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Supply System for Cold Neutron Sources for the ESS-Project.

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ABSTRACT.

This paper describes the cooling plant behind the hydrogen moderators in the ESS-project.

1. Introduction.

Background

In the plans for the European Spallation Source, Cold Neutron Sources are a major part of the project.

This part of the study has its background in three existing cold neutron sources placed at RISØ (DEN), HMI and GKSS (GER). The Risø source, which has been in service since 1975, was designed and manufactured by RISØ staff alone, and the two others were produced by a consortium of Interatom (GER) and RISØ (DEN), and started operating in 1989. The experiences with these three sources are the basis for this study, which later will result in a price estimation for the ESS project and a preliminary design.

2. Safety Philosophy.

Hazard with hydrogen only exist, when oxygen is present too, and it may occur in two ways. Firstly, if some source of ignition is present, the elements combine exothermically to form water. Secondly, if atmospheric air is irradiated at cryogenic temperatures, ozone is formed from oxygen, and nitrogen may form oxides and ozonides which decompose explosively and initiate a hydrogen/oxygen reaction.

The basic principle for safety of a cold neutron source is to preclude any possibility, that air may enter either the hydrogen system or regions of the equipment containing hydrogen, especially at cryogenic temperatures and in fields of high radiation.

By adopting the triple containment philosophy, se fig.1, the above mentioned basic principles for safety are fulfilled. For the cold neutron source the triple containment philosophy is used for all hydrogen equipment inside the target hall i.e. all hydrogen equipment is contained

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within a high-vacuum system, which again is surrounded by a third containment filled with helium. The helium in the "blanket" is always at a small positive pressure, so that a leak in the system can be detected, and no atmospheric air can penetrate. In that way it is ensured, that even in the event of a leak developing in the vacuum casing, no hazard will arise, as air is precluded, and helium will enter into the vacuum system and give a pressure increase indicating the leak.

3. Basis for the study.

In the ESS study there are foreseen two target stations, one at 1 MW and one at 5 MW. The two targets are foreseen equipped with moderators cooled in two different ways: With water at room temperature, or with hydrogen at 25 K. This paper only describes the supply systems for the hydrogen cooled moderators

Specifications:

1MW target: Two moderator chambers cooled with supercritical hydrogen at 25K. Necessary cooling capacity is 15kw for both chambers.

5MW target: Up to six moderator chambers cooled with supercritical hydrogen at 25K. Necessary cooling capacity is 15kw for all six chambers.

It is foreseen, that the two targets are equipped with systems independent of each other, but identical as far as possible, giving the best possibilities for sharing spare parts, repairing staff, workshops, subsuppliers etc.

As the layout has been taken from existing reactor installations, also the emergency and safety precautions are as demanded for at reactors. There will be other conditions and wishes, when the neutron sources are coupled to spallation targets, but until these are described and discussed with relevant authorities, the "reactor conditions" will serve as reference.

4. The supercritical system. (Fig.1)

General description:

In principle the cold neutron source consist of hydrogen filled moderator chambers placed close to the spallation target. The moderator chamber and the hydrogen pipes are surrounded by a vacuum containment. This vacuum is used to insulate the cold parts and act as the second safety barrier for the hydrogen. The vacuum system is surrounded by a helium containment, to form the third safety barrier for the hydrogen, in the triple containment system.

Hydrogen is used as moderating material and as moderator chamber coolant at a pressure of 15 bar, which is above the critical pressure (see later). The hydrogen is circulated between the moderator chamber and the heat exchanger by means of fans. The minimum moderator temperature is 25K.

As mentioned the system is supercritical, i.e. the hydrogen pressure - 15 bar abs. - is above the critical pressure, which is 13 bar abs. Above this critical pressure hydrogen will always remain in a single phase. As the temperature during operation is expected to be adjustable between 25 and 35K, it may be seen from T-S charts, that the density will vary from 68- to 23 g/l.

The supercritical system offers some advantages over other systems, as no phase change takes place, and as the density of the hydrogen changes with the temperature. The absence of phase change also admits standby cooling of the moderators just by circulating the hydrogen. Furthermore it may be possible to optimize the neutron gain by adjusting the temperature.

5. Cooling plant. (Fig.2)

The cold hydrogen circuit is heated by radiation and by different other kind of heat input. This heat is removed from the hydrogen in a heat exchanger, where the necessary cooling is provided by a flow of cold helium gas from a cryogenic cooling plant.

The heat exchanger is of the counterflow plate and fin type. It is not yet decided whether there will be one common heat exchanger for each target station, or the system will be split up in f.ex. one heat exchanger for each moderator chamber. This is dependant on the accessibility of the system, and the length of the various liners, because it is important to keep the liners between heat exchanger and moderators as short as possible,(the triple containment liners) while the helium liners between expansion turbines and the heat exchangers are less critical.(Only vacuum isolated liners), and the liners between compressor and expansion turbines are almost uncritical. The approximate temperatures and pressures in the systems can be seen at figure 2.

The amount of hydrogen passing the heat exchangers will be approx. 700 ccm/sec/kw when cooled from 26 K to 24 K.

The cryogenic cooling plant (the expansion turbine) is connected to the helium compressor (screw compressor) by a double helium liner at room temperature. This compressor can be placed in some distance from the target hall. Furthermore there is a buffer in the helium system, and the position of this is also relative free, as it can be placed in open air and the length of the connecting pipe is of less importance.

The principle function of the helium cooling plant can be explained from figure 2. He-gas is compressed to maximum 16 bar in the screw compressor, after which it passes a series of oil separators and filters, of which the last one is a charcoal filter. This system is very effective, so effective that the amount of oil in helium after the separators is measured not in parts per million PPM, but in parts per billion PPB.

After having passed a series of heat exchangers the gas is expanded in the expansion turbine unit. This unit can be constructed in various ways, dependent on the supplier. It can be with a two step expansion with two turbines in serie, with heat exchangers after each step, or with a one step expansion after a pre-cooler, cooled with liquid nitrogen.

After the expansion unit the helium will be at 2 bar at minimum 18 K and ready to pass the heat exchanger where the hydrogen is cooled. After this the returning helium will act as coolant in the heat exchanger at the inlet to the expansion turbine, and it will be back at the entrance of the compressor at approximately room temperature and 1,8 bar.

The heat exchanger B and the expansion turbine unit are contained in a "cold box", with continuously pumped vacuum and highly thermal insulation. (See fig.3). The "cold box" is a unit assembled on a skid, which also contains some auxiliary systems and instrumentation and control for the cooling plant. Also the pipes to and from the helium/hydrogen heat exchanger are insulated by this vacuum system.

An example of an expansion turbine with gas bearings is shown in fig.4. This turbine is a small single-stage centripetal turbine, that drives a directly coupled single-stage centrifugal brake compressor. The turbine is equipped with selfacting gas bearings, supplemented by auxiliary magnetic bearings for start up. The work (energy), which the turbine extracts from the helium, is transferred into the brake compressor circuit and from here transferred as heat to the cooling water in a helium gas/water heat exchanger. The turbine rotates with approximately 200.000 rpm. The turbine does not require maintenance, and is in many ways comparable to turbochargers, which has become almost standard equipment in many automobiles.

6. Hydrogen circuit. (Fig.5)

Hydrogen at 15 bar is circulated in moderator chambers and heat exchanger by one of the two fans in the circuit. Under normal conditions only one of the two fans is in operation. The other fan is standby and start is initiated by a rise in temperature of the moderator chamber. The hydrogen temperature is measured both at inlet and outlet of heat exchanger and at the moderator chamber.

Hydrogen buffer system.

The purpose of this system is to keep the hydrogen pressure within the operational range during the temperature changes and to provide the system with clean hydrogen.

This system is placed outside the target building. The size of the buffer tank depends upon the total volume of the complete hydrogen system, as the volume should be big enough to avoid formation of liquid hydrogen in the system, which is formed, if the pressure falls below the critical pressure, 12.8 bar, by decreasing temperatures. Furthermore, pressures above 18 bar are avoided, when the system is heated up. The pressure changes during cooling down and operation. The buffer vessel is isolated from the system, by closing two remote operated valves near the vessel, if the pressure falls below 14 bar.

The supply system is based upon the use of high purity hydrogen, i.e. hydrogen with a purity better than 99.99%. Even though there is used high purity hydrogen, it is passed through a cleaning device, before it is fed into the system.

If the system pressure is higher than 18.6 bar, the pressure control system opens a blow off valve, and if that fails, a relief valve opens at a pressure of 19 bar, and the system is vented

to open air through the relief box, outside the target hall.

7. Hydrogen standby cooling circuit. (Fig.5)

This cooling circuit is started by the control system whenever temperature in the system exceeds a certain level, f.ex. when heated by target radiation without the cryo cooling system operating. The signal to start the standby circuit is taken from thermocouples on the moderator chambers, and the circuit is circulated by separate and more powerful fans placed in the outdoor part of the circuit. These fans will operate in series with the already operating fan.

8. Vacuum systems. (Fig.5)

All hydrogen containing equipment in the target building will be contained within high vacuum systems. For the cold hydrogen equipment the vacuum is further acting as thermal insulation.

This vacuum containments will be split up in sections as there are different demands upon the various parts. The sections which covers the parts being radiated must fulfil the triple containment philosophy, and here it is necessary, that the pumps also are contained in the helium containments. Therefore these section are sealed off after being pumped down, and further pumping is performed by iongetter pumps, inside the helium containment. The other vacuum containments are pumped down in usual way with turbomolecular pump sets.

The various vacuum systems are protected against over pressure by exhaust to open air via systems of relief valves and bursting discs.

9. Helium blanket system. (Fig.5)

Where the triple containment principles must be established, the vacuum containments must be surrounded by a helium blanket. This blanket is also divided in sections following the vacuum systems. The helium is always at a small positive pressure, say 1.3 bar abs., so the helium pressure will decrease if there is a leak in the containment. This decrease gives a warning in a 1-out-of-3 connection at 1.2 bar, and shuts down the cooling plant in a 2-out-of-3 connection at 1.2 bar. The helium containment systems are connected to a common helium supply system.

10. Cooling of vacuum and helium containment casings. (Fig.5)

Heat absorbed in radiated parts of vacuum and helium containments is removed by arrangements of water cooling, with water circulated in closed systems. The water can be pressurized with helium, if there is need for leak indication, when the water circuit passes vacuum pumped vessels f.ex. the volume around the target.

11. Syphon type moderators. (Fig.6)

In this arrangement, the liquid moderating media is contained in a vessel placed at the lower end of a vertical supply liner. The pressure and temperature in cryo conditions are 3 bar and 25 K.

The supply liner is composed of two concentric pipes, one for the upstreaming gas phase and one for the downfloating liquid phase of the moderator media. The media is evaporated in the moderator chamber and condensed in the heat exchanger at the top of the liner. The circulation goes on without fans or other mechanical equipment but by natural circulation. Therefore the heat exchanger (condensor) must be placed in a position above the moderator chamber, and the supply liner must be arranged in vertical or slanting position without obstacles of any kind.

If the cryo cooling fails, there is no way of establishing an alternative cooling, and therefore the spallation source must shut down if there is any trouble with the moderator.

When not operating at cryo temperature the moderating media will be kept in a metal hydrid store. This store consist of one or more vessels filled with a hydrid transforming alloy. This vessel is cooled (by water) when producing hydrid and heated (by electricity) when the moderating media is released. The hydrid vessels must be carefully constructed in a way giving no possibilities for overheating or water leaks into the metal hydrid.

The chemical binding in the hydrid is perfect in an order bringing the remaining pressure in the system down to 10 Pa.

To prevent pressure over a certain level, it is necessary to incorporate a buffer tank, and a complicated system of remote controlled valves and bursting discs in the system to satisfy the safety precautions, just as is the case with the supercritical neutron source. Buffer tank and hydrid vessels must be covered by protection gasses also for safety reasons.

Arguments for the two types. (Fig.7)

Thermo Syphon.

- Simple circulation with no fans or pumps.
- Low pressure in the moderator system.

Supercritical system:

- No boiling in media
- Forced circulation giving no restrictions for liner geometry.
- Standby cooling.
- Large components can be placed outside the target hall.
- No hydrid store tanks.
- Relative small heat exchangers.

12. Triple containment liners. (Fig.8 and 9)

There are two design arrangements of the triple containment liners which can be compared. One with parallel running forward and return pipes for the hydrogen, and one with concentric

running hydrogen pipes. (see fig.8). Both concepts can be used, but the one with parallel pipes seems to have some advantages, (especial in this project, which will have substantial length of this liner systems.)

- Easier and cheaper to fabricate.
- Coupling arrangements between sections are more simple.

In both concepts the hydrogen pipes must be polished on the outside, and the vacuum pipes on the inside - if possible - to minimize heat radiation. The hydrogen pipes can be wrapped in super insulating material in pipe sections not passing highly radiated volumes.

The heat loss is approximately (for both concepts):

- 7 W/m pipe, and
- 4 W/m with super insulating material on hydrogen pipes.

No organic material can be used in regions with high radiation, and metal seals must be used in all couplings (Aluminium or Indium).

These liners are expensive and complicated to build (see fig.9) and operate, so the total layout must favour as short liners as possible, i.e. joint boxes placed close to the targets.

13. Moderator chambers. (Fig.10 and 11)

The design is determined partly by geometrical considerations and partly by the nuclear heat and the neutron absorption.

The closer the chamber is to a ball-shape, the less material is necessary to contain a certain volume of hydrogen in the vessel. Also geometrical considerations in relation to the cross section of the beam liners have to be examined. At the moment there are two different suggestions for these chambers.

- A square shaped chamber designed at KFA. (fig.10)
- A super elliptical shaped chamber designed at RISØ. (fig.11)

A third parameter can also be determining these designs, and that is the lifetime of the material in the chambers. The shorter the life, the simpler the design and the easier production and replacement procedures of in-pile parts are necessary. A suggestion for a simple in-pile part design is shown at fig.12.

For the 1 MW target there are only foreseen two moderator chambers. This could give the possibility for using the Syphon type hydrogen circuit, as there might be more room on top of the target shielding. This decision has to wait till more specific target designs are available

14. Power consumption for system.

The power consumption for the complete system at maximum load (25K and 15 kw pr. target) will approximately be:

- Compressor unit 900-1000 kw
- Cryocooling unit(s) 40 kw
- Joint box(es) 5 kw
- Water cooling of in-pile parts 40 kw
- Instrumentation, pumps, etc. 40 kw

All together about 1,1 MW pr target.

Necessary supply systems for the operation of the cold neutron sources are:

- Electricity
- Water
- Compressed air
- Nitrogen (option for precooling of expansion turbines)

15. Maintenance.

With reference to existing cold neutron sources, there should be no problems with the ratio between maintenance time and operation time of less than 10%, which is the goal for the project, but during the detail design phase great attention must be paid to the question of accessibility and handling time when repairing or shifting components. Especially at the 5MW target with the 6 moderators it is important, that the chambers can be shifted fast and easy, and that the supply system is split up in sections, able to operate independently of each other, as suggested in fig.13. Thereby it will not be necessary to shut down the complete spallation source plant, just because of problems with one moderator chamber.

16. Final arrangement. (Fig. 13, 14, 15 and 16)

The exact arrangement of the moderators, the supply liners and the cooling systems must wait, till the first drawings of the targets are ready, but a suggestion for placing of the main components is shown at fig.14 and 15. A diagram for a complete cold neutron source is shown at fig.16, including most of the valves and measuring points in the system.

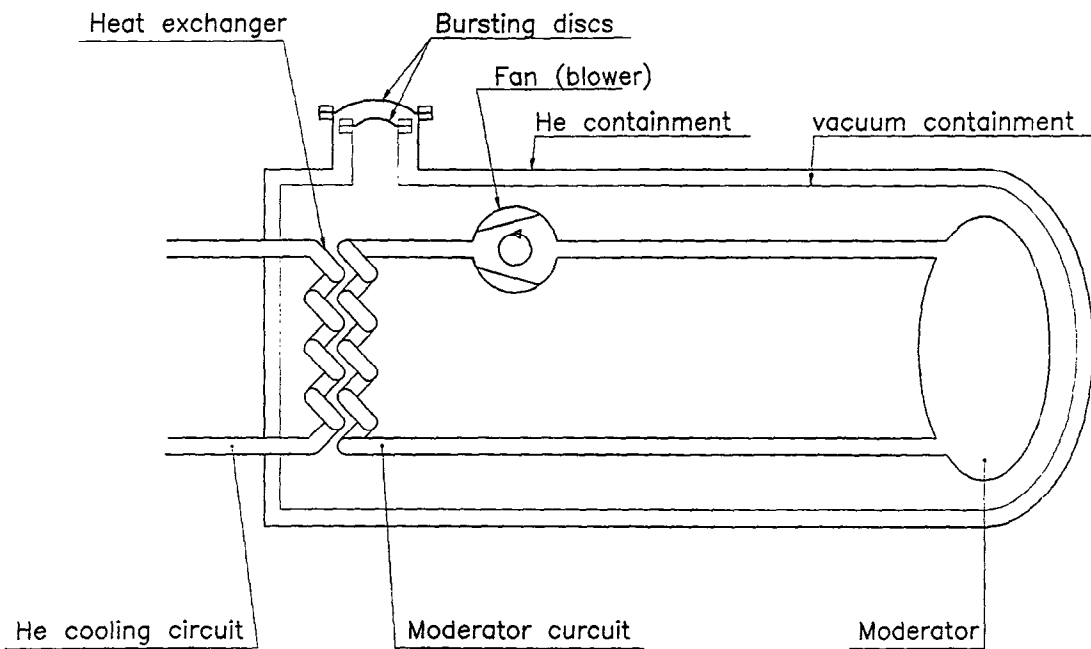
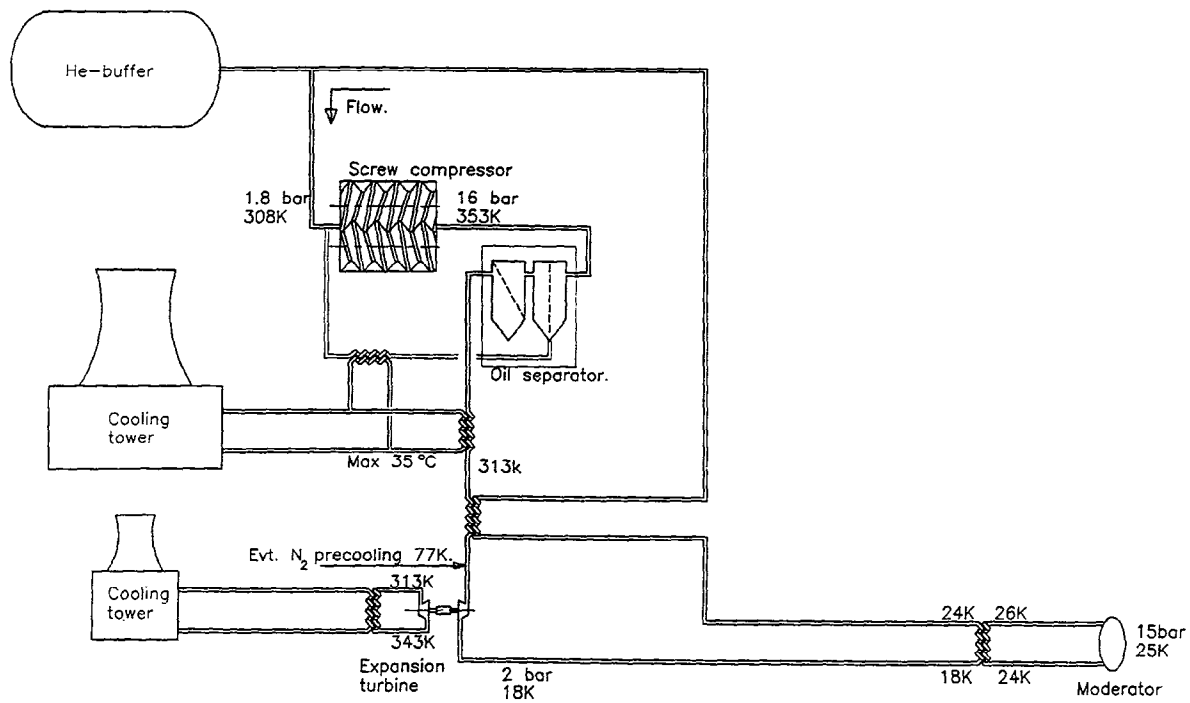


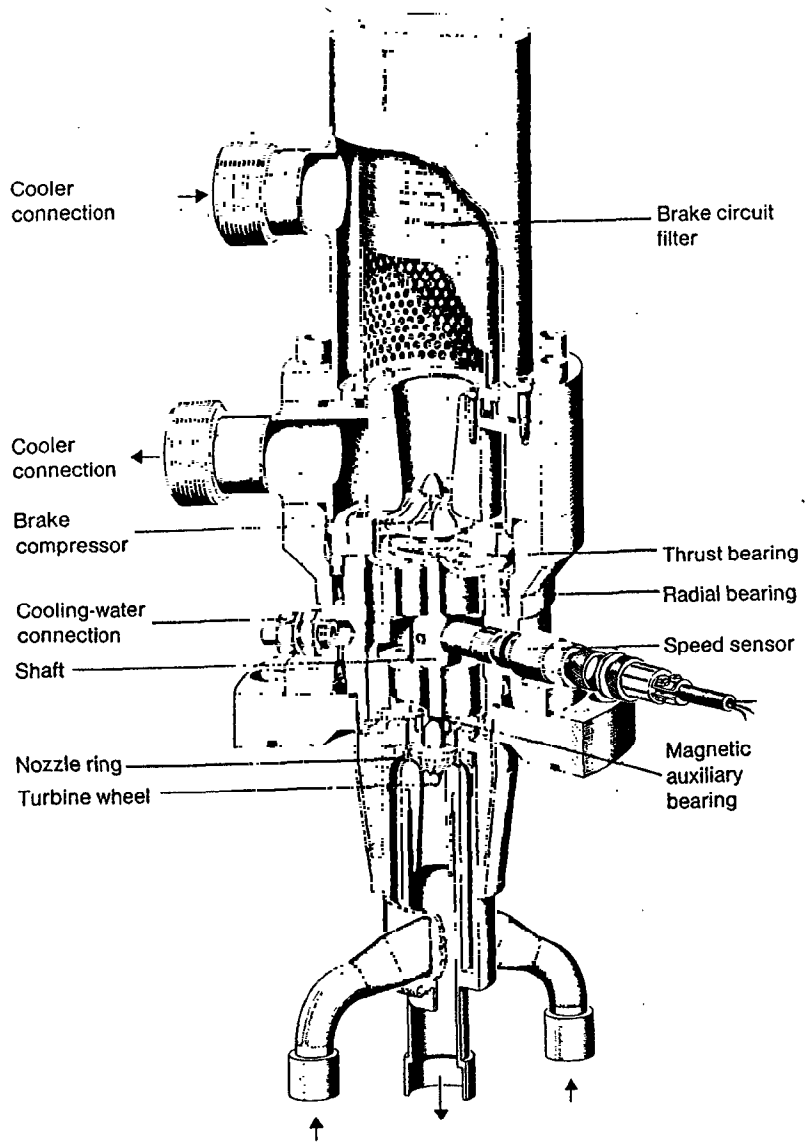
FIG.1

(Kilde1)

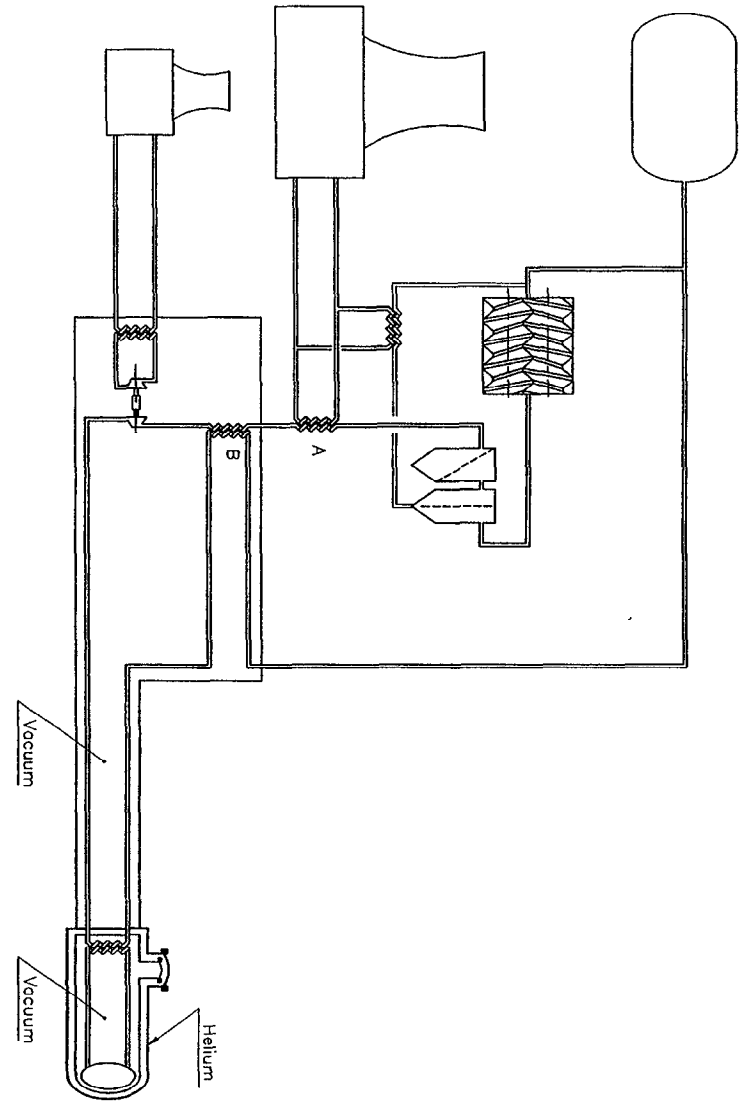


He-circuit

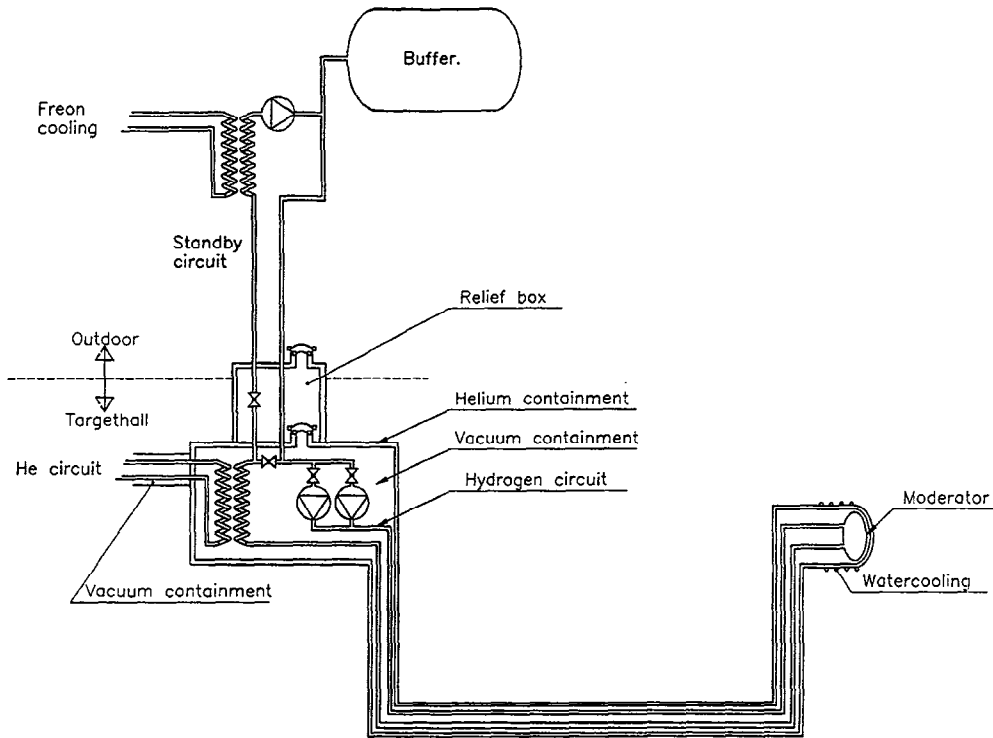
FIG.2



Expansion turbine.
FIG.4

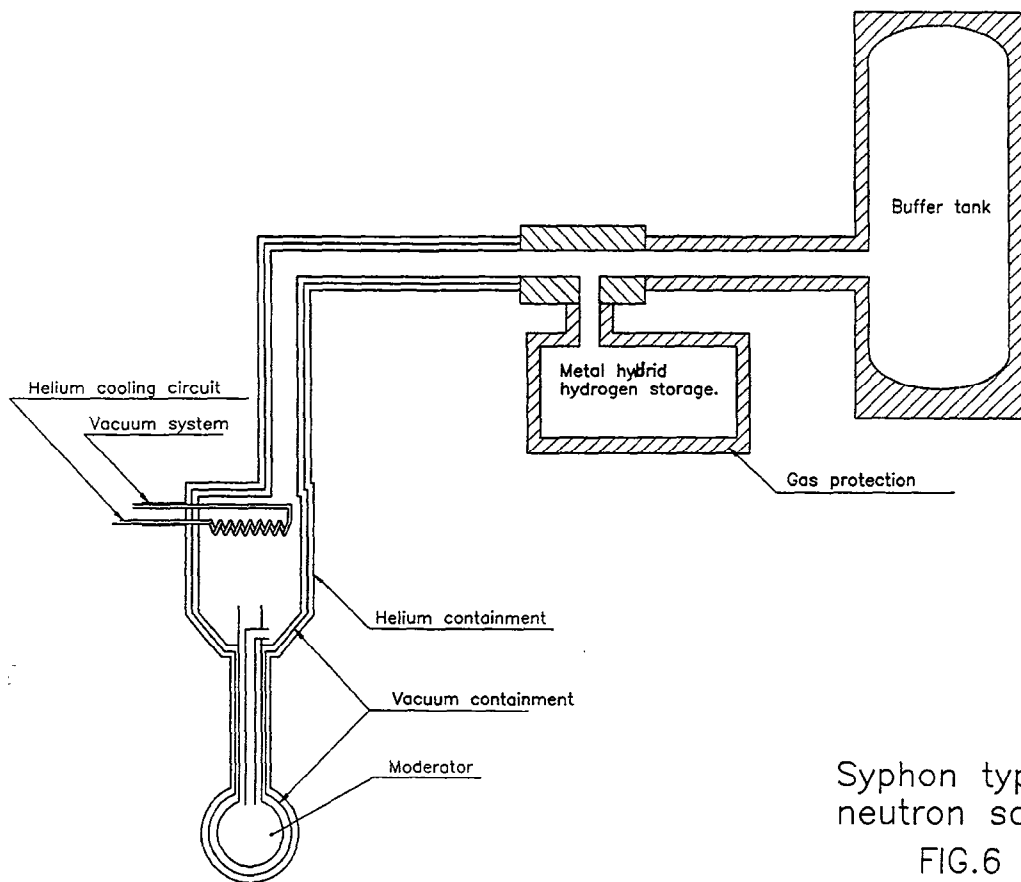


He-circuit
FIG.3

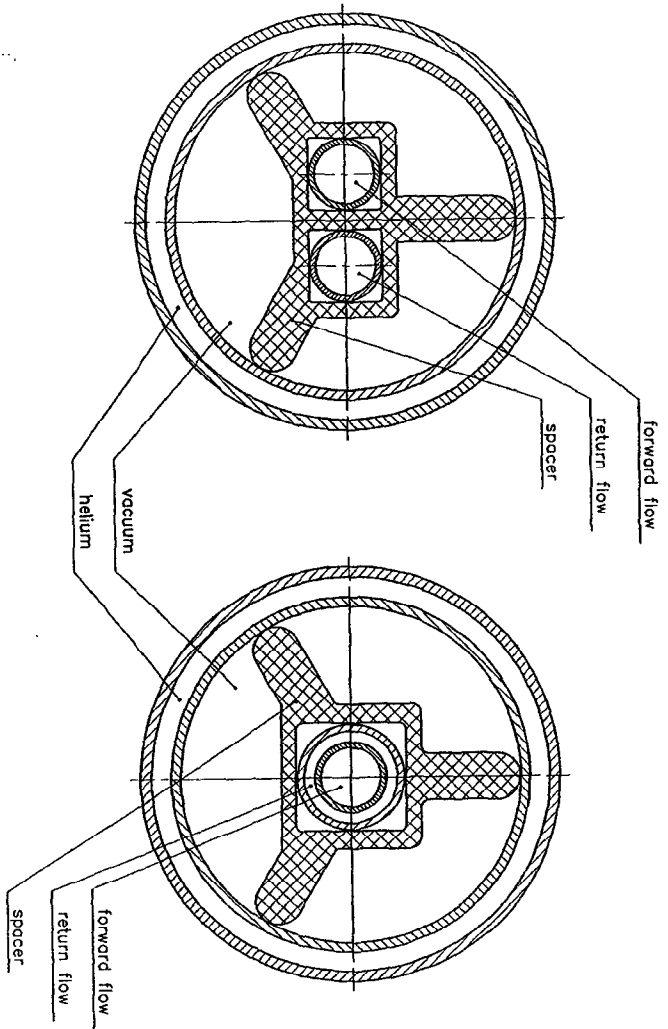


Supercritical source
FIG.5

(11005)

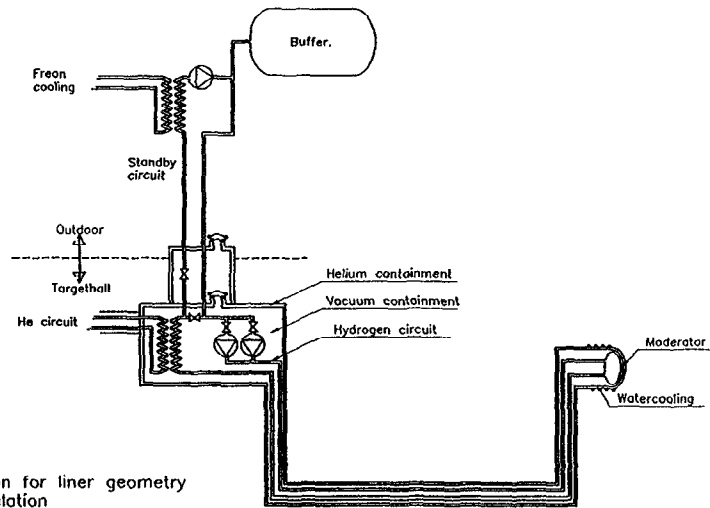


Syphon type
neutron source
FIG.6



Triple containment liners.

FIG.8



No restriction for liner geometry
 Forced circulation
 Standby cooling
 Smaller heat exchangers via higher pressure
 No hydrid store tanks.
 Large components outside target hall
 No boiling in moderating media.

Supercritical source

No fans no pumps
 Natural circulation
 Low pressure in moderator system

Syphon type source

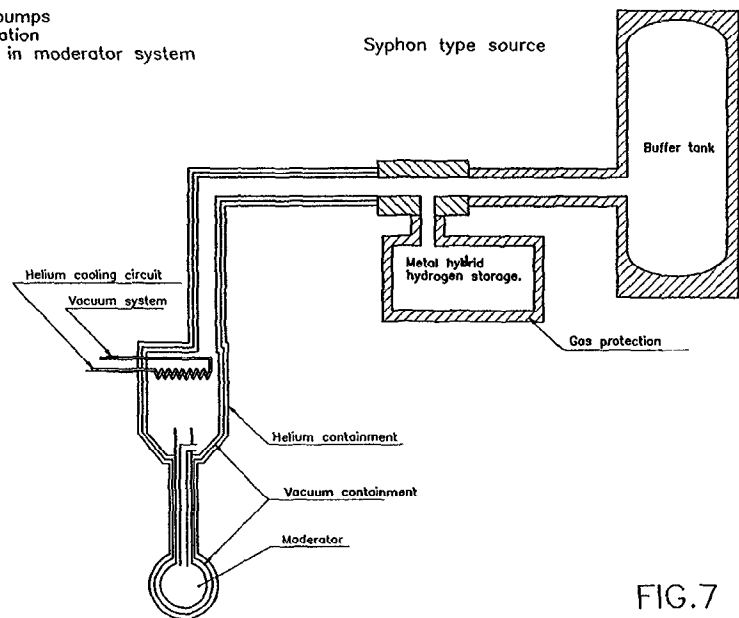
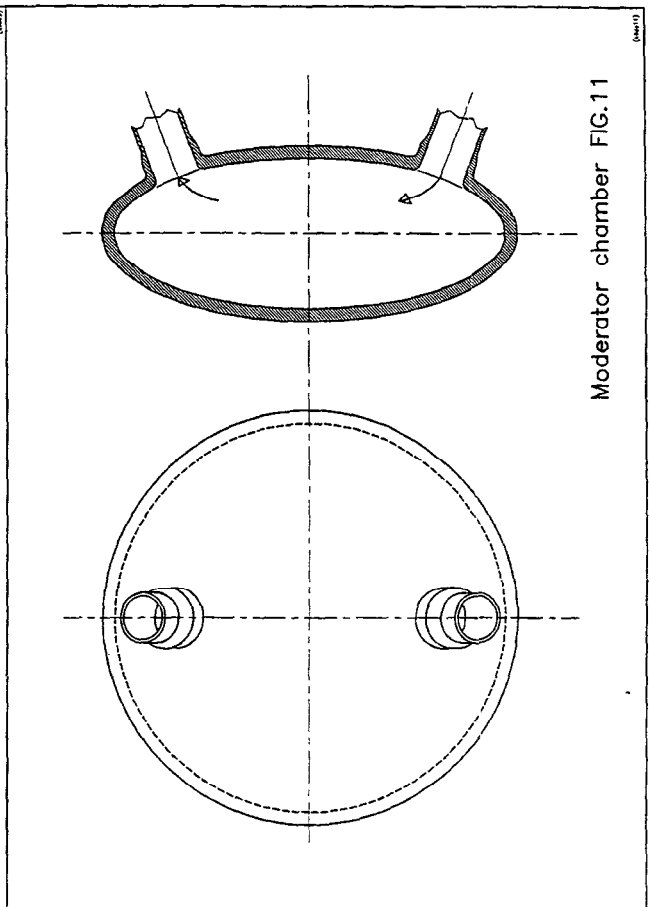
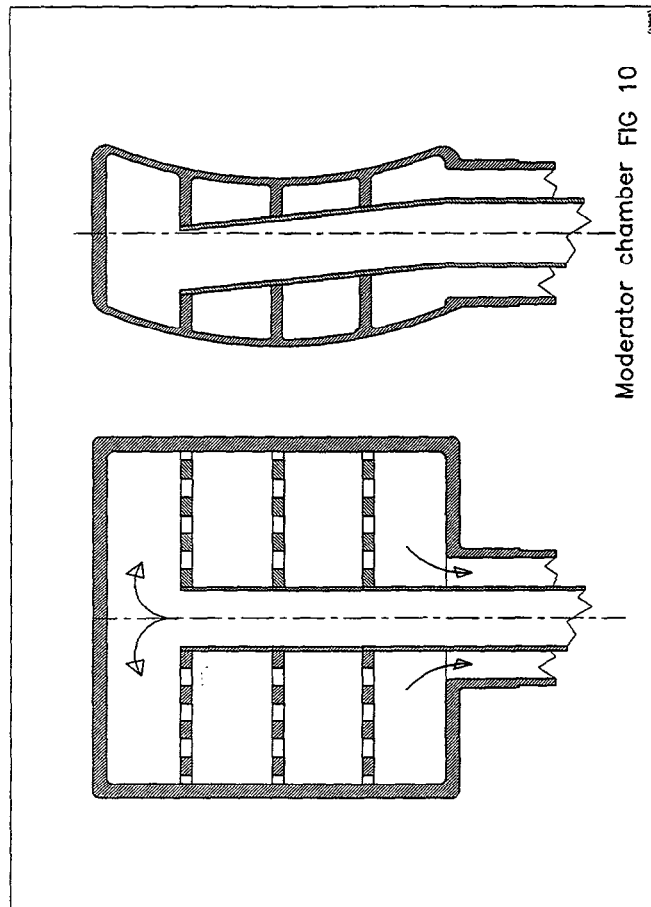
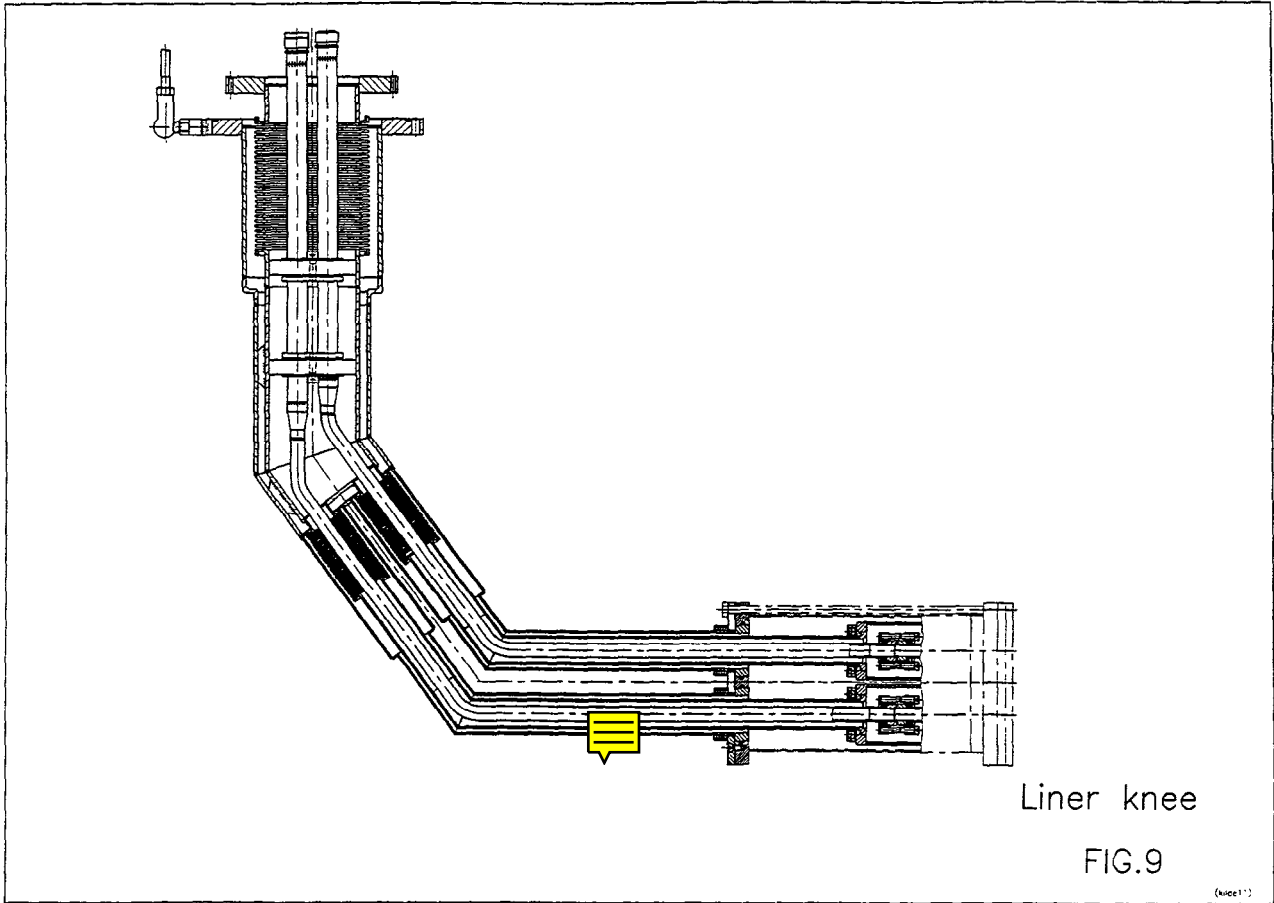


FIG.7

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(10090)



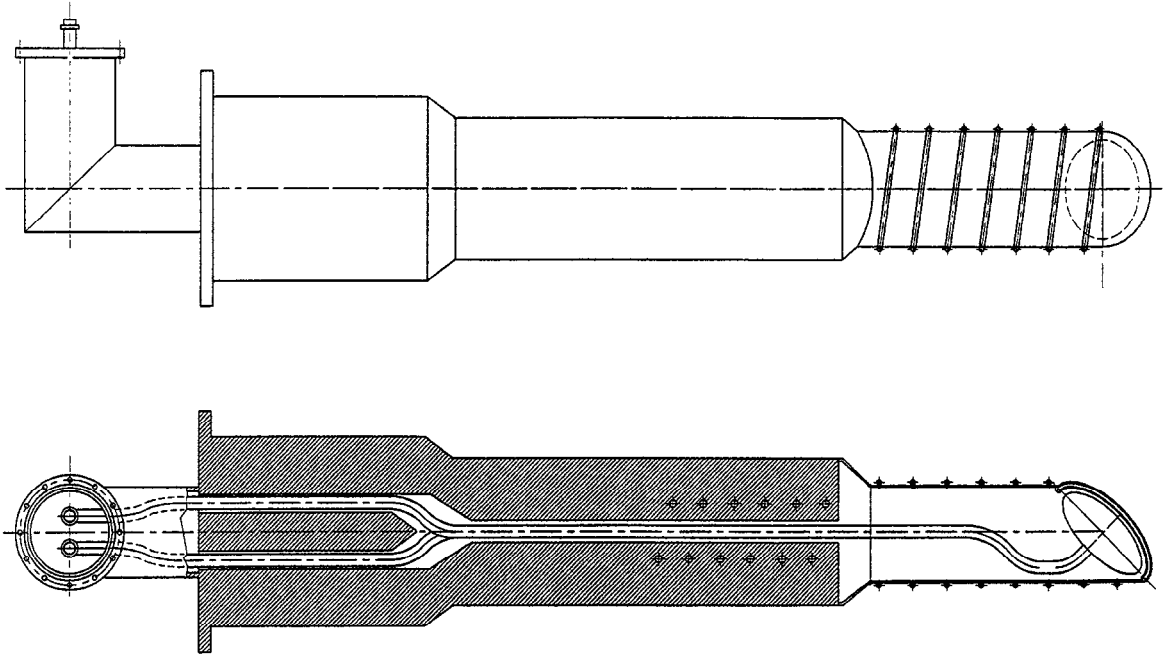


FIG.12

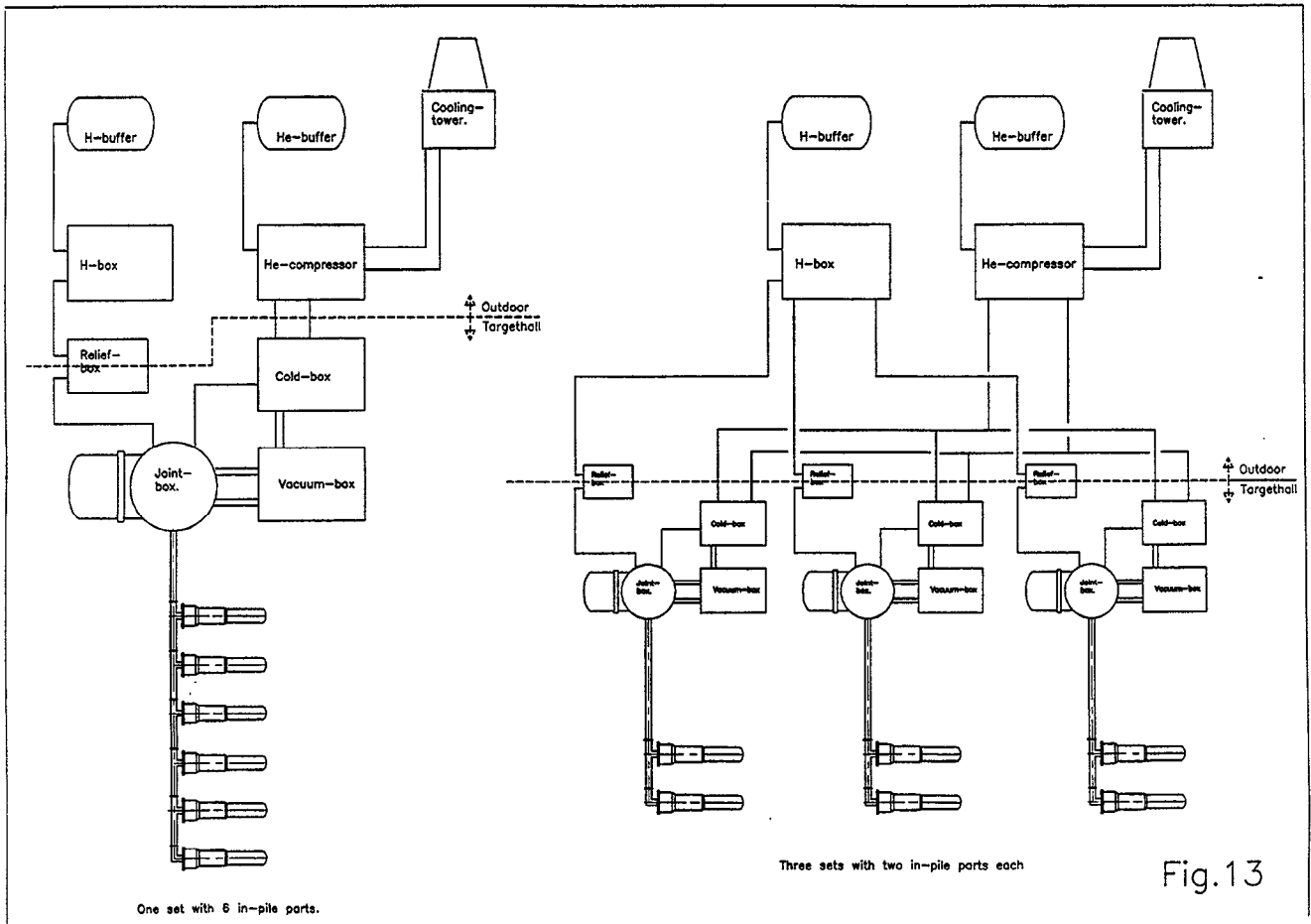
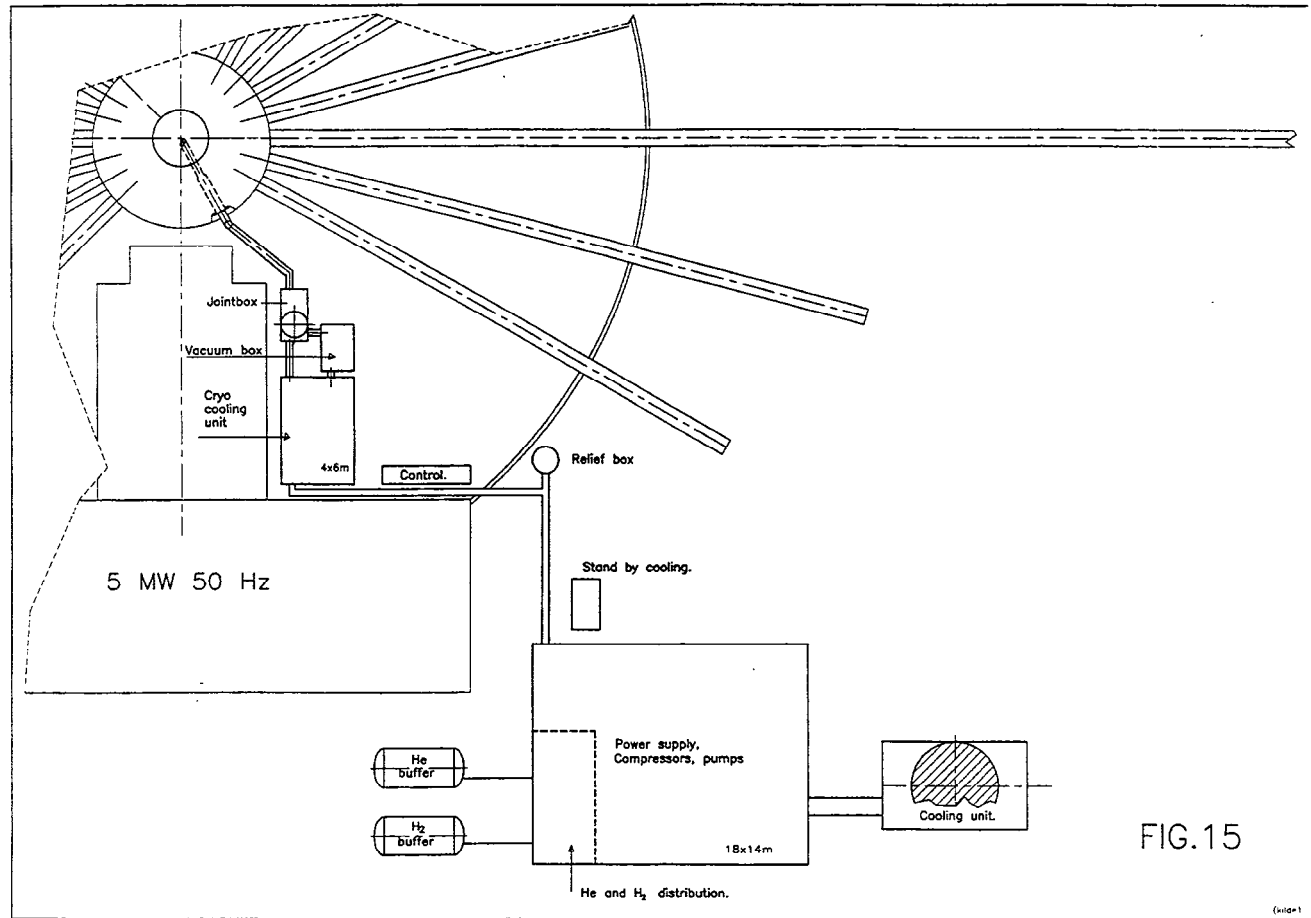
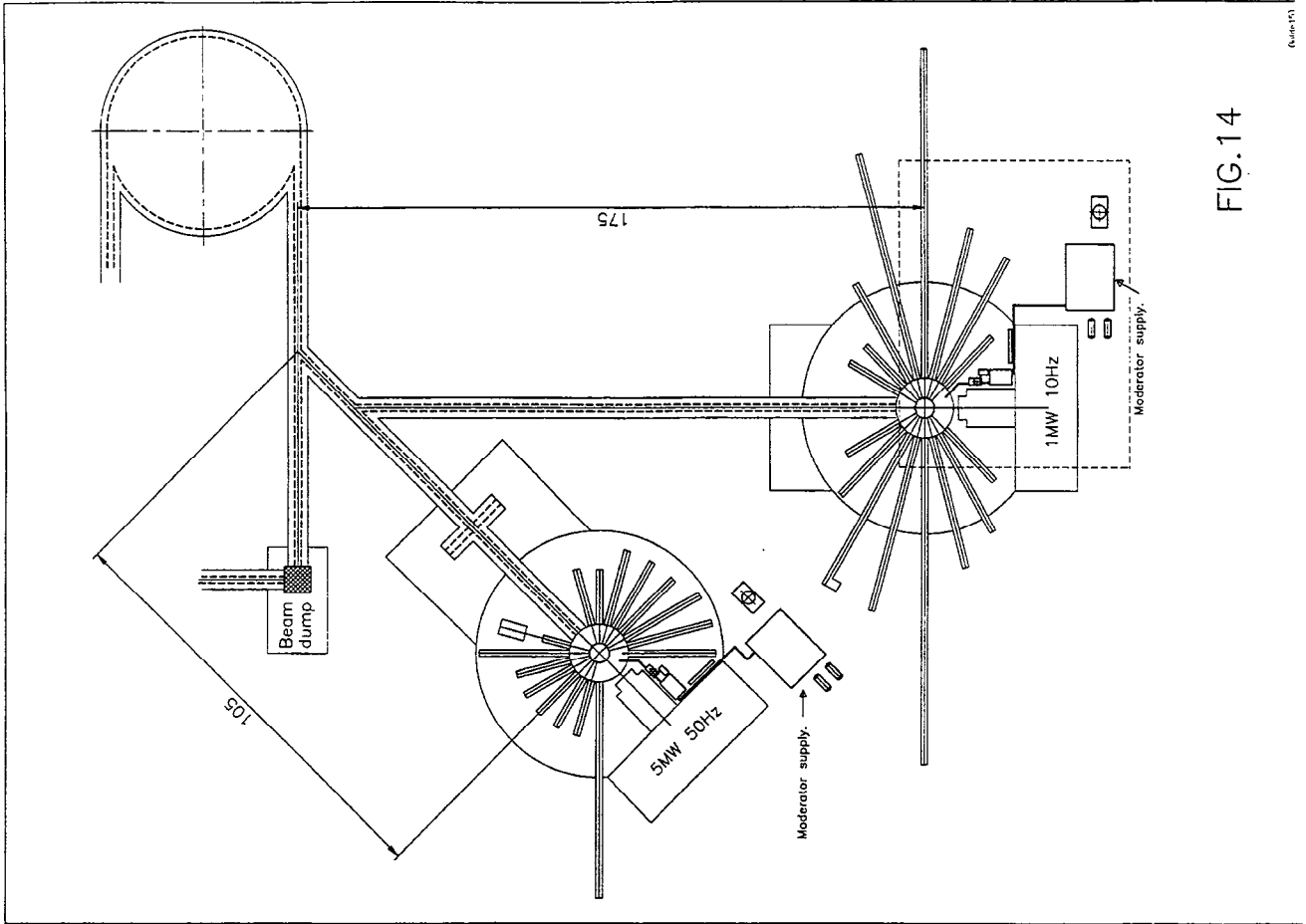


Fig.13



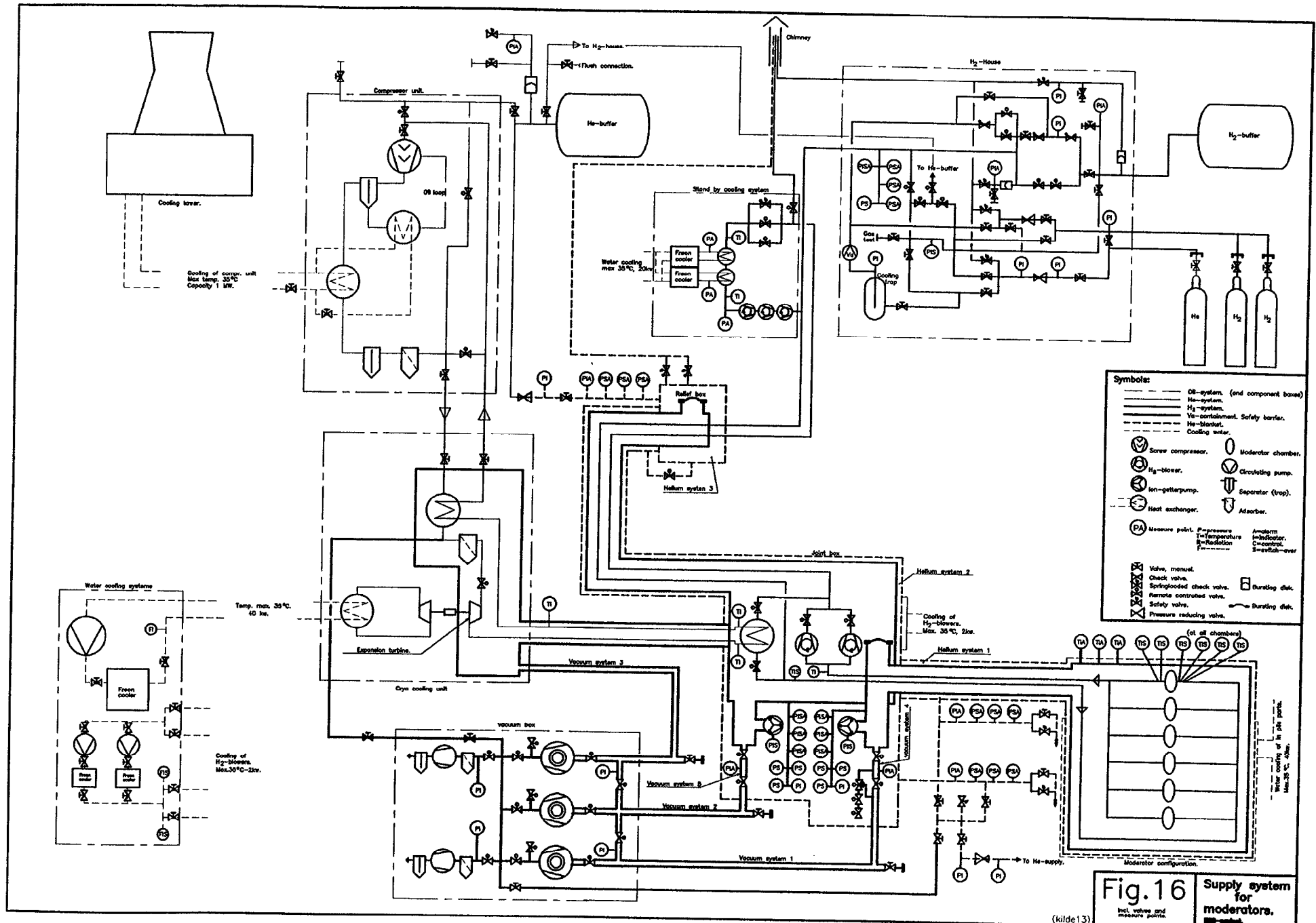


Fig.16 Supply system for moderators.
Incl. valves and measure points.
SIB-project, sheet 6-1-61.

(kild13)