neutrons in the D_2O-reflector, we may find the optimal position of the cold source as well as position and size of the neutron tubes for the extraction of thermal neutrons. The sphere drawn in Fig. 9 indicates the possible position of the containment of a liquid D_2 (20° K) source. Neutron guides would look towards the hatched region of the cold source. The nuclear heating of the source at this position is estimated to be about 2.5 kW for a proton beam current of 2 mA.

In the same figure we have drawn the cross section of a slit beam hole for thermal neutrons - the one parallel to the z-axis in the suitable position for a vertical target, the other for a horizontal (tilted) target. From these positions of the beam tubes and the flux distribution we realize that the hole for the vertical target version couples somewhat better to the neutron flux. The average flux over the beam hole cross sections are

$\bar{\phi} = 0.75\ \phi_{max}$ for the horizontal version

$\bar{\phi} = 0.9\ \phi_{max}$ for the vertical version

Beam Tubes and Instrumentation

Figure 10 shows a possible arrangement of beam tubes and the cold source for the horizontal - or tilted - target version. (The target tilt is not indicated in the figure.) The reflector volume above the target is reserved for the cold source, the corresponding beam tubes and the connections to the guides for the cold neutrons. The thermal neutrons will be extracted through beam tubes, all situated below the target. All beam tubes are in a tangential position with respect to the target. Figure 11 gives an idea about the distribution of spectrometers at the spallation neutron source with the arrangement of beam tubes just presented in Fig. 10. The monochromator shielding may be partly inserted into the main shield, depending on the angular range needed by the particular spectrometer.

It may be interesting to compare this beam tube arrangement with the one which seems to be feasible for the vertical target version. The set-up, shown in Fig. 12, should be understood as a maximal possible set. The actual number of tubes may be rather smaller and should be subject to negotiations with the potential users.

We would like to give finally some estimates of the flux for thermal neutrons at the monochromator of a typical beam tube. It is assumed that a vertical focussing monochromator allows us to accept a beam with divergencies

0.5° horizontal
3.0° vertical.

The corresponding slit tube has the dimensions 5x30 cm^2. According to our knowledge of the target yield and the flux distribution in the reflector we expect from a Pb/Bi target of the

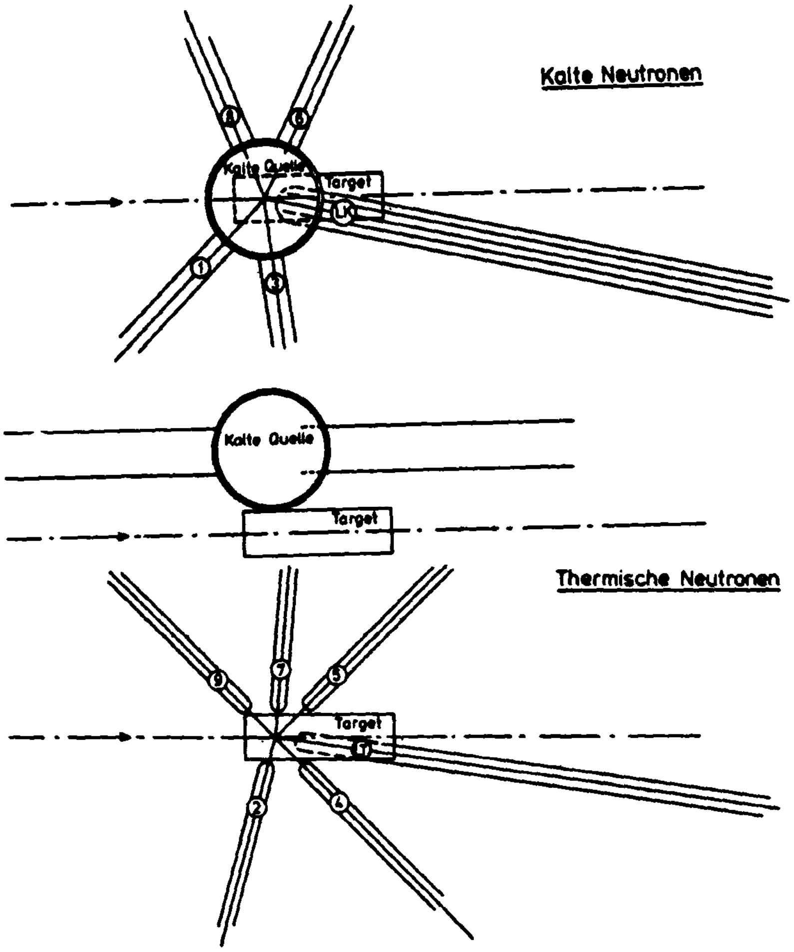

Fig. 10
Possible arrangement of beam tubes for the horizontal or tilted target version.

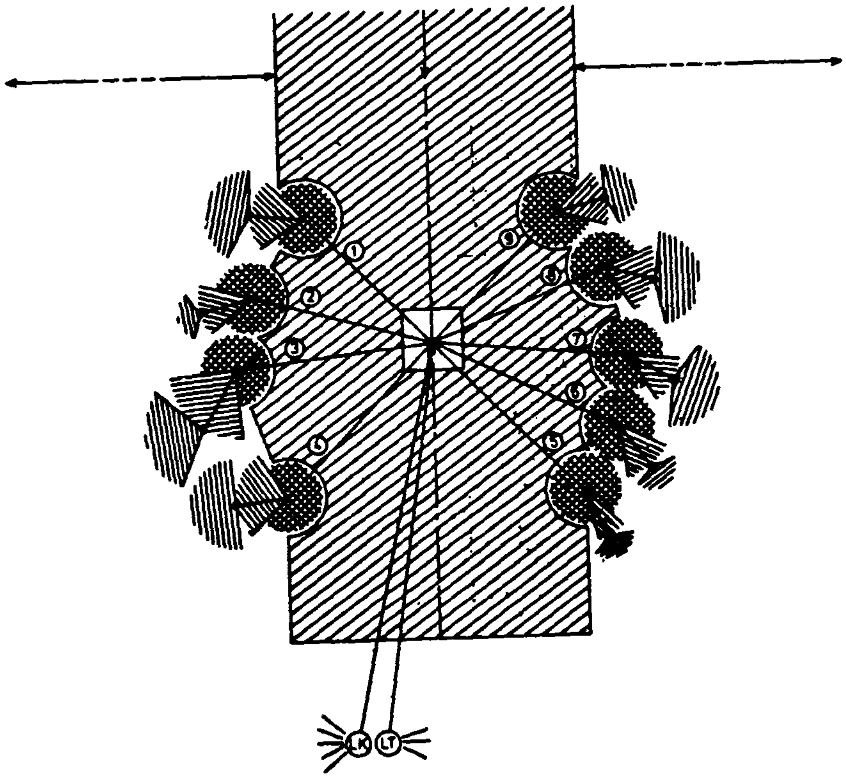

Fig. 11
Distribution of spectrometers with the arrangement of beam tubes shown in Fig. 10

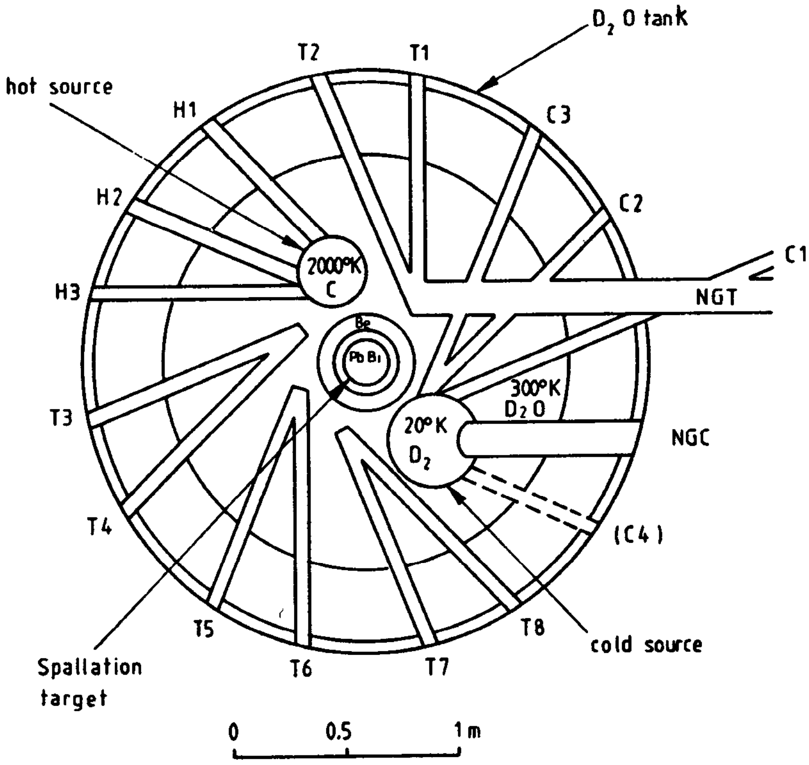

Fig. 12
Maximal possible set of beam tubes in the vertical version of the spallation neutron source.

horizontal version

45^{o}	$1.3 \cdot 10^{9}$ n/cm^{2} sec. mA
135^{o}	$1.8 \cdot 10^{9}$ n/cm^{2} sec. mA

depending on the direction of the beam tube with respect to the beam axis (different shield thickness!). For the vertical target concept the flux at the monochromator is

$$1.9 \cdot 10^{9} \text{ n/cm}^{2} \text{ sec. mA}$$

independent of the beam tube direction.

Table I shows the instrumentation, which would be installed at the beam ports of the version presented in Fig. 10 and Fig. 11. The instruments are labeled with the numbers of the beam hole (see Fig. 10), where the spectrometer is supposed to be placed. This instrumentation is based on an evaluation of long-term research projects made in 1978, proposed by five study groups for

structure research
solid state physics
chemistry
biology
material research

Since then, no new aspects appeared which could have modified the planning of the scientific exploitation of this neutron

Table I

Phase 1 : 1987		
2 Triple-Axis Spectrometer	1, 7	
1 Two-Axis Spectrometer	6	
1 Four-Circle Spectrometer	2	
1 Powder-Diffractometer	3	
Phase 2 : 1988		
1 Small Angle Scattering Spectrometer	LK1,	cold source (guide)
1 Spectrometer for Polarized Neutrons	9	
1 Triple-Axis Spectrometer	8	
Phase 3 : 1989		
1 Back-Scattering Spectrometer	LK2	cold source (guide)
1 Triple-Axis Spectrometer	4	
1 Four-Circle Spectrometer	5	
Phase 4 : 1990		
1 Powder-Diffractometer	LT1)	at thermal
1 Triple-Axis Spectrometer	LT2)	guides

source.

The beam tubes could essentially be exploited by national requirements; at the neutron guides some capacity for international participation would still be available. The potential concerning the number of beam ports would, however, be larger at the vertical version of the neutron source.

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