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ORPHEE REACTOR. UPGRADE OF THE INSTALLATION.

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ABSTRACT

Designed by the end of the seventies, the ORPHEE Reactor is equipped with two hydrogen cold sources, one hot source and six cold neutron guides. The neutron beams are extracted by nine beam ports and used in two experimental halls, the reactor hall and the neutron guide hall. After fourteen years of use, a modernisation programme is in progress. One step concerns the neutron guides, another one the cold sources with the modification of the cell geometry in order to increase the cold neutron flux. This operation requires the use a new cryogenerator to ensure liquefaction capabilities for the new cells. It is also scheduled to replace the Zircaloy core housing in order to avoid difficulties linked to the expansion under irradiation.

1. INTRODUCTION.

After fourteen years of continuous run of the ORPHEE reactor, about 70 per cent of the experimental facilities are using cold neutron beams (see figure 2) and the demand for such neutron beams is increasing. In order to fulfil such an increase several actions have been started [1] and are in progress.

One immediate step is a modernisation programme for a more efficient use of the neutron beams. It consists in the improvement of the present neutron guides. This is the result of the co-operative development with industry of the metallic super mirrors. A medium term step is the creation of new cold neutron guides. Preliminary study has been done and is the so-called ORPHEE PLUS project described in a previous paper [2]. On line with the modernisation programme and induced by this last project, is the change of the shape of the cold source cell and the cryogenerator. On a longer time scale the possible production of super-mirrors with larger critical angles offer the possibility of creating efficient thermal neutron guides.

At short time another important operation on the reactor will be the change of the Zircaloy core housing. With these improvements the ORPHEE reactor and its experimental set-up will remain a modern neutron source for the next decades.

2. PRESENT NEUTRON GUIDES UPGRADE.

An extensive study of production of metallic multilayers to get reliable and efficient super mirrors has been developed at the Laboratoire Leon Brillouin these past years in close collaboration with the industry [3]. It results now in an industrial production of very good reflectors with a critical angle two times greater than that of the natural nickel (for that reason these mirrors are called "super mirrors $2\theta_c$") at an acceptable price. This new possibility is now extensively use at the ORPHEE reactor first to improve the present neutron guides and second to create new beams by using benders :

- *Present guides.* In the original design all the neutron guides were curved in order to act as a filter. A curved neutron guide is characterised by a "critical wavelength" below which the transmission is very low. It is now clear that a too large value of this wavelength is not necessary and could be an handicap for many experiments due to the limitation of the wavelength range. Two of the six ORPHEE reactor guides have a strong curvature, G1 and G2 with a characteristic wavelength of respectively 6 Å and 4 Å. During the 1994 winter shut-down, the natural nickel mirrors of the curved part of the G2 guide have been replaced by $2\theta_c$ super mirrors. The result is a decrease of characteristic wavelength from 4 Å to 2 Å and an increase of the transmitted flux in the low wavelength range (figure 4). The next step will be the same operation for the G1 guide.

- *New benders*. Few years ago, in order to increase the end guide positions, two benders have been installed using an old multichannel technique with Ni58 coating. Replacement of this old bender by a multi channel super mirror bender leads to an increase in the transmitted flux. In a first step this has been done for the G3 bender (figure 5). More recently a third bender using a super mirror coating has been installed on the G5 guide [1].

3. NEW COLD SOURCES.

a) Old design.

- In the original design of the reactor, the choice of liquid Hydrogen for the moderator [4] has led to use two small cells in order to feed enough cold neutron beams. Due to the geometry of the beam tubes looking at the cold sources (figure 1) it was decided to design a "flat" cell in order to fully illuminate the corresponding beam tubes. The cell size, made of stainless steel, is 205 mm height, 125 mm large and 50 mm thick.

- Boiling hydrogen enclosed in the two circuits of the cold source n°1 (beam tube 8F) and n°2 (beam tubes 9F and 4F) is re condensed by frigorific exchange with an helium refrigerator according a BRAYTON cycle. This cryogenerator delivers gaseous helium at 17°K by mean of two turbines (one on each circuit). That helium exchanges its frigories with gaseous hydrogen by the way of two condensers located in the pool of the reactor. Hydrogen circulation between the condenser and the cell is made by natural convection in a closed circuit under vacuum completely immersed in the pool.

- The thermal power produced by nuclear radiations in each "flat" cell during reactor operating is about 700 Watts. The cryogenerator designed in 1979 and built by AIR LIQUIDE was able to deliver 1400 Watts at 20°K to cool and liquefy hydrogen [5].

b) New design.

- The best suitable shape for the cell designed for ORPHEE PLUS, is a cylinder of 130 mm in diameter [6]. To reduce the neutron absorption this cylinder must be hollow (see figure 6). The thickness of the liquid Hydrogen layer was determined by calculations based on results of experimental studies done for the High Flux Reactor of Grenoble [7]. A value of 15 mm was determined for the best neutron gain below 7Å, the wavelength range used by the majority of the experimental set-up.

- The size of the new cell increases the Hydrogen volume and the thermal power balance of the old cryogenic plant was too low. It was then decided to design a new cryogenerator. The frame of the project was :
  - to keep unchanged the Hydrogen circuit,
  - to design a new cryogenerator able to deliver 1850 Watts at 17°K,
  - to modify as less as possible the existing installation, re-using all parts that can be, considering their design size,
  - to change all the parts whose technology was out of date and to replace them to permit an elaborated automatism.

- A new design study has been set up to verify the evolution capacity of each existing part of the old system. The conclusion of that study has shown :
  - it was necessary to replace the helium compressor and the helium turbine to reach the 1850 Watts,
  - the hydrogen condenser was able to cool and liquefy the hydrogen for the new annular cells,
  - the intermediate helium exchanger (cold box) was limited to 1700 Watts.
  - An increase of helium mass flow in the helium pipes between the compressors and the cold box do not bring significant increase of pressure drop.

- Considering these conclusions it was decided to study a new cryogenerator for a power of 1850 watts. The main characteristics are the following :
  - complete automatic system,
  - automatic start up after failure of electric power, air instrument, or water cooling system,
  - no regeneration of helium before restart,
  - possibility of outside control and telediagnostic,
  - operation through high feasibility components.

c) The new cryogenerator.

The different units of the new cryogenerator built by AIR LIQUIDE are the following :

- the compressor unit,
- the oil removal unit,
- the helium pressure control unit,
- the "cold-box" including heat exchangers, the absorber and only one expansion turbine,

- the helium temperature regulation unit,
- the control command unit.

- *Compressor unit.* The compressor unit is set with two screw compressors settled on the same frame including the bulk oil separator.

  The main characteristics of the screw compressors are :
  - admission pressure : 3.7 bar,
  - delivery pressure : 17.4 bar,
  - number of stage : 1,
  - mass flow rate : 60 g/s (for each compressor),
  - electric power : 125 kW,
  - water cooling flow rate : 40 m^3/h.

  The bulk oil separator is placed just after the compressors. The oil is send back to the compressor's bearings and casing through water cooling exchanger and filter.

- *The oil removal unit* (see figure 7). Leaving the bulk oil separator, pressurised helium (25 ppm of oil) goes to the oil removal unit. Aerosol of oil are kept into a serial of three filters. Small particles of oil are agglomerated along very small diameter fibbers. The drops of oil fall down by gravity and are collected at the lower part of the filter and back to the compressor. The very last quantity of oil vapour is absorbed on an active coal bed.

- *The helium pressure control unit.* This unit is settled near the compressor unit. The regulation valves ensure high pressure and low pressure regulation, specially when the compressors are starting.

- *The "cold-box"* (see figure 8). This box contains components running at low temperature; they must be thermally isolated, and are placed in a large cylinder under vacuum. The two heat exchangers (serial) are plate and fin type heat exchangers. They ensure temperature decrease of helium from 300°K to 23°K with a very low pressure drop (0.07 bar).

  The turbine with gas bearings is built by AIR LIQUIDE (see figure 9). High pressure helium at 17 bar and 20°K is expanded into the distributor. The expansion of the gas goes on in the wheel and the diffuser. The wheel drives the shaft supported by the gas bearings (pivoting system) which transfers a torque to the wheel of the brake compressor. The energy absorbed by the brake compressor is turned into heat by helium compression and drained out by a cooling water exchanger.

The helium flow cooled (15°K) and expanded (3.7 bar) goes to the hydrogen condensers.

- *The helium temperature regulation unit*. The hydrogen pressure in the cells is regulated by the temperature of cold helium in the condensers. As the helium temperature of gas going out of the turbine is constant, the gas is warmed by electrical resistance just before the condensers. The electrical power delivered to the helium flow represents the available frigorific reserve of the cryogenerator.

  Large variations of the reactor power during test period (from 14 MW to 4 MW at 1.2 MW/minute), has shown quick answer of the regulation and low variations of hydrogen pressure.

- *The control command unit.* The control command is ensured by a process controller supplied with electronics gauges, relative humidity control and vacuum gauges. The interfaces cards ensure connections between the central unit and the process. They receive directly signals from the gauges and send back orders to the components (valves, electric resistance, ...).

  The process informations are available on a display screen, with a keyboard. The cryogenerator is piloted from that keyboard. The regulation parameters values can be also changed from that system.

d) Normal operation.

The operator can choose among different ways of operation and gives simple :
- starting order,
- starting vacuum,
- forbidding of the turbine running (used during test periods),
- cleaning the cold box (the air staying in the cold box is evacuated and replaced by helium),
- cold box regeneration (the air staying in the absorbers and water set down in the exchanger are evacuated).

In case of emergency or utilities failure, the whole system is protected. All the valves set in the safe position.

If the electric power failure is less than 20 seconds, the helium turbine is fed up with gas coming from a safety capacity. High pressure is kept at 17 bar and low pressure helium is discharged to the atmosphere. When electric power is back, the first compressor starts ; the second one three seconds later and the valves recover their normal position. The turbine does not stop and the cryogenerator runs normally.

The cryogenerator re-vamping at the ORPHEE reactor is the first step of the modernisation programme of this reactor. It allows the increase the cryogenic power delivered to the cold sources and to get a modern device. Setting up the cryogenerator needed two months of reactor shutdown including cryogenic test and neutron tests. The next step of that programme will be the replacement of the flat cell of the two cold sources by new annular cells. This step is foreseen during the 1995 summer shut-down.

4. *FUTURE PLANS.*

- *New cold neutron guide hall.* This project, called ORPHEE-PLUS, consists in extracting new cold neutron beams by neutron guides exiting in a new neutron guide hall and increasing by about 30 per cent the number of beam positions. It was largely described in the previous IGORR meetings [1]. Technical designs are in progress.

  After a preliminary design, it has been decided to choose two straight neutron guides starting from the end of the beam tube up to external face of the reactor building. The crossing of the wall of this building will be done through safety valves. The beam section will be large, 160 mm height and 50 mm large, in order to easily split each in two secondary guides in the new guide hall (figure 12) leading to four guide ends. The coating will be a super mirror with $2\theta_c$.The biological shielding in the reactor hall is under calculation and will be made by concrete blocks.

  The design of the collimator is now completed. It has a converging part looking at the cold source (figure 10) and the guide separation is done in the in-pile collimator in order to minimise the shielding. In this part the support of the mirror will be made with an aluminium alloy finely polished and then coated with Nickel 58. Experiments are in progress to determine if it is possible to use super mirror coating in this area due to the high radiation level [3]. This collimator will be enclosed inside the plug set in the beam hole tube (figure 11) looking at the cold source n°2.

As previously presented [1], this project will lead to a large modification of the experimental set-up in the reactor hall. Seven of the present eleven instruments have to be moved. At that occasion large modifications of the beam tubes will be done.

The first one is to create a new cold neutron beam tube inside the reactor hall by extending the tube T1 up to the cold source N°1 set in front of the tube F8 (see figure1). Because this new beam tube is nearly at right angle with the beam tube F8, the cold cell must be cylindrical in order to fully illuminate the two beam tubes. The second modification concern the size of the in-pile collimators for thermal neutron beams. They will be increased from 40 x 80 mm^2 to 50 x 120 mm^2. This modification will results in a large increase on available flux on sample.

- *Thermal neutron guide*. The present development of the super mirror coating with large critical angle will allows to produce efficient thermal neutron guides. At present time coating with $2\theta_c$ super mirror is extensively used but is not really enough for a good thermal neutron guide. Experiment are in progress in order to determine the parameters for an industrial process. When good super mirrors will be available, the project is to extract thermal neutron beam from the beam hole 6T (see figure 13) and to use it in an external guide hall.

5. REPLACEMENT OF THE ZIRCALOY CORE HOUSING.

The core housing of the ORPHEE reactor serves the following purpose :
- containing fuel elements and ensuring their correct position,
- channelling water cooling flow through the core,
- keeping water lightness between primary light water and heavy water in the reactor tank.

Because of its position in the reactor, the Zircaloy of the core housing is placed under a huge neutronic irradiation. To get a good knowledge of Zircaloy behaviour under neutronic irradiation, a specific device has been settled in the middle of the reactor core, inside the beryllium reflector block. That device has permitted to follow the evolution of Zircaloy properties with anticipation as the fast neutron flux in the middle of the core is 20 % higher than in the most irradiated area of the core housing.

The different results obtained from 1986 and their extrapolation following a reasonable evolution process for more important doses, have shown that the maximal available growth of the core housing will be reached before the end of the lifetime foreseen for the reactor. That maximal value of the length has been calculated to keep normal stresses in the materials (nut and bolt, bending stresses of the reactor tank head). The maximal over length is 0.79 mm for the 1000 mm of the most irradiated area of the core housing. That over length could be reached during the year 1998 and it has been decided to replace the core housing at the end of the year 1996.

Replacing the core housing is an important operation whose duration has been estimated up to three months. The main phases are :

- emptying and drying the reactor tank from heavy water, then filing it with light water,
- dismantling of the whole mechanism of the control rods,
- taking out the positioning grid, the core grid and the convergent tube,
- dismantling of the upper bolts of the core housing, then of the lower bolts (fixation of the lower flange on the bottom of the reactor tank),
- carrying out the core housing to the storage pool,
- settling the new core housing in the reactor tank,
- leakage test,
- emptying and drying the reactor tank from light water.

The design of the new core housing has been modified to take account the growth of Zircaloy under irradiation. A dilatation compensator made of two concentric bellows with leak detection between the two bellows have been put at the upper part of the core housing (see figure 15).

6 CONCLUSION.

The modernisation programme of the ORPHEE reactor and the experimental devices defined some years ago is in progress. The new fact is the success in the industrial process of the super mirror coating leading to an extensive use for the replacement of old Nickel coating. This is done in places where it will bring a very efficient use of neutron beams : in curved part in order to lower the characteristic wavelength, in bender in order to increase the transmitted flux. The creation of new cold neutron guides of the ORPHEE PLUS project has been slowed during the shut down of the Grenoble High Flux Reactor. It is now in the design stage and the decision to start the construction is linked to the collaboration with foreign laboratories.

Together with the restart of the HFR, the present refurbishment of the experimental facilities of the ORPHEE reactor and the possibility to increase the cold neutron beams potential will give to the European scientific community the opportunity to access neutron beam facility for the next decades.

FIGURE CAPTIONS.

Figure 1.	Horizontal section of the reactor. The nine beam tubes are referenced by the nature of the neutron beam: T thermal, F cold, C hot.
Figure 2.	Instrument layout in the two experimental halls: reactor hall and neutron guide hall. 30 instruments are installed around the reactor, 11 in the reactor hall and 19 in the neutron guide hall. 21 are using cold neutron beams (i.e. 70 %). A neutronography installation set at the end of the G4 guide is used for industrial tests.
Figure 3.	Measured reflectivity of natural Nickel mirror (critical angle θ_c) and super mirror with a critical angle $2\theta_c$.
Figure 4.	Measured neutron flux for the new G2 guide.
Figure 5.	A) Sketch of the G3 and G3 bis guides. W is the width of the elementary channel. B) Measured neutron flux for the G3 bender with Nickel 58 and with super mirror.
Figure 6.	Schematic view of the annular cold cell.
Figure 7.	Compression system of the cryogenerator.
Figure 8.	General diagram of the cryogenerator.
Figure 9.	Cryogenic expansion turbine.
Figure 10.	Design of the beam tube for the two guides of ORPHEE PLUS.
Figure 11.	Design of the beam tube for the two cold neutron guides.
Figure 12.	New neutron guide hall and the splitting of the two guides.
Figure 13.	Neutron guide halls proposed for ORPHEE: ① present hall, ② new cold neutron guide hall, ③ proposed thermal neutron guide hall.
Figure 14.	Vertical section of the ORPHEE reactor showing the position of the zircalloy core tube.
Figure 15.	New zircalloy core tube with the compensator bellow.

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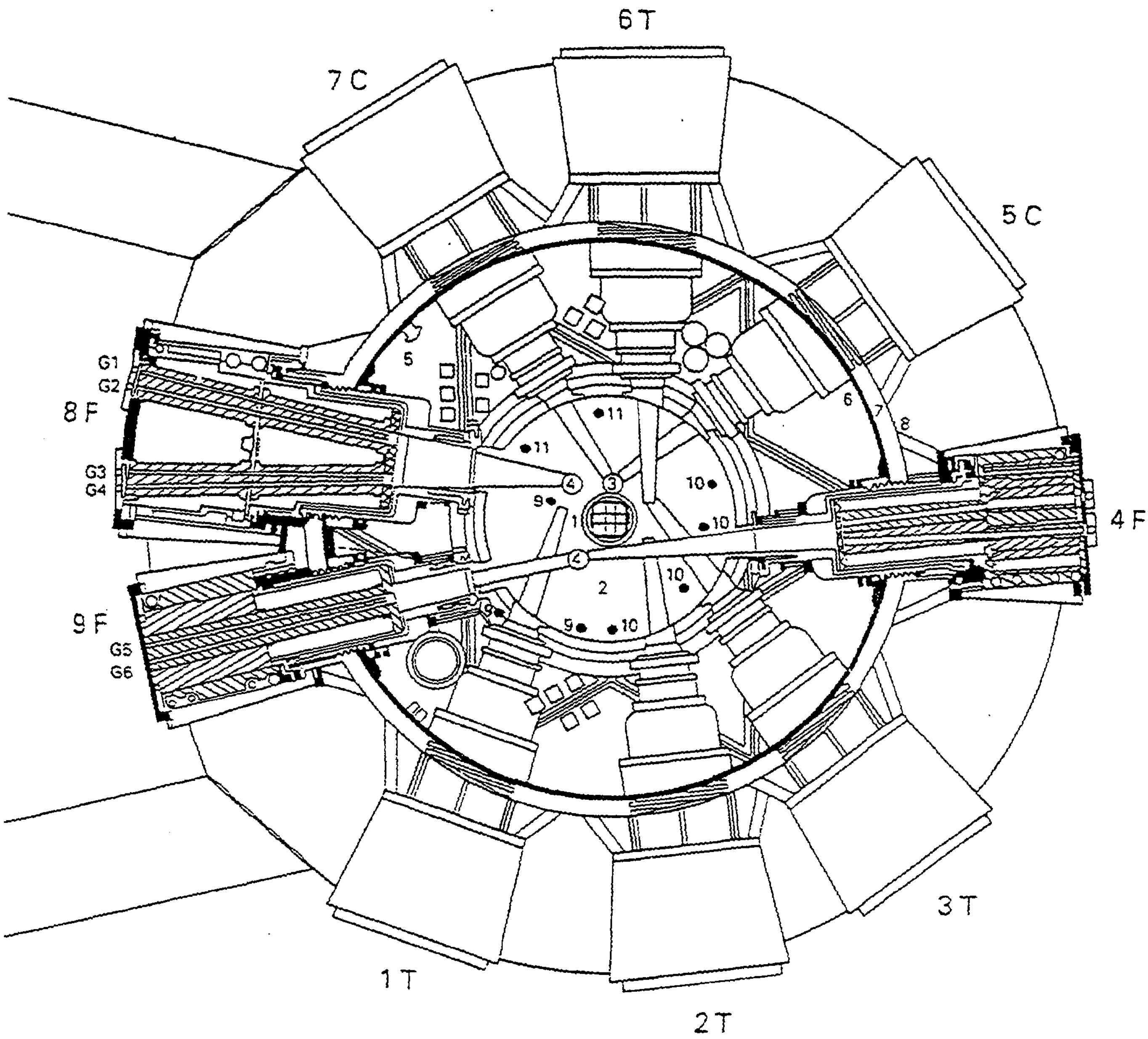


1. core
2. heavy water reflector
3. high-temperature source
4. low-temperature source
5. pool
6. pool inner wall
7. annular space
8. pool outer wall
9. radio-isotope production channel
10. shuttle tube
11. vertical irradiation channel

Figure 1.

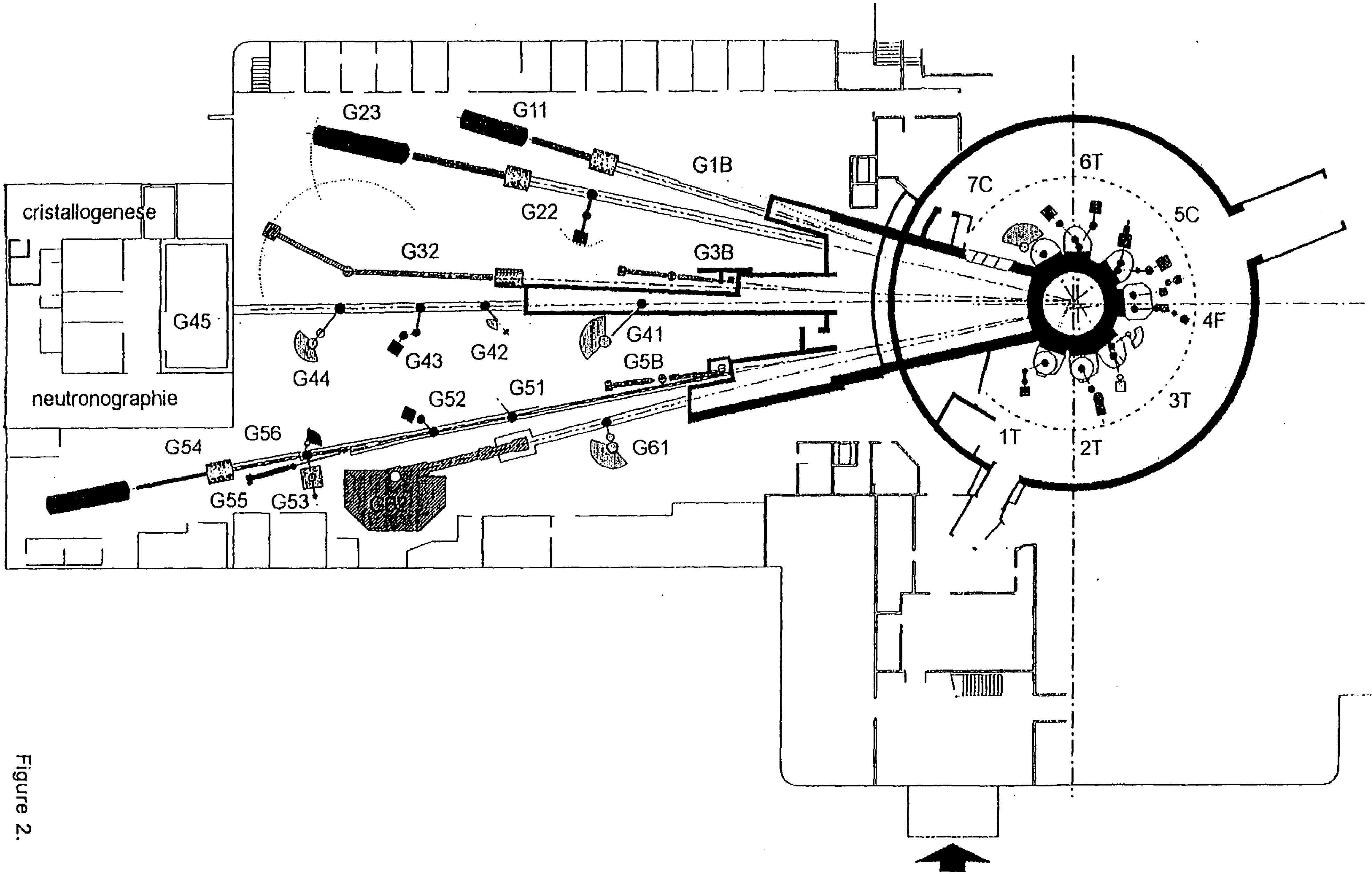
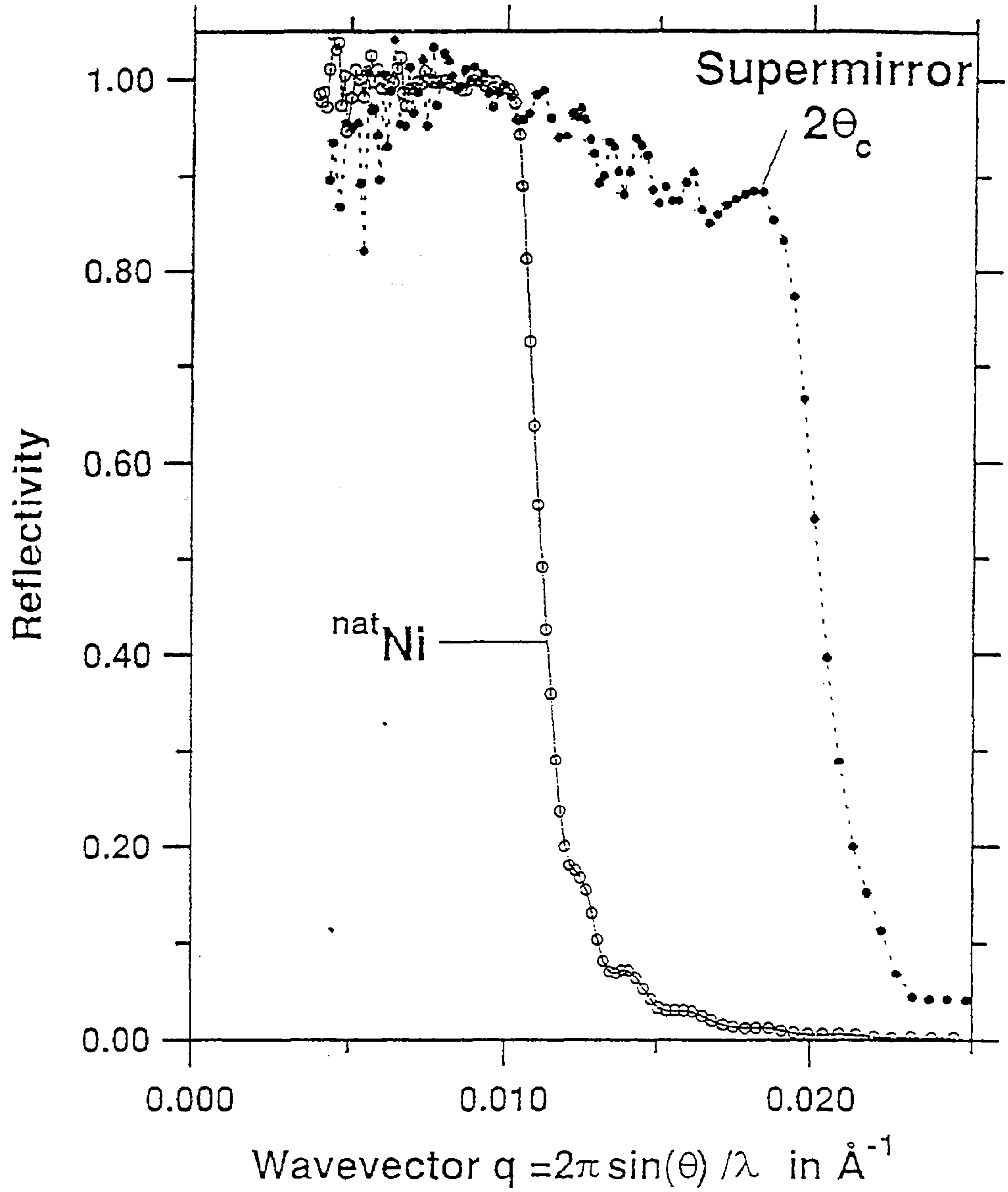
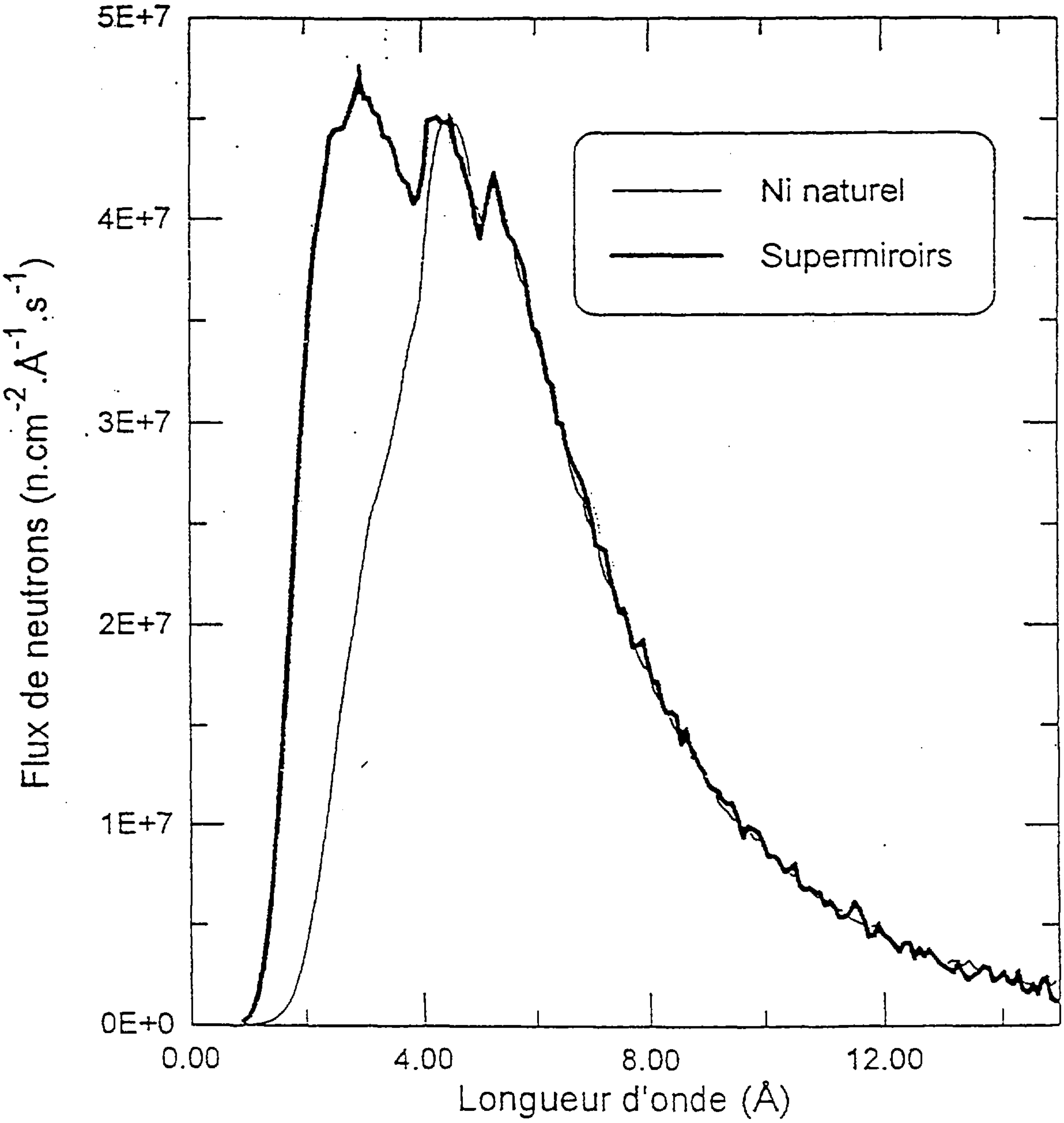

G23
G11
G1B
6T
7C
5C
cristallogenese
G22
G32
G3B
G45
4F
G41
G44
G43
G42
G5B
neutronographie
G52
G51
3T
G56
G54
1T
2T
G61
G55
G53
G62

Figure 2.



Supermirror
$2\theta_c$
^{nat}Ni
1.00
0.80
0.60
0.40
0.20
0.00
Reflectivity
0.000
0.010
0.020
Wavevector q =2π sin(θ) /λ in Å^{-1}

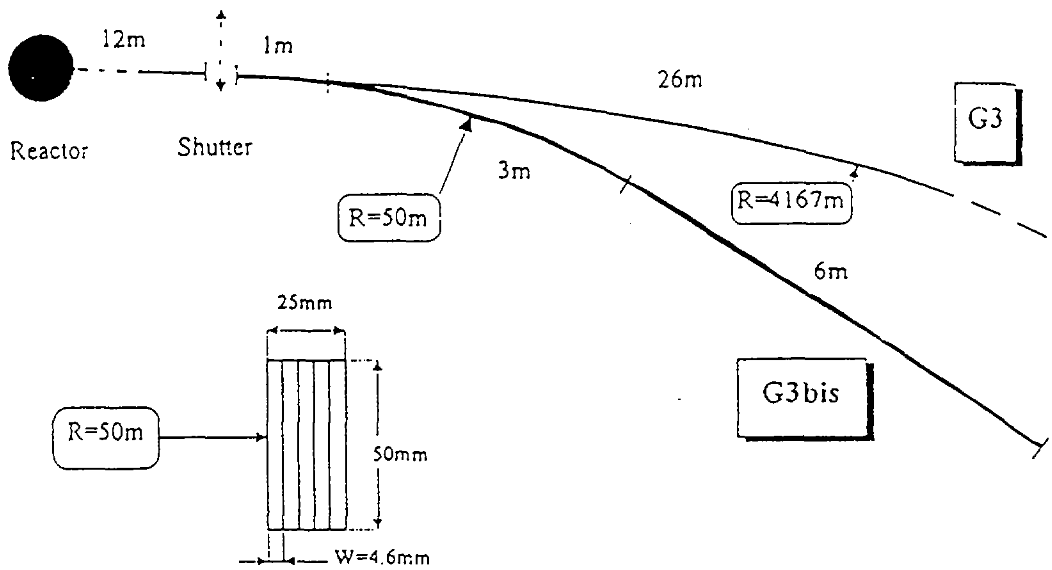
Figure 3.



Measured neutron flux for the new G2 guide.

Figure 4.

A


12m
1m
26m
G3
Reactor
Shutter
3m
R=50m
R=4167m
6m
25mm
G3bis
R=50m
50mm
W=4.6mm

B

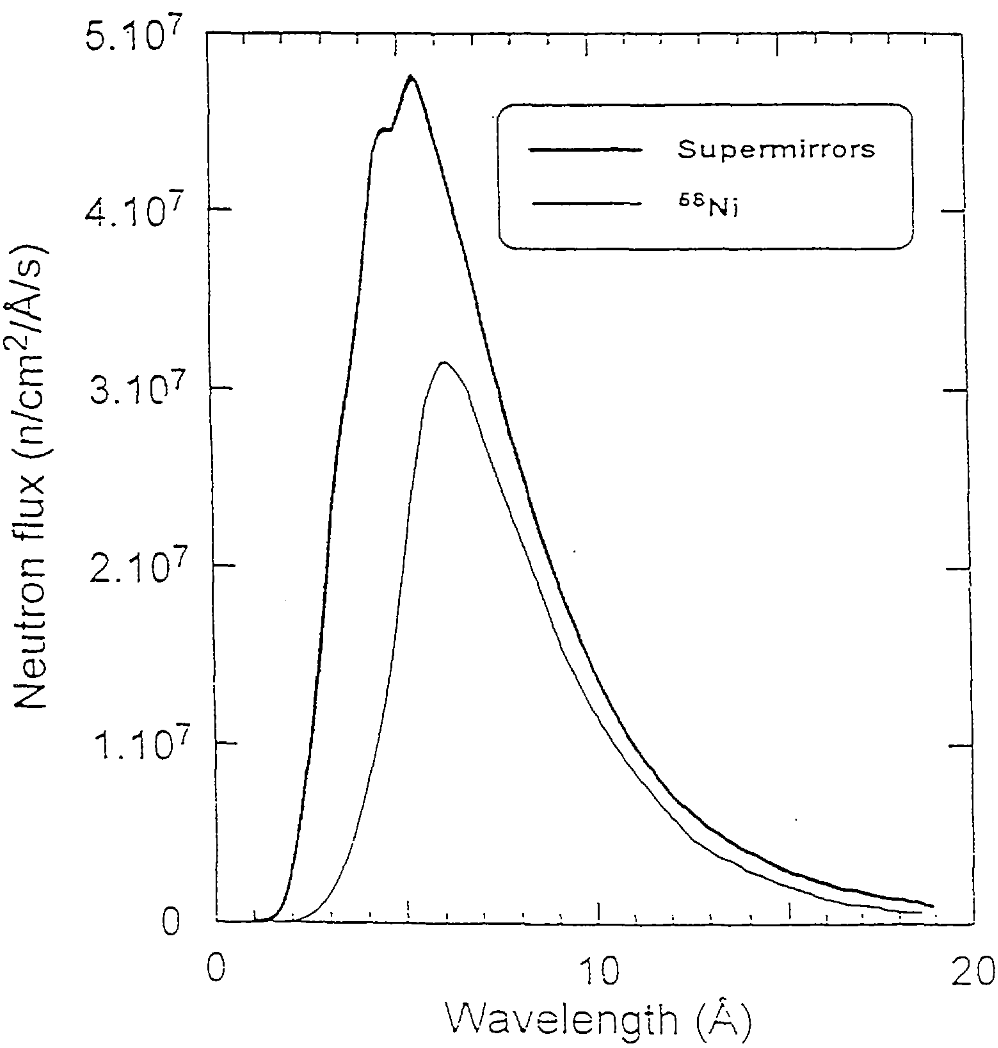

5.10^7
4.10^7
3.10^7
2.10^7
1.10^7
0
Neutron flux (n/cm^2/Å/s)
Supermirrors
58Ni
0
10
20
Wavelength (Å)

Figure 5.

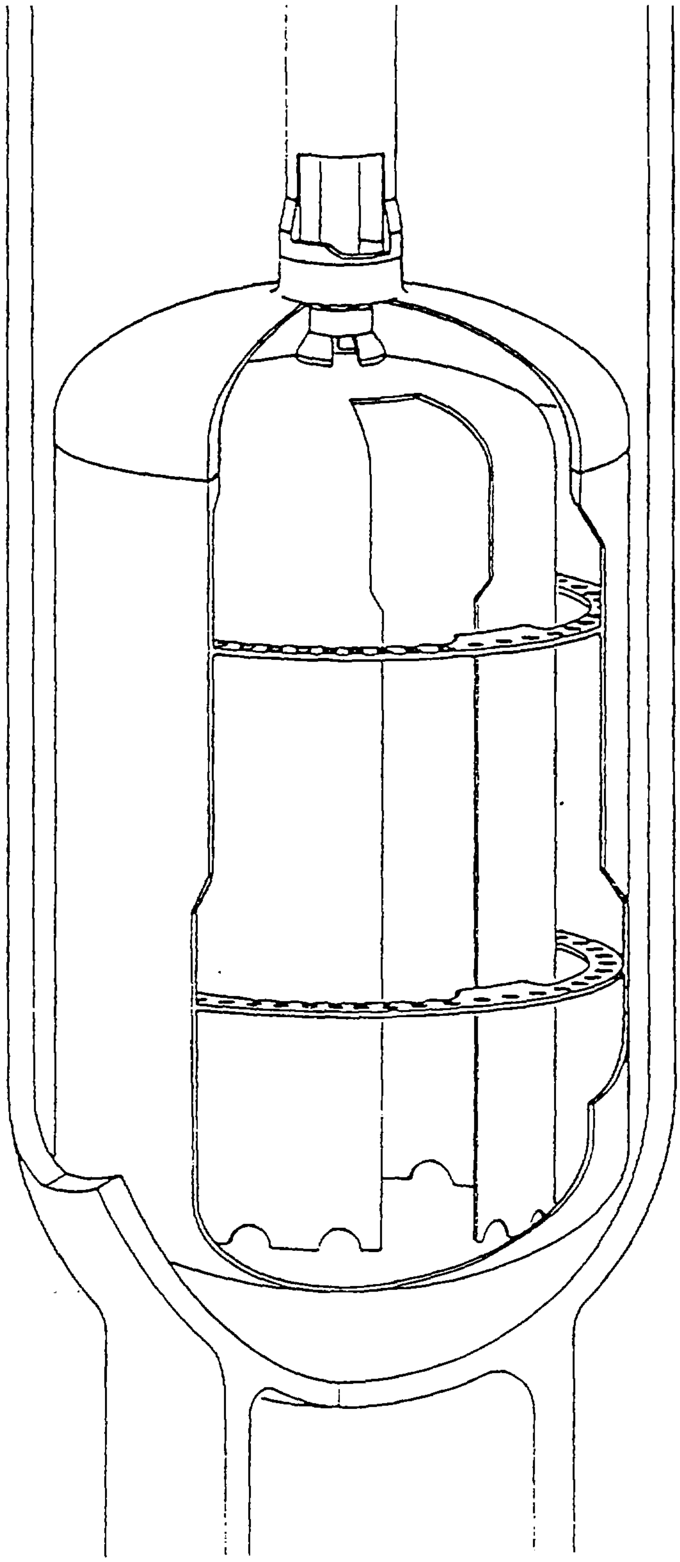


Figure 6.

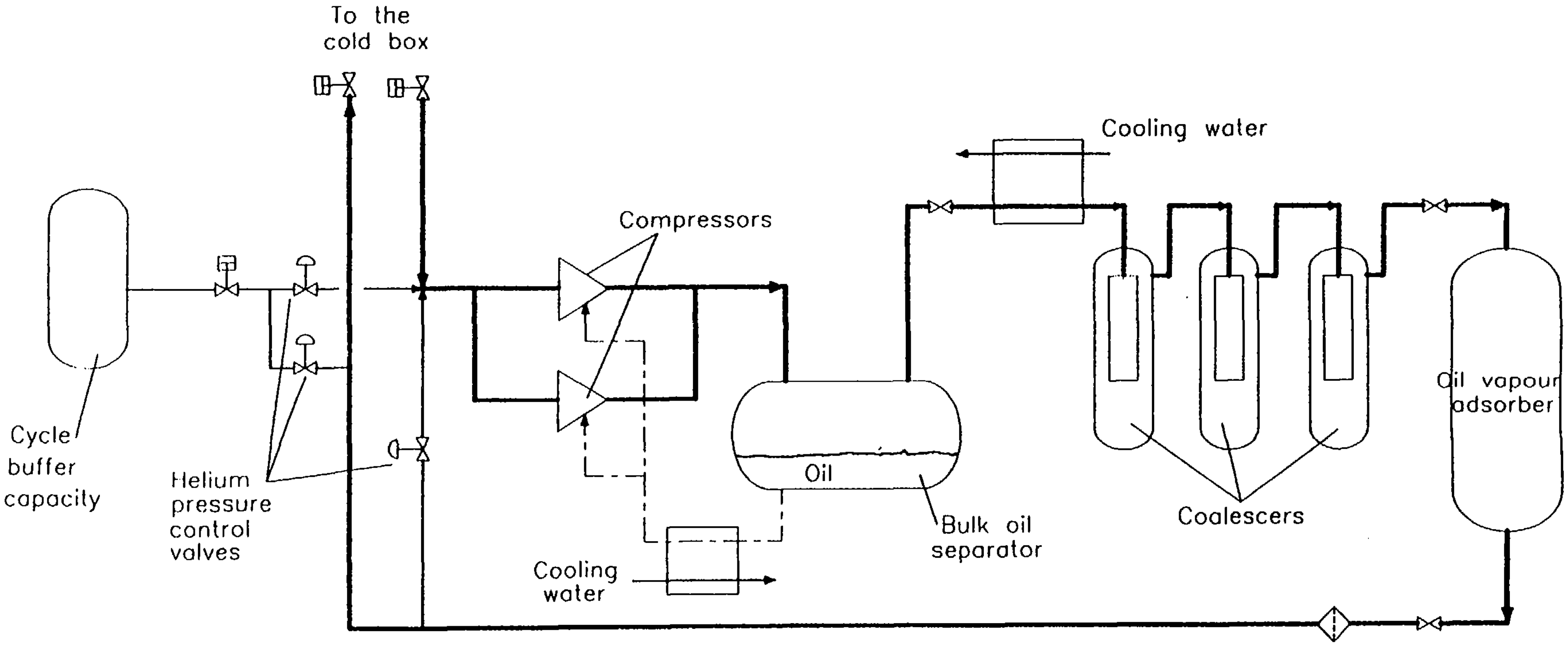

To the
cold box
Cooling water
Compressors
Cycle
buffer
capacity
Helium
pressure
control
valves
Oil
Bulk oil
separator
Coalescers
Oil vapour
adsorber
Cooling
water

Figure 7.

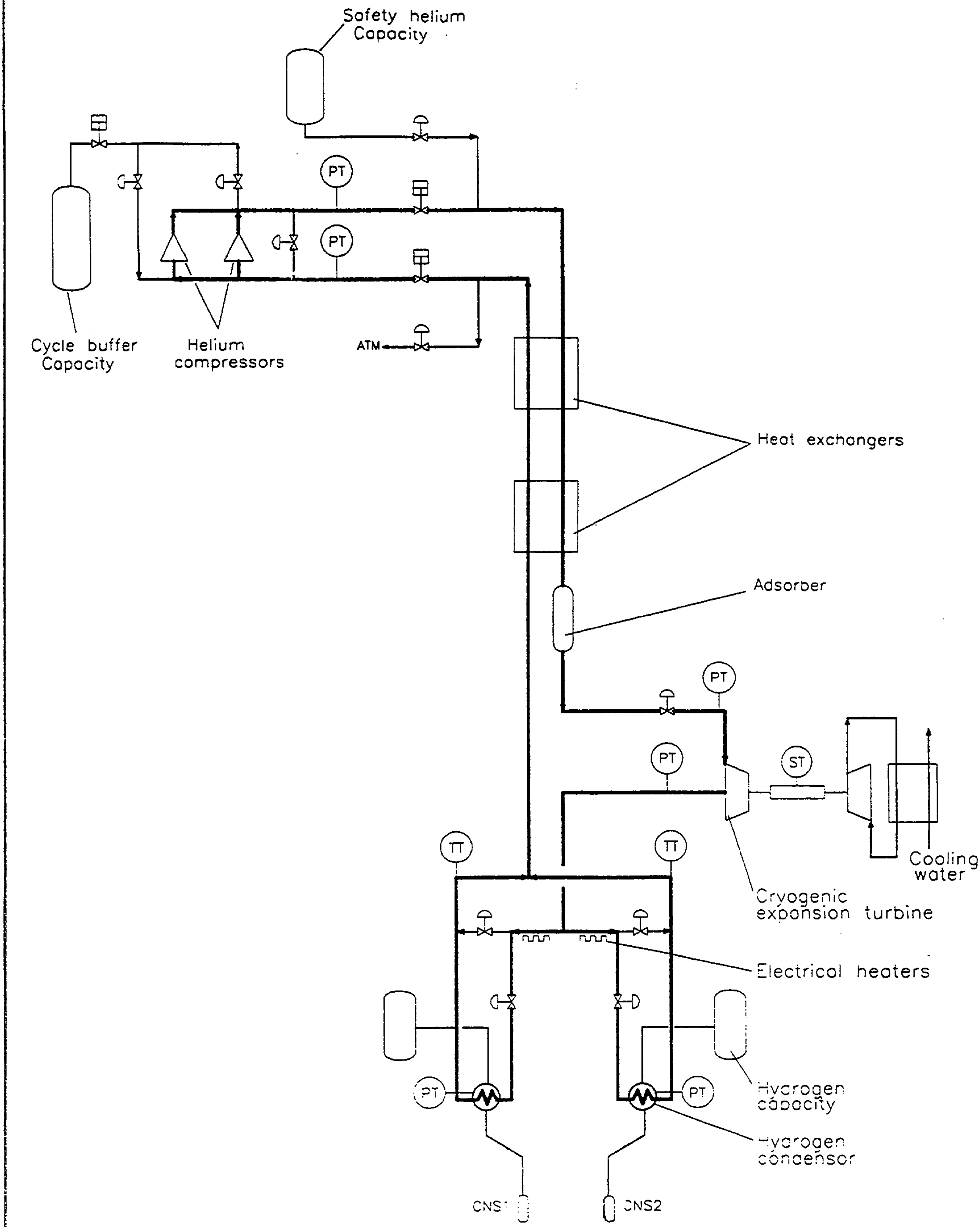

Safety helium
Capacity
PT
PT
ATM
Cycle buffer
Capacity
Helium
compressors
Heat exchangers
Adsorber
PT
PT
ST
Cooling
water
TT
TT
Cryogenic
expansion turbine
Electrical heaters
PT
PT
Hydrogen
capacity
Hydrogen
condensor
CNS2

Figure 8.

CRYOGENIC EXPANSION TURBINE

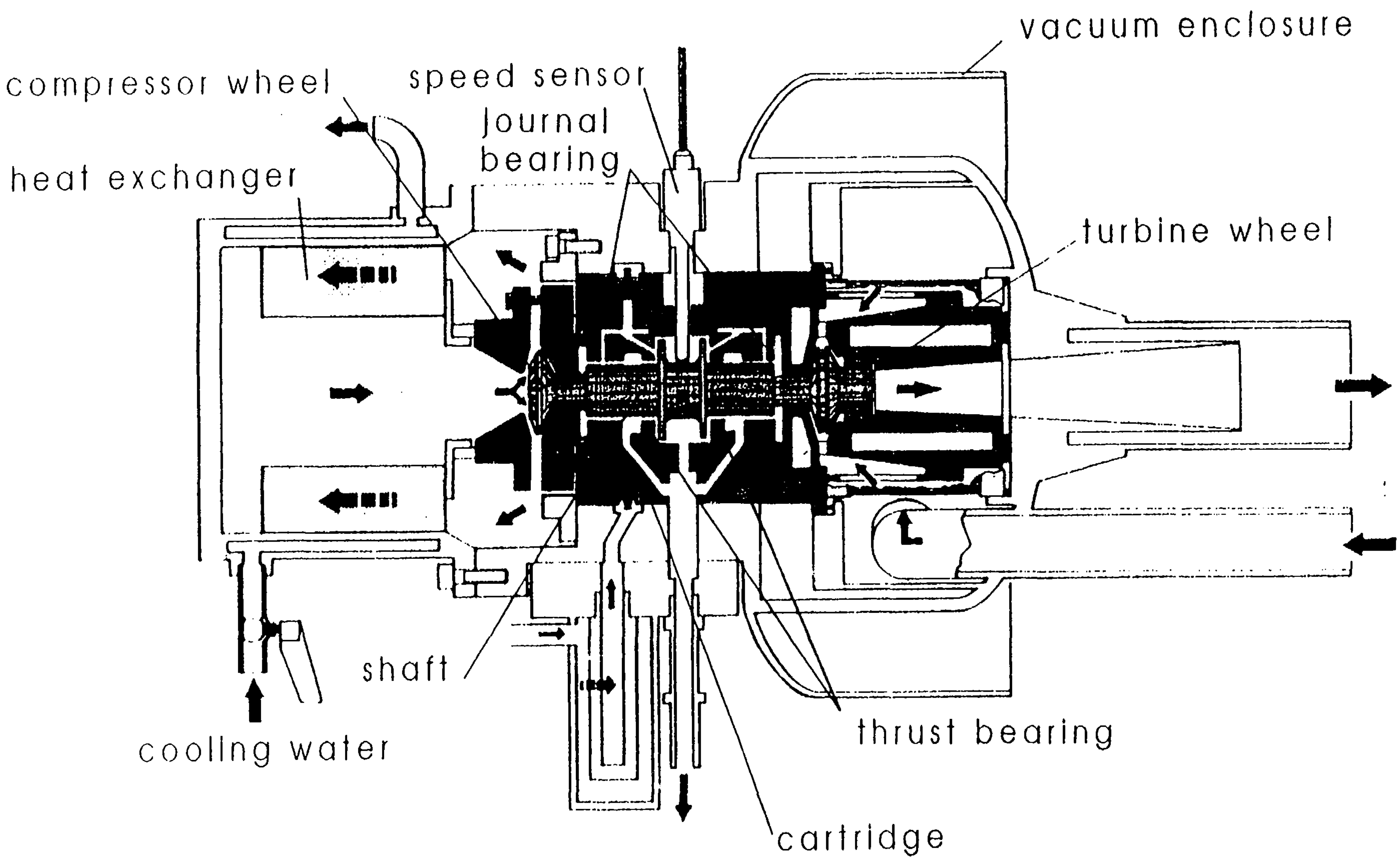
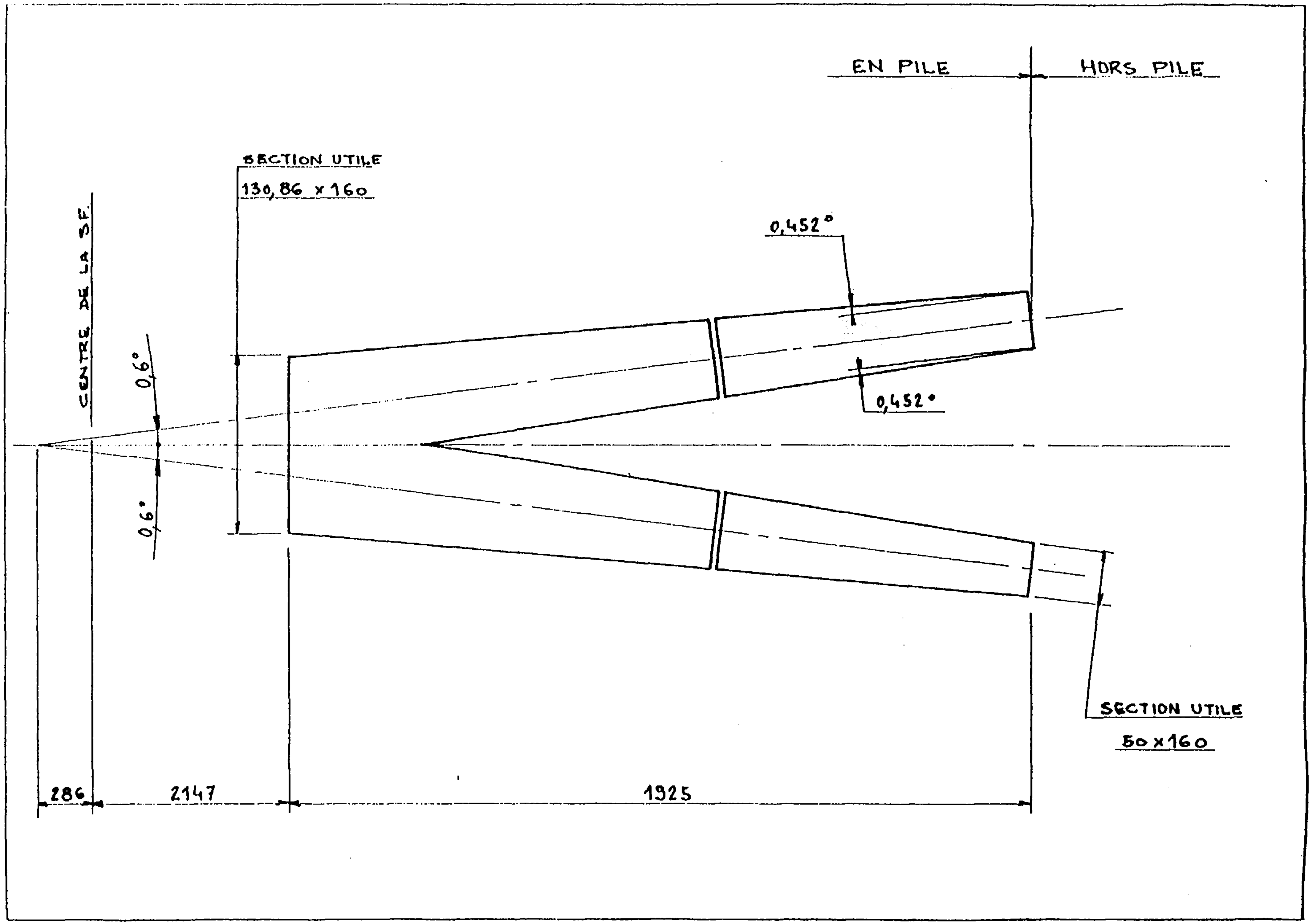


Figure 9.



EN PILE
HORS PILE
SECTION UTILE
130,86 x 160
0,452°
0,452°
CENTRE DE LA S.F.
0,6°
0,6°
SECTION UTILE
50 x 160
286
2147
1925

Figure 10

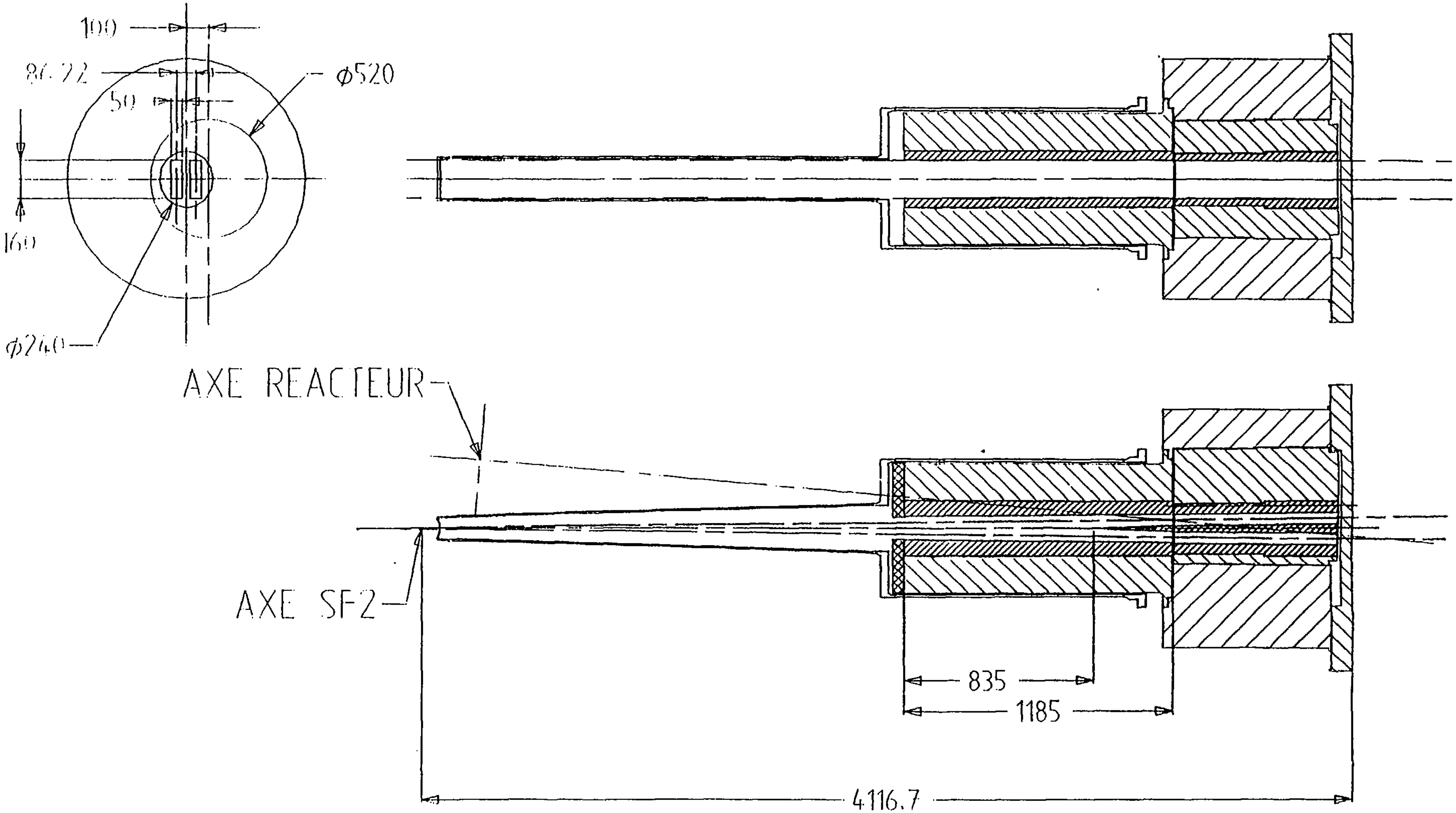


Figure 11

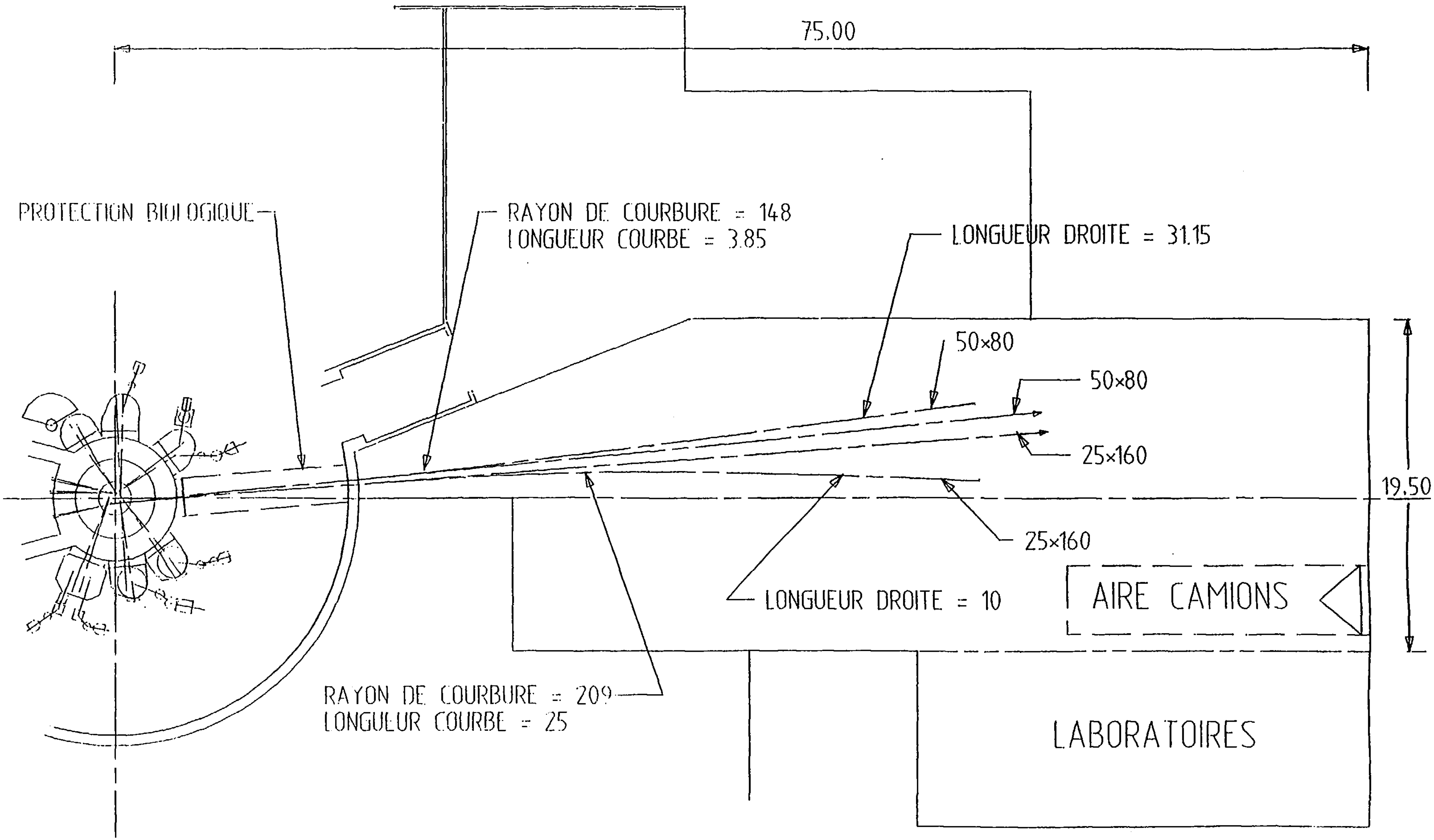

75.00
PROTECTION BIOLOGIQUE
RAYON DE COURBURE = 148
LONGUEUR COURBE = 3.85
LONGUEUR DROITE = 31.15
50×80
50×80
25×160
19.50
25×160
LONGUEUR DROITE = 10
AIRE CAMIONS
RAYON DE COURBURE = 209
LONGUEUR COURBE = 25
LABORATOIRES

Figure 12.

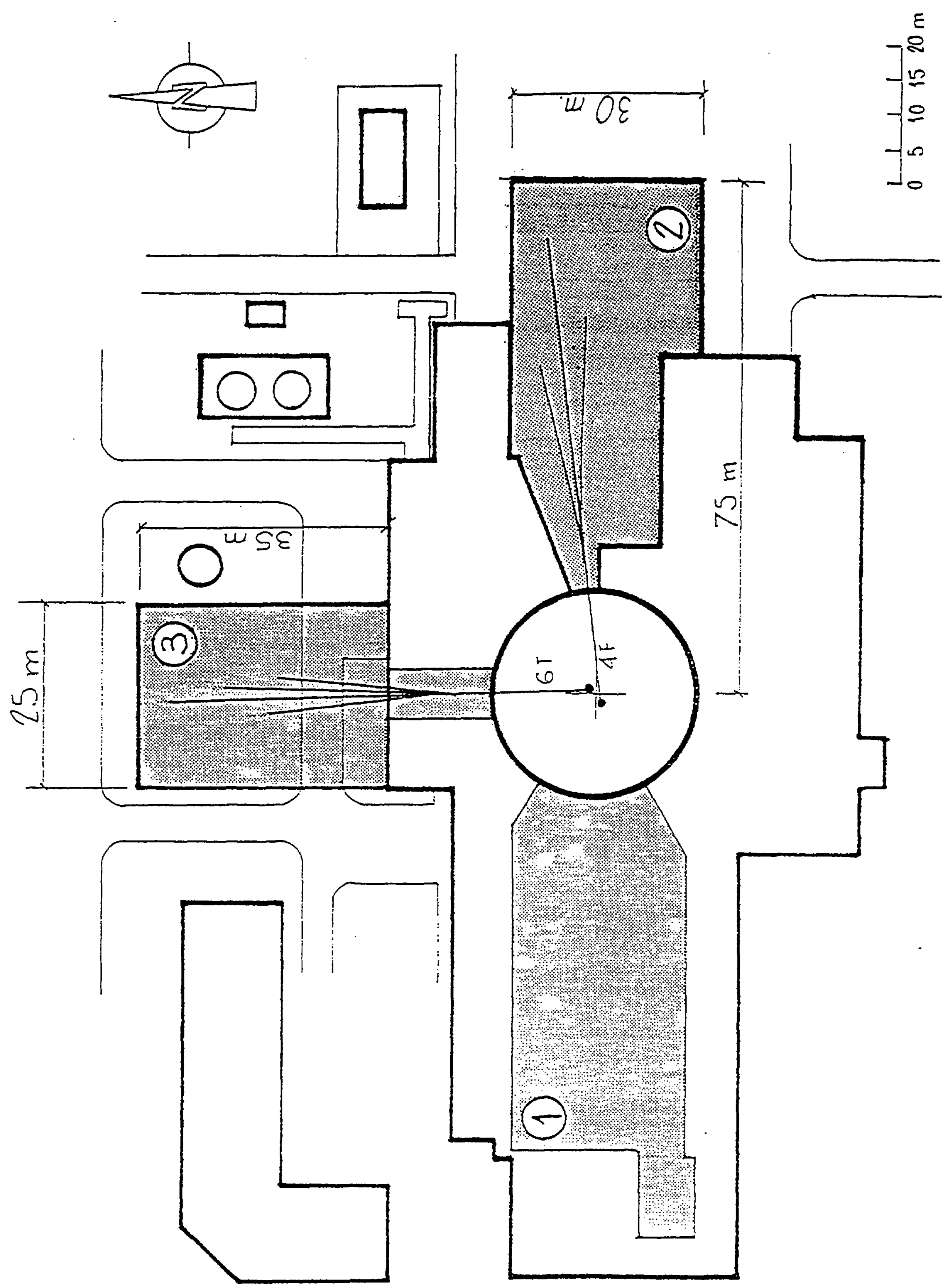
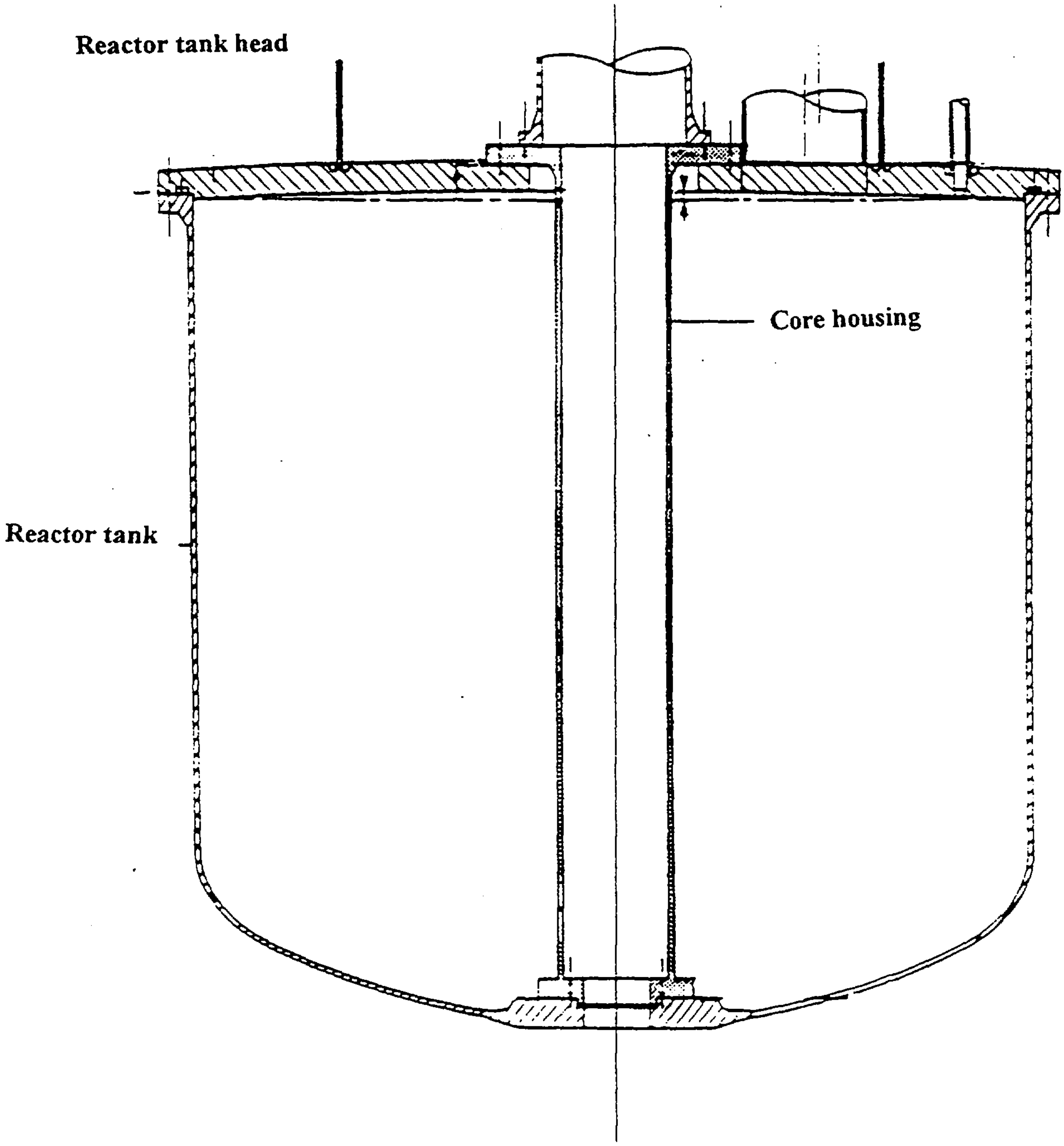


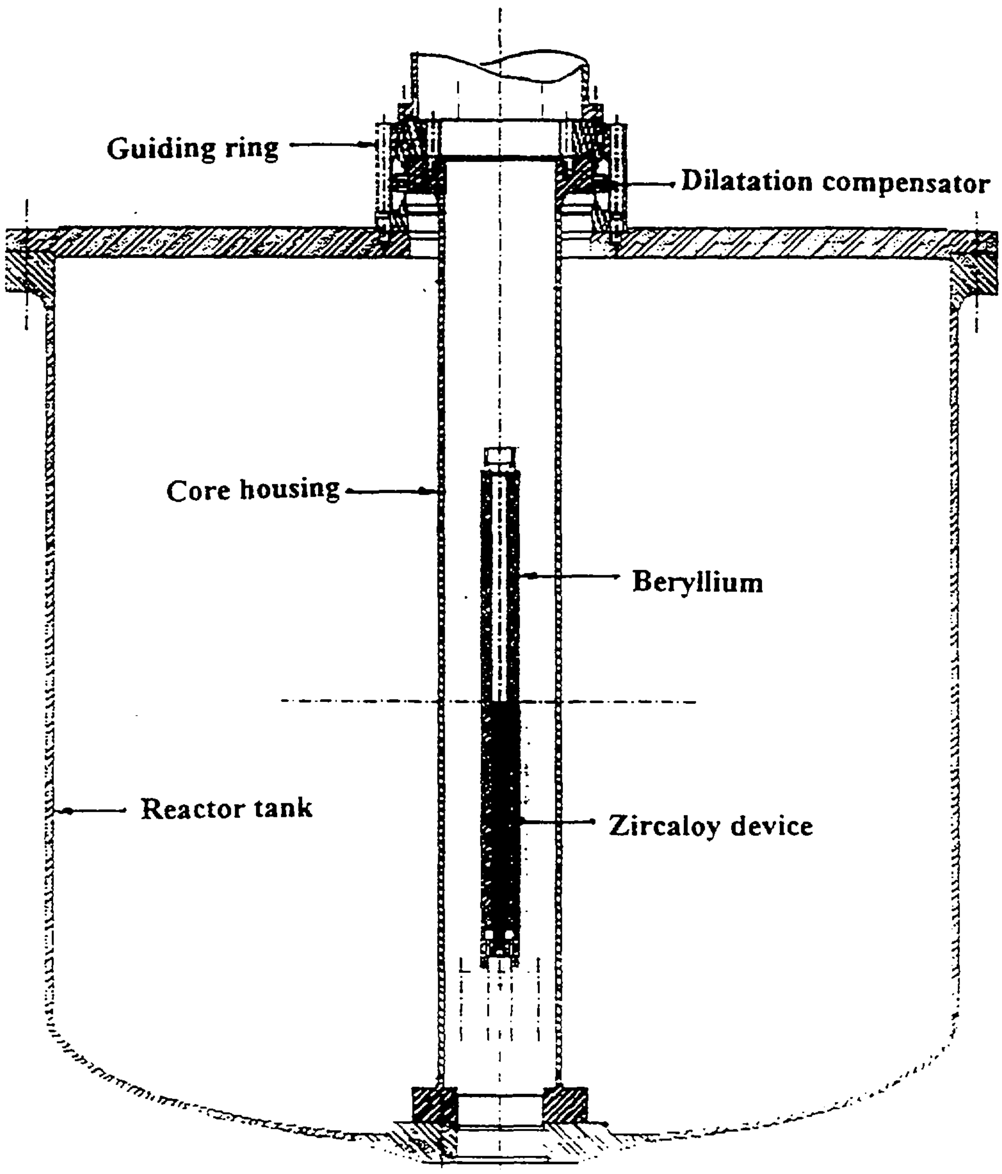
Figure 13.



Vertical section of the ORPHEE reactor tank

Initial assembly of the core housing

Figure 14.



Vertical section of the ORPHEE reactor tank
New assembly of the core housing with dilatation compensator

Figure 15.