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THE PRESSURIZED AND BOILING WATER LOOP OF THE TECHNOLOGY DIVISION AT ISPRA

by

H. HERKENRATH and P. MÖRK-MÖRKENSTEIN

1971

Joint Nuclear Research Centre
Ispra Establishment - Italy

Technology

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ABSTRACT

The following report describes the pressurized - and boiling water loop of the Technology Division at Ispra. This loop is specially designed for the investigation of heat transfer to water at pressures up to 250 bar, and allows investigations of test sections of realistic dimensions with a maximum power input of 3.0 MW. The detailed description of all elements of the loop demonstrates its great versatility.

KEYWORDS

PRESSURIZED WATER REACTORS
BOILING WATER REACTORS
COOLANT LOOPS
MOCKUP
HEAT TRANSFER
WATER
PRESSURE

CONTENTS Pages

INTRODUCTION *)

The high pressure, boiling water loop of the Technology Division at the Joint Nuclear Research Centre of Euratom at Ispra was constructed in order to test the heat transfer and hydrodynamic behaviour in fuel element assemblies for reactors planned for the future. The installation was also intended to serve for fundamental research in the heat transfer field.

The first investigations scheduled were on heat transfer to water, under near critical pressures and with high heat flux densities. With this in mind the loop was prepared with the following operating data:

TABLE 1

DESIGN DATA OF THE TEST LOOP

Max. working pressure	250 bars
Max. delivery rate	30 and 100 m^3/hr
Max. head	300 & 120 m liq. col.
Max. heat input	3.0 MW
Max. circuit temperature	450 ^oC
Max. pump temperature	364 ^oC
Installation length for test section	7 m

The cooling medium is demineralized and gas-free water. Since the operation began, several test sections have been studied.
These were mostly single smooth tubes, but rod clusters, coiled tubes, annulus geometries and test sections for visualization of flow patterns (see 8), were also studied.

A detailed description of the loop demonstrates its great versatility.

*) Manuscript received on April 2, 1971

1. The Loop

Fig. 1 and 2 show the arrangement of the test loop. The circuit works as a closed cycle under forced flow. The most interesting elements besides the test section are the pump, preheater, separator, pressurizer, condenser and subcooler.

The method of operation is illustrated by the mass flow sheet of Fig. 3. The water brought into circulation by the reactor pump (1), passes selectively three pipes of different nominal diameter and their corresponding regulating valves (2, 3, 4). The pipes and valves with a nominal diameter of NW 25, NW 40 and NW 50 are so dimensioned that the entire mass flow range can be passed through in three steps, each with the ratio 1:10. Were the test section(7) to be entered with a two-phase mixture , the desired quality would be generated by the preheater(6). Test sections with length up to 7 m can be installed. The water-vapor mixture leaving the test section is transferred to the separator(8). After separation the vapor condenses in the condenser(9) and the condensate becomes mixed with the water in the lower part of the separator. The entire mass of water then flows into the subcooler(10) in which the temperature is lowered to the desired test section inlet temperature. From here the water returns to the pump and the cycle begins again.

There is a pressurizer(11) to stabilize the operating pressure independently of the heat input to the test section.

Because the desired flow-rate is often very low, whereas the pump corresponding to its Q-h-line should not operate below the minimum mass flow, there is a bypass with a regulating valve(5). A quick-acting gate valve(12) is installed to avoid high pressure vapor exhaust should a test section be destroyed by burnout.

All pieces coming into contact with water are made of austenitic alloy steel:

- DIN X 8 CrNiNb 1613 material nr. 1.4961 and
- DIN X 10 CrNiMoNb 1810 material nr. 1.4580.

As previously mentioned, the coolant is demineralized and gasfree water, with an electrical conductivity of 0.2 micro-Siemens.

1.1 The Circulating Pump

The two pumps are 3-stage, vertical glandless circulation pumps, which differ in the delivery and the delivery head

pump I (KSB, Fig. 4a):	Delivery max.	100 m^3/hr
	min.	40 m^3/hr
	Delivery head	120 m liq. col.
	speed	2920 rpm
pump II (STORK, Fig. 4 b):	Delivery max.	30 m^3/hr
	min.	18 m^3/hr
	Delivery head	300 m liq. col.
	speed	2920 rpm

Both pumps are built for a max. temperature of 364°C at an operating pressure of 250 bar. The permissible temperature of the motor of pump I is 180°C, and of pump II 165°C. Both are connected to high pressure coolers, which recool the motor cooling medium (connection s. 2.2, locking mechanism 2.6).

1.2 The Preheater

The preheater consists of 3 paralleled directly heated coils of pipe proportioned in length (22 m) and diameter (18 x 2 mm) to the available power source. The total power amounts to 500 kW and can be regulated ridgeless from 0-100% by ignitrons. The heating is so calculated that the heat flux density does not exceed 20 W/cm^2.

1.3 The Evaporation Cooler

Both cooler and condenser are constructed as an evaporation heat exchanger; that is, the water used for cooling evaporates so that all the evaporation heat can be used and only a small quantity of cooling medium is therefore necessary.

The heat exchange surface is made of Duplex-tubes (stainless steel inner tube and a coating brass tube). A very small air gap is obtained by not bringing the brass tube into metallic contact with the stainless steel tube, and this gap serves to keep the heat transfer so low that the thermal stress in the wall of the stainless steel tube remains below the permissible value. This is valid above all under the extreme conditions at 250 bars. The temperature difference between the water in the tube and the cooling water outside can amount to 300 ^{o}C without disturbance of heat transfer by partial film formation. Both cooler and condenser are built for a max. power of 1.2 MW and 2.0 MW respectively, at which level this power is controllable, within broad limits, by the water level. The regulation is obtained by an overflow system consisting of a jacked tube and a fixed and movable inner tube. The cooling water is pumped into the coating tube which is in communicating contact with the cooler or the condenser respectively. When the movable inner tube is regulated at the desired level by means of an electrical regulating switch, the surplus water flows away between the tubes (level regulation s. 2.5).

1.4 The Separator

The separator consists of two vertically arranged vessels in which water and vapor are separated by force of gravity.

1.5 The Pressurizer

The pressurizer or pressure stabilizer has a power of 40 kW for heating pressurized water up to 400 ^{o}C at 250 bars. The pressurizer consists of 6 cartridge heaters in spiral plate formation with a diameter of 37 mm and a length of 2450 mm in vertical arrangement. Voltage 380 Volts with one phase connection of 6500 Watts each (s. 2.4 and 2.6.4).

2. The Electrical Installation

2.1 The 2.4 MW Rectifier Plant

The rectifier plant ready for work at present consists of 8 rectifiers with 300 kW each (Fig. 5) which are remote-controlled over power switch and contactor from the switch-gear.

A communication on the direct current part makes it possible to work in following voltage steps:

384 V - 6250 Amp
192 V - 12500 Amp
96 V - 25000 Amp
48 V - 50000 Amp
(24 V - 100000 Amp)

Up to the corresponding maximum values, the voltage can be regulated infinitely from 0 until 100% by regulating transformers. The connection to the test section is set up by Cu-current bars, in which shunts are incorporated for the current measurements. The cross-section of the current bars amounts to 42000 mm^2, designed for a permanent current of 50000 Amp and a temporary current of 100000 Amp.

From a switchboard it can be changed over from "single" - to "parallel" operation. For "burnout" tests on the primary of the regulating transformers quick-break switches (Sace) are installed with a disconnection time of 20 ms.

The primary voltages of 4 rectifiers are stabilized by double rotary transformers. More details are shown in the electrical wiring scheme (Fig. 6) (blocking s. 2.6.2).

2.2 The Circulating Pump

The circulation pump is remote-controlled from the switch-gear by power switch and a contactor (blocking s. 2.6.1).

2.3 The Preheater

The power of the preheater is regulated from the switchboard. For reading the actual value, an instrument calibrated in kilowatt is used (blocking s. 2.6.3).

2.4 The Pressurizer

The pressurizer is also remote-controlled from the switchboard by a power switch and a contactor. For regulation of the heating power a 40 k W transducer is connected in series, and operated from the switch-gear by a source of constant current with ± 10 mAmp modulation (blocking s. 2.6.4).

2.5 Electrical Auxiliary Drives

The regulating valves (5) (bypass) and (2, 3, 4)(test section inlet) and also the evaporation valve (s. 6) are connected with Reinecke-motors. The control is adjusted from the switch board. The level in both the cooler and the condenser is controlled by servo-motors, which are also operated from the switchboard. Additional equipment is shown in block diagram (Fig. 6).

2.6 Blocking

To eliminate human errors blocking switches and safety elements are installed.

2.6.1 Pump Start-up Blocking

The circulation pump cannot be switched on, if the regulation valves (5) and (2, 3, 4) are closed.

2.6.2 Rectifier Switching on Blocking

The rectifiers can only be started if the ventilators and the servo-motors of the double rotating regulator (voltage stabilizer) are switched on. In the case of failure of a ventilator or servo-motor the corresponding power switch releases. Should the pump fail to operate, the power switches of the rectifiers cannot be switched on. If the pump breaks down during operation, the power switches will disconnect the whole rectifier group.

2.6.3 Preheater Blocking

If the pump does not circulate the preheater cannot be worked. Moreover a burnout of the preheater tubes is prevented by excess temperature cutout.

2.6.4 Pressurizer Blocking

During a test period the circuit also remains under pressure at night, ready for operation by automatic regulation (for the test program ca. 50-150 bars). As regulator a two point hoopdrop regulator is used and as test value transmitter a piston gauge (Siemens). The required safety is ensured by multiple blocking.

2.6.4.1 In case of lowering of level, i.e., in case of water loss under minimum value by an unexpected leak, the power switch is switched off by a hoop drop regulator.

2.6.4.2 In case of decrease of pressure a contact manometer installed in the upper part of the separator goes into action and switches off the contactor.

2.6.4.3 An increase of pressure is made safe by a threefold blocking:

I. Step: In case of a pressure increase up to 170 bars, the pressure switch I, placed parallel to the contact manometer (2.6.4.2), switches off the contactor.

II. Step: In case of failure of the pressure switch I and further increase of pressure, the pressure switch II at the condenser takes action. The latter switches off the corresponding power switch and thus also the heating power.

III. Step: If pressure switch II does not operate either, a bursting plate has been installed as a third safety device. This bursting plate is designed for a pressure of 227 at ($\pm$ 10%).

2.6.5 Emergency Cutout

In case of rupture of the test section, it is necessary to cut off all the heating power (rectifiers, preheater and pressurizer) immediately and to close valves 2, 3, 4, and the quick-closing valve 11. These operations are combined in an emergency button.

2.7 Acoustical and Optical Signaling

Defects in different functions during operation are registered by horn and light signals.

These defects are:

1 - Failure of cooling water for the circulating pump,

2 - Temperature of pump cooling water becomes too high (max. 80 °C),

3 - Constant current sources have fallen out,

4 - If at change-over to night operation the "automatic" for the pressure regulating is not switched on, the signal "P3 alarm fails" lights up.

5 - If "emergency cutout" is released, thereby closing the regulating valves (2, 3, 4) and the quick-closing valve (11), the signal "valves closed" lights up. This also happens at power failure. The valves (2, 3, 4) only can be adjusted, if "valves closed" is liberated and the signal extinguished.

3. Control Instrumentation

3.1 Circuit Temperatures

At 12 important places in the loop are installed thermocouples which control the temperatures continuously and record them over a 12-point-printer (Polycomp H & B).

Another thermocouple, which controls the pump cooling water temperature is secondarily connected with a hoop drop regulator, which releases light and horn signals, if the cooling water temperature becomes too high.

3.2 Mass Flow

To control the mass flow a Barton-element is connected with an indicating instrument and a continuous-line-recording instrument. The Barton-element is joined to a diaphragm in parallel to an U-shaped manometer (s. 4.2).

Pressure

The operating pressure is controlled by tube spring manometers (indicating range 0-400 at).

Separator Level Control

The level in the separator drums is recorded over a Barton-element (3600 mm water column) on switchboard instruments.

Cooler and Condenser Level Control

The cooling water level in cooler and condenser is also recorded on switchboard instruments. A tube spring manometer (3000 mm water column) is used as a test-value transmitter.

Measuring Device

Temperature

1 The temperatures of the operating medium at inlet and outlet of the test section are measured with weld coated thermocouples.

2 Test Section Temperatures

For recording the wall temperature of the test section in steady state an integral-digital-voltmeter (Hewlett-Packard) including a data printer is used.

To perform a test as quickly as possible an automatic selector switch is installed, to which up to 600 measuring points can be connected. Nonsteady measurements can be made by a continuous-line-recording instrument (Linecomp H & B, sort 0,25%) or by a light-ray high speed recorder with 22 channels (Lumiscript H & B). The zero point suppression is made by a Knick-standard voltage transmitter. Moreover, during the start-up and re-adjustment of a test, some of the test section temperatures can be observed by 20 profile-indicating instruments (indicating range 0-800^{o}C). These indicating instruments can be disconnected by relays.

4.2 Mass Flow

Depending upon the mass of cooling medium required, two selective diaphragm sections can be installed. In each of these sections there are two ring chambers to take up diaphragms of different diameter (calibration s. 7). The effective head is measured by a mercury U-shaped manometer (Debro, ND 400, test range 800 mm mercury column, accuracy of reading 1/10 mm mercury column) with magnetic indication (Fig. 8).

4.3 Pressure

Both the pressures measured at inlet and outlet of the test section and the system pressure are recorded by Siemens-rotating piston gauge (indication error 0.1% of test range final value) (Fig. 8).
Test range: 6 at

Zero point suppression: minimum 12 at
maximum 258 at

To measure the pressure drop over the test section at the pressure gauge nipples at the inlet and outlet a mercury U-shaped manometer (Debro, ND 400, test range 2400 mm mercury column, accuracy of reading 2/10 mm mercury column) has been installed.

4.4 Electrical Values

4.4.1 The current measurement is carried out by Iso-shunts of 15000, 30000 and 60000 Amp, (Companie des Compteurs, sort 0.1%) to which is connected a continuous-line writer or a millivolt-mirror galvanometer (sort 0.5%).

4.4.2 The voltage can be read by a digital-voltmeter or by a continuous-line-writer. Moreover various direct-reading table-instruments (moving coil or moving iron instruments, sort 0.2) can be used.

5. Electrical Installation of the Test Sections

The most widely used form of dc current direct heating needs a current-insulated mounting of the test sections. A flanged joint, developed in the Heat Transfer Division at Ispra [1], containing insulation rings of SPK-Oxide ceramics (Al_2O_3) is used.

Fig. 9 shows such flanged joints, and Fig. 10 shows insulation rings and joints of various sizes and types.

To improve the sealing effect of the lenticular joints and in partial compensation for the different dilation of ceramics and austenite the faying surfaces are covered with a thin silver layer.

6. Starting Procedure

After complete filling and air-venting the circuit will be closed and the pressurizer put into operation.

When, by means of heating the water, the pressure has reached 15-20 bar, some of the water evaporates over a valve located at the condenser, which can be regulated by a servo-motor from the switchboard.

During the same process a final degassing occurs. The evaporation continues until the level in the separator is reduced to a value corresponding to the operating pressure desired (evaporation time about 4-5 hours).

Then the circuit is closed again and the pressure is increased (corresponding to the test program 50-150). To keep the loop under pressure during the night the installations as described in 2.6.4 have been provided. Before starting a test series the loop temperatures must be equalized. Therefore the pump is started and the mass flow is first passed through the by-pass. The permissible heat-up and cooling speed for the pipe system, as well as for the pump, amounts to $5^{o}C$ per minute.

Depending upon the equalization of the temperatures the mass flow is then also carried through the test section and to obtain the desired operating pressure some power is applied to the test section, or the preheater is started. If the loop is already prepared and has remained under pressure during the night, one needs about 3 hours to reach the operating state. To reduce the operating state of the loop one needs about 1.5 hours.

7. Calibration of the Mass Flow Instruments

Because a great part of the tests performed are made with very small mass flows (down to below 100 l/h) the mass flow measurement becomes difficult.

Besides the diaphragm section described under 4.2, rotameters and turboflowmeters have been available.
Both these last mentioned instruments have been unsuccessful under the given operating conditions. The rotameters are designed and calibrated for even, fixed conditions. A recalculation of the instantaneous operating conditions did not give satisfactory results. The mass flow measurements with turboflowmeters failed through purely technical difficulties. The sapphire seating of the propeller did not withstand the high temperature conditions and fractured after only a few operating hours. For this reason we had to return to the diaphragm measuring section. Although here also several uncertainties had to be eliminated, it could be seen that this measuring method would ensure sufficient accuracy. The standard diaphragm, finished according to the DIN-standardization 1952 are to apply to all tube diameters $D \geqq 50$ mm. The aperture ratios can lie between 0.05 and 0.7.
The diaphragm sections used in the case under review have the following data:

Section I	D = 32.25 mm
	d = 4; 6; 8,7; 10; 13; 18 and 23 mm
Section II	D = 20 mm
	d = 4; 5; 6; 8; 10; 13 and 16 mm.

Because these values lie somewhat lower than the above-mentioned ranges of DIN 1952, each diaphragm had to be calibrated. To reduce largely the possibility of error we made a cold water calibration as well as a calibration under operating conditions - up to 300 °C and 250 bar.

Figs. 11 and 12 show two of the calibration curves obtained. The drawing contains the curve calculated by DIN 1952 as well as the measured values during calibration.

The deviation amounts max. ± 1.5%. The drawing shows that in the case under review the mass flow measurement standardization would also be valid for a non-standard diaphragm.

8. Review of Investigations

As mentioned in the introduction, several heat transfer investigations have been performed in the loop. To give an idea of these experiments some types of test sections are presented and a number of references reported. A major program of investigation has been the heat transfer to water at near critical pressures, particularly the "heat transfer crisis" and DNB [2-10]. Fig. 13 shows a test section used in those experiments.

A further investigation concerned the influence of twisted tapes on DNB in rod clusters (Fig. 14), which is referred to in [11-14]. Burn-out heat flux measurements on 9-rod bundles have been carried out in view of longitudinally and transversally uniform heat generation [15]. Measurements of wall temperatures and of local heat transfer coefficients with coiled tubes and the visualization of flow pattern in an annular test section have been carried out. The last section is shown in Fig. 15.

Future experiments with a 9-rod cluster (Fig. 16) will be concerned with DNB-measurements with nonuniform heating, particularly the influence of various spacer geometries on DNB.

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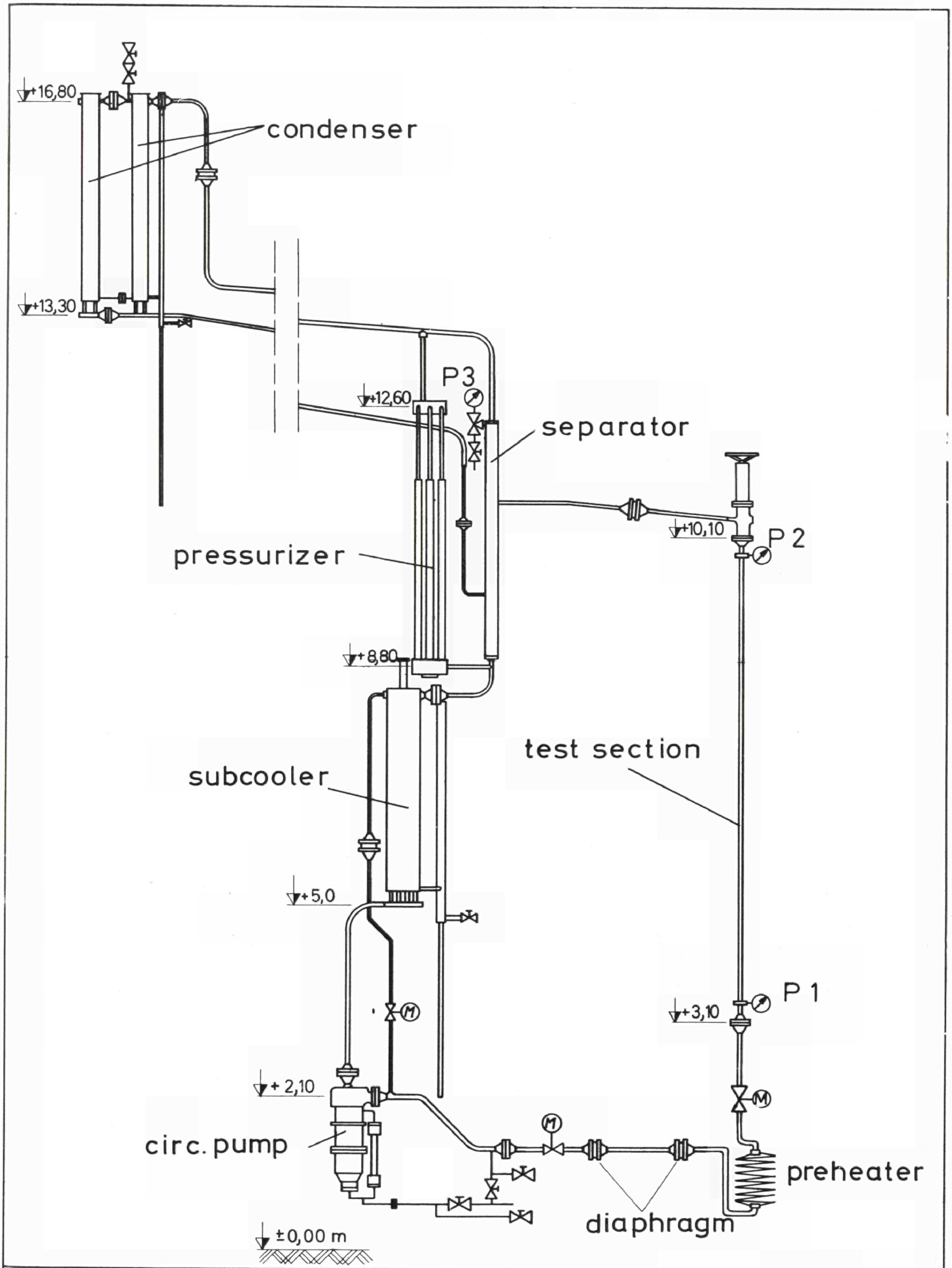


Fig.1 High pressure boiling water loop

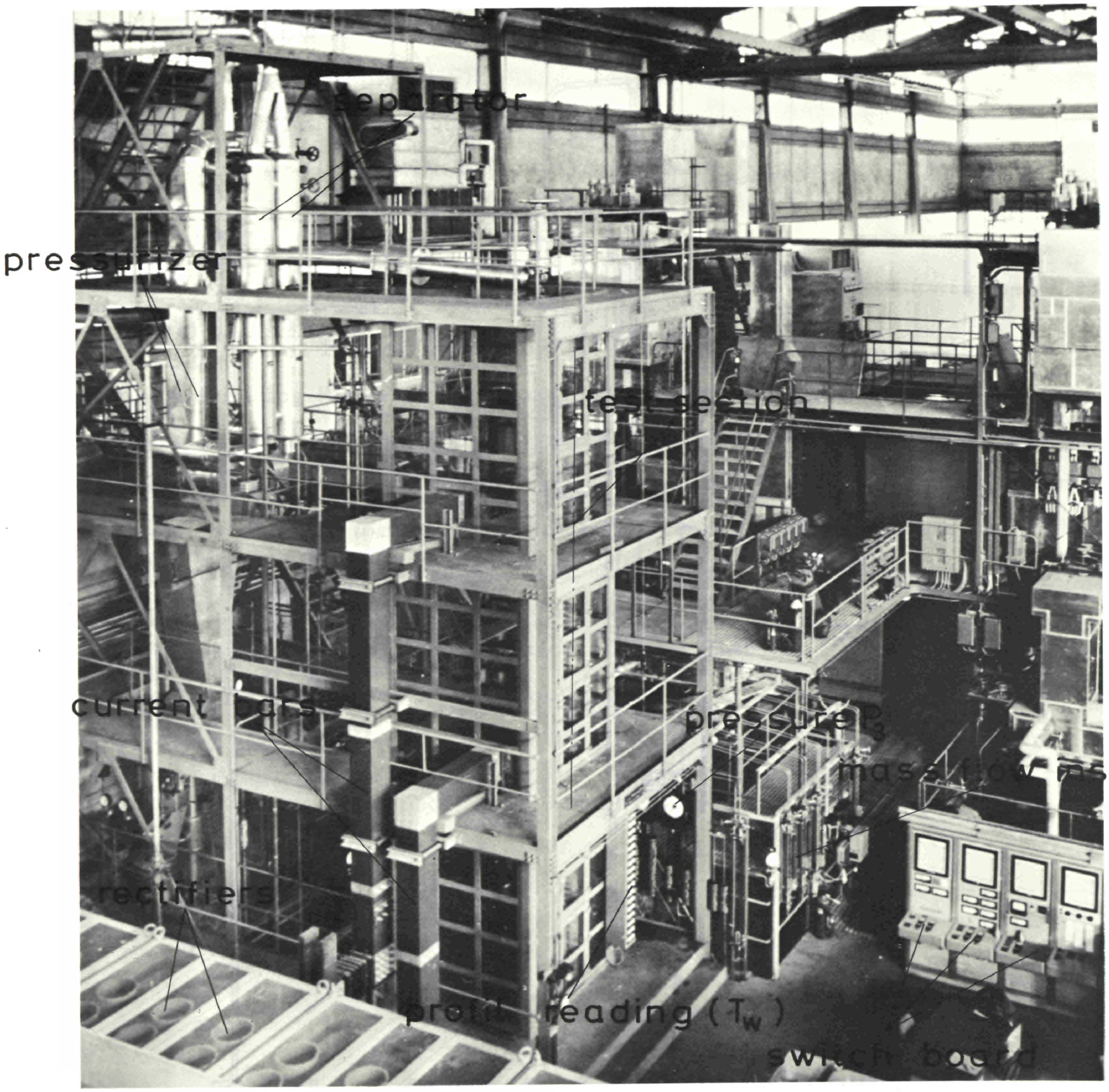


Fig. 2 View of the high pressure boiling water loop

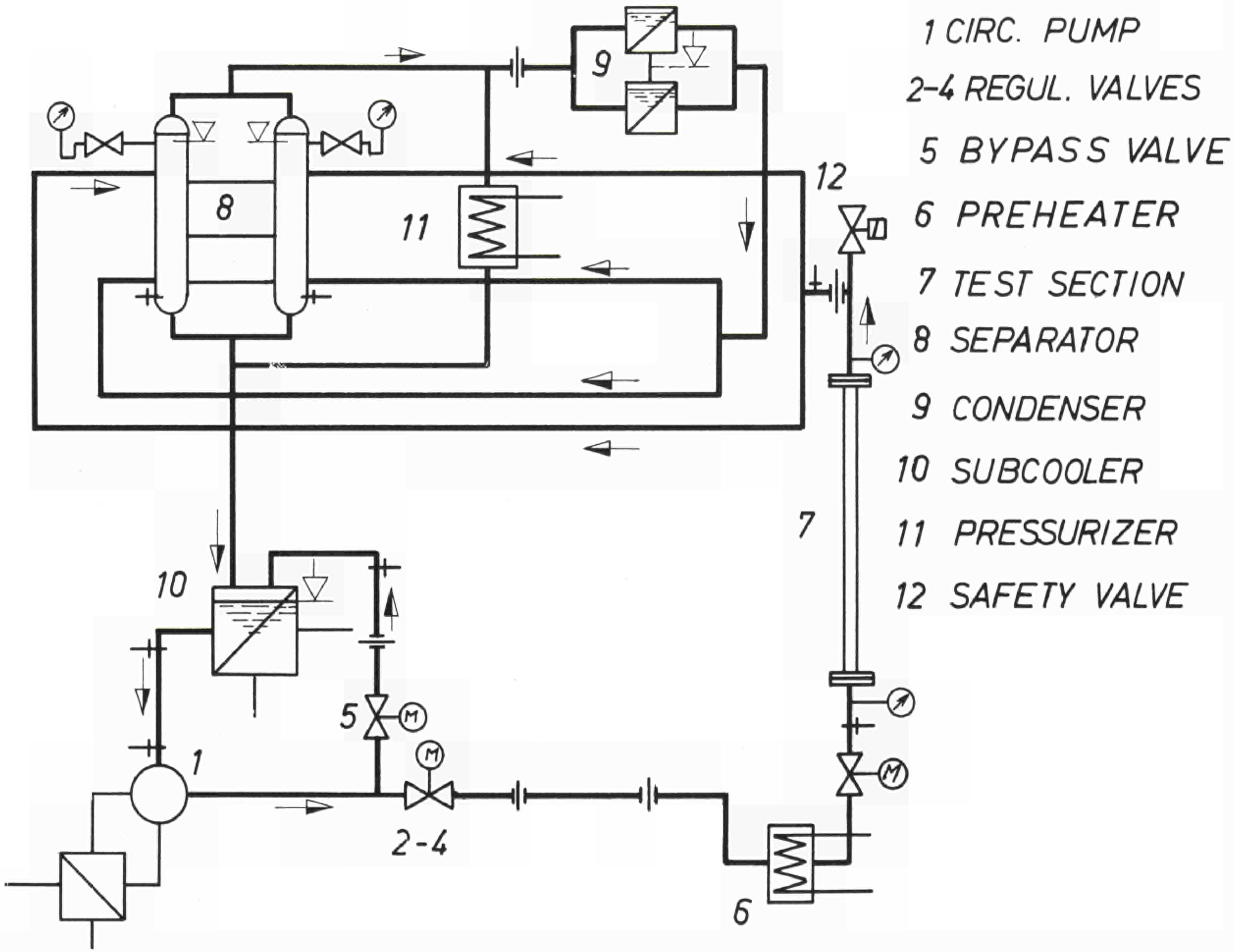


Fig. 3 Massflow sheet

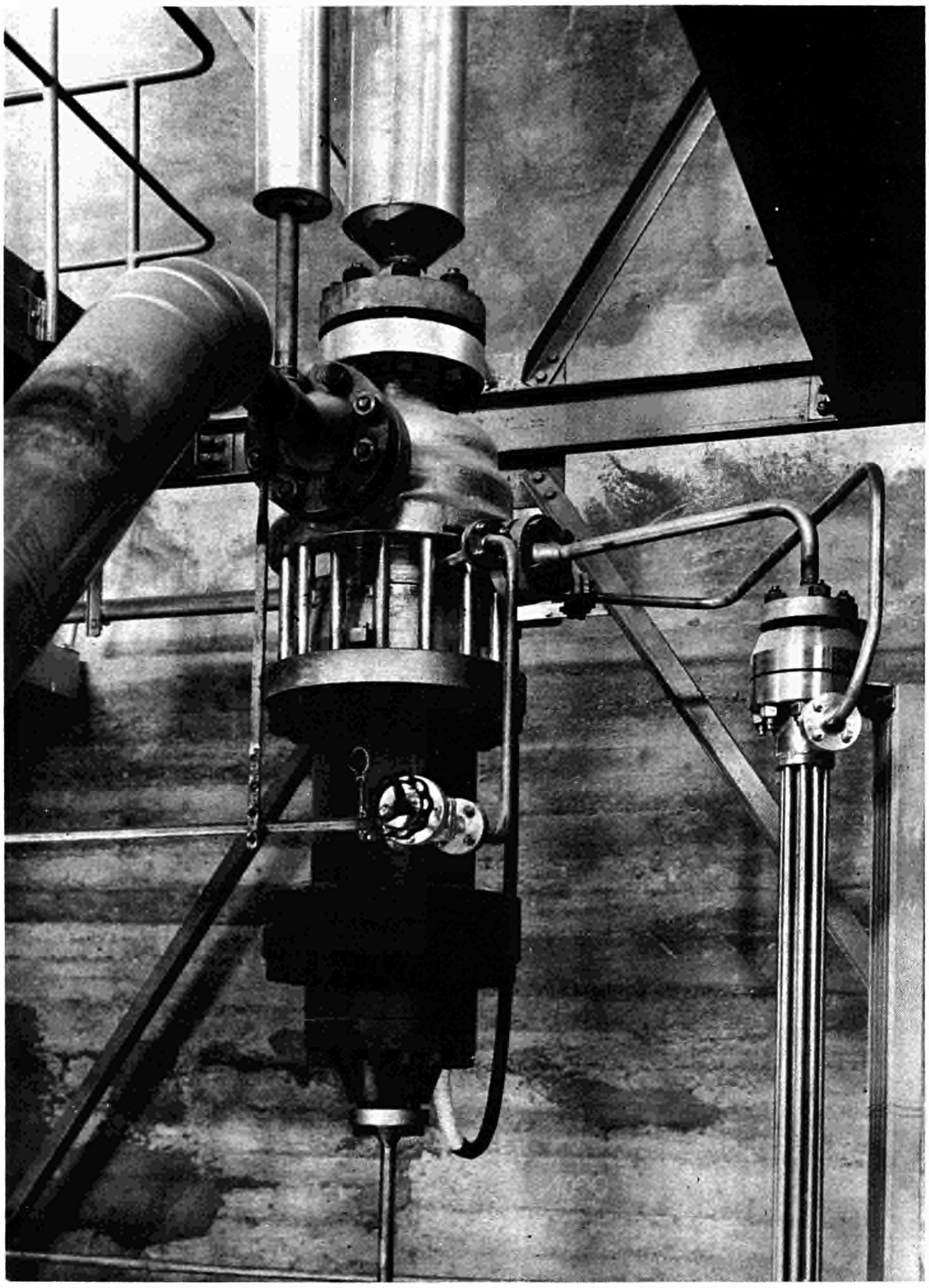


Fig. 4a Circ. pump (KSB)

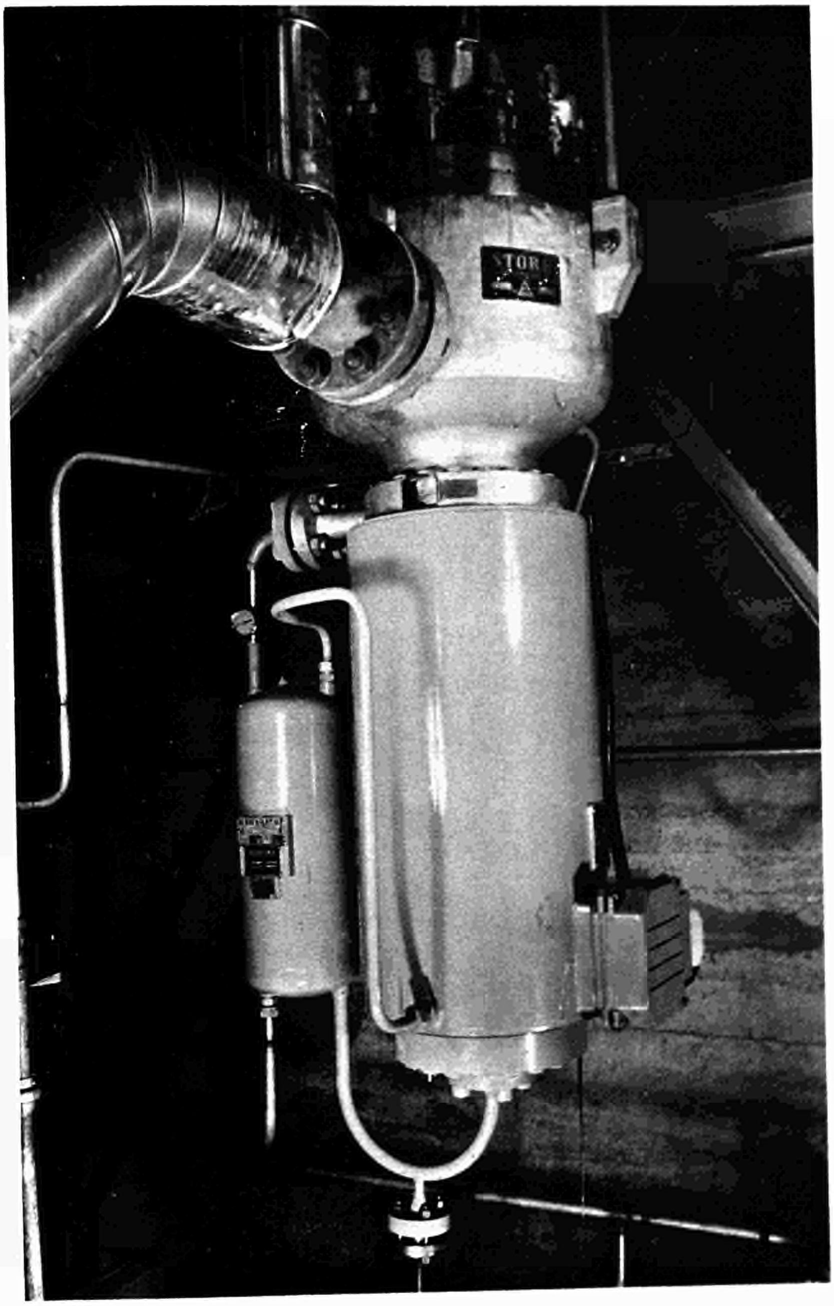


Fig. 4b Circ. pump (Stork)

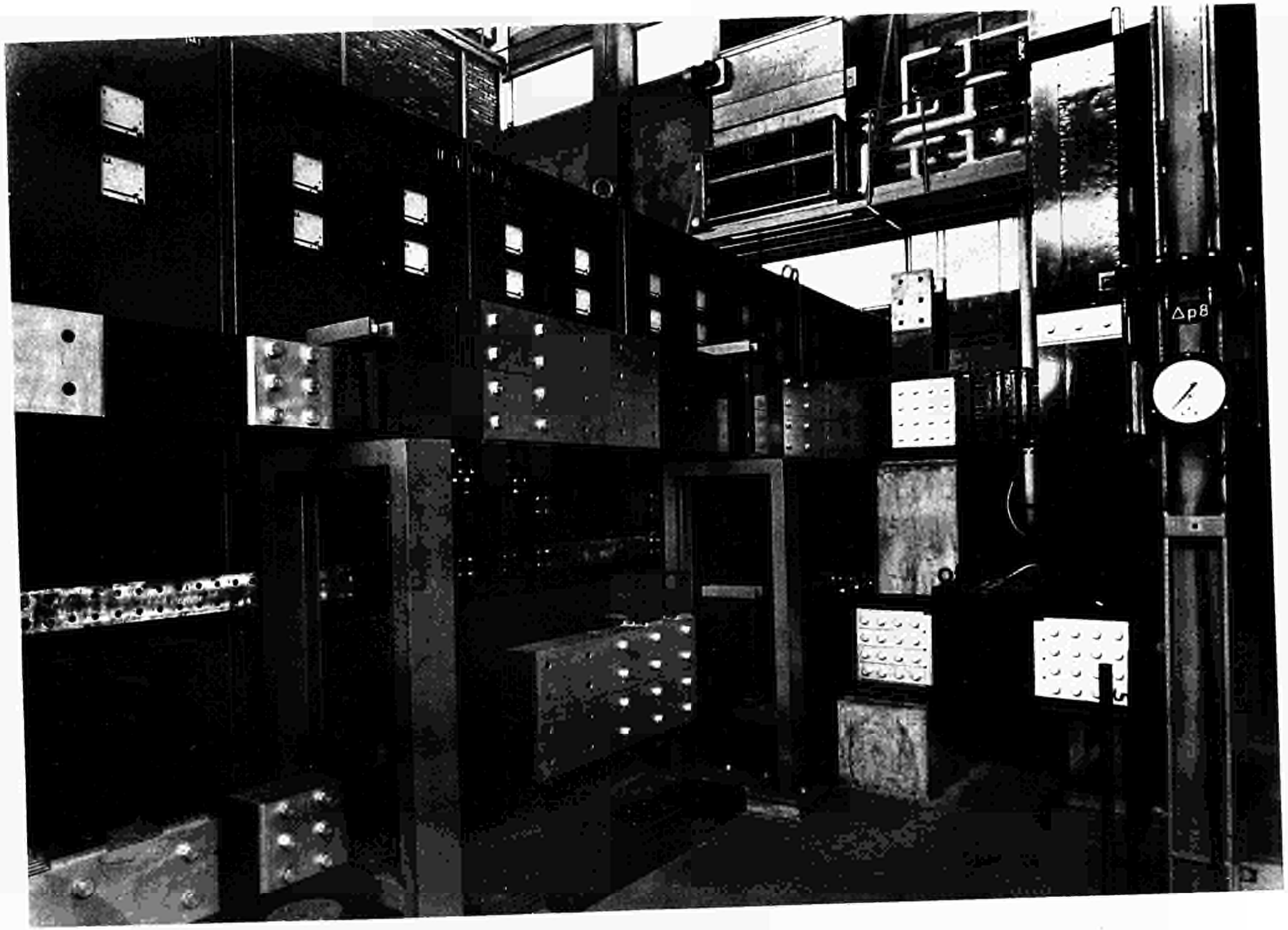


Fig. 5 Rectifier group with current bars and Iso-shunts

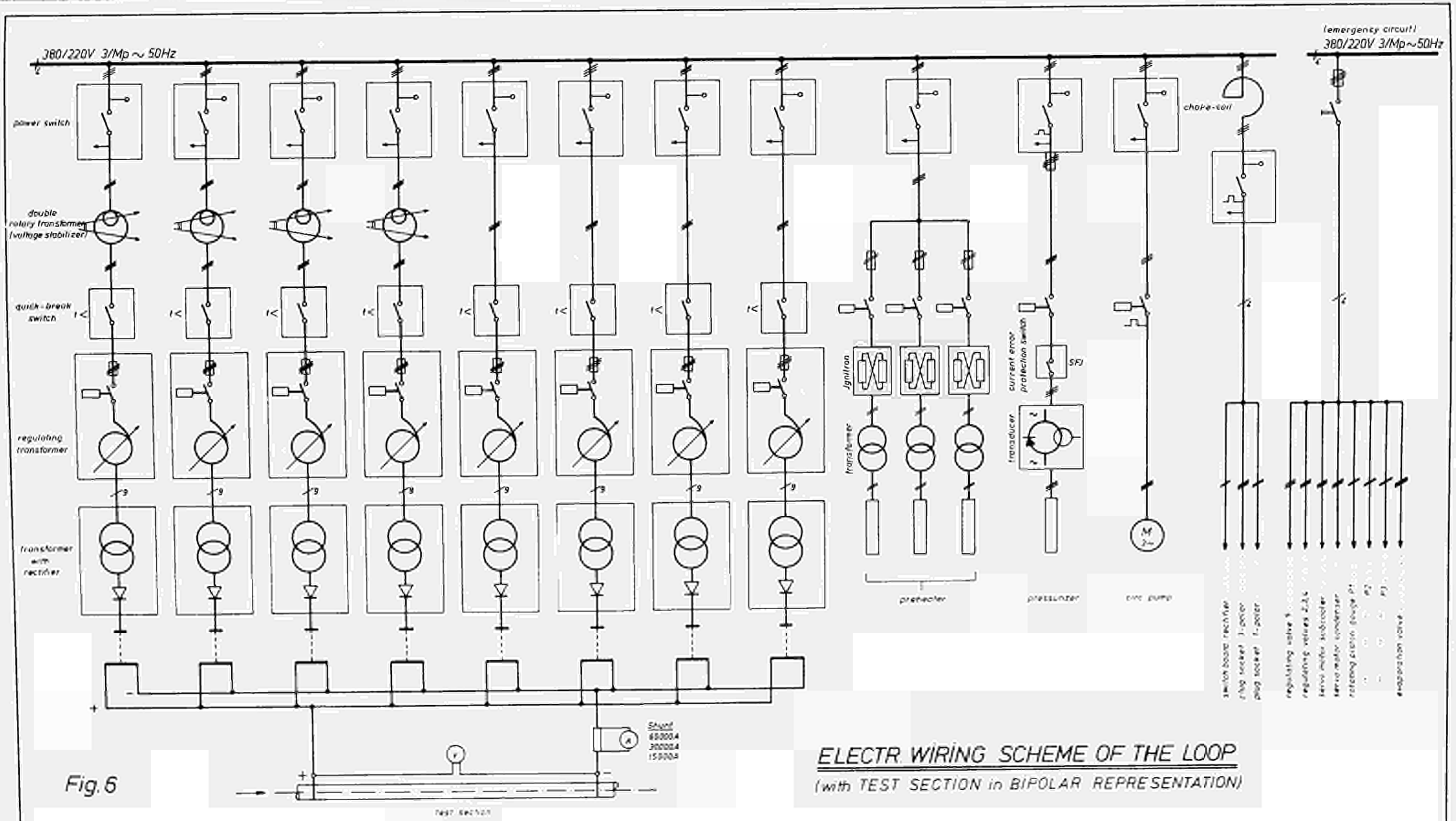


Fig. 6

ELECTR. WIRING SCHEME OF THE LOOP
(with TEST SECTION in BIPOLAR REPRESENTATION)

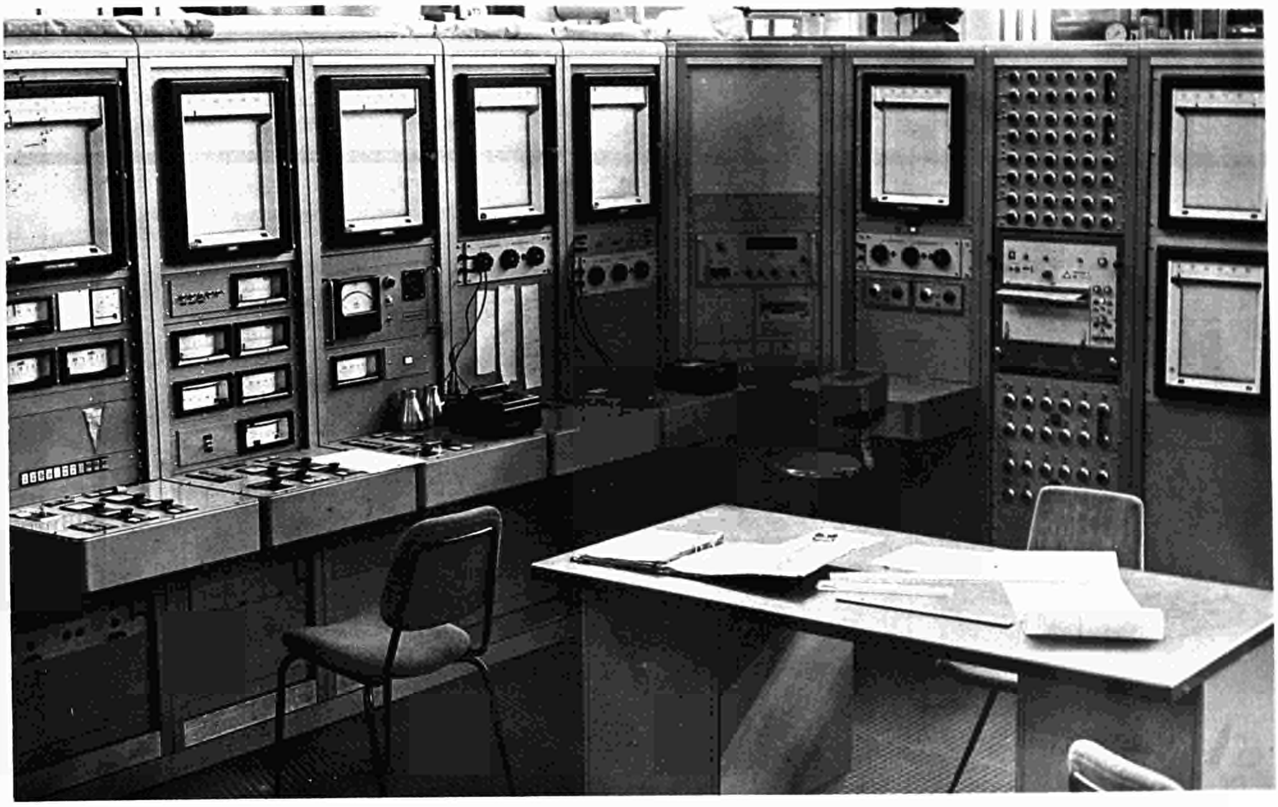


Fig. 7 Control and switch board

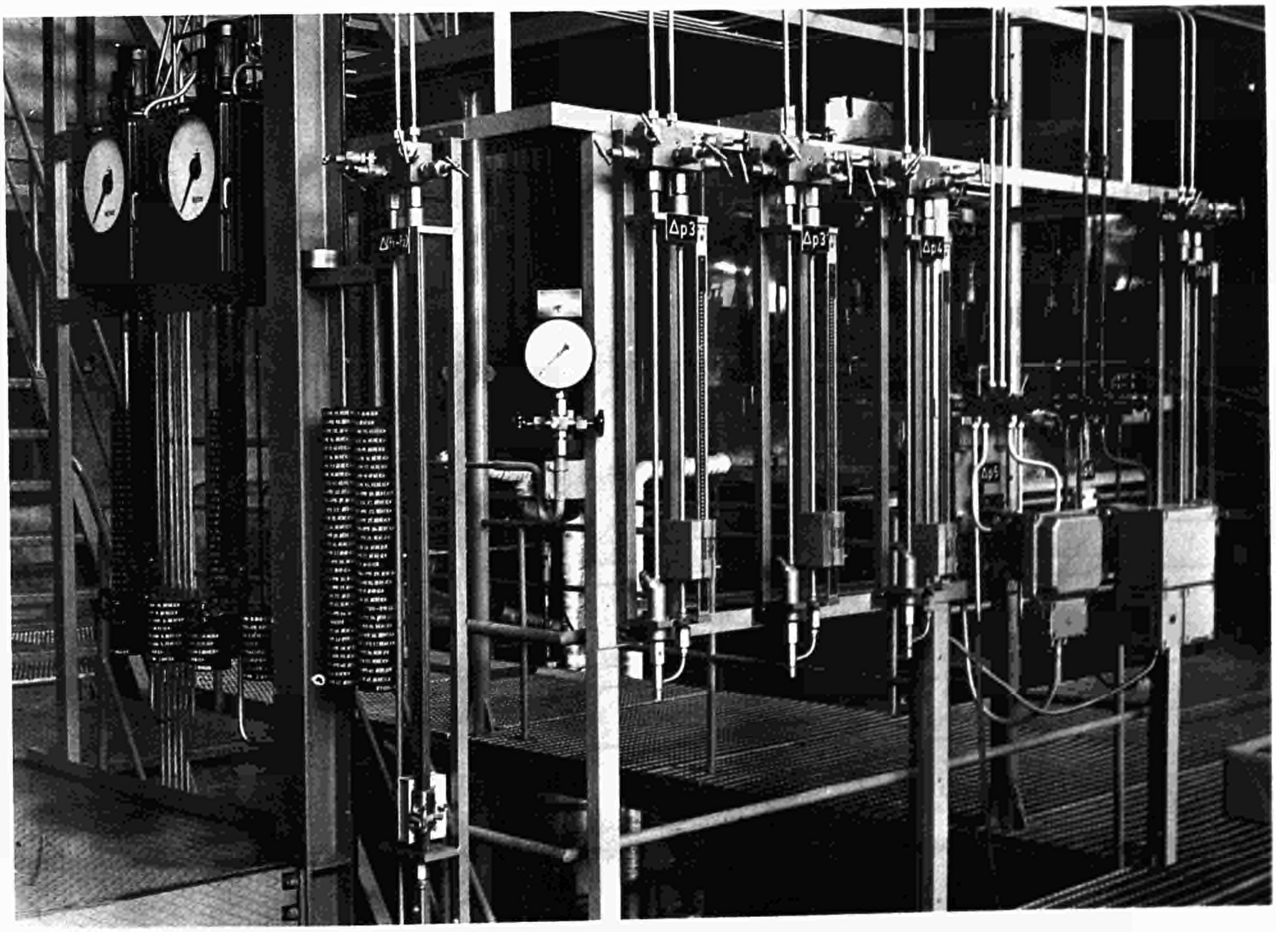


Fig. 8 Massflow- and pressure measuring instruments

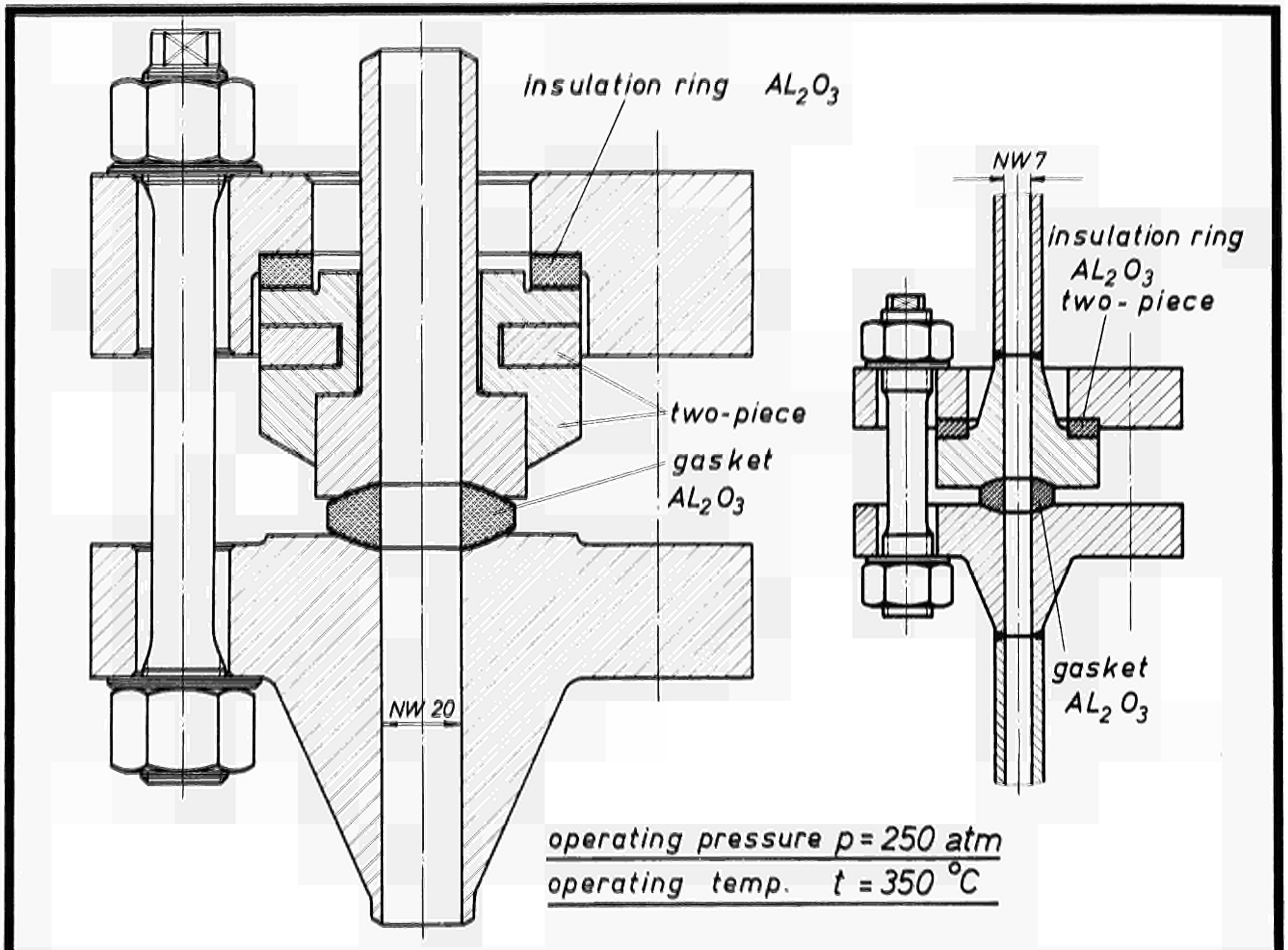


Fig. 9 Electrical flange insulation

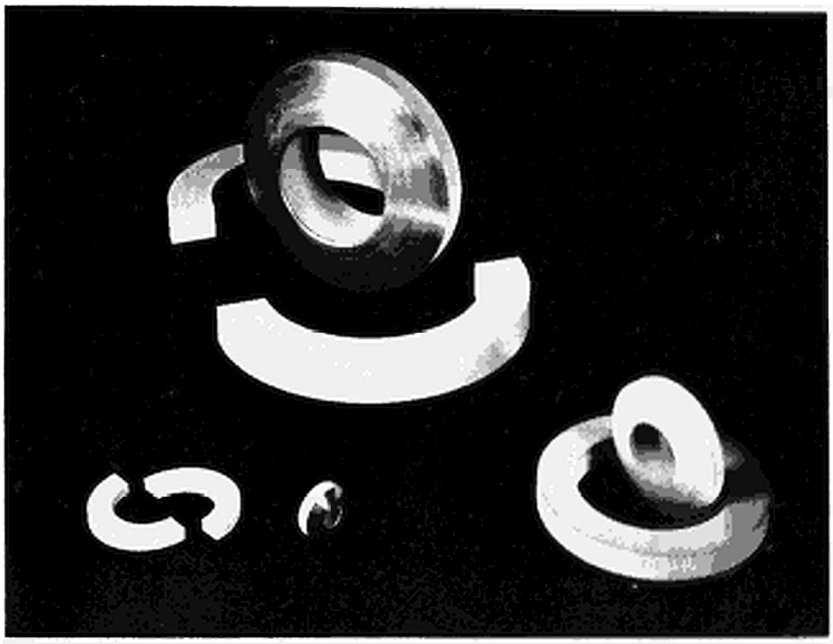


Fig. 10 Insulating rings of SPK - oxide ceramics (Al_2O_3)

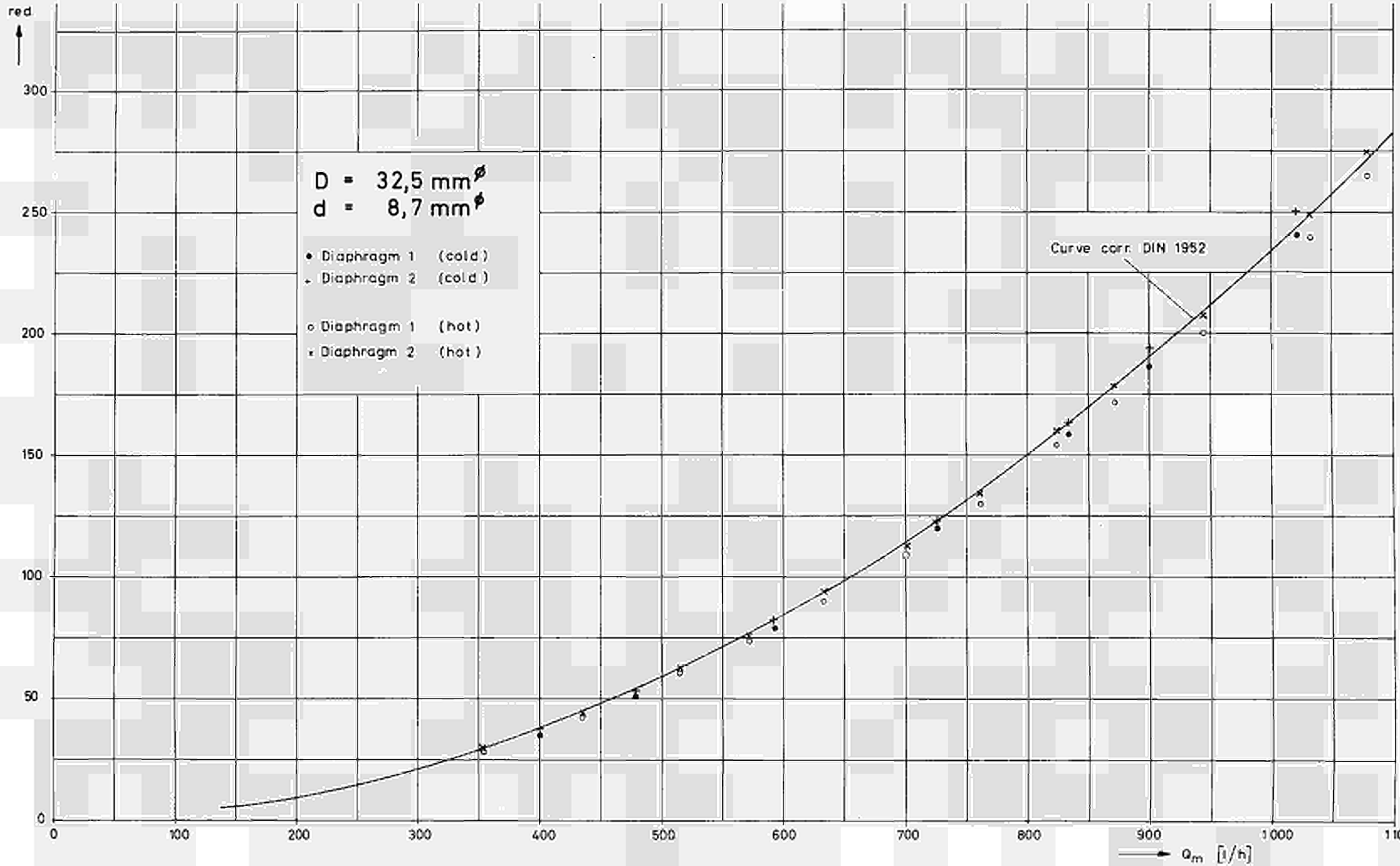


Fig. 11 Calibration curve diaphragm section I

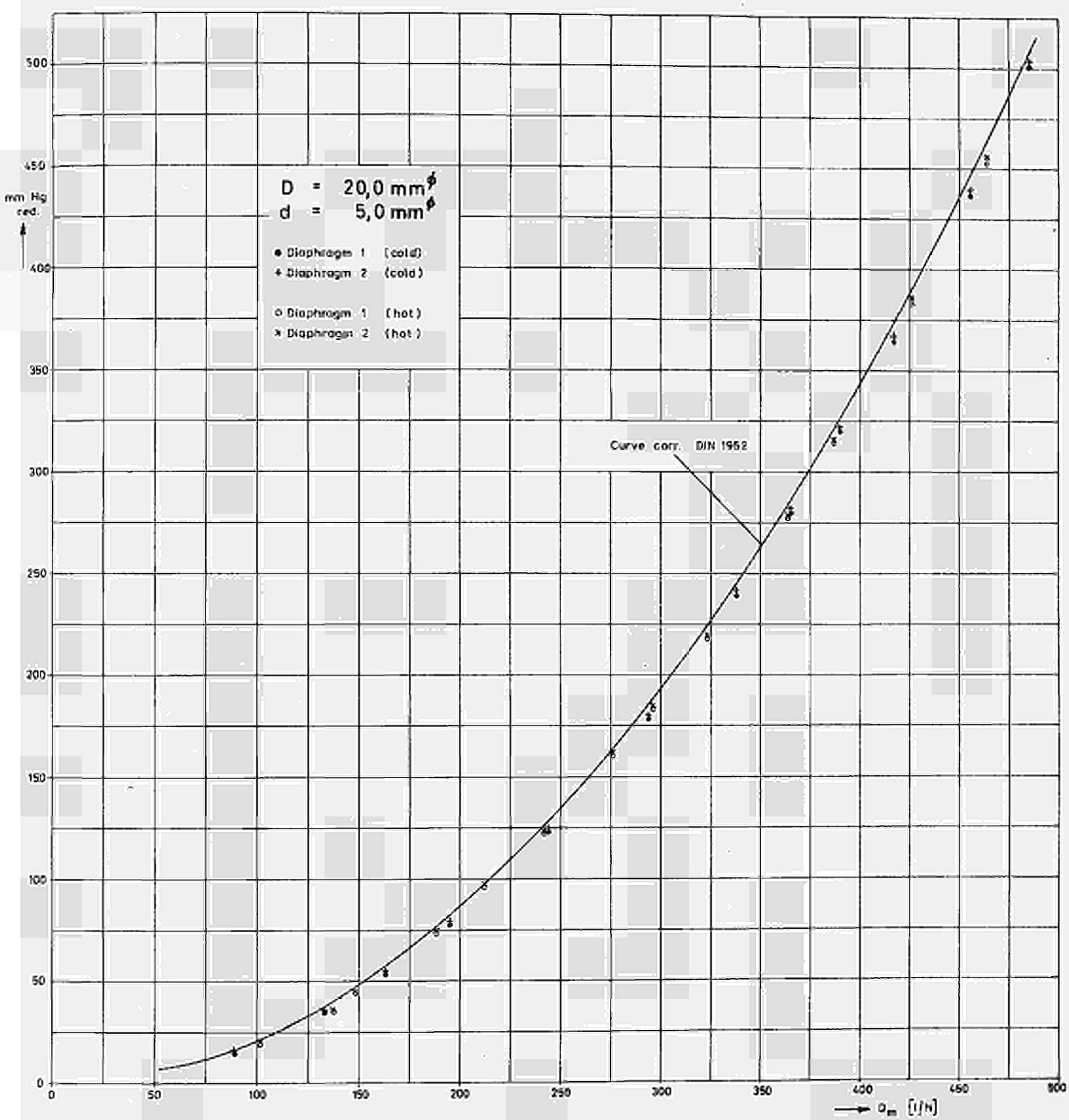


Fig. 12 Calibration curve diaphragm section II

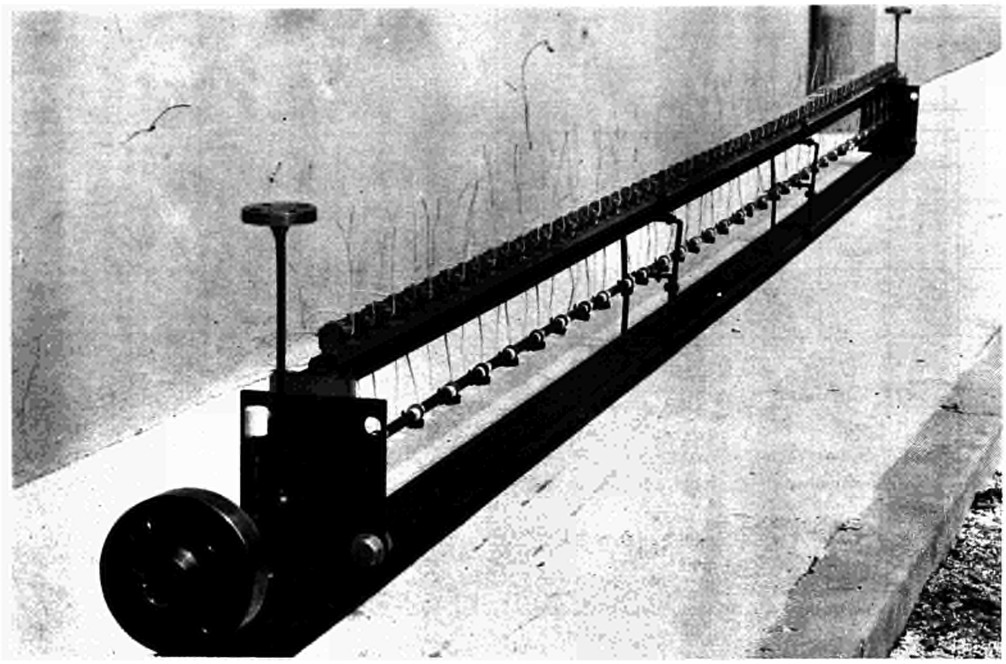


Fig. 13 Test section for investigation of the heat transfer to water at high pressures (d_o = 14 mm, d_i = 10 mm, l_h = 5100 mm)

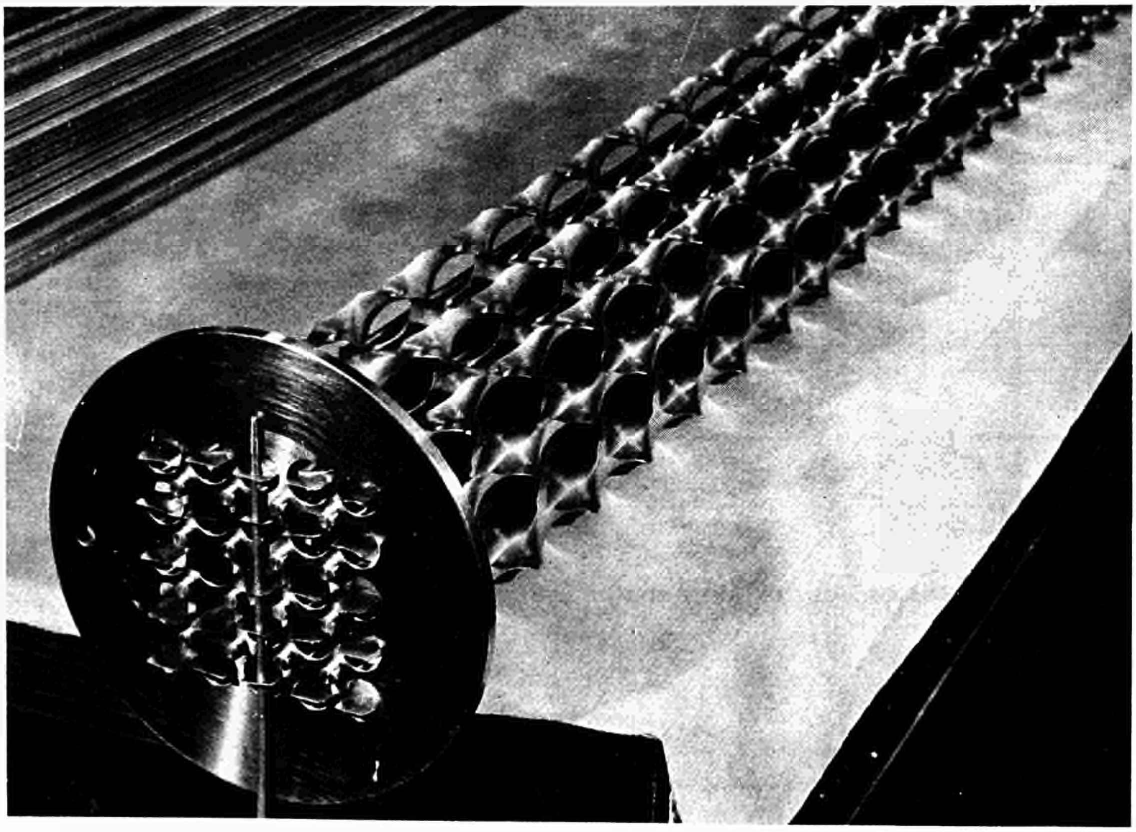


Fig. 14 Rod bundle with twisted tapes (SNECMA)

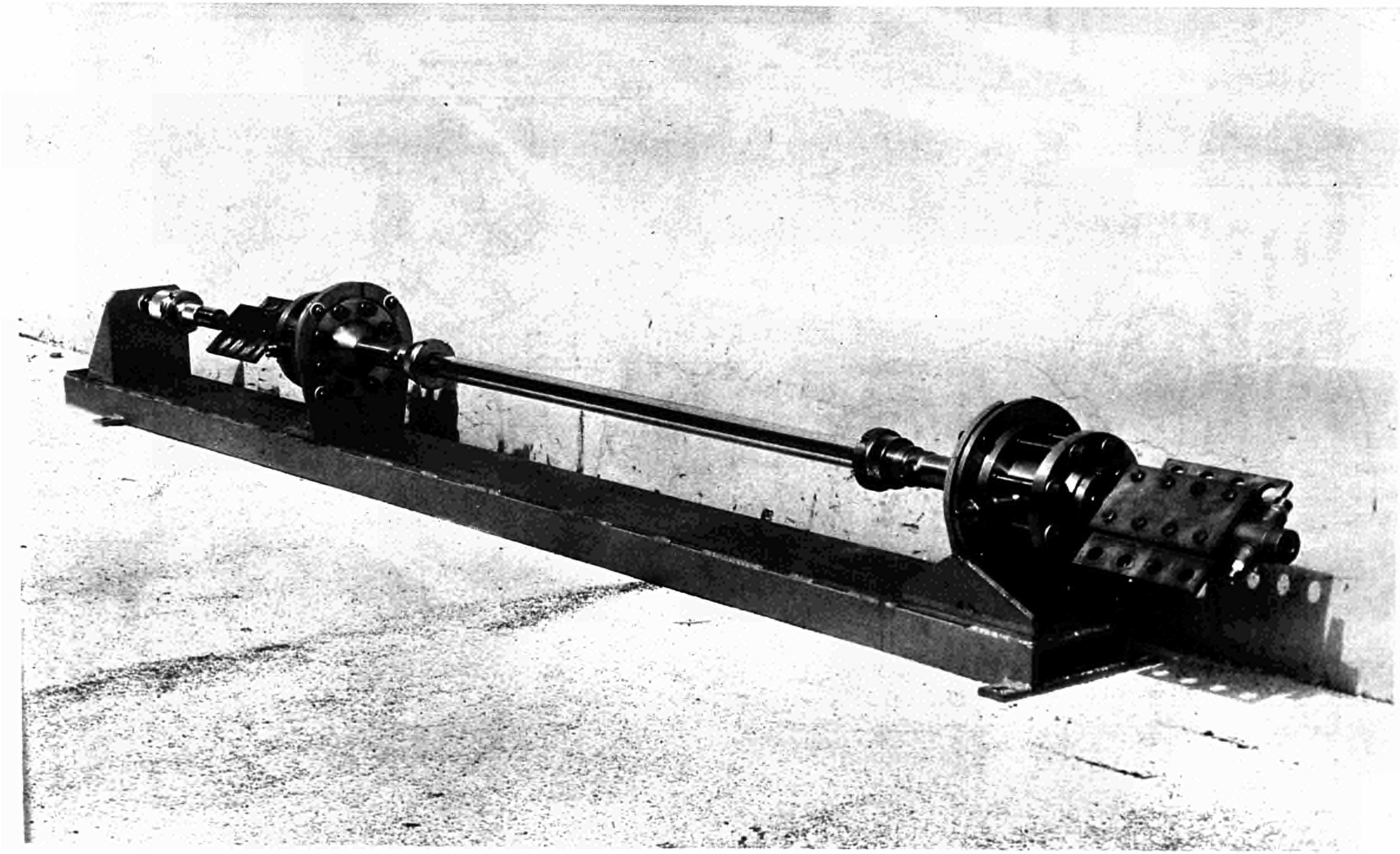
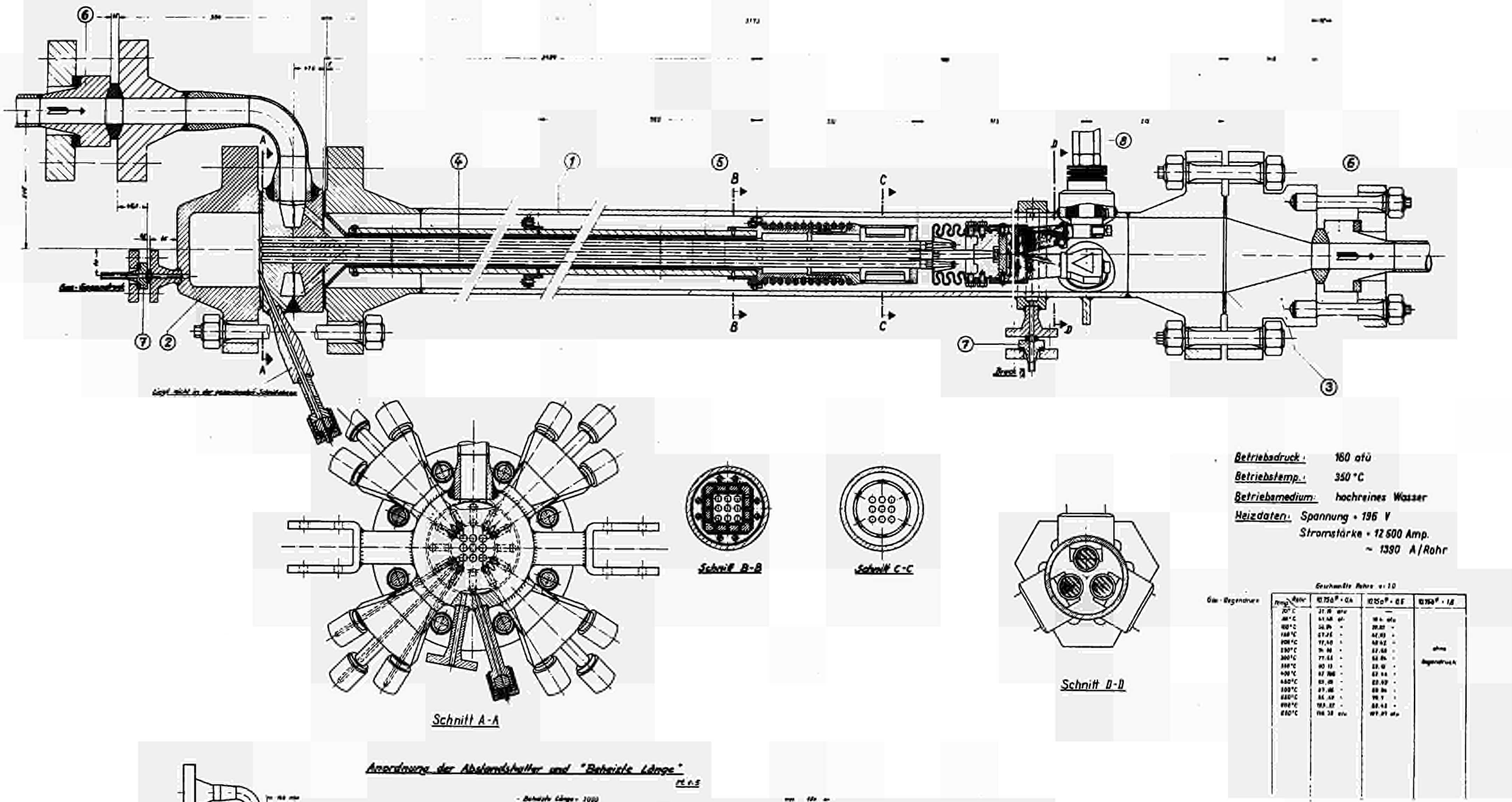


Fig. 15 Testsection for visualization of flowpattern



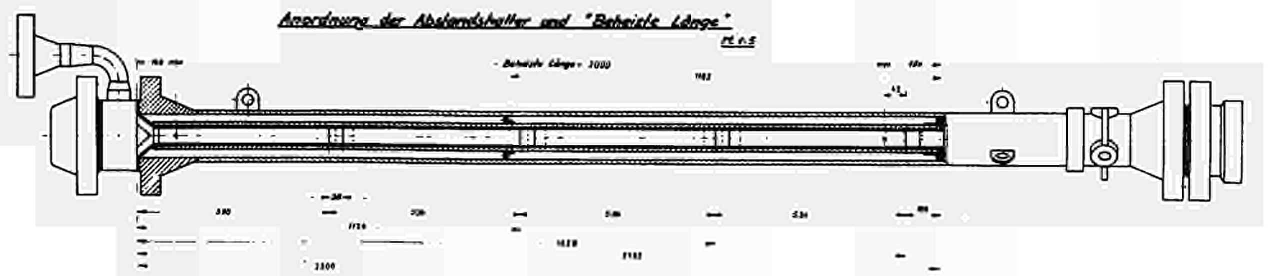


Fig. 16

9-Rod Bundle for DNB-Problems

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Alfred Nobel

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