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Technical concept of the liquid D_2-cold moderator for SINQ

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ABSTRACT

At the continuous, high power Spallation Source SINQ design provisions have been made in the D_2O-moderator tank for both, a D_2- and H_2-cold moderator. While the H_2-moderator will be available as a long term option, the D_2-moderator, equipped with a neutron guide system will be a day-one facility to provide the low-energy neutrons for the guide-hall instrumentation. The paper describes details of the the technical concept of the D_2-cold moderator which takes into account boundary conditions, considerations on flux optimization, operational feasiblity and safety.

I INTRODUCTION

The principle design considerations of the D_2-cold moderator for SINQ, balancing the different requirements within the boundary conditions of the SINQ general concept, were outlined at the previous ICANS meeting |1|. Meanwhile, a detailed technical design has been evaluated on the basis of the principle layout. The design is supported and refined by theoretical thermal-hydraulic investigations of the operational features, safety rquirements and failture management which are treated separately |2|. The present contribution concentrates on the technical layout of the moderator tank, the cryogenic system, shielding plug and subsystems for the D_2-handling.

II GENERAL DESIGN OF THE SINQ COLD D_2-MODERATOR

In order to minimize radiation damage of the cryogenic system, it was decided not to place any components of the cold moderator system other than the moderator vessel itself into areas of high radiation fields of fast neutrons. This means that a horizontal insertion port for the cold moderator was foreseen and the heat exchanger of the natural convection system was moved back into a well shielded region. This results in fairly long tubes between the moderator vessel (main heat source) and the heat exchanger (heat sink) and hence requires a large vertical separation of the two to overcome the frictional forces in the tube system by the buoyancy force of the liquid-gas mixture flowing back from the moderator vessel.

Experiments carried out by Hoffmann |3| in conjunction with the development of the second cold moderator at the ILL-reactor |4| showed that such a system could be operated over a large range of heat input. In our case we decided to place the vertical leg partway to the outside of the shielding block for three reasons:

1. The need for shielding behind the horizontal leg would have blocked space valuable for neutron scattering experiments
2. Placing the heat exchanger in the shielding block automatically provides good mechanical protection
3. The length of the tube and hence the amount of liquid D_2 as well as the frictional forces could be reduced.

This design implies that the horizontal and vertical leg of the cold source cannot be installed as one unit, but have to be put in place separately with a connection made before the shielding plug behind the horizontal leg can be mounted. The vertical cut through the SINQ target station shown in Fig. 1 illustrates the geometric arrangement of horizontal and vertical leg inside the main shielding.

Cryogenic equipment (cold box) and the control system for the source will be placed next to the main shield at a level of 9.5m above ground on top of the neutron guides with a connecting channel to the service areas and to the D_2-storage tank and parts of the gas handling system, located outside the neutron target hall on the roof of the equipment access building.

A block diagram of the various sub-systems is shown in Fig. 2.

III THE COLD MODERATOR SYSTEM

The design of the cold moderator part was governed by the neutronics considerations presented earlier |1|. Its location with regard to the target centre was optimized based on flux calculations as shown in Fig. 3. In order to avoid rethermalization of cold neutrons upon extraction from the moderator, the cold moderator insertion port will be connected to the neutron extraction port resulting in a T-shaped structure inside the moderator tank, Fig. 4.

The mechanical stability of this structure under thermal loads, buoyancy forces and various differential pressure conditions is presently under investigation by computational methods.

Fig. 4 also shows the D_2 moderator vessel in the T-shaped tube structure and the D_2O reflector volume which should compensate most of the losses occuring due to reflector volumes displacement by the cold source insertion tube.

The horizontal cold moderator insert is completely independent of this T-structure. It is shown composed (Fig. 5a) and disassembled to the main sub-units (Fig. 5b) which are:

- a double-walled vacuum jacket with a helium barrier between the outer and the inner tube. The part of the vacuum jacket intruding into the D_2O-tank consists of an outer 2 mm thick $AlMg_3$-tube and an inner zircalloy tube, 3 to 4 mm thick, which is the pressure safety tube and will withstand an internal pressure of 30 bar.
- The source plug, comprising the moderator vessel, the concentric transfer tubes for liquid deuterium (inner tube) and liquid-gas mixture (outer tube) of the heat removal system and a protective support tube which changes to a massive shielding sleeve outside the D_2O tank.
- The shielding and reflector plug comprising a D_2O reflector volume to be located behind the D_2 moderator to minimize losses, its associated D_2O circulation tubes and the cylindrical central shielding plug of the insert.

The moderator vessel itself will be made of 99.5 % pure aluminium, semi-hard with one welding seam around its cylindrical surface at the far end with respect to the target. Material softening by the weld requires the wall thickness of the vessel to be increased from 3 to 5 mm in this region to obtain the desired strength to resist an internal pressure of 4.4 bar. Fig. 6 shows a vertical cut through the moderator vessel and its concentric D_2-flow tubes. Some relevant data are given in table 1.

Material	Al 99.5	
Outer diameter	296/300	mm
Length	354	mm
Wall thickness	3/5	mm
Total volume	22.3	l
Volume filled with liquid D_2	~ 20	l
Total mass of Al	4375	g
Total weight of filled vessel	~ 7.6	kg
Design internal pressure	~ 4.4	bar
Max. operating pressure	2.8	bar
Heat deposition at 1 mA proton current:		
front cover	173	W
cylindrical part	67	W
back cover	15	W
deuterium	1250	W
Total	1505	W
Max. surface heat flow	0.2	W cm^2

Table 1: *Some relevant data for the D_2-vessel of the SINQ cold moderator*

The vertical leg of the cold moderator system is shown in Fig. 7. It will be inserted from the top into the shielding, and connections to the horizontal leg will be made inside the connector box where the two inserts meet. This box will afterwards be sealed to connect the insulating vacua of the two inserts. The second flange on the connector box shown in Figs. 5 and 7 completes the protective helium barrier (see below).

The main components of the vertical insert are:

- the vacuum jacket surrounding all cold parts for thermal insulation
- the D_2/He heat exchanger (plate heat exchanger with interconnectors) to remove the total of 2.65 (Ip = 1.5 mA) kW of heat load from the D_2 (capacity 3 to 3.5 kW).
- the phase separator located beneath the heat exchanger to remove the liquid from the phase mixture coming up from the moderator vessel.
- the concentric D_2-transfer tubes ending in the phase separator in such a way that liquid D_2 is flowing downwards in the inner tube and the liquid-gas mixture comes up in the outer tube to a higher level for phase separation
- the vacuum dome above the heat exchanger where the cold He-transfer tubes and the D_2 gas tube penetrate the cold moderator insulating vacuum space.

IV THE COLD HELIUM SYSTEM

Refrigeration of the D_2 in the heat exchanger is accomplished by cold helium gas from an existing cold box whose capacity is being upgraded to $\sim$ 3 kW. With a total of 2.65 kW to be removed from the D_2-source, this offers some reserve. The helium will be supplied to the heat exchanger at 18 K and 7.5 bar and will return at 25 K, 7 bar. The cold box will operate at constant cooling power; at reduced source power heat will be provided to the system by auxilliary heaters in the helium circuit, controlled by the D_2-pressure in the system. The cold helium transfer line between the cold box and the heat exchanger will be 20 m long each way and will be in a channel inside the target shielding block. Its outer diameter will be 90 - 100 mm.

V SAFETY PROVISIONS

The safety concept of the D_2-cold moderator in the first place pursues two objects, first to ensure secure enclosure of the (tritium contaminated) deuterium, and second to prevent the formation of an inflammable mixture of hydrogen and oxygen. For these purposes, it relies on **passive** safety devices which are:

- multiple containment for D_2
- protective barrier system
- mechanical protection
- remote positioning of storage tank and gas handling devices

These passive devices are complemented by **active** devices which ensure early detection of anormal operation conditions and, in case, suitable automatic actions to prevent accidents and damage of plant components. Among these devices are:

- control of pressures and contaminations in the protective gas barriers
- pressure control and residual gas analysis in the insulating vacuum
- temperature monitoring of the moderator vessel and the surrounding vacuum jacket
- control of the purity of the deuterium before filling and during operation

The containment and barrier system is designed to avoid any possible contact between deuterium and oxygen from the air which could ultimately form an explosive gas mixture. Although the SINQ beam ports are filled with helium which also surrounds the horizontal insert of the cold moderator, it was decided to have a separate additional helium system around the cold part of the D_2 circuit for the following reasons:

- the pressure in the beam-tube gas system is below atmospheric pressure to make sure that in case of a leak the flow always is to the inside to avoid spreading possible radioactive contamination into the atmosphere. By contrast, the pressure in the protective He-barrier of the cold source should be above atmospheric pressure (1.1 bar) to avoid contamination with oxygen in case of a leak to the outer atmosphere

- the cold moderator helium barrier will be continuously monitored for oxygen contamination which suggests having as small a volume as possible
- in case of the need for access to the structural parts of the cold moderator system, the beam port helium system needs not be opened.

The helium gas in the protective barrier will be continuously circulated, carefully monitored for pressure loss and contamination by other gases and refrigerated to remove the heat it picks up from the walls in the region of high neutron flux.
Outside the main shield all system parts containing warm D_2-gas will be surrounded by a N_2-gas barrier rather than helium for the following reasons:

- N_2 is much cheaper than helium
- Helium is used for leak detection on experimental facilities and thus should be present in the smallest possible amounts in the air
- monitoring for deuterium is easier in nitrogen than in helium

The pressure in the N_2 protective barrier will also be kept at 1.1 bar to avoid oxygen-intake in case of a leak.

REFERENCES

1. F. Atchison, W. Bucher, A. Höchli, I. Horwarth and L. Nordström "The D_2 cold-neutron source for SINQ" in "Advanced Neutron Sources 1988", Institute of Physics Conference Series No. 97, D. K. Hyer, ed. Bristol and New York 1989, pp. 473 - 482

2. K. Skala, H. Spitzer, and G.S. Bauer, in these proceedings.

3. H. Hoffmann: "Natural convection of a cold neutron source with vaporizing deuterium at temperatures of 25 K", NATO, Advanced Study Institute: Natural Convention, Fundamentals und Applications, July 16-27, 1984 Izmir Turkey

4. K. Gobrecht, Proc. Int. Workshop on Cold Neutron Sources, Los Alamos NW, USA (March 1990)

Q(E.P.Shabalin): May be, I missed but you did tell nothing about vacuum layer between D_2 and He. Is there evacuated volume outside the vessel?

A(W.Wagner): The entire cold D_2-system, in the horizontal and vertical inlet, is encapsulate by cryo-vacuum.

Q(T.Kawai): Why do you use the phase separator in addition to the heat exchanger?

A(W.Wagner): Because the system is based on isothermal natural circulation, driven by bubbles of D_2-gas in the liquid D_2-back-flow line.

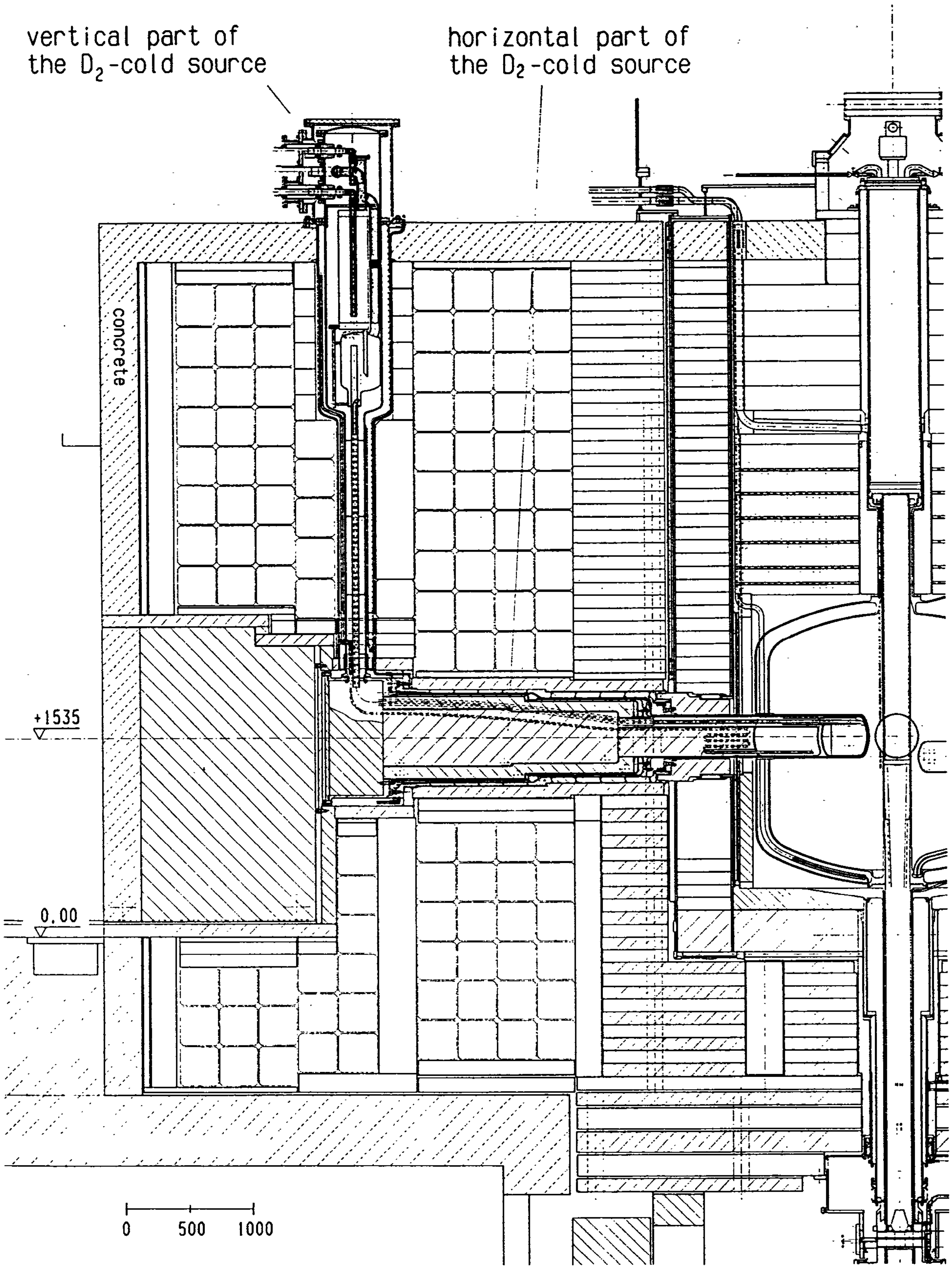

Fig. 1 Section through part of the SINQ target block along the plane of the D_2-cold moderator inserts. For detailed parts designation see Figs. 5 and 7.

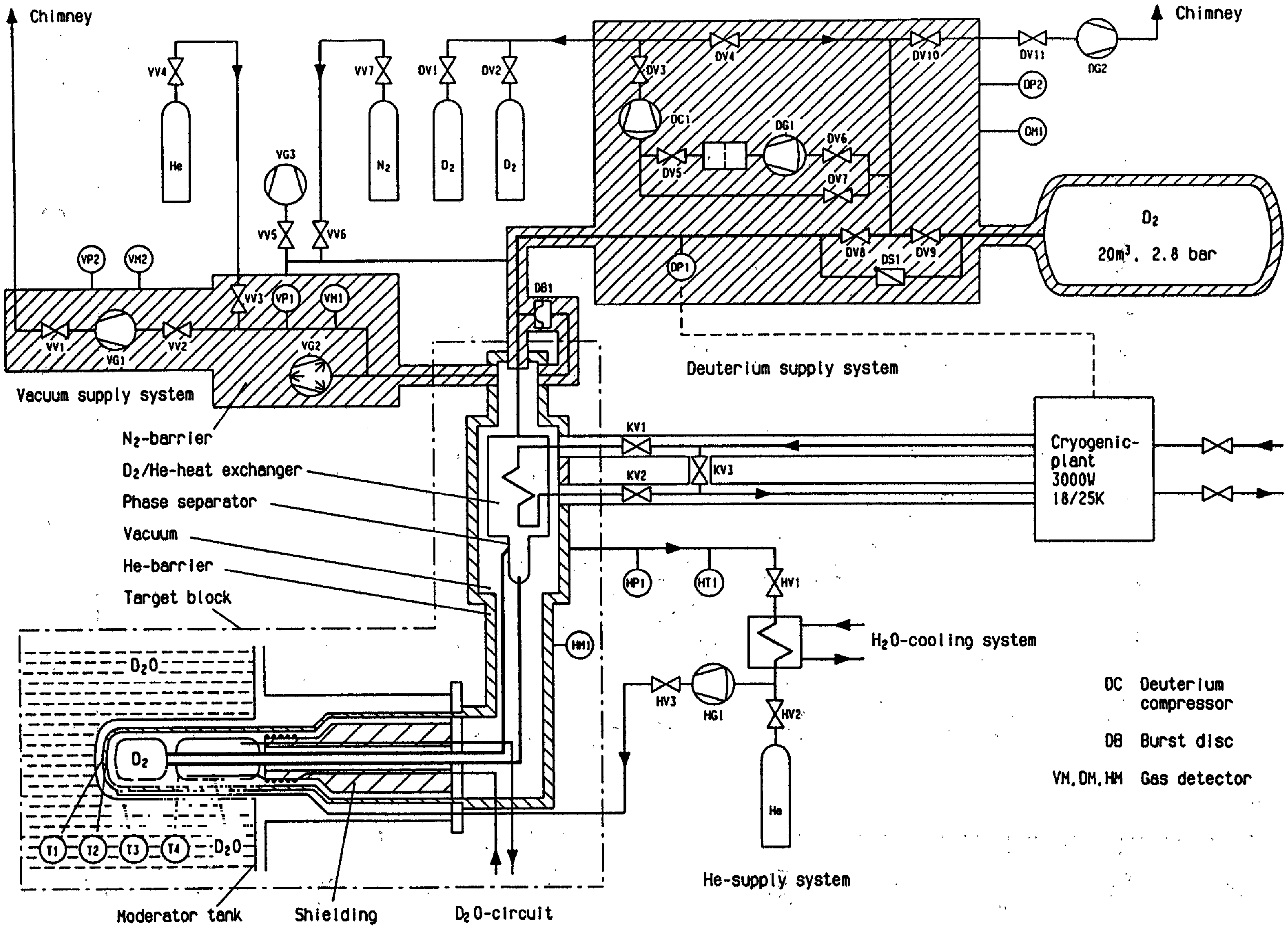

Fig. 2 Simplified diagram of the various subsystems of the D_2-cold moderator for SINQ. Helium is used for the protective barrier of the D_2-system only inside the target block. Outside the target block N_2 is used.

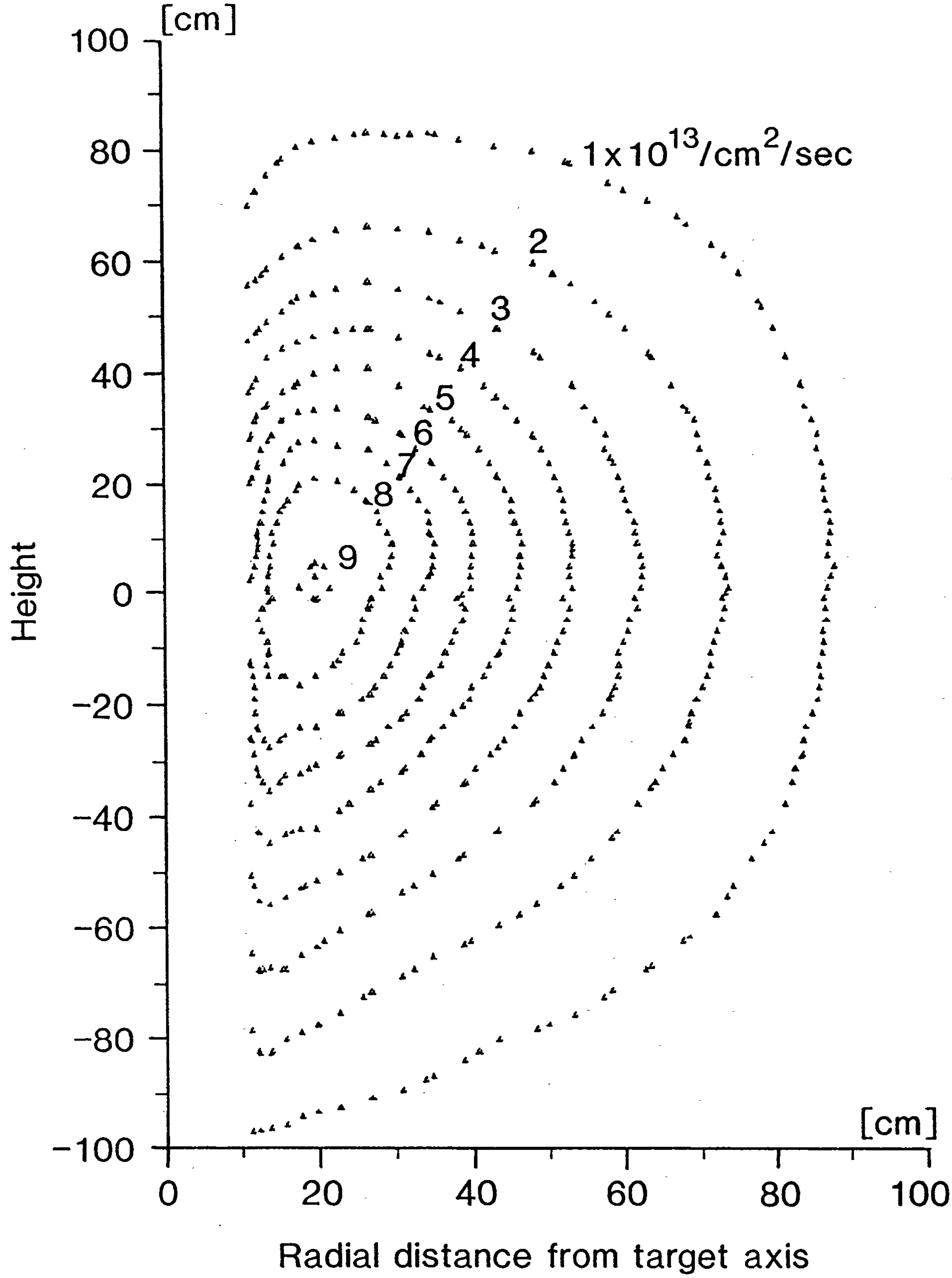

Fig. 3 Undisturbed thermal-neutron flux map in the heavy-water for 1 mA proton current on target.

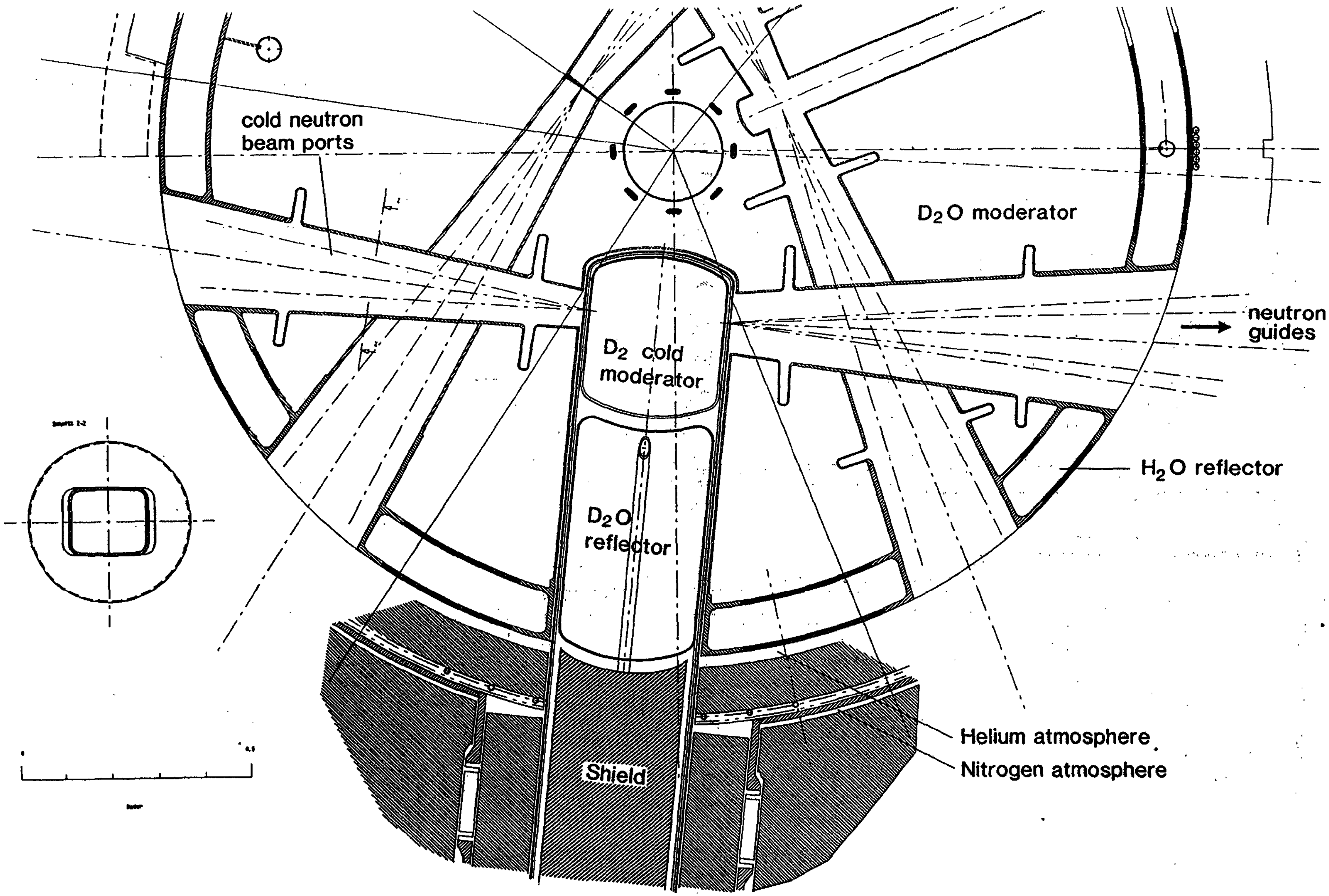

Fig.4 Layout of the SINQ-D_2O-tank with T-shaped structures for cold moderator insertion and neutron extraction, avoiding rethermalising D_2O-layers.

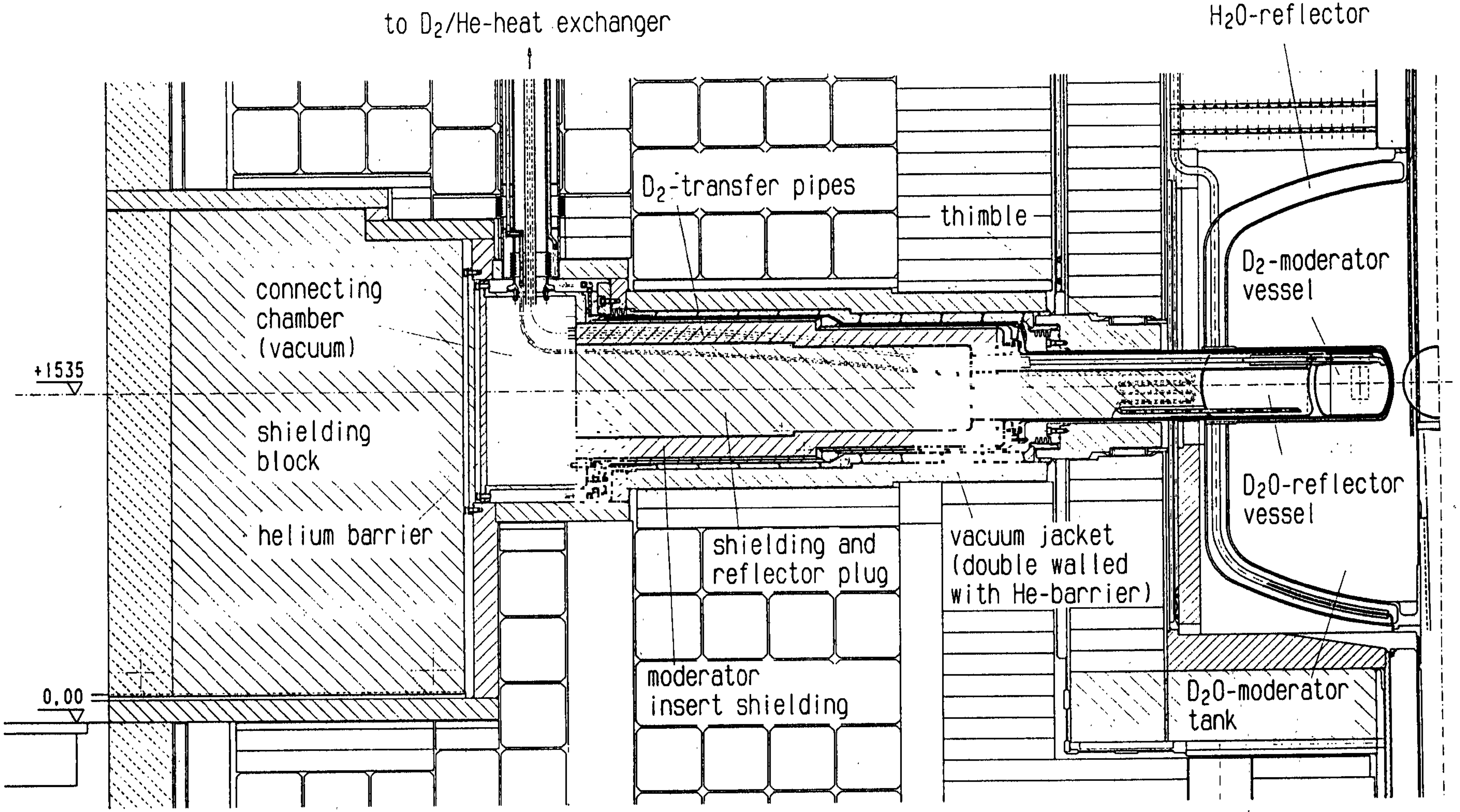

Fig. 5a Vertical section through the horizontal insert of the SINQ cold D_2-source.

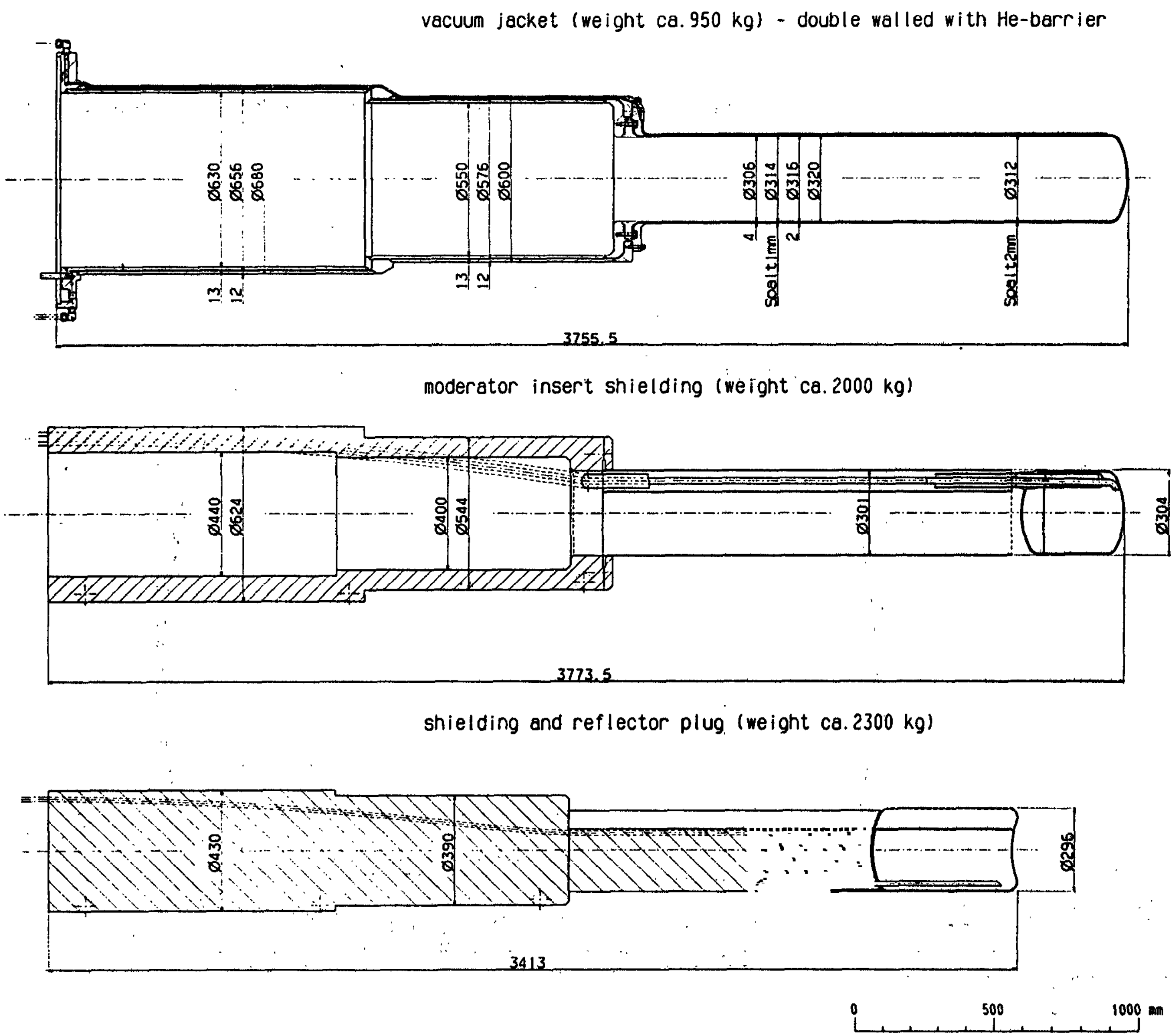

Fig. 5b Vertical section through the parts of the horizontal insert, i.e. the double walled vacuum jacket, source plug with moderator vessel and concentric transfer tube, and shielding and reflector plug.

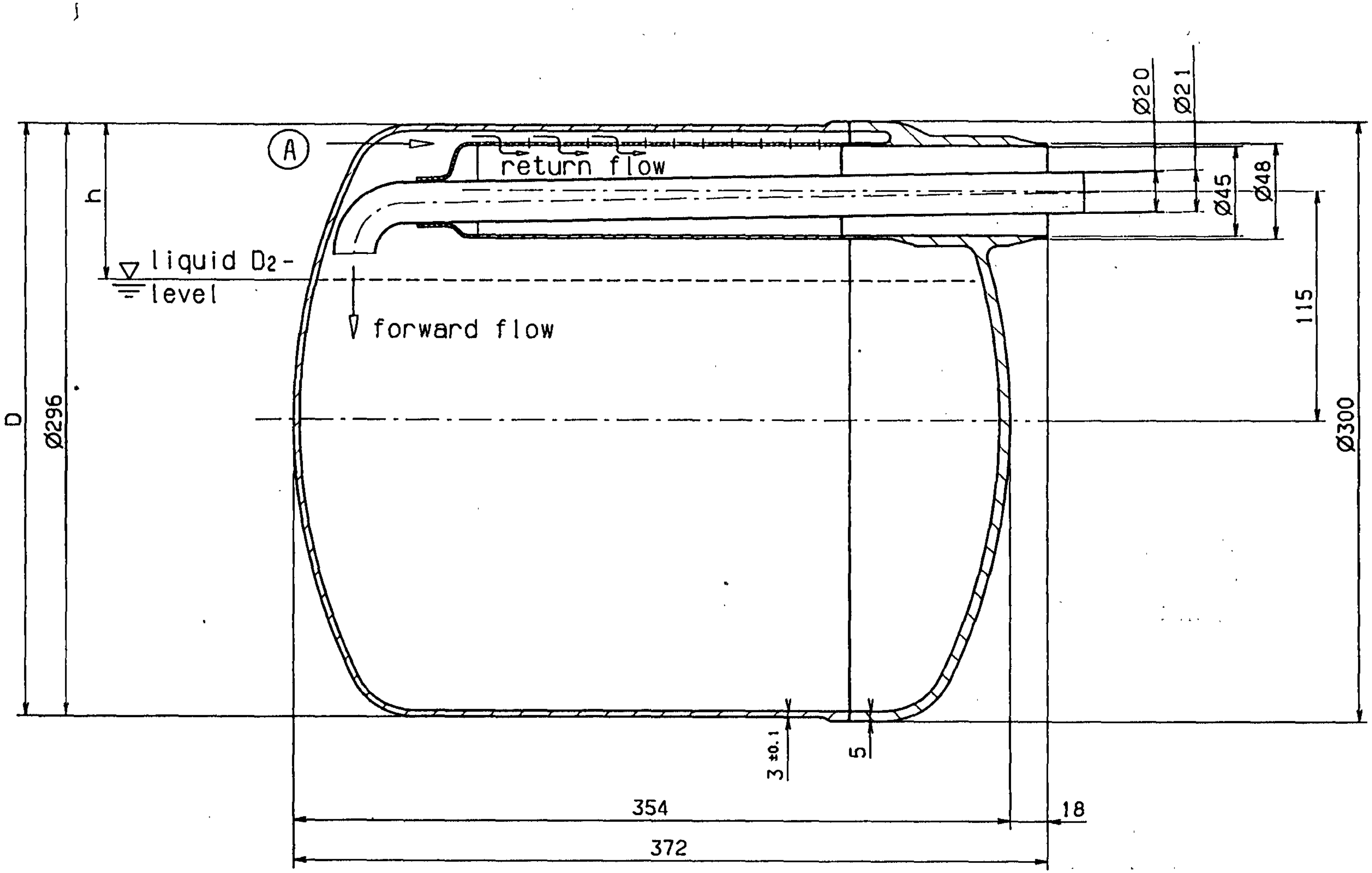

Fig. 6 The D_2-moderator vessel and its concentric flow tubes (vertical section).

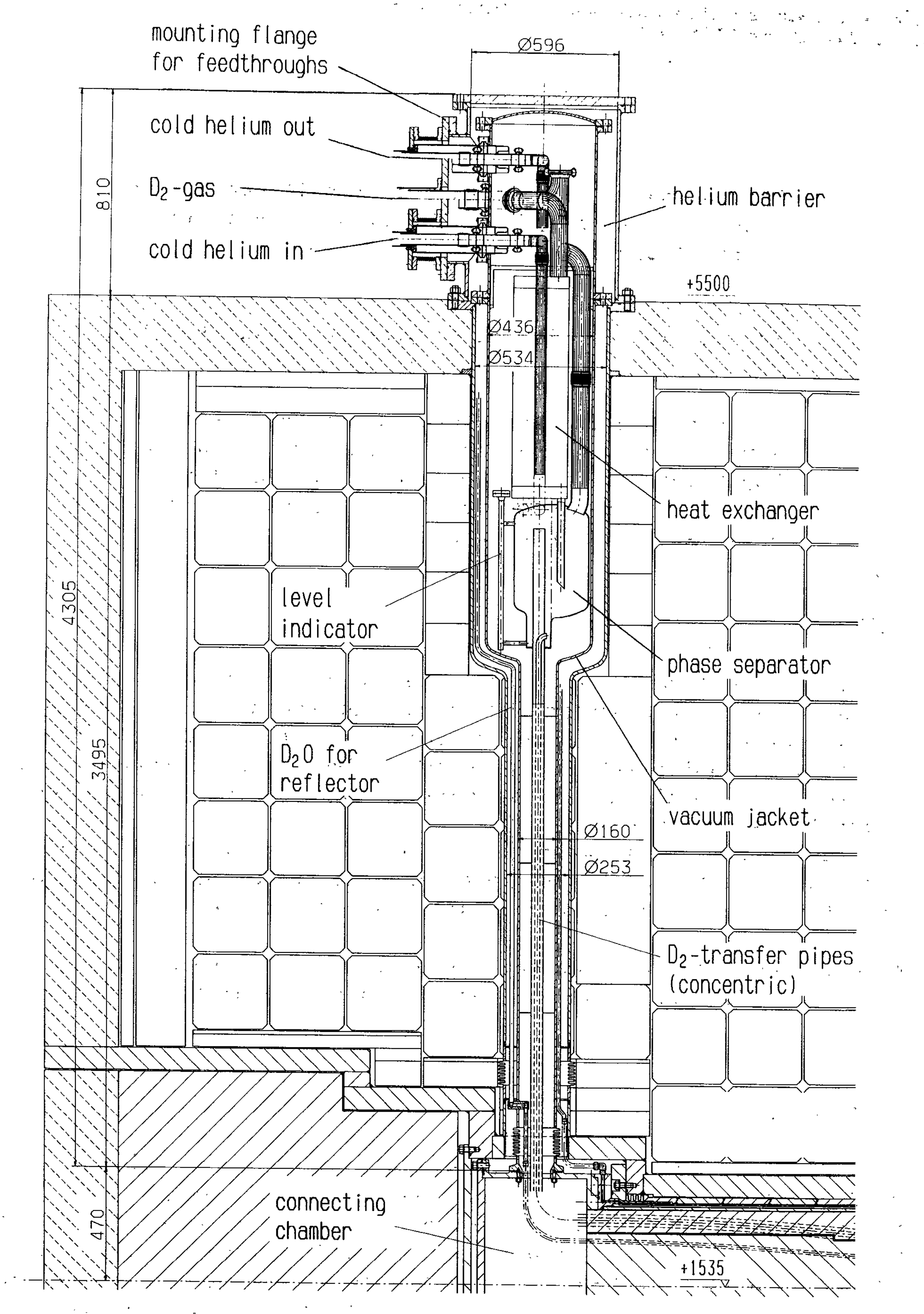

Fig. 7 Vertical section through the vertical insert of the SINQ cold D_2-source (pipe system, phase separator and heat exchanger).