SPALLATION NEUTRON SOURCE AT SIN

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1. Accelerator

The meson factory SIN (Schweizerisches Institut für Nuklear-forschung) started operation in February 1974. It was built as a research facility mainly for nuclear and particle physics using high flux beams of pi-mesons and muons as probes. These particles are produced by a primary proton beam which is accelerated first by a sector focussing injector cyclotron to 72 MeV and then by a separated magnet isochronous ring cyclotron to a fixed energy of 595 MeV (Fig. 1). At present, beam currents of 0.1 to 0.15 mA are used routinely and 0.2 mA peak has been achieved in short-time trials. The beam has a macro-duty cycle of 100 %. The micropulses are about 0.5 ns long and are separated by 20 ns.

Since the available current from the present injector is limited to a few tenths of milliamperes, it was decided to build a new injector (II) which is now under construction. It is a ring cyclotron similar to the main accelerator but with four sector magnets instead of eight. It is in turn fed by a Cockroft-Walton injector of 0.8 MeV. The current capacity of injector II is expected to be beyond 2 mA.

The main cyclotron (ring) should be able to accelerate about

0.5 mA using existing hardware. The limitation is beam loading of the four RF acceleration cavities. A boost of the RF power from the present 0.6 MW to about 2 MW is planned, which would allow beam currents of 1 to 2 mA. Beam losses in the accelerator are not expected to be a serious limitation since extraction efficiencies of 99.98 % are routine today.

In order to be able to handle proton beams of more than about 0.2 mA, the external proton beam channel and the two meson production targets have to be upgraded. The second target station (thick target E) and the beam dump will be rebuilt entirely such that the waste beam after target E can be either deflected into the dump or extracted through the dump shielding and injected into a neutron source placed in a new East Hall adjacent to the main experimental hall. Depending on the thickness of target E (5 to 10 cm of graphite), 50 % to 75 % of the primary proton beam will reach the neutron source.

2. Choice of neutron source

In principle the quasi continuous beam from the SIN cyclotrons could be pulsed (kHz or slower) by either a fast chopper, a buncher at the injector or a compressor (storage ring) in the extracted beam. The fast chopper would reduce the average current to incompetitive levels and the acceleration of bunched pulses is difficult and limited to peak currents well below 10 mA. Both these modes would further handicap meson experiments severely. A compressor ring for the waste beam is extremely difficult to conceive because of the large phase space of the beam and a compressor for a partial beam split off from the main beam would again suffer from low average beam. Furthermore, the cost of a compressor ring would be comparable to the cost for the entire neutron source.

For these reasons it was decided to build a continuous spallation source at SIN for a proton current of 1 to 2 mA using a first generation target made from non-fissionable material. Calculations and measurements have shown that thermal neutron fluxes comparable to medium flux reactors can be expected. Since spallation sources release much less power per neutron produced, a cold neutron source (liquid D_2 moderator) can be placed closer to the region of maximum neutron flux than in a reactor. Estimates suggest that this feature together with modern cold source design and optimized coupling to neutron guides would yield cold neutron fluxes comparable with those of existing high flux reactors. A cold source of about 30 l of liquid D_2 is therefore included in the concept of the SIN neutron source.

3. Source concept

3.1 Lay-out

The proposed layout of the SIN neutron source is shown in Fig. 2. The proton beam enters the target at an incline of about 5 % to the horizontal. Beside areas for about 6 thermal neutron ports, a large area is provided for experiments with

cold neutrons.

3.2 Target concepts

3.2.1 Target material

A first generation target is to be made of a liquid lead-bismuth eutectic (LBE). The well known advantages of LBE are a high spallation neutron yield as well as a low thermal neutron absorption cross section which allows relatively large targets and beam diameters and thus lower power densities. Low melting point (123° C), large liquid phase temperatur range (∿ 1'400° C), zero volume change on freezing and a well known corrosion behaviour make LBE ideal for use as a circulating target which eliminates heat transfer and radiation damage problems in the target proper.

3.2.2 Beam window

An unavoideable requirement for a liquid target is a beam entrance window. Even in the case of a proton beam plunging vertically onto a "free" surface of an LBE target, a thin window is generally needed to hold back vapors and gases from the hot target. Feasability of a beam window depends primarily on the question of radiation damage to the window material. Since graphite (either pyrolytic graphite or normal graphite coated by pyrolytic graphite) is an ideal material for windows from the termo-mechanical and neutron physics point of view, samples have been irradiated with the SIN proton beam. As a first test, a 3 mm thick disk of normal graphite was irradiated by a 100 µA-beam of about 0.2 cm^2 cross section at about 1'200° C for 200 hours yielding an irradiation density of 100 mAh/cm^2. The sample showed no visible damage or distortion. Detailed structure studies are in progress. A sample of pyrolytic graphite of 6 mm thickness was irradiated in the same beam at 1'500 - 2'000° C for 800 hours and a sample of high grade pyrographite is currently included in the A5-target at LAMPF (0.4 mA of protons at 800 MeV). Results of both tests are expected by the end of the year. Based on the irradiation density of the first sample, a minimal life time of about 2'000 mAh can be assumed for a graphite window in a typical proton beam of 5 cm diameter. For a conical graphite window of a thickness of 5 mm which is cooled on one surface, calculations yield thermal strains below 10 % of the breaking strain. If the same window is cooled by radiation only, the strain is even less and the maximal temperature about 2'000° C which is acceptable for graphite.

Thus a graphite entrance window to a liquid target, even under pressures of a few bar, seems eminently feasible. Since it provides great freedom of choice of target and source geometries and allows to design compact targets with accordingly modest requirements on handling and service facilities, it was adopted in all concepts of the SIN neutron source.

3.3.3 Forced convection target

In the present concept for the LBE target, the LBE is pumped through the target by a mechanical pump and cooled by an external heat exchanger. The target, shown in Fig. 3, is a

cylindrical vessel centered on the proton beam. The LBE enters concentrically around a conical entrance window, cooled by the LBE, and returns again concentrically along the wall of the vessel. The target vessel is placed inside a cylindrical helium container which acts as a confinement. The unit is attached to a cylindrical shielding block about the beam vacuum chamber. Together they constitute the target plug which can be uncoupled from the beam vacuum and the LBE circuit and extracted from the source by a remotely controlled shielding cask. The loaded cask is lifted out of the proton channel by crane and then transported to a hot cell for service or repair on the target. A similar arrangement is used at present for servicing the meson production targets at SIN.

The LBE circuit is shown schematically in Fig. 4. The target is at the highest point of the circuit in order to minimize the pressure on the target window. The circuit, including the sloping target section, is layed out in such a way that the entire LBE content drains into a shielded reservoir as soon as the pump is turned off. The vertical section of the circuit has the effect, among other things, that in case of a leak through the window, the pump runs dry after about 20 % of the LBE content of the circuit are lost and prevents the rest from being pumped out through the leak, even if the pump is not stopped.

The entire LBE circuit is encased in a containment filled with helium gas. The gas is also used to preheat the circuit at startup.

The LBE system is therefore inhearently safe: Even if all detection devices and active control measures fail, the target vessel is drained automatically of its LBE content in case of leaks, pump failures or stoppages, thus preventing an explosion due to oberheating by the beam. Even a simultaneous failure of both LBE and helium windows would at worst result in part of the LBE content to flow down the beam pipe and be caught in a shielded dump. Emergency cooling of the activated LBE is not necessary as the total power emitted by the reaction products is estimated to be less than about 1 % of the beam power.

Preliminary data for the LBE system are shown in table 1.

Table 1:

Flow data for a forced convection LBE target

LBE circuit		Entrance window	
beam power	1 MW	heat density	500 W/cm^3
r.m.s. beam diameter	5 cm	surface heat flux density	250 W/cm^2
LBE flow rate	4 l/s	heat transfer number	1.2 W/cm^2 K
LBE temperature range	170° C - 340° C	max. window temperature	500° C
		LBE pressure at window	1 bar
LBE pump pressure	3.5 bar		

3.3 Source structure

The structure of the proposed neutron source is shown in Fig. 5 - 7. The target is embedded in a cylindrical heavy water moderator tank with a vertical axis, a diameter of

2.5 m and a volume of about 12m^3. Horizontal beam tubes for thermal neutrons originating above and below the target tube extend out radially within an angular region of about 45°-135° on both sides of the proton beam. A cold source in the shape of a cryogenic container filled with about 30 l of liquid deuterium is placed directly on top of the target. The expected power of about 1 kW deposited in the cold source per mA of proton beam is removed by a vertical D_2-heat pipe system with a condensor on top of the shielding.

The source is shielded by a cylindrical stack of cast iron of about 6 m outer radius. It contains the neutron beam tubes and beam shutters. It is surrounded by a layer of additional shielding made essentially of iron and concrete of 1-2 m thickness which can be individually adjusted and designed to suit the experiments. The cylindrical part of the shielding is extended in the direction downstream from the target to shield against the intence flux of forwardly produced high energy neutrons.

4. Alternative source concepts

4.1 Free convection target

In order to simplify the proposed LBE system, we studied the possibility of a sealed target vessel extending at an incline through the inner layer of the shielding. At the bottom end of the cylindrical vessel the proton beam enters through a conical graphite window as in the case of the forced convection target.

The top half is cooled by an array of cooling pipes thus setting up a convection current in the LBE. A schematic drawing of a vertical target version is shown in Fig. 8. The target vessel should be long enough (~4m) such that the residual activation at the top end is low enough to permit manual decoupling of the vaccum connection, the cooling pipes and monitoring devices. The entire target vessel is then handled and serviced like the target plug of the forced convection system.

First calculations show that, once a stationary convection current is reached, flow rates and temperatures similar to the forced convection case can be achieved. Estimated for the start up phase of the convection current indicate that initial temperatures close to the evaporation point would be reached if the full power of the beam would be switched on at once. However, the rather large latent heat of evaporation of LBE would prevent evaporation even in this extreme case. Thus a free convection target, especially a vertical one, seems to be possible for SIN beams. It would considerably reduced the complexity and cost of a spallation target system and will therefore be investigated in more detail.

4.2 Vertical beam lay-out

In alternative source lay-out has been studied at SIN featuring an entirely cylindrical source geometry centered on a vertical proton beam entering from the bottom (see Fig. 9 and 10). In

contrast to the "free target surface" concept with a vertical beam entering from the top as was proposed elsewhere, the SIN version allows genuine 360°-access to the neutron source analogons to a reactor without the exceedingly expensive bridge structure required to support a shielded proton channel over the experimental area. Instead only a slit trench in the floor of the neutron source hall is required into which the proton beam descends beneath to source and is then bent upwards by a large bending magnet. The slit trench is covered by a modest amount of heavy shielding to protect the experimental area above it. From the technical point of view the vertical beam concept would allow an optimal geometry for a free convection target. Furthermore, in case of a window failure the LBE would be collected in the slit trench thus reducing the danger of wide-spread contamination.

Although the vertical beam concept is somewhat more expensive, it offers a significiant increase in available thermal beam ports. It is therefore studied further as an alternative to the horizontal beam version.

5. Performance

In the past year extensive measurement of neutron spectra and fluxes from a mock-up spallation source were carried out on the 1nA proton beam at SIN. Targets of Lead-Bismuth and of U^{238} in various shapes were studied without moderator and with light and heavy water moderators and simulated neutron beam pipes in various geometries. Preliminary results for the LBE target surrounded by a beryllium multiplier and placed in a D_2O moderator of about 1 m radius indicate that a realistic flux of about 10^{14} n/cm^2 mAs can be expected for 600 MeV protons.

6. Timetable

The present long range planning for the development of SIN facilities calls for completion of injector II by early 1983, upgrading of the proton beam to 2mA capacity by late 1984, installation of the RF power booster of the ring cyclotron by late 1985 and completion of the neutron source by 1986. Proton currents of 1mA or larger are also expected by 1986.

Scientific opinion on the proposed neutron source and response from potential users has been almost unanimously positive. In view of this and the relatively modest cost, the odds are very much in favour of the project. A decision is scheduled for January 1981.

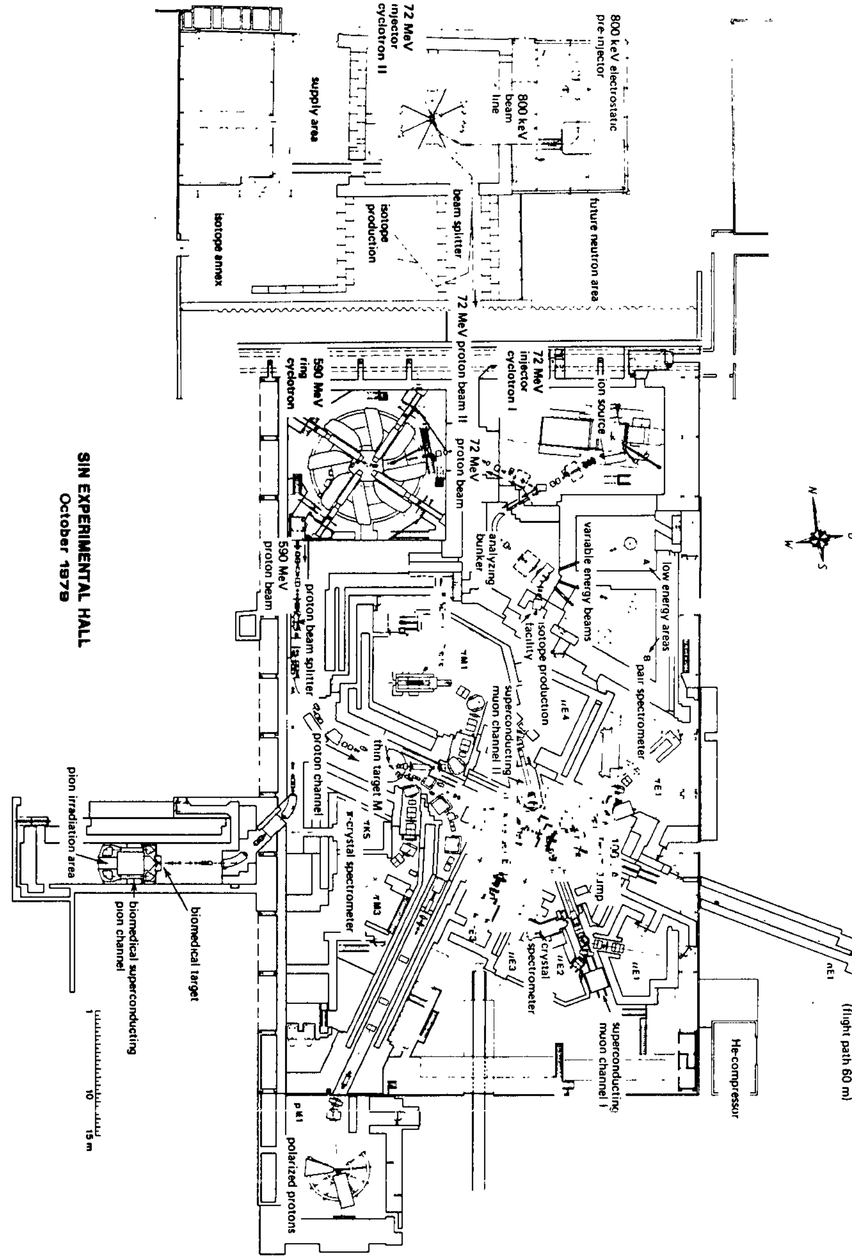


Fig. 1 : Lay-out of the SIN meson facility

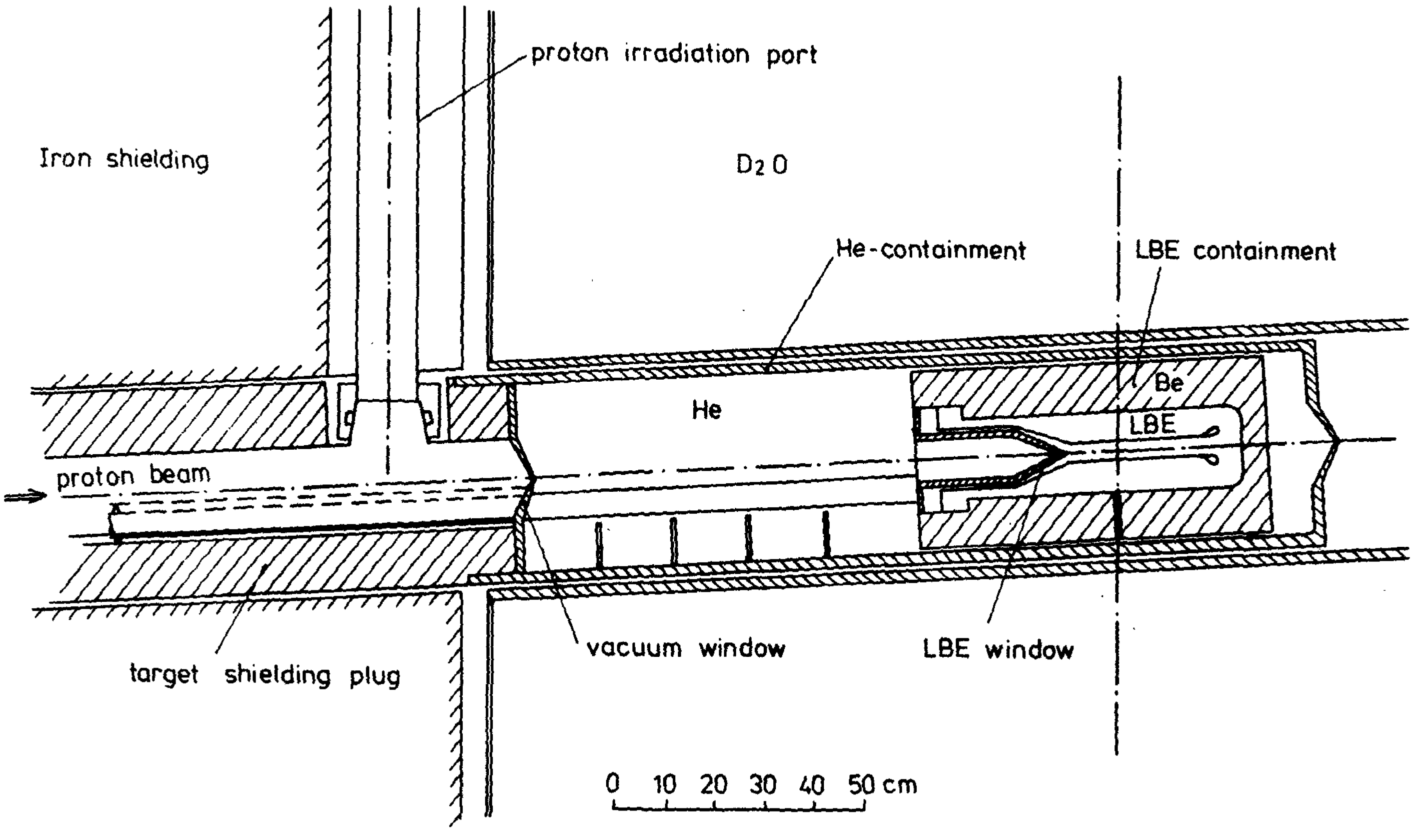


Fig. 3 : Cross section through a forced convection LBE target

Fig. 2 : Lay-out of the SIN spallation neutron source

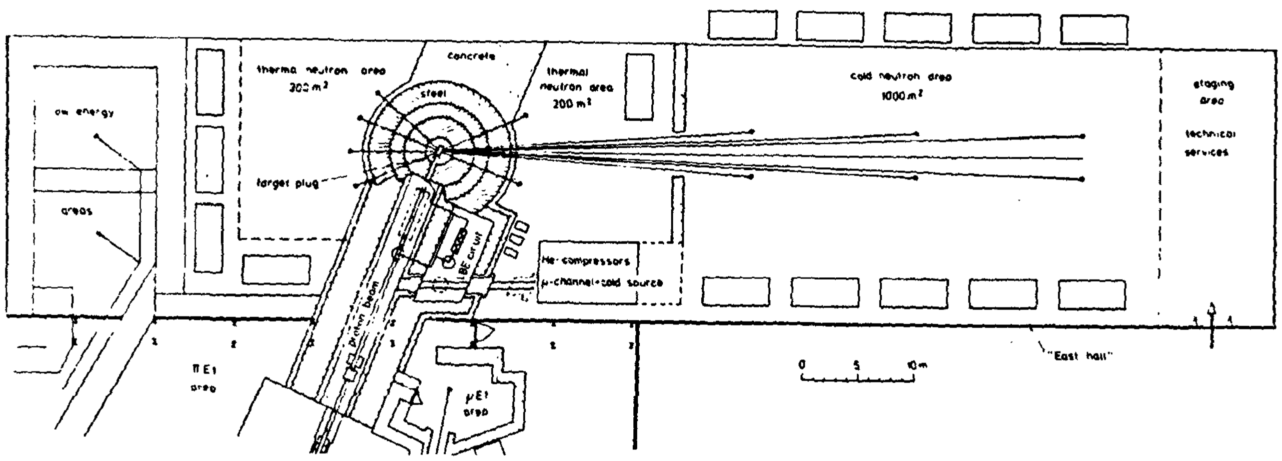
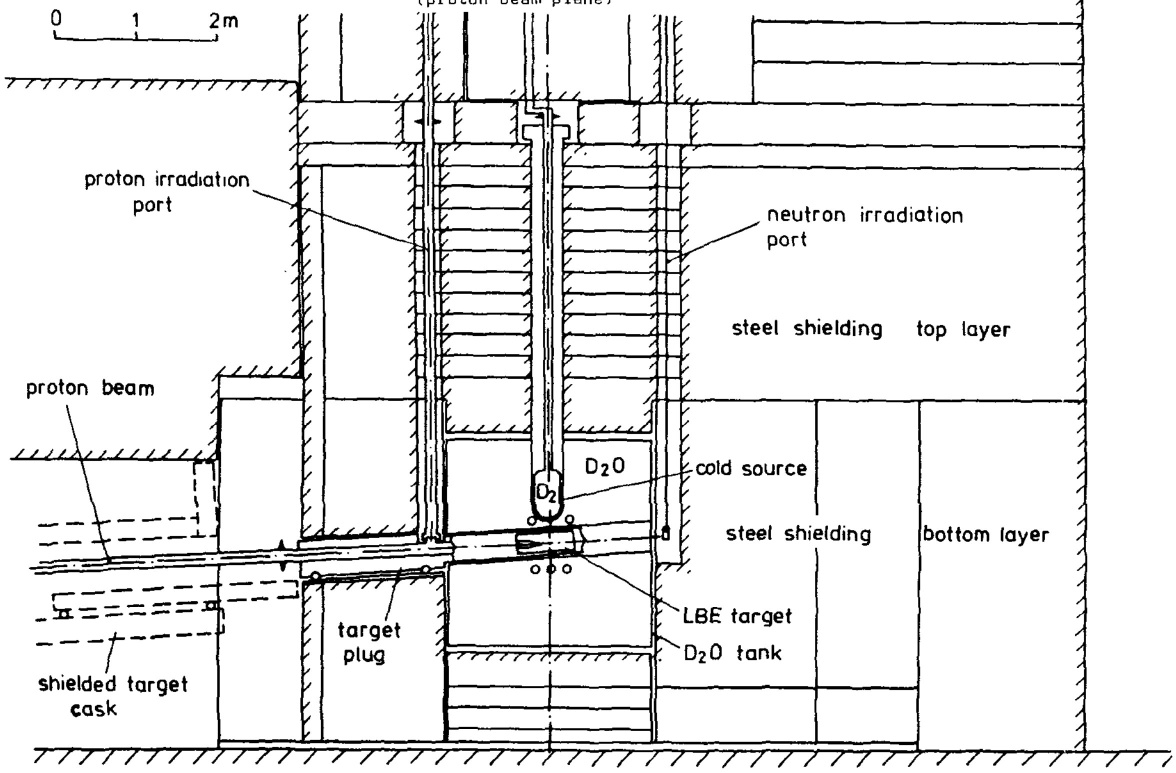


Fig. 5 : Vertical cross section through the source (proton beam plane)



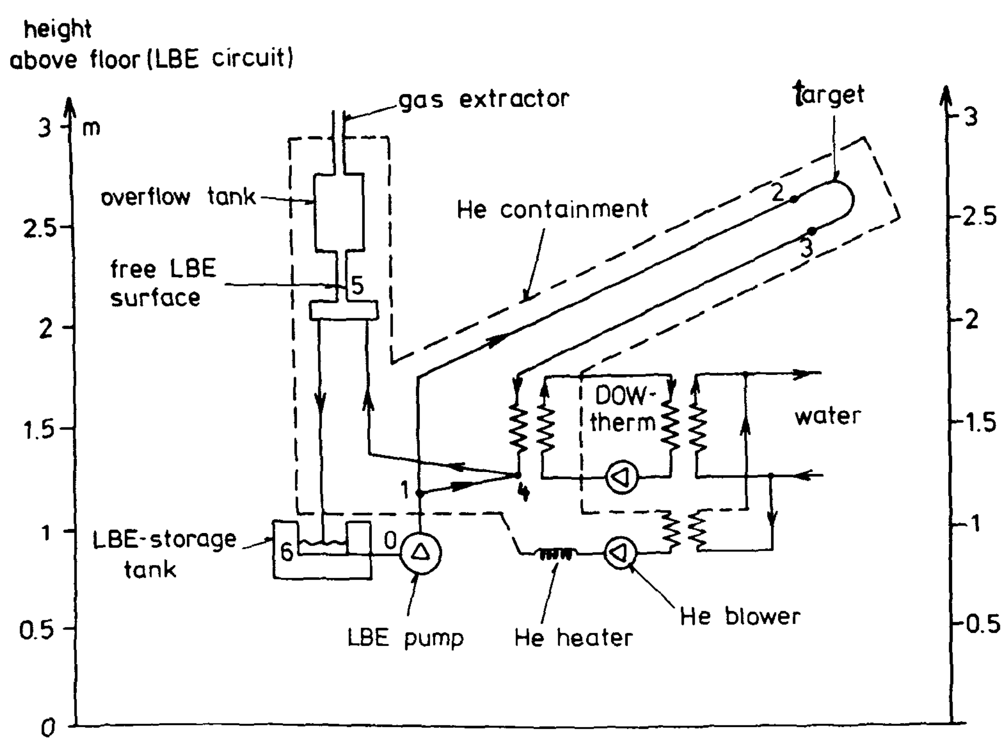


Fig. 4 : Schematic LBE circuit

Fig. 6 : Vertical cross section through the source (perpendicular to proton beam)

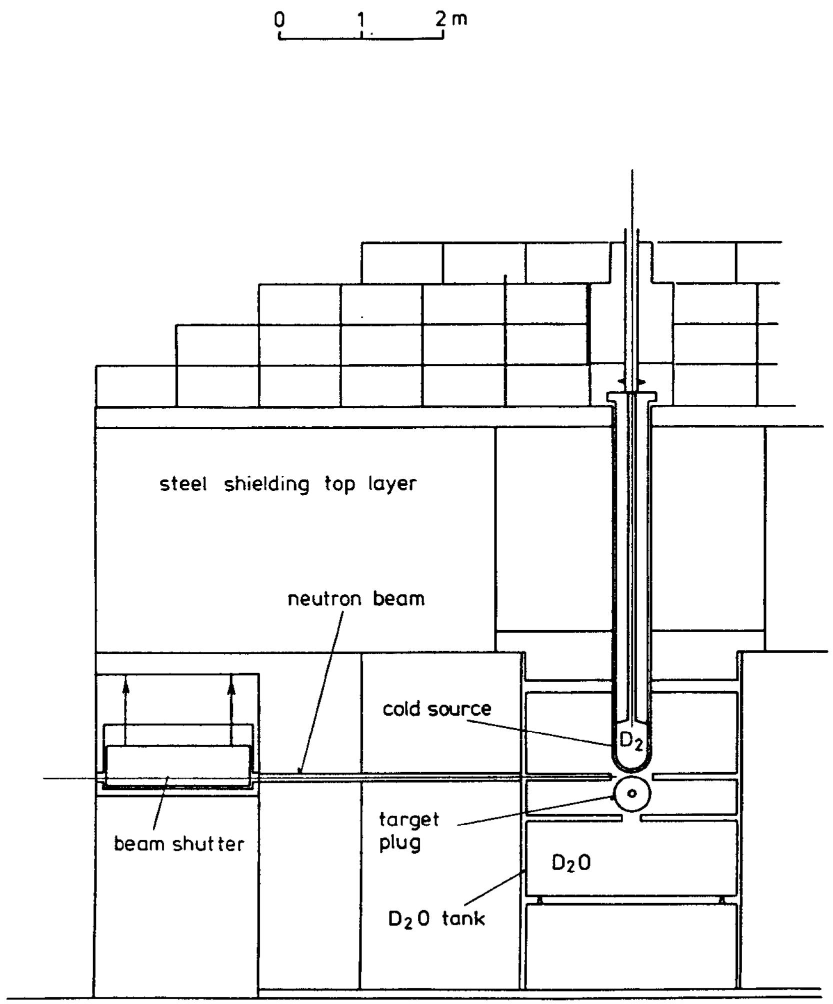
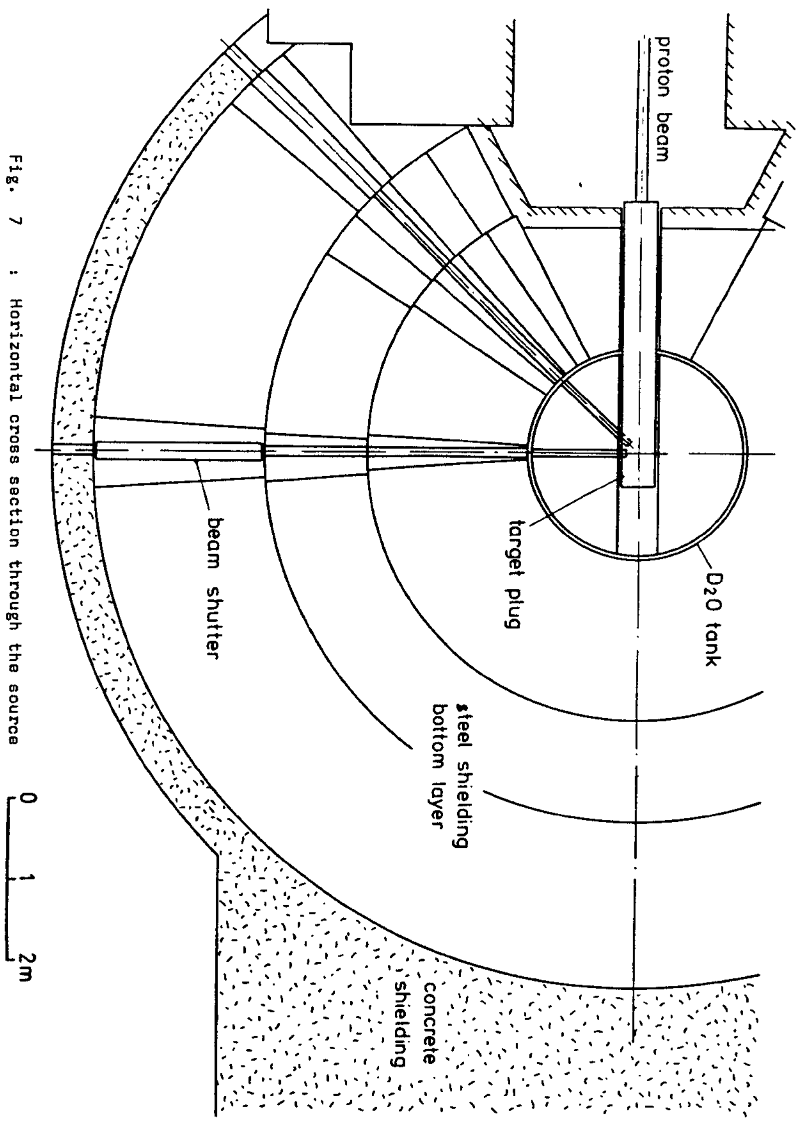


Fig. 7 : Horizontal cross section through the source



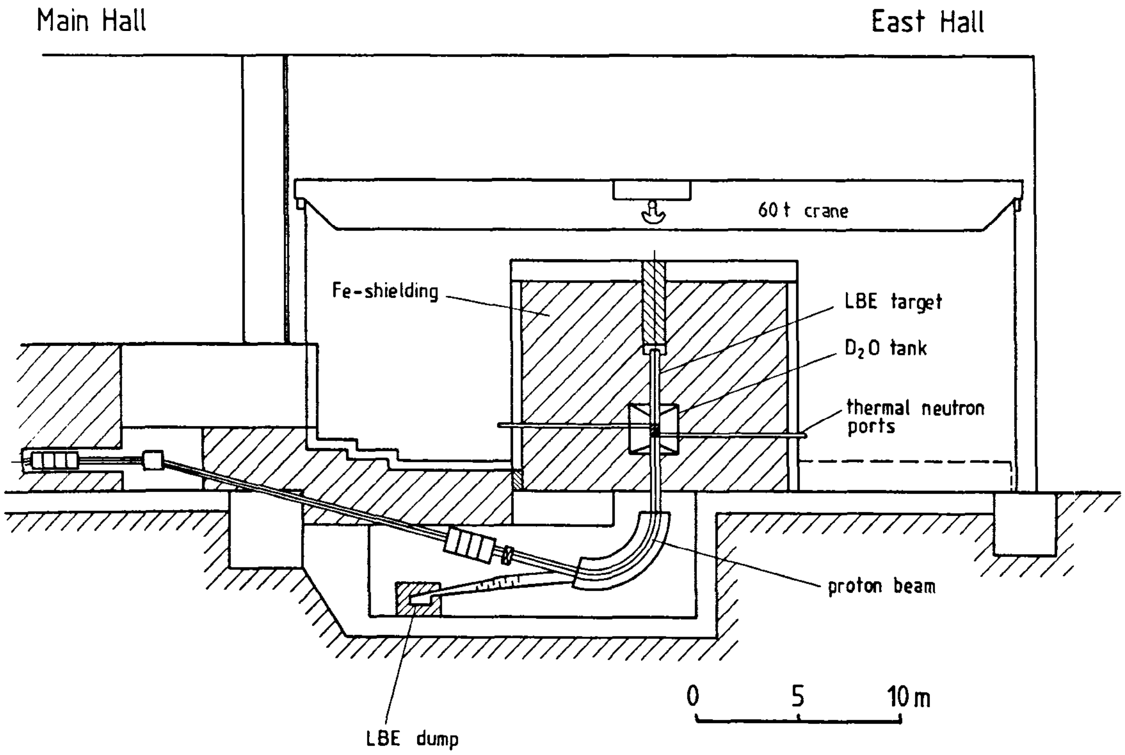
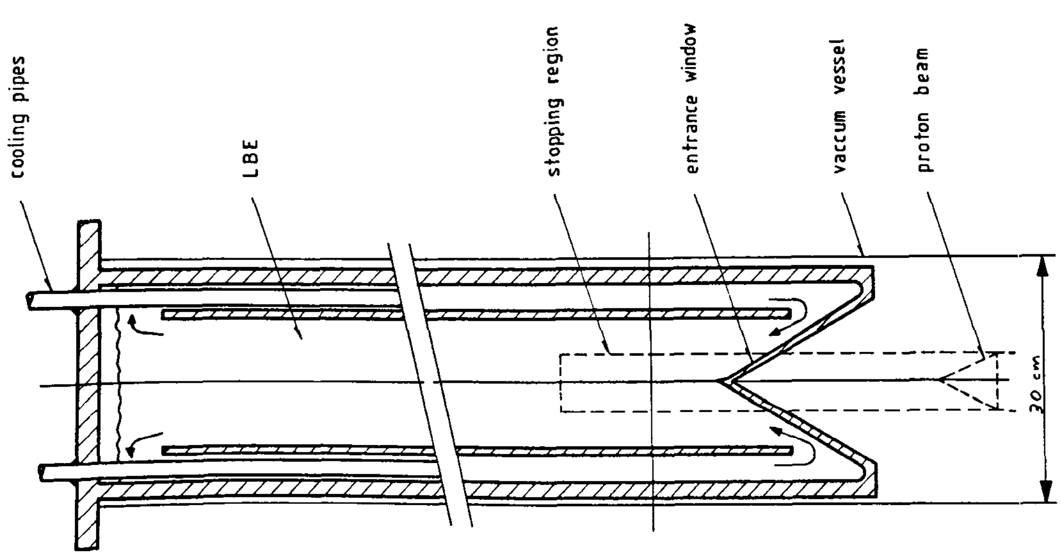


Fig. 9 : Vertical beam concept of a neutron source; vertical cross section

Fig. 8
Free Convection LBE Target



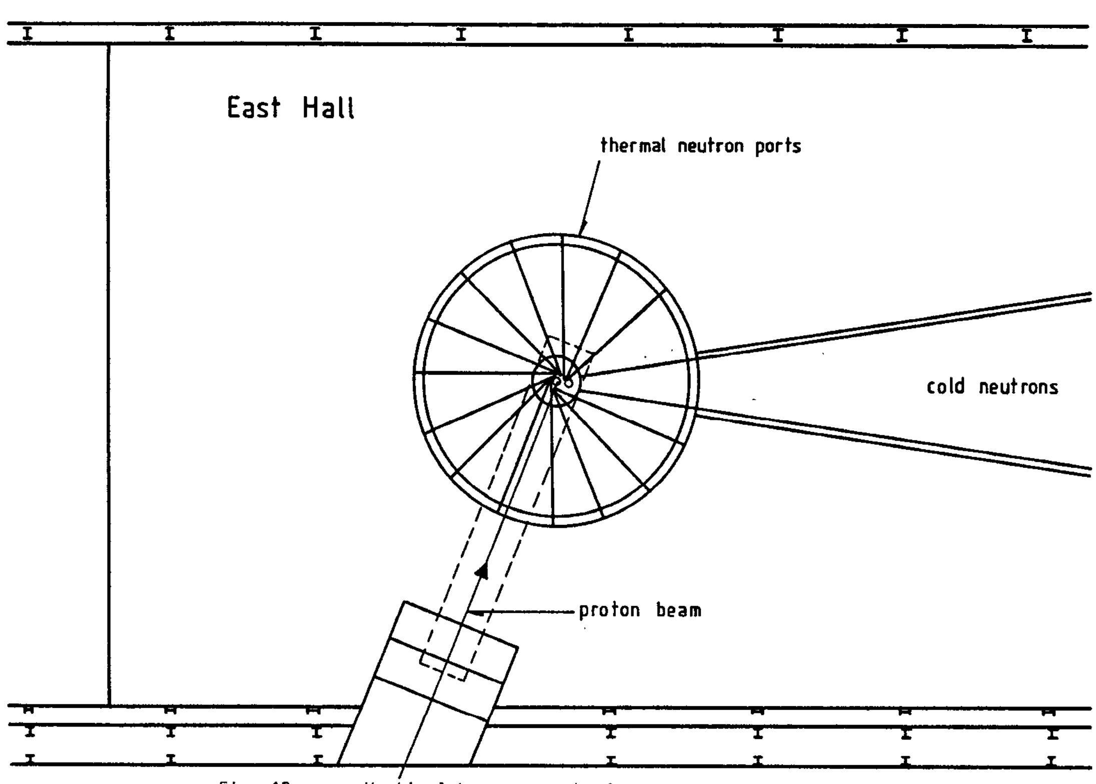


Fig. 10 : Vertical beam concept of a neutron source; horizontal cross section