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Status of the development of hot gas ducts for HTRs

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1. Introduction

In the PNP nuclear process heat system the heat generated in the helium cooled core is transfered to the steam reformer and to the successive steam generator or to the intermediate heat exchanger by the primary helium via suitable hot gas ducts. The heat is carried over to the steam gasifier by the intermediate heat exchanger and a secondary helium loop.

In both the primary and the secondary loop, the hot gas ducts are internally insulated by a ceramic fibre insulation to protect the support tube and the pressure housing from the high helium temperatures. A graphite hot gas liner will be used for the coaxial primary duct with an annular gap between support tube and pressure shell for the cold gas counterflow. A metallic hot gas liner will be installed in the secondary duct.

2. Operational data and design criteria

The most important operational data for dimensioning and design are as follows:

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	Primary loop	Secondary loop
He-temperature	950° C	900° C
He-pressure	40 bar	42 bar
Mass flow	37 kg/s	37 kg/s
Flow velocity	60 m/s	60 m/s
Heat loss	50 kW/m	10 kW/m
Outer cooling	coaxial flow with helium at 300° C	free convection and radiation to ambient air

Table 1: Operational data for hot gas ducts

The most important design criteria concern both, primary and secondary ducts:

- Compensation of thermal expansion

- Integrity against pressure and temperature transients during normal and upset operating conditions

- Homogeneous insulation to avoid thermal loads on the metallic supporting structures

- 30 years lifetime

- Feasibility of inservice inspection of the supporting tube and the pressure housing

- Dismantling and replacing possibilities in the case of failure

- Demonstration of the integrity for the licensing procedure (analytical and experimental)

In addition in the case of the primary duct the leakages between hot and cold flow have to be minimized.

3. Design and construction of the hot gas ducts

3.1 Primary hot gas duct

The reference primary duct developed by INTERATOM is shown in Fig. 1. Fibre mats consisting of aluminium oxide are wrapped round the graphite hot gas liner. Graphite foils inserted between the single mats are used as radial convection barriers. A metal supporting tube separates the hot gas from the cold gas. The liner is positioned radially and axially in the support tube by high density aluminium oxide supports. These are arranged in two cross-sections for each liner assembly unit. Four ceramic ball supports are located in each cross-setion for the radial alignment. The lower two supports are rigidly set, the upper two are positioned with a spring and limit stop. One cone-shaped support in each cross-section takes care of the axial positioning. All support elements are inserted from the outside of the supporting tube through corresponding windows. After installation, the inserts are welded to be gas-tight. The single liner units are connected by overlapping grooves with a calculated axial clearance at ambient temperature. This clearance will be closed at design temperature.

In principle the same design is used for two compensating units in the hot gas duct between reactor and heat exchanger. The total unit, hot gas duct and compensating unit are inserted into the pressure retaining shell with an annular gap for the cold helium backflow. This pressure shell is insulated at the outside.

3.2 Secondary hot gas duct

The secondary duct consists of a inner section with a metallic liner and fibre insulation for flow guidance and heat insulation, and a outer shell for pressure containment. This concept has already been applied for different high temperature loops. The significant advantage of this design is based on two facts:

- The simple procedure for dismantling and for exchange of internals

- Accessibility of the pressure housing for inservice inspection

Fig. 2 shows the reference secondary hot gas duct, developped by INTERATOM. The different parts viewed from the inside to the outside are:

- The metallic hot gas liner

- The perforated metallic tube for the inner limitation of the insulation

- The ceramic friction bearing spacers between the two tubes to exclude the danger of friction welding. The annular gap allows a pressure balance between the hot gas channel and the insulation

- The wrapped fibre mats of 95 % aluminium oxide

- The intermediate tube to reduce the radial convection space

- The wrapped fibre mats of 55 % aluminium oxide

- The support tube

- The V-shaped thermosleeves to limit the axial convection and to centre the flow guidance tubes

- The support tube for all internals

- The pressure tube into which the assembled support tube is inserted as a slide-in unit. Each internal assembly is sealed and fixed at the flange of the pressure tube.

This system, including the slide-in technique, is also used for the secondary loop elbows and compensators (Fig. 3).

4. R + D work

The R + D work for the development of the hot gas ducts can be divided into four main tasks:

a) Material development and testing
b) Component part tests
c) Scaled down component tests
d) 1 : 1 scale component tests

In the meantime, the materials, metals, graphite and ceramics, have been investigated with good results. The tests listed under b) to d) are carried out under all expected demands such as steady state thermal loads, transient temperature and pressure conditions and, in some cases, superimposed additional mechanical loads.

The support elements of the primary duct, the ceramic balls and cone shaped parts, were tested with temperature gradients and transients and, in addition, with alternating mechanical loads. These tests demonstrated the integrity of these support elements.

A similar test programme will be carried out for the primary graphite liner. A suitable test rig is under construction. Test operation will start in summer 84.

The assembly method for wrapping the fibre mats was developed during preliminary tests and the specific assembly data for the applied insulation qualities were optimized. The fibre mat insulation can be compressed to such an extent that it is almost possible to exclude the formation of cavities during the lifetime.

The extreme requirements in the case of accidents are generally simulated during the component part tests. The main objective of the large component tests is to demonstrate the integrity of the overall assembly under original operating conditions.

Important details for improving the design can be obtained during the assembly work of the component test sections. The efficiency of the insulation was proved during thermal examinations in the high pressure helium channel of the Nuclear Research Centre Jülich. First results indicated that the open insulation systems were severely impaired by free convection, resulting in thermal loads on the metallic support structures. Therefore the insulation had to be modified with adequate convection barriers.

With reference to the secondary hot duct insulation a lot of experience and test results had been obtained from the preceeding tests for the hot gas piping of the High Temperature Helium Test Loop KVK at INTERATOM and from other test facilities. As a result, it was possible to take these test data into account for the planning and design of an originally-scaled test section. It was therefore possible to install such a large test component of 6 m in lenght in the KVK before the first start-up period of the test loop. In the meantime this component has endured about 5000 hours of operation under various conditions without any indications of failures.

The test component was equipped with thermocouples in different axial cross-sections. In each measuring plane, chromel-alumel thermocouples were installed over two perpendicular diameters in different radial positions. The corresponding outer wall temperature can be measured using resistance thermocouples. The measurements were carried out in the KVK under different operating conditions between helium temperatures of 400° C to 950° C and helium pressures of 14 bar to 40 bar.

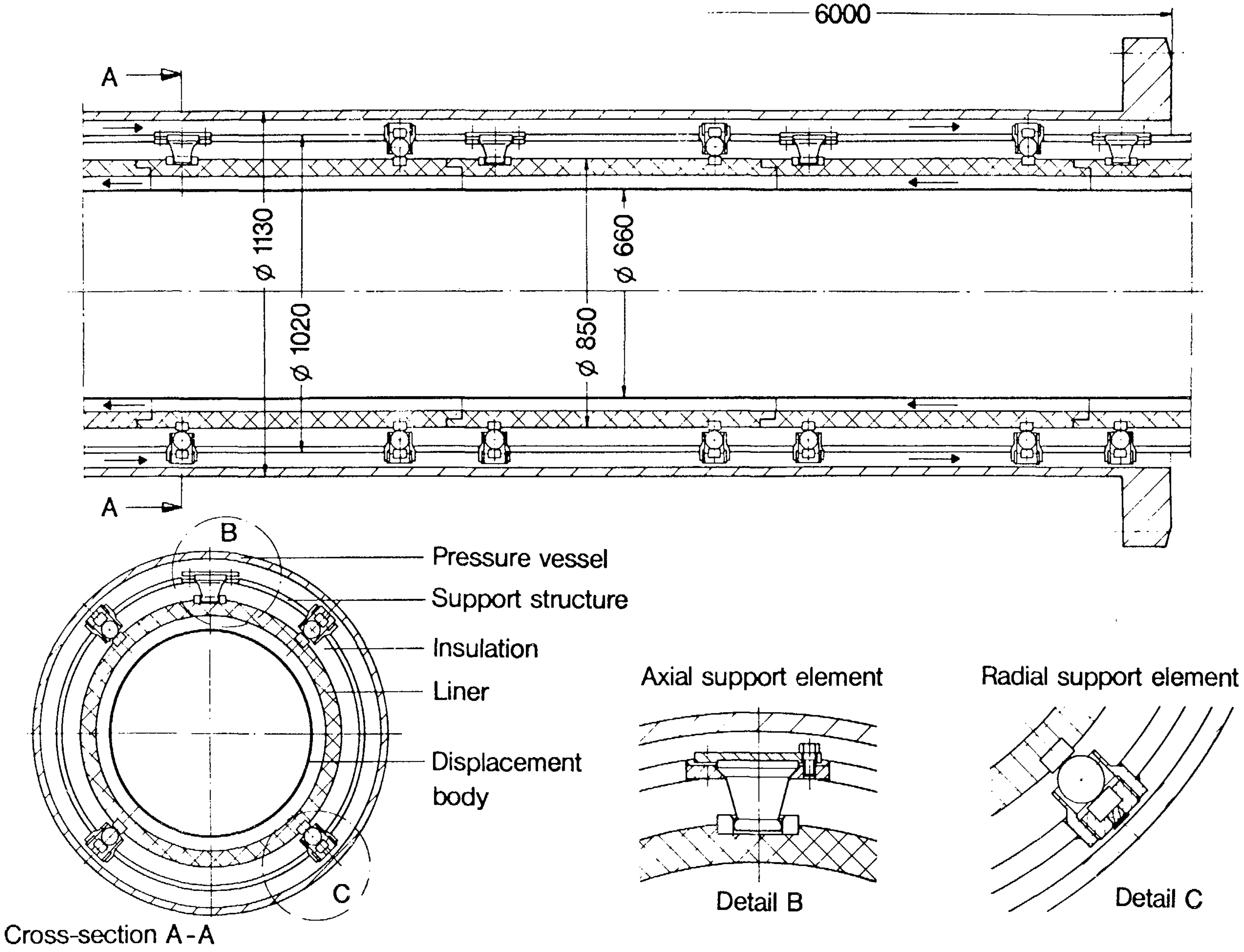
Figs. 4 and 5 present the radial temperature profiles in two different measuring planes for a helium temperature of 936° C and a pressure of 20 bar. The two measuring planes are situated upstream (B) and downstream (B') of the axial extention gap between two liner units. The radial temperature profiles are pointed out in all four angular directions. There are small variations for the different directions due to geometric disalignments of the metallic structures, possible inhomogeneities and convection in the insulation. A remarkable temperature decrease can be noted across the annular gap between the support tube and the pressure shell. This decrease is different in the two measuring planes. A definite explanation of this difference can be given after improvement of the alignment during dismantling.

Fig. 6 shows the outer wall temperature of the pressure tube as a function of the helium temperature. The mean values of the four measured temperatures in each measuring plane are marked together with the maximum deviations. All these deviations are smaller than 10 % of the mean value, an indication that hot spots do not exist.

The azimuthal temperature distribution around the pressure tube surface is shown in Fig. 7 for different helium temperatures. The curves represent the relative deviation in percent from the mean temperature. There is a strong asymmetry in the vertical direction for low helium temperatures decreasing with increasing helium temperature. This behaviour clearly shows the influence of free convection in the insulation, which is characterized by a modified Raleigh number for porous materials proportional to p^2/T^4.

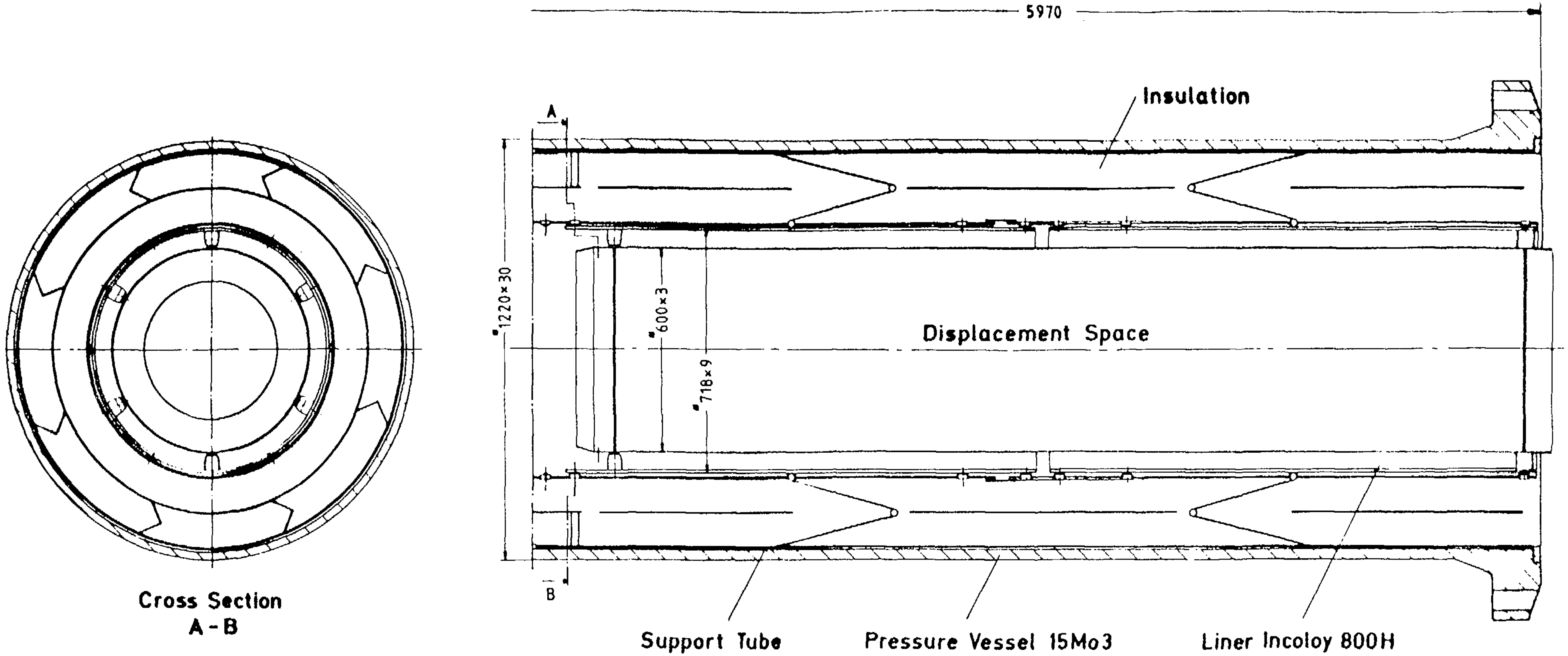
The specific heat loss to the environment as a function of the helium temperature in two measuring planes is shown in Fig. 8 in W/m^2 of the pressure tube surface and in W/m tube length. The upper curves represent the total heat loss, the lower ones the convection ratio.

Summarizing all experimental and operational results, the integrity of the component has been demonstrated and the design calculations have been confirmed as being conservative. The measured heat loss at helium design temperature was less than 70 % of the calculated value.



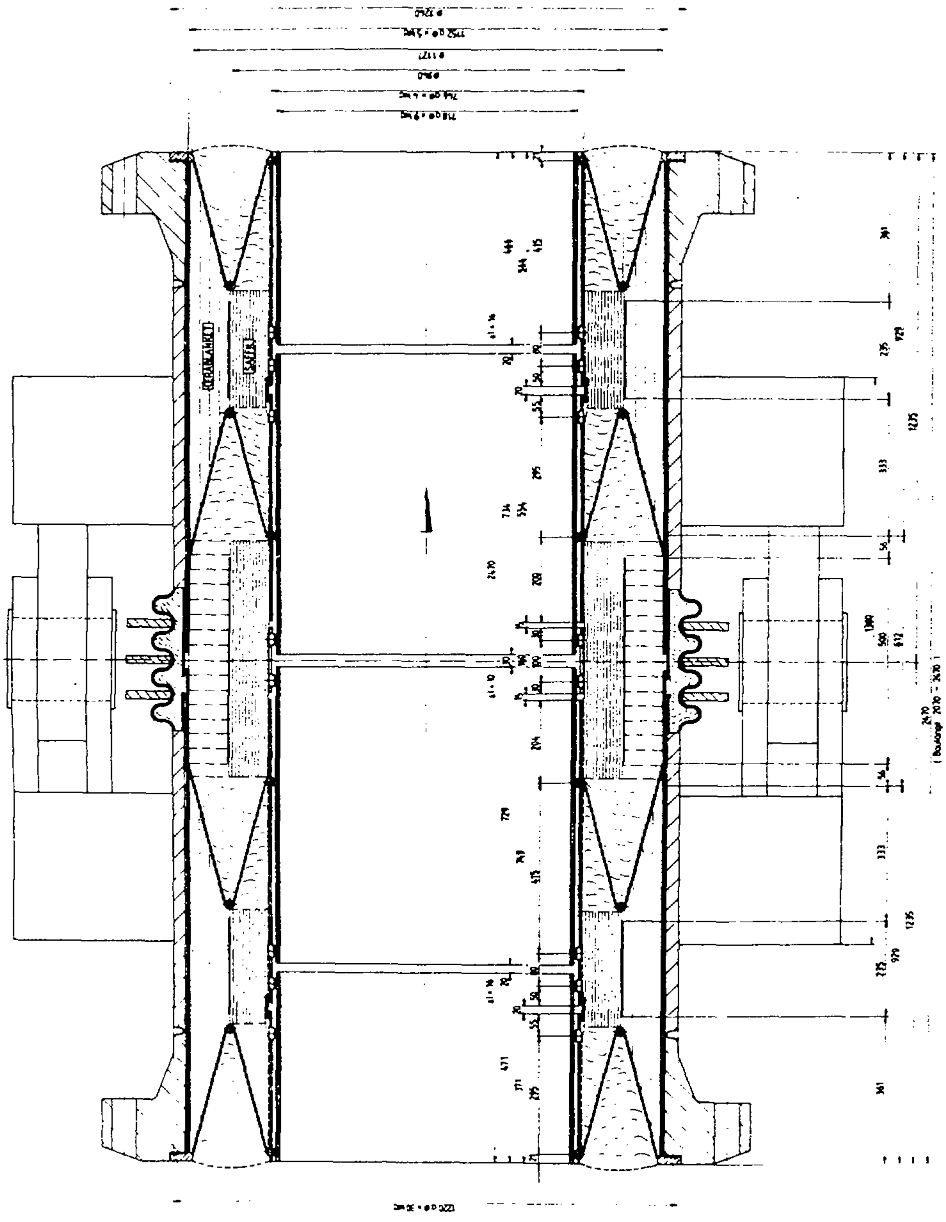
Test Section Primary Hot Gas Duct

Fig. 1



Secondary Hot Gas Duct with Metallic Liner and Fibre Insulation

Fig. 2



Secondary Compensator

Fig. 3

The conversation of these energy resources to gaseous and liquid products enables us to do so. Of all the nuclear reactors developed today, the high temperature reactor is predestinated to play a key role, as it can supply the heat which is necessary for the conversion processes at the required high temperatures of between 800° C and 950° C.

In conjunction with special process technology, this leads to a considerable reduction of the pollutant emissions of SO_2, CO_2 etc. and of dust.

Above all, the CO_2 emission, which is much lower than in autothermal gasification processes, deserves special mention, because of the CO_2 influence on the temperature increase at the earth's surface.

2. The Plant Concept

In order to clarify the functions of those components which are the subject of the following presentations, I would like to consider the PNP plant with both gasification processes, namely steam gasification and hydrogasification of coal, in more detail.

Let us first consider the steam gasification of coal (Fig. 1). The reaction of steam with hard coal requires high temperature heat since it is endothermic. For this process a secondary helium loop is advisable for safety reasons.

The secondary helium is heated to 900° C in the He/He intermediate heat exchanger and enters the gas generator at approximately this temperature. The helium is cooled to around 815° C here because of the carbon-steam reaction.

The helium leaving the gas generator is cooled in the process steam superheater and then conveyed to the steam generator.

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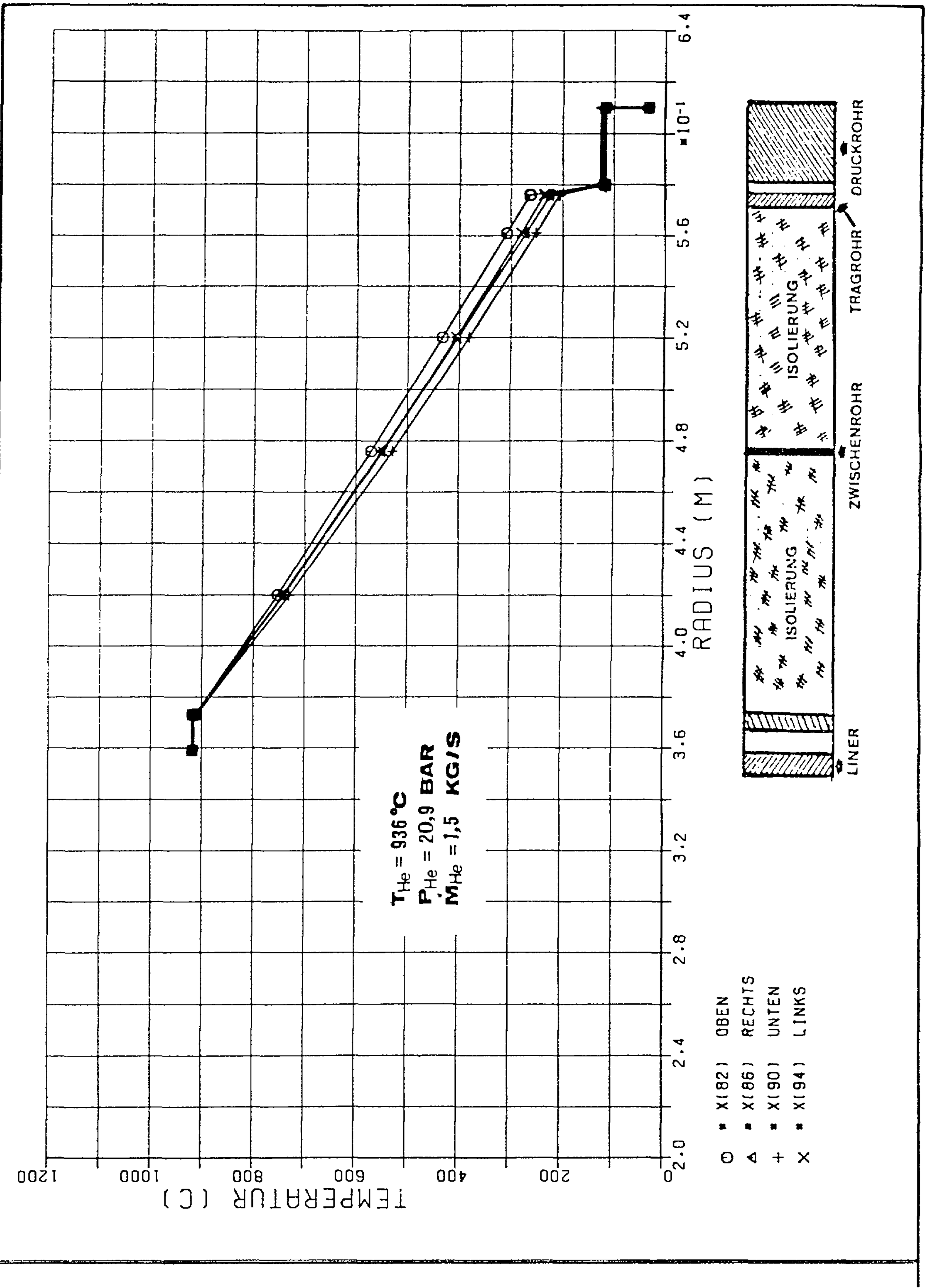

Secondary duct test component Radial temperature distributions Measuring plane B'

Fig. 4

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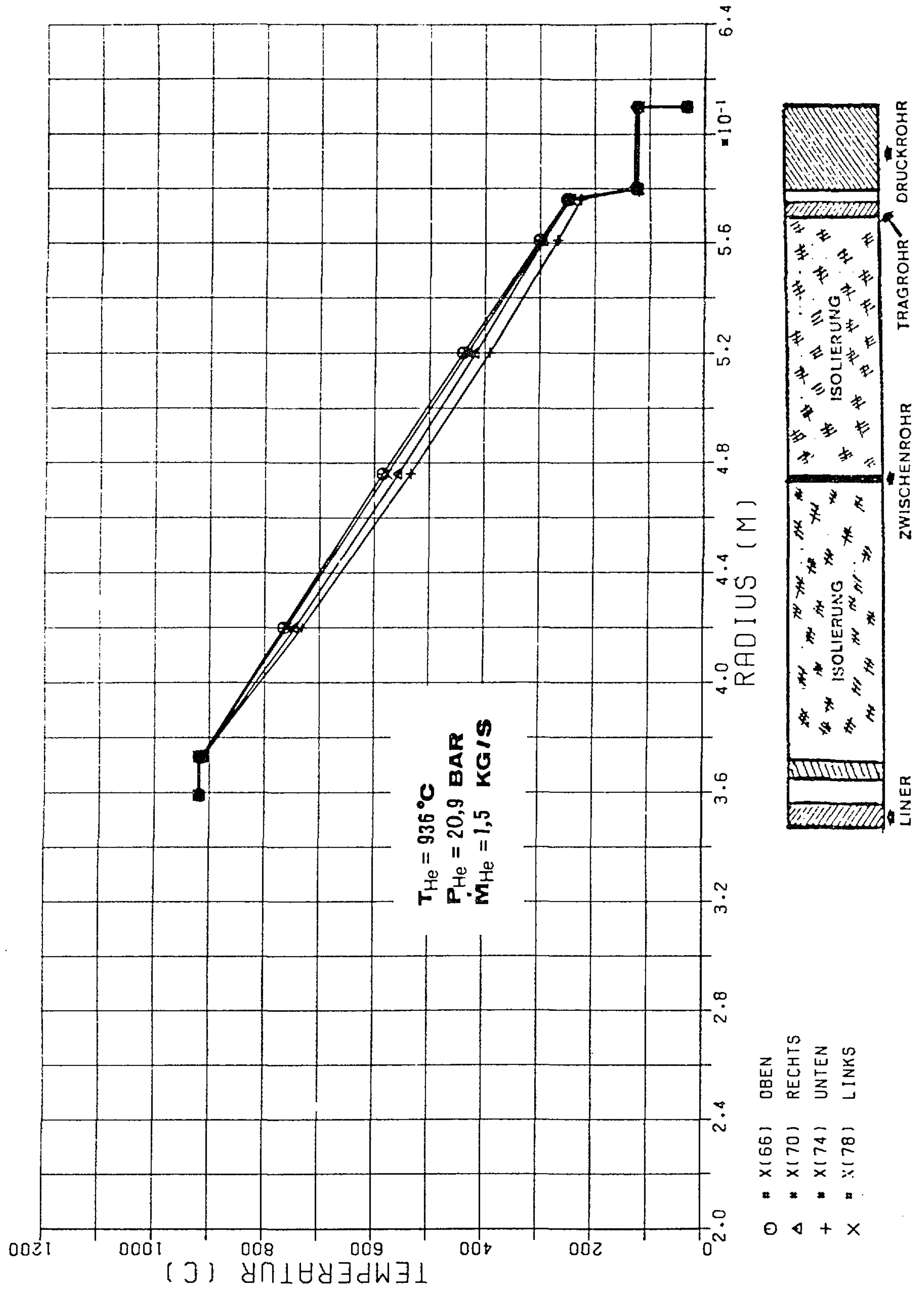
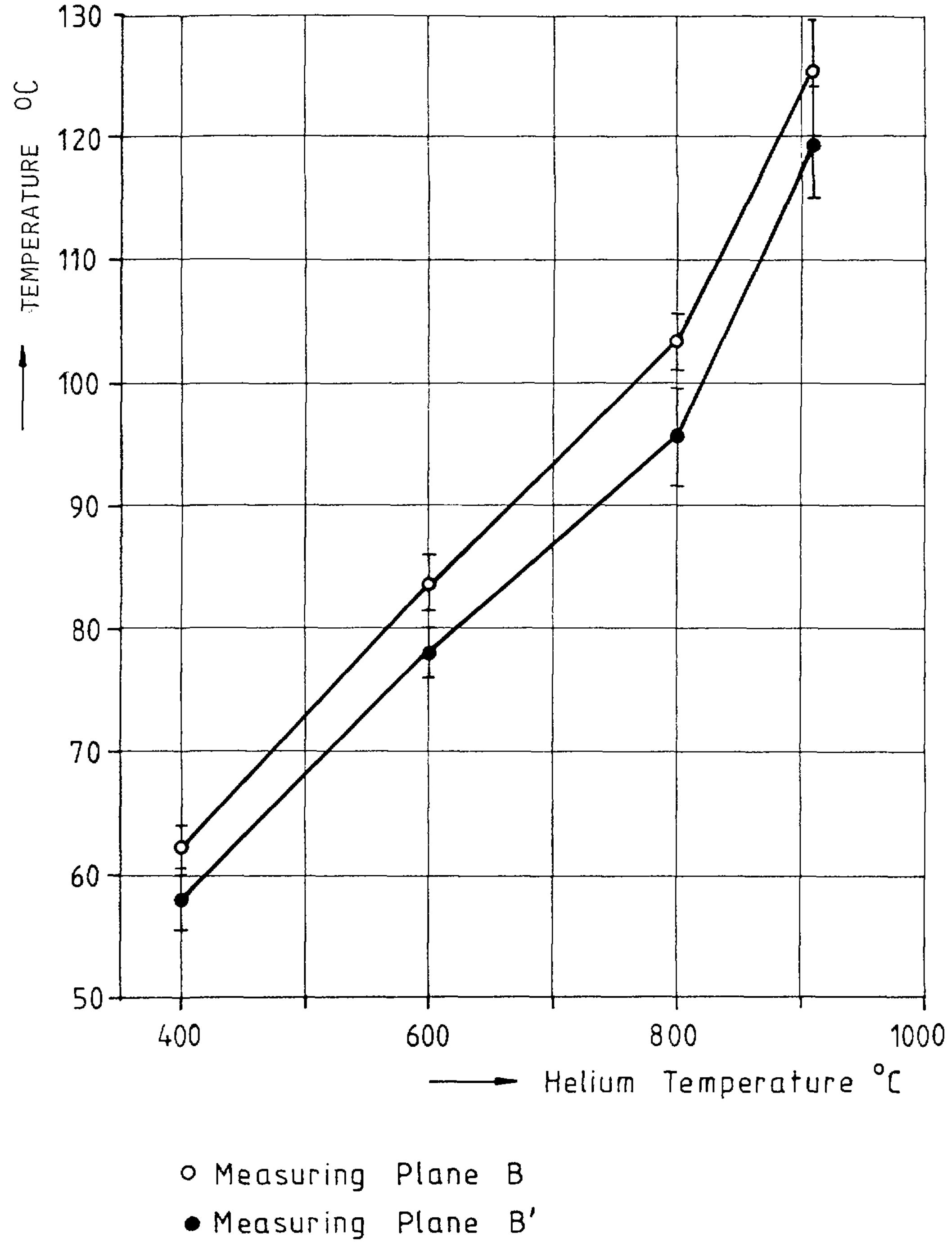


Secondary duct test component Radial temperature distributions Measuring plane B'

Fig. 5



Mean values of the outside pressure tube temperature as a funktion of helium temperature and maximum deviations

Fig. 6

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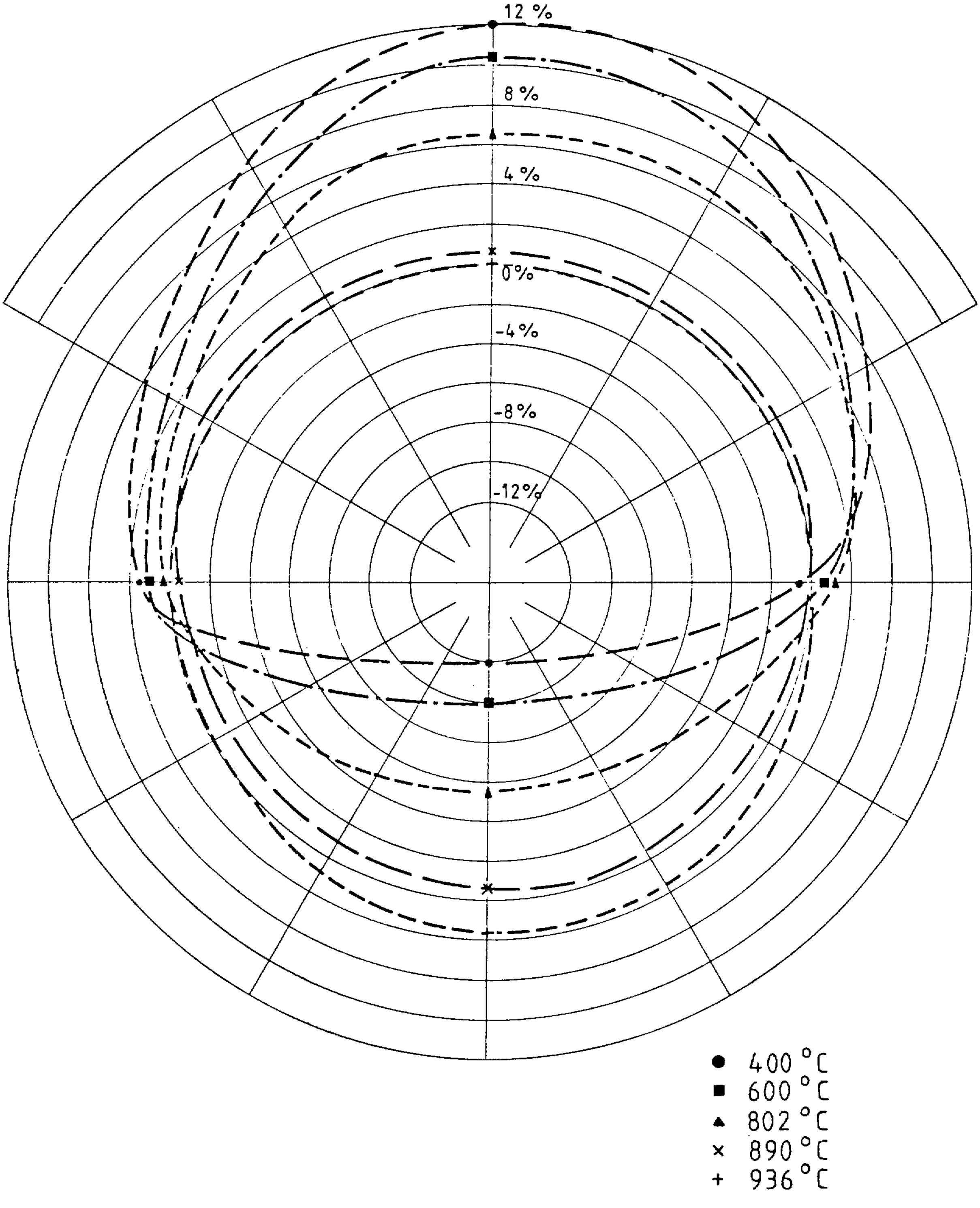
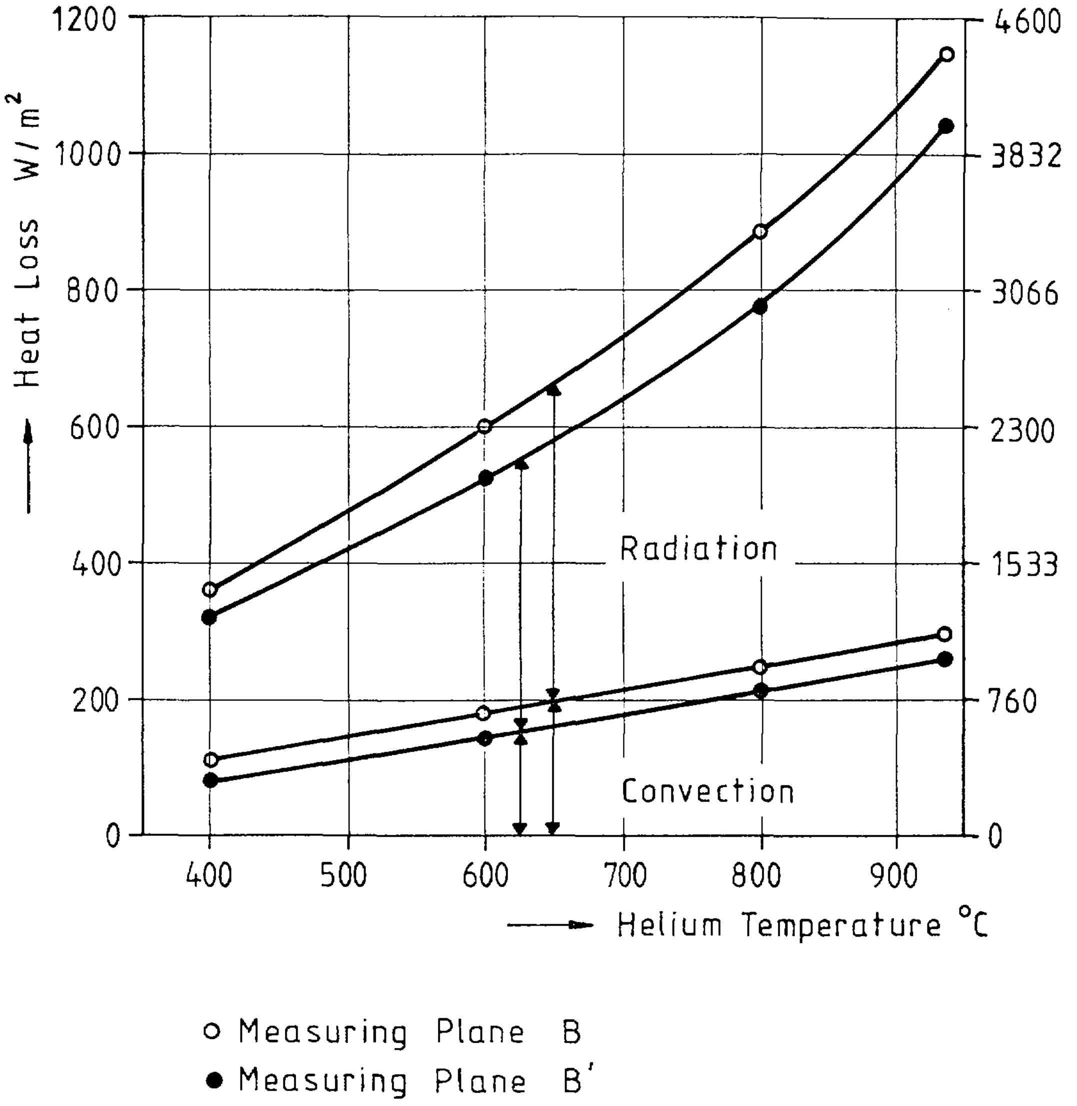


Azimuthal temperatur distributies on the pressure tube outside for different helium temperatures

Fig. 7



Specific heat loss in W/m^2 and W/m duct length as a function of the helium temperature

Fig. 8