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# AN ALTERNATE COOLING SCHEME FOR THE TESLA PROJECT

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# I INTRODUCTION

Cryogenics plays a leading role within the TESLA project. It is a quite delicate and critical tool, taking into account the huge size of the plant. The foreseen cryogenic solution is currently based on a single saturated superfluid helium bath, like the one used in CEBAF. The time needed to develop the CEBAF cryogenic installation does not however seem very favourable in view of the difference in scale of TESLA.

For twenty years, our laboratory has been interested in the pressurized bath technique, of which the main applications that have been used until now are the 32 T hybrid coil of the "Service National des Champs Intenses" (National Department of Intense Fields), in Grenoble and the toroidal coil winding of Tokomak TORE SUPRA in Cadarache which has been working for over 10000 hours (reference 1). We are currently studying two-phase helium flows in partnership with the CERN for the LHC cooling.

The cryogenic solution which we are here proposing for TESLA, is derived from the TORE SUPRA and LHC solutions. It is based on the utilization of a pressurized bath around the cavities. The bath itself is cooled by a two-phase superfluid bath. The main advantage of this solution is the ability to uncouple the temperature and pressure of the bath around the cavities. This allows the pressure around the cavities to be precisely regulated, and thus the tuning conditions are notably improved. This choice seems to be adapted to TESLA where we wish to avoid systematic recourse to magnetostrictive bars.

# II SUPERFLUID HELIUM: TWO POSSIBLE COOLING METHODS

## II.1 PRESENTATION OF THE SATURATED BATH

Traditionally, superfluid is obtained by pumping on a He bath in a way that maintains a vapour pressure lower than 50.4 mbar. We can thus speak of a saturated bath. At interface level, the helium is in a liquid-vapour equilibrium, its temperature being directly linked with its pressure.

When an infinitesimal volume is isolated inside the saturated bath, its pressure is equal to the pressure around the interface increased by $\rho g h$ (h being the immersion depth). Its pressure is equal to that around the interface if no heat flow is brought to the bath. In the opposite case, the equations describing the Gorter-Mellink flow rate (reference 2) allow the temperature gradient up to the interface to be calculated. Nevertheless, the maximum flow authorized on the heating element is limited by the appearance of film boiling. This is due here to an increase in temperature so that the liquid joins the liquid-vapour curve (see figure 1), the available overheating inside the liquid thus depends on the depth of immersion. Figure 2 shows some peak heat flux results depending on temperature and depth of immersion.

## II.2 PRESENTATION OF THE DOUBLE BATH (OR PRESSURIZED BATH):

The double bath technique has been used (reference 3,4) mainly in our laboratory. Its most well known application is the Tokomak TORE SUPRA cryogenics. A concise principle of this application is illustrated in figure 3. A cold source comprised of a saturated superfluid helium bath is used as an exchanger to a helium bath maintained under pressure. This pressurized bath allows the various heat gains to be drained by pure thermal conduction (favoured by the extremely high conductivity of the HeII) towards the cold source. The temperature of the pressurized bath depends on the exchange surface with the cold source as well as the heat flow to be extracted. As regards the pressure, it can be set at any value between the saturated bath pressure and 20 bars (helium solidifying limit).

If we want to use the maximum available temperature difference inside He II ($\Delta T_{max}$), the pressure must be higher than 50.4 mbar (see figure 1). In this case, the temperature of the heated surface inside the pressurized bath can increase to as much as $T\lambda$ before getting the peak heat flux. He II $\Delta T_{max}$ is thus much greater than for the saturated bath. Moreover, it no longer depends on the depth of immersion. The peak heat flux will thus also be higher than for the saturated bath. The values of the pressurized bath peak heat flux for a conduit length of 1 cm and a pressure of 1 bar are given in figure 4. From a thermal point of view, the optimum pressure is 50.4 mbar. Beyond that, when the pressure is increased, the temperature Tλ drops (causing the available overheating to drop also), and moreover the thermal conductibility of the helium decreases (see figure 5).

Furthermore, the pressurized solution offers the advantage of a larger enthalpic reserve. Indeed, with the temperature margin ranging from Tbath to Tλ, the Cp increasing up to Tλ (see figure 6), the $\int_{T_{Bath}}^{T\lambda} Cpdt$ integral will be much higher, thus allowing large amounts of energy deposited in transient flow rate to be absorbed.

## III APPLICATION TO TESLA PROJECT : SOME POSSIBLE DOUBLE BATH SOLUTIONS:

### III.1 CHOICE OF PRESSURIZATION VALUE:

The choice of bath pressure can *a priori* range from the saturating vapour pressure to the atmospheric pressure, and even beyond. The supraconducting cavities behave mechanically like bellows, with the vacuum inside, and this explains why it is preferable to set a stable pressure value around the cavities. It thus seems inopportune to apply too much outside pressure to the cavities since this would cause serious distortions. Furthermore, the pressurization "thermal optimum" is obtained as soon as 50 mbar is reached (see previous paragraph). Moreover, it is easier to obtain a stability of one tenth of a mbar around 50 mbar than around the atmospheric pressure. Thus 50 mbar appears to be the best pressurization choice which is something new compared with projects using supraconducting magnets, the latter being insensitive both to high pressures and pressure variations.

## III.2 LOCALIZATION OF THE COLD SOURCE (SATURATED BATH) :

The pressurized solution can be adapted in numerous ways. To simplify matters, we might consider two large families, depending on the localization of the exchange surface between the pressurized bath and the saturated bath.

In the TORE SUPRA type of solution ("localized heat exchanger" solution, see figure 7), the cooling source (saturated bath) is localized heat exchanger in a precise place, the heat extracted from the cavities being drained by conduction through the superfluid to the exchange surface between the two baths. Thus we have a saturated static bath at each cryostat.

In the LHC type "distributed heat exchanger" solution (see figure 8), the saturated helium flows along the cryostats, and the exchange surface is shared at each cavity. The flow is continuous along the whole length of a string.

### III.2.1 "Localized heat exchanger" solution (figure 7)

In this solution, a small saturated helium bath is created in each 12 metre long cryostat, and is connected by a fitting to the $\phi$300 pumping line. This bath is supplied by an autonomous J.T. valve regulated by Fontaine pressure so that the level of liquid in the bath is maintained at a constant level. In this way we can be sure to make full use of the bath exchange surface.

The cavities are immersed in a bath that has been pressurized at 50 mbar by two valves, one connected to the 4.5K circuit (supplying the pressure), the other to the pumping line (releasing the pressure). In the event of a major accident, especially in the event of isolating vacuum loss, the helium contained in the entire pressurized circuit is evacuated thanks to a cold safety valve and a cold magnet valve set at 1.3 bar and opening into the $\phi$300 pumping line. The pressurized circuit is hydraulically calculated to allow emergency evacuation with a reasonable pressure drop on the one hand, and on the other hand to ensure that the heat is conducted towards the saturated bath. The two pressurization valves and the two precooling valves can be shared by one or more strings.

### III.2.2 "Distributed heat exchanger" solution (figure 8)

In this solution, the saturated helium, whose flow is controlled by a J.T. valve shared by one or more strings, flows along the cryostats and absorbs the heat generated by the cavities across the shared exchange surface.

As it flows, the saturated helium injected by the J.T. valve evaporates under the effect of various heat inleaks, and finally pours itself from the string end into a separating box which is worked at a constant level. Given the distance between the J.T. valve and the separating box, using the level to directly regulate the J.T. valve flow seems risky, considering the length of response time. It seems more realistic to create pre-established impedances (i.e. flow) in the J.T. valve and to control the electric heating in order to regulate the level of helium. The liquid helium surplus arriving as far as the separating box is thus evaporated. In this way, the J.T. valve can have several positions corresponding to the various operating situations, the flow having been gauged beforehand. The pressurization, precooling and emergency evacuation systems are similar to those in the "localized heat exchanger" solution.

### III.2.3 Comparison of the two pressurized solutions

The "localized heat exchanger" solution uses one J.T. valve per cryostat, but they may be auto-regulated valves, both simple and without connection to the outside. The two main advantages are :

- there is no more two-phase flow and thus the risk of instabilities is reduced.
- the flow in each cryostat is independently auto-regulated and depends on the actual loss made. Contrary to the "distributed heat exchanger" solution, the liquid is not burnt wastefully.

The "distributed heat exchanger" solution, on the other hand, allows us to use only one J.T. valve for one or more strings, and the liquid waste can be reduced by the use of openings at preset values. There is thus little difference between the actual flow and the necessary flow. Since the work is done at a constant flow over long periods of time, there are less fluctuations along the pumping line which is better for the pumping systems.

In both cases, the pressure around the cavities, i.e. that of the pressurized circuit, remains constant. If the variations in the saturated helium flow cause variations in the pressurized bath temperature, the resulting variations in density do not in any way affect the pressure since the pressurized circuit is equipped with expansion bellows.

### III.3 ADVANTAGES OF THE PRESSURIZED SOLUTION COMPARED WITH THE PRESENT SOLUTION :

As well as the stability of pressure on the cavities, the pressurized bath solutions , in spite of being quite complex, offer the following further advantages :

- A higher critical flow which can be useful in the event of a cavity defect
- A greater enthalpic reserve due to the available temperature margin and the specific heat excess around $T\lambda$ . In the event of ill-timed heat inputs, the cavities are protected from overheating and thus quite large transient heat flows can be tolerated.
- The absence of connections at several parallel levels which avoids flutters and other types of instabilites or erratic variations, which may occur in the present solution. The question of the stability of a multiple level system on a cyrogenic installation as big as TESLA is a difficult problem to treat in model form. It is thus advisable to take the minimum amount of risks at the design stage.

### III.4 SPECIFIC COMPONENTS TO BE DEVELOPED:

Having chosen to use a cold pumping line, it is necessary to use cold magnetic flap valves for emergency evacuation in order to avoid using a hot line specially designed for this purpose.

In order to develop a magnetic valve, or an equivalent sudden opening mechanism which would work at low temperature and hold the atmospheric pressure, a minimum amount of research and development must be done. This goes without saying for the pressure regulation to a tenth of a mbar, as well as for the auto-regulated by Fontaine pressure J.T. valves (even though the latter have already been successfully tested in our laboratory).

## IV CONCLUSION

This document summarizes the presentations made at the Saclay and Ambourg TESLA meeting in 1993 and it includes the improvements suggested during discussions with Mr Tom Peterson.

The use of pressurized helium in TESLA cryostats offers advantages which justify an in-depth study in spite of the increased complexity of the cryogenic circuits. This is why it is preferable to develop one or more pressurized solutions, solutions which could be tested on T.T.F

## REFERENCE

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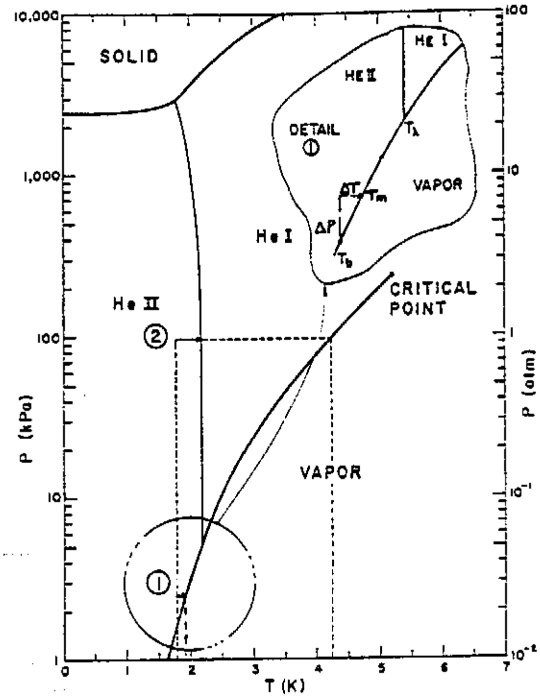
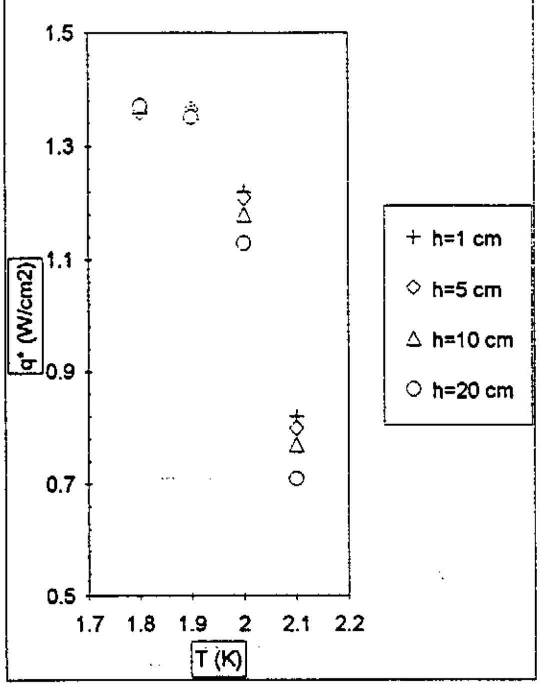


Fig 1: Phase diagram of helium showing location ① of near saturation conditions and location ② of subcooled conditions.

**Fig 2: Limiting heat flux in He II near saturation conditions for various depth of immersion**



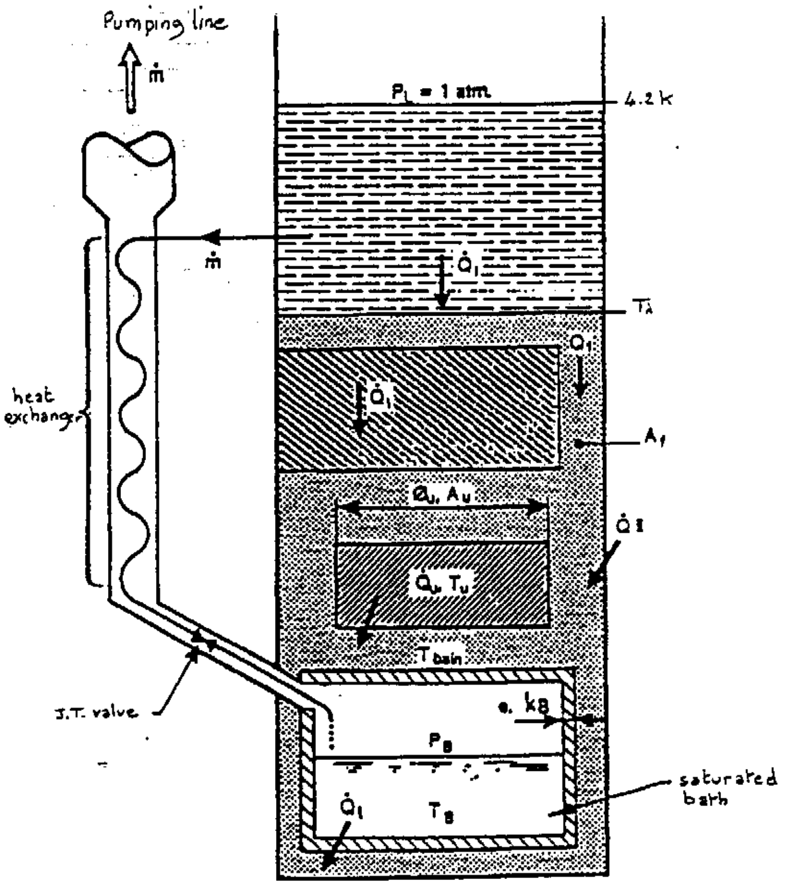


Fig 3: Schematic view of "Claudet" bath

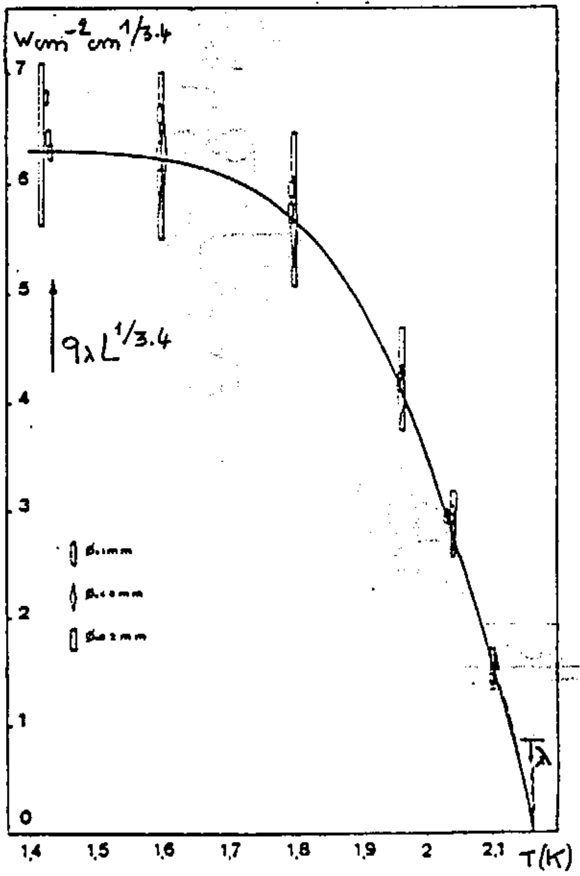


Fig. 4 . Limiting heat flux in He II at 1 bar represented in reduced variables
Solid line : Calculated correlation formula

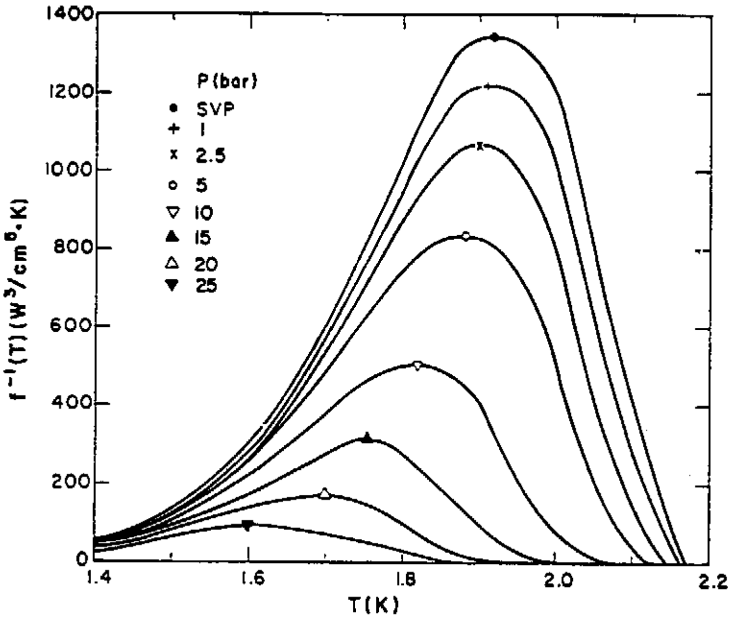


Fig. 5. Heat conductivity function for turbulent He II. Symbols indicate the location of the peak value.

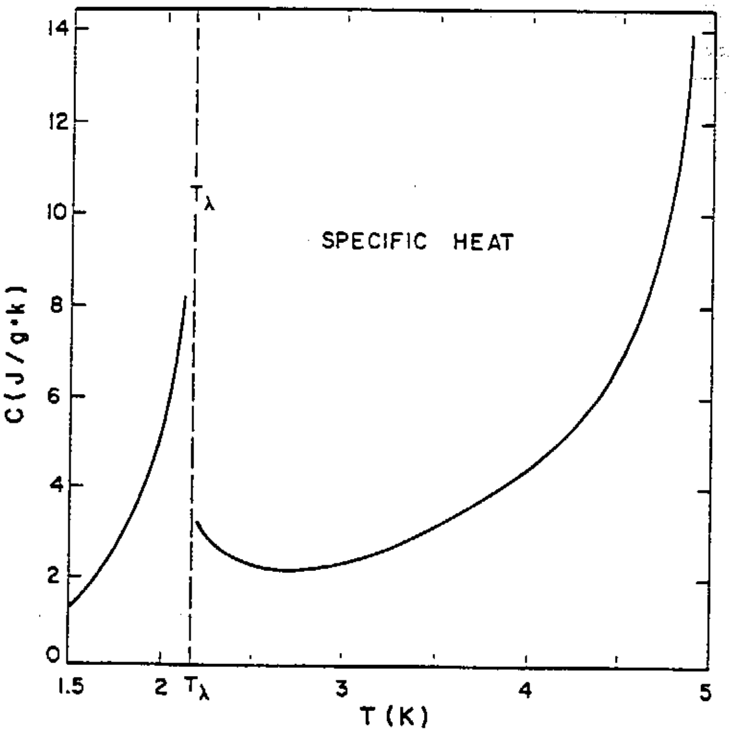


Fig. 6 Specific heat of liquid helium at saturated vapor pressure.

Fig 7 : "Localized heat exchanger" solution

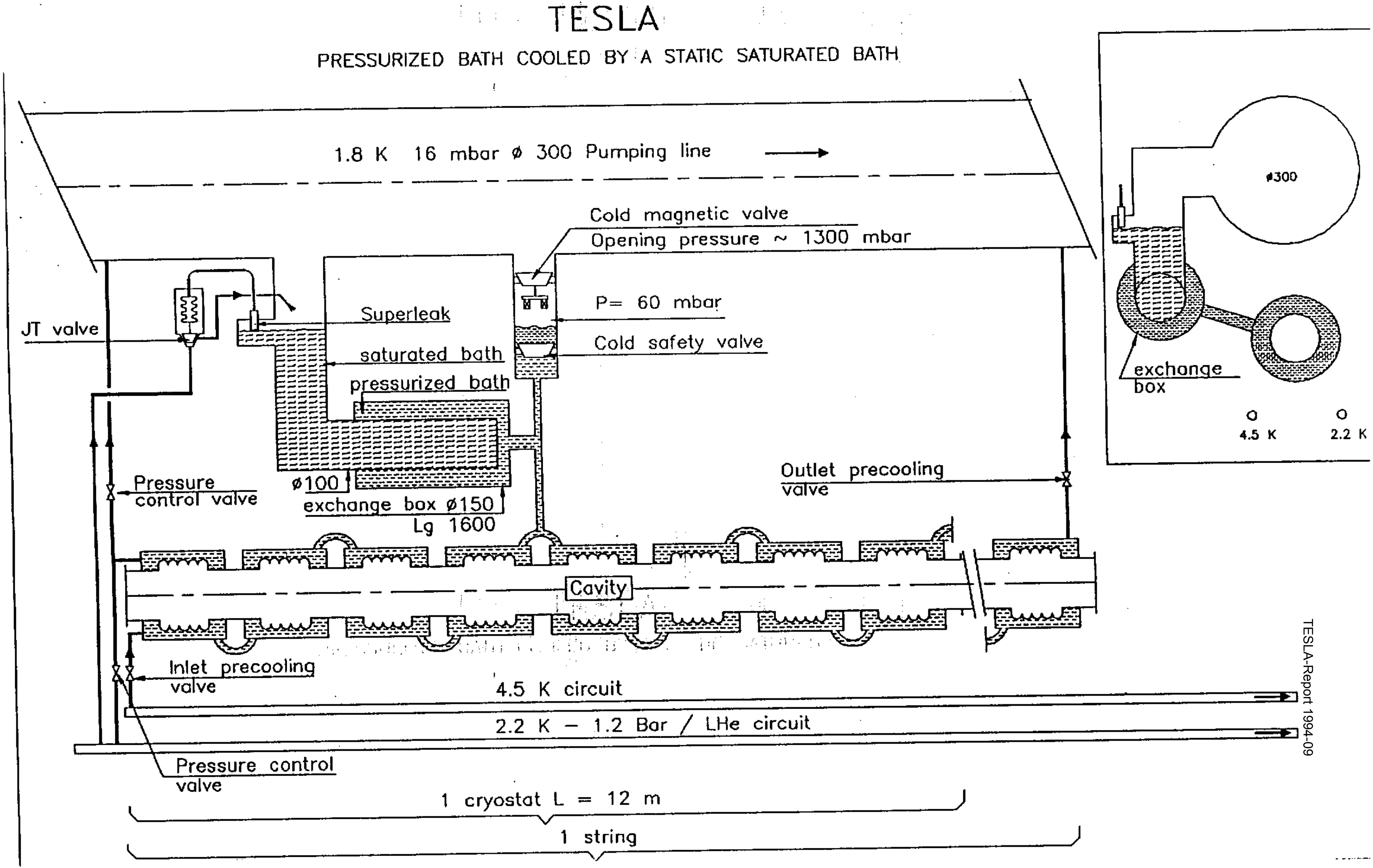


Fig 8: "Distributed heat exchanger" solution