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ORGANIC IN-PILE-LOOP EXPERIMENT

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Abstract

In order to study organic coolant moderators exposed to the mixed radiation and to the design temperatures and pressures of possible operating power reactors, an in-pile loop is designed, built and loaded into the VVRS research reactor.

Design problems, the experimental setup, operating conditions of the in-pile loop as well as part of the measurements performed during the testing operation are described.

ORGANIC IN-PILE-LOOP EXPERIMENT

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The experimental aim is to study the behaviour of organic coolants under operating conditions of power reactors. The problems to be investigated are partly the chemical changes induced in various coolants by irradiation within the reactor, partly the effect of these chemical transformations on characteristic properties concerning engineering and technology of moderators and coolants to be used in organic power reactors.

In-pile-loop experiments are devised for radiation chemical and thermodynamical measurements, corrosion studies, possibly fuel element tests, performed in a restricted area under simulated operating conditions of the planned power reactor.

The test loop is actually an isolated in-pile section of a power reactor loaded into another operating reactor in which the coolant moderator system, heat generation, cooling, in other words the primary, ambient circuit of a fuel element in the reactor under consideration are being simulated. It is usually a closed coolant circuit with or without an uranium fuel element, suitable for reproducing and measuring the combined effect of the power reactor design parameters.

Before going into problems encountered in designing an organic loop, it seems of interest to recall some characteristic properties of organic coolants such as

1/ Lower saturation pressure than that of steam at the same temperature	e.g.at 350°C 168.8 ata for steam 5,74 ata for diphenyl. Thus the latter enables the use of less heavy structural material, of particular importance for pressurized vessels.

2/Negligible corrosion

The corrosion observed on Al- alloys and carbon-steel was not more than that produced by water on stainless steel. For U-metals and U-alloys the corrosion caused by diphenyl was far less than caused by water under similar conditions.

3/No activation process

Since the organics in question do not necessarily contain oxigene, the liquid itself will not be activated, unless it contains impurities.

4/Less wear of tube walls

Considerably less wear was observed on carbon steel and stainless steel for diphenyl than for water flow.Diphenyl shows in addition good lubricating properties.

Drawbacks

1/Radiolysis and pyrolysis when irradiated at higher temperatures in a reactor

Exposed to fast neutrons and gamma radiation the molecules dissociate due to ionization and recombine to compounds of higher molecular weight /e.g.diphenyl recombines to terphenyl releasing gas in the process/.At temperatures above 400^{o}C there is a marked disintegration due to pyrolysis.

2/ Lower heat transfer coefficient

Due primarily to the lower thermal conductivity of diphenyl e.g.at 260^{o}C the heat transfer coefficient for diphenyl is only 22% that for water.

3/ Higher melting point

The melting point of a number of organic coolants is above 0^{o}C and this may cause difficulties in the starting up of a reactor.

Considering now these drawbacks, the disintegration affecting power reactor economy through increased make-up costs, could be overcome as follows:

1/ Use of low cost coolants

2/ Use of coolants less subject to polymerization

/Actually, to find such coolants is the main purpose of present experiments./

3/ Addition of inhibitors

4/ Purification of the high boiler contaminated liquid, possibly the immediate use in the primary circuit of an economical and simple regenerating technique.

The lower heat transfer coefficient may also be compensated for by

1/ increased fuel element surfaces /fins/

2/ surface boiling heat transfer by which the heat flux becomes more independent of coolant velocity, since in this case the heat transfer is proproportional to the third power of the temperature gradient between fuel element surface and liquid.

The organic test loop built at our establishment differs in principle of the usually adopted scheme seen in Fig.1., since it had to meet some special requirements:

1/ Short circulation path for minimizing the time while the coolant is not being irradiated. For this reason the whole circulation was kept within the reactor shell and takes place in a Field tube system using a built-in centrifugal pump as circulator, while it is being cooled by the water from the cooling system of the reactor. This arrangement helps in addition to achieve the following objectives:

2/ Low consumption of experimental liquid, since the coolant to be tested may be expensive or not readily available, therefore also the sizes of ancillaries, containers, pipings etc. are restricted to the minimum.

3/ Adequate safety, because no contaminated liquid can leave the reactor but when sampled from the pipes mounted for this purpose on the reactor cover.

In addition we had to provide for

4/ Possibly continuous operation in coordination with that of the reactor which serves simultaneously as a radiation source for physical experiments and for isotope production. This may necessitate discharge from the loop during operation and securing the continuance of reactor operation for a certain time, even in the case of loop failure.

5/ Easily removable loop channel and accessible components permitting quick exchange if needed, since it may involve radiation hazards.

Block diagrams of loop and ancillaries are shown in Figs 2 and 3, respectively. A schematical drawing of the connections and the general out-lay of the loop and the loop channel in the reactor hall are shown in Fig.4.

In principle the loop is an "U" shaped tube /1/ with the liquid feeder tank /2/ at one, and the expansion tank /3/ at the other end. Actually, the two shanks are combined into an outer and inner tube giving thus a so-called Field tube system in which the liquid flows downwards in the inner, and upwards in the outer section. The two tubes communicate at the upper and lower ends. The centrifugal pump is mounted on the inner tube. The closed circuit is connected by the expansion /5/ and feed-discharge /6/ pipes to the expansion tank and the discharge tank, respectively. The latter permits the system to be refilled or discharged even during operation.

A bypass of the main circuit is provided for degassing by means of the degasifier /8/ mounted immediately under the reactor cover. Both the liquid and the gas generated in the process are sampled from the degasifier through pipes /9/ and /10/, respectively.

Feed and discharge gas pressures are controlled from a nitrogen gas container /19/.

The Field tube is contained in an Al insulating can /11/ and surrounded within the can by an insulating blanket either of nitrogen /12/ or of helium /13/ depending on the measure of heat transfer required from loop channel to the cooling water of the reactor.

The built-in centrifugal pump /4/ circulating the experimental liquid is driven by air motor /14/. The compressed air duct /15/ and the water cooling system /16/ of the pump are also shown in the figure. Both the expansion and the feed tank are provided with vapour condensers /17,18/. The system is kept under pressure from the gas container /19/. The exhaust tank /20/ is connected to the degasifier as well as to the venting and safety valves of the loop and vents into the reactor stack /21/. The cooling water is delivered to the condensers and exhaust tank through leads from the cooling water pump /22/. The insulating gas is discharged from the aluminium can /11/ through gas duct /24/ into the exhaust tank.

The natural convection within the inner Field -tube is sustained by means of gas blanket /25/. In addition to this safety measure, there is an external pump available on the reactor cover /26/ to keep the liquid circulating in case of emergency.

In addition to above, there are following devices to be seen in Fig. 4.: Pressure manifolds of compressed air /27/ for the air motor and for system pressure /28/ and for the insulating gas /29/ within the Al-can, centrifugal pump and vacuum pump drains /30,31/ and a receptacle equipped with a level gauge /32/ for the liquid leaking from the centrifugal pump.

The work of the built-in pump is taken over by the external pump upon closing the upper vent of the inner Field tube by using flap /35/.This enables the external pump to force the liquid through the delivery pressure tube under the flap into the inner Field tube and on its way through the outer tube and expansion pipe /5/ into the degasifier /8/ from where it returns through pipe /36/ to the sump of the external pump. Thus, the emergency circuit is closed. The ideal solution, of course would be an automatic switch-over to the emergency circuit. This would necessitate the automatic closing of the flap with a simultaneous locking of the centrifugal pump shaft to prevent it from acting like a turbine. Since such a device would overcomplicate the design of the built-in pump, and make it too bulky, it was decided for the time being to use manual operation and to possibly avoid the need of external circulation.

Controlling, measuring and monitoring system

The block diagram of the loop control system is shown in Fig.5./The general outlay is to be seen in Fig.6./

1/ Thermometers

The temperatures at various points of the loop are measured by thermocouples or resistance thermometers coupled to temperature recorders.

a/ Thermocouple detectors are used with two line- and one point recorder, all EP-09 type. The thermocouples are positioned to duplicate the measurement at three main points, namely liquid temperatures at the inlet, outlet and below the heater /T1,T2,T3,T4,T5,T6/.

b/ Resistance detectors are used with two MSzR1 type recorders. One for measuring the system temperature, the other for the expansion temperature /R_1, R_2/.

2/ Temperature control

Two ways are available for setting the temperature at a given value. The first is to force an appropriate mixture of helium and nitrogen gas into the insulating blanket of the pump /the conductivity of the insulator is known to depend on the helium to nitrogen ratio/. The second is to vary the speed of the air motor of the built-in pump. The use of the latter method is illustrated in Fig.T5. The electro-pneumatic, P1-type control system consists of a thermocouple, a pneumatic membrane valve and the variable speed air motor.

3/ Monitoring system

The signals of safety and failure monitors are transmitted to a receiver unit on the reactor control panel.

a/ Overspeed

A tripping circuit prevents an overspeed of the air motor that is likely to endanger the safety of the operation of loop or reactor because of excessive mechanical vibration.

b/ Overheating /T_5, T_2/

The temperature is monitored by the EPP type 1,2 and the MSZR1 /R_1,R_2/ type 1,4 recorders, each of them giving off light signal plus audible warning at a given temperature and tripping the heater if the temperature continues to rise.

c/ Liquid level

The liquid level in the degasifier is monitored by means of an inductive transmitter connected to a receiver equipped with a phase discriminating triode.

d/ Air motor leakage indicator

Buoyant contact transmitter connected to a relay receiver giving off light and audible warning signals.

The positions of the various safety monitors are shown in Fig.5.

e/ Decrease in system or insulating gas pressure as well as variation in inner gas blanket pressure are monitored by light and audible warning signals.

The positions of the various safety monitors are shown in Fig.5.

Preliminary operation tests and measurements

The originally planned heating of the loop by an EK-10 type uranium rod, simulated in off-pile tests by an electrically heated mock-up fuel element, was eventually replaced in the in-pile version by a 4kW electrical resistance heater mounted on the upper end of the outer Field tube. Additional heating is due to the mixed radiation from the reactor core. This permitted some further modifications of the original design e.g. omission of the insulating gas duct of the inner tube in the in-core section since without uranium-heating it was not necessary to sustain natural convection, while the amount of liquid circulating within the core could be increased.

In order to obtain true information from loop experiments the parameters to be measured must be close to those prevailing in operating power reactors.Furthermore the operation both of loop and reactor has to continue even at extreme values of these parameters.

The in-pile rig was positioned at ghe 9/8 core position of the reactor and the γ -dose rate as well as the fast and thermal neutron fluxes at this position were measured.

Off-pile tests

Using a mock-up fuel element, the effect of natural convection on fuel element surface temperature upon tripping of the forced circulation was investigated.

It is apparent from Fig.7. that the ceasing of forced circulation results in a sudden rise of temperature /as measured at the mock-up element surface,e.g. a temperature rise from 82°-C to 157°C in about a minute was observed for 600 W heat output upon interrupting the forced circulation rate of 3,6 m/sec/.In a short while the cooling effect of natural convection makes itself felt, the peak temperature rapidly drops by 18-19° within 1,3 minutes and continues to decrease for about 5 minutes then it starts again to rise gradually almost up to the peak value. Restarting of the forced circulation results in a steep decrease in the temperature curve. The diagram shows the rather poor cooling effect of natural circulation. The temperature decrease on heater surface is only about 4°C in the present case. Consequently natural convection would not be sufficient to ensure safe operation at the rated 370-380°C fuel element surface temperatures. The maximum cooling rate observed at the onset of natural circulation, however, is useful for decreasing the peak temperature in 1-2 minutes.

The effect of the variation in pumping speed /flow rate/ on liquid bulk temperature was also investigated. It was found that an increase from 1000 to 7000 rpm did not reduce the bulk temperature by more than 12-13°C. Of course, a decrease in heat output is much more effective for reducing liquid bulk temperature, but we were interested above all in the effects of natural convection and of speed variation in the case of 2 MW reactor power.

In the out-of-pile experiments the heat output of the mock-up fuel element could not be increased above 1,8 kW for insulation sake and also because of dimensions so that test runs were performed at 600 W.

Investigating the insulating effect of the two kinds of insulating gas, the Al-shell was filled once with helium known to be of better conductivity, then with the less conductive nitrogen. It was found that at 600 W heat output, 2300 rpm pump speed and 18°C cooling water temperature /in off-pile tests the rig was placed into a cooling water tank/ the change in liquid bulk temperature due to the difference in insulating gas was not more than 6°C.

The temperature curves shown in Fig.8,9,10 have been measured under various conditions of in-pile runs, as seen from the legends. These temperature values are due to the mixed radiation of the core only, since the electrical heating was not turned on. Further experiments are still under way.

Thanks are due to a number of colleagues and technicians for useful cooperation and assistance in carrying out the work reported here.

Data

Neutron flux /without screening/ in the 9/8 in-pile section /values measured at the Institute/	
maximum thermal neutron flux	$2,37 \cdot 10^{13}$ n/cm^{2}sec
maximum fast neutron flux	$5 \cdot 10^{12}$ n/cm^{2}sec
Maximum fast neutron dose rate calculated for experimental liquid	50 M rad/hour
Maximum gamma dose rate calculated for experimental liquid	191 M rad/hour
Dose rate integrated over core height:	
Integrated fast neutron dose rate	$2,2.10^{24}$ q.eV /hour
Integrated gamma dose rate	$1,18.10^{25}$ q.eV /hour
Liquid circulated in the in-pile loop	8,5 litre
Liquid in the in-core section	949 cm^3
Liquid sample per sampling process	50-100 cm^3
Inactive, liquid discharged with sample	200 cm^3

Gas sample volume	50 cm^3
Normal speed of circulating built-in pump	3000 rpm
Delivery rate at normal /3000 rpm/ pump speed	0,64 lit/sec
Flow rate in in-core section at 3000 rpm	2,04 m/sec
Delivery height of pump at 3000 rpm	190 mmHg
Air motor speed variable in the range	1000-10000 rpm
Liquid bulk temperature due exclusively to gamma heating at 2 MW reactor power	145° C
Liquid bulk temperature in in-pile section only for electrical heating at 3,3 kW heat output	about 155°C
Rated system pressure	32 atm
Rated system temperature	450°C
Construction material	stainless steel

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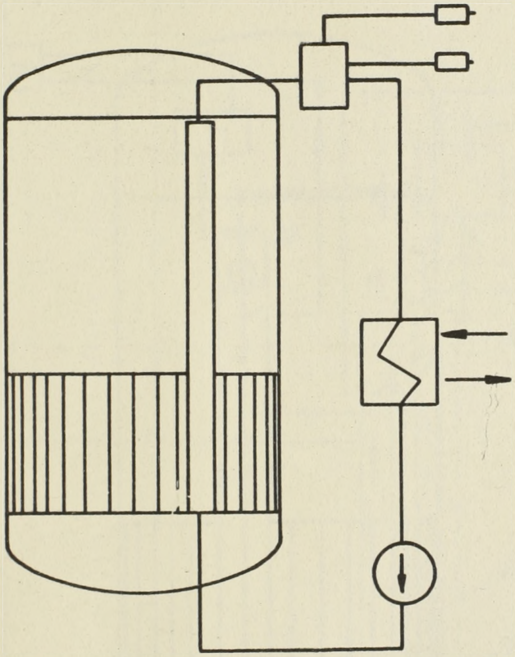

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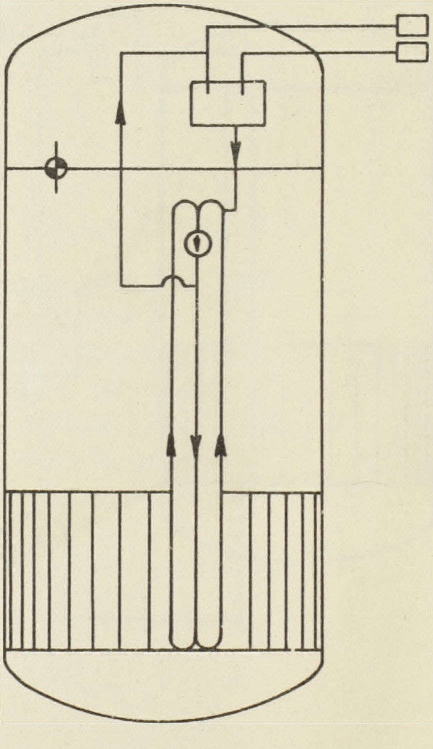

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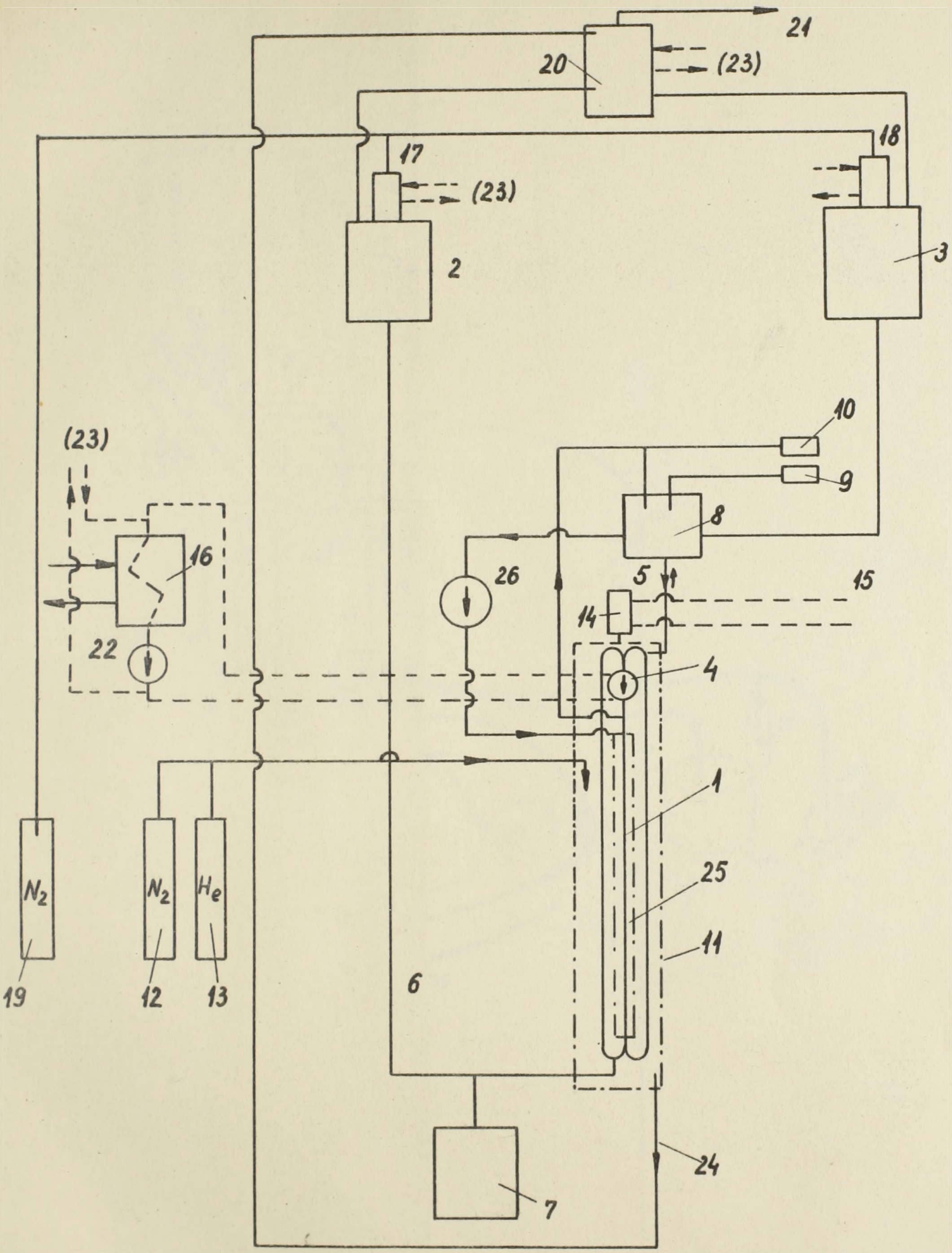
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17
(23)
18
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8
(23)
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26
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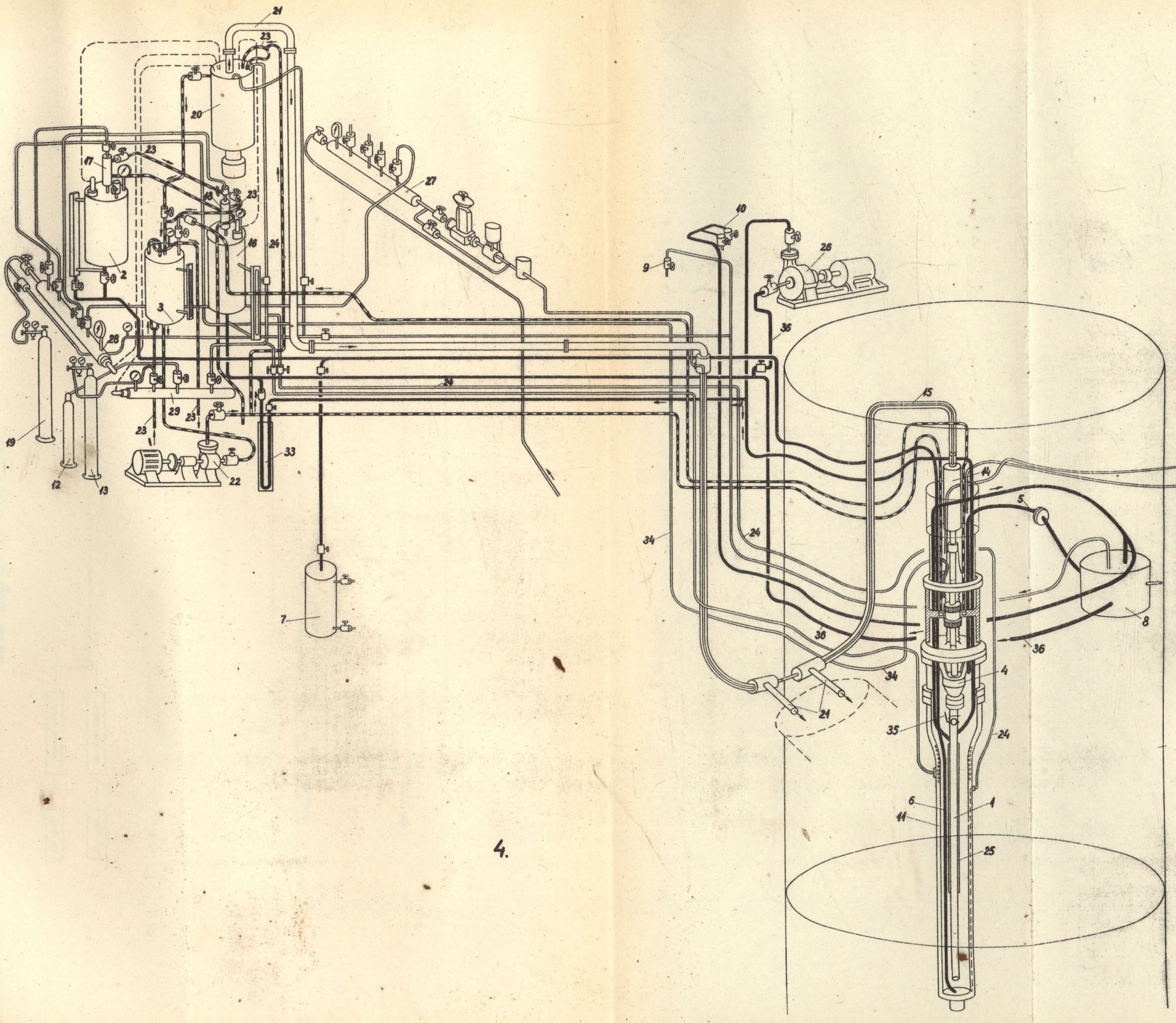
12
13
6
24
7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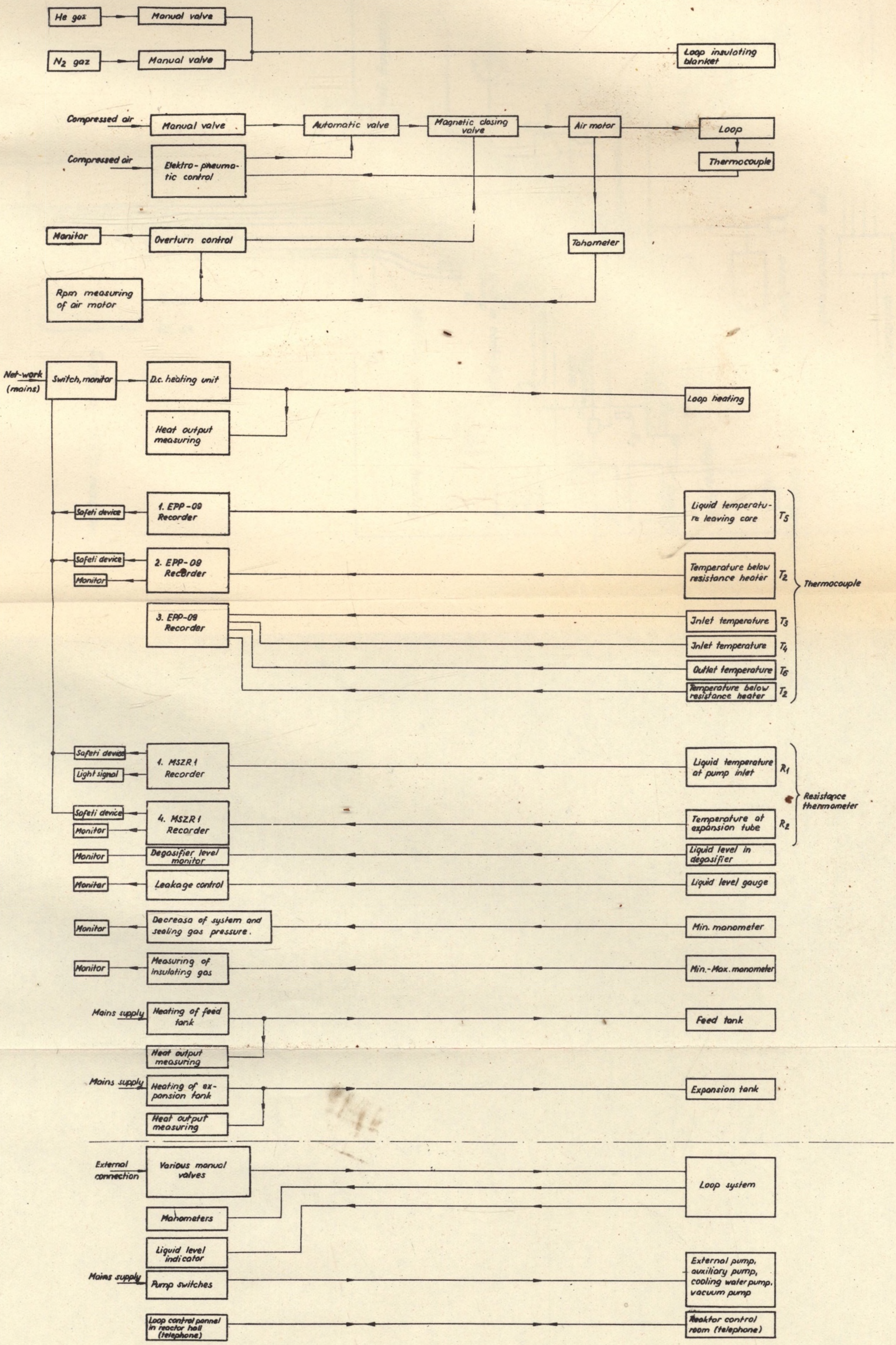
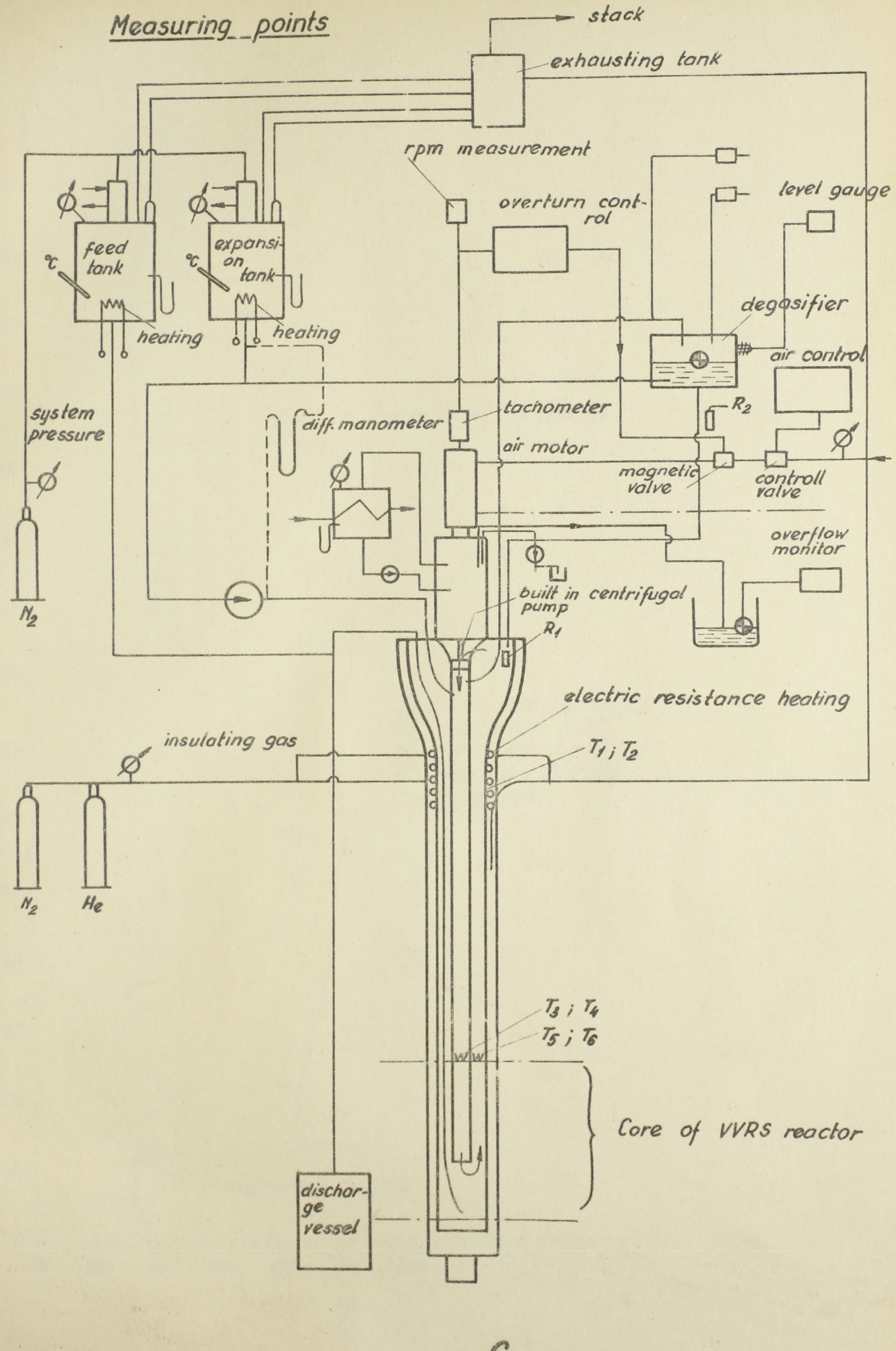
11
1
25

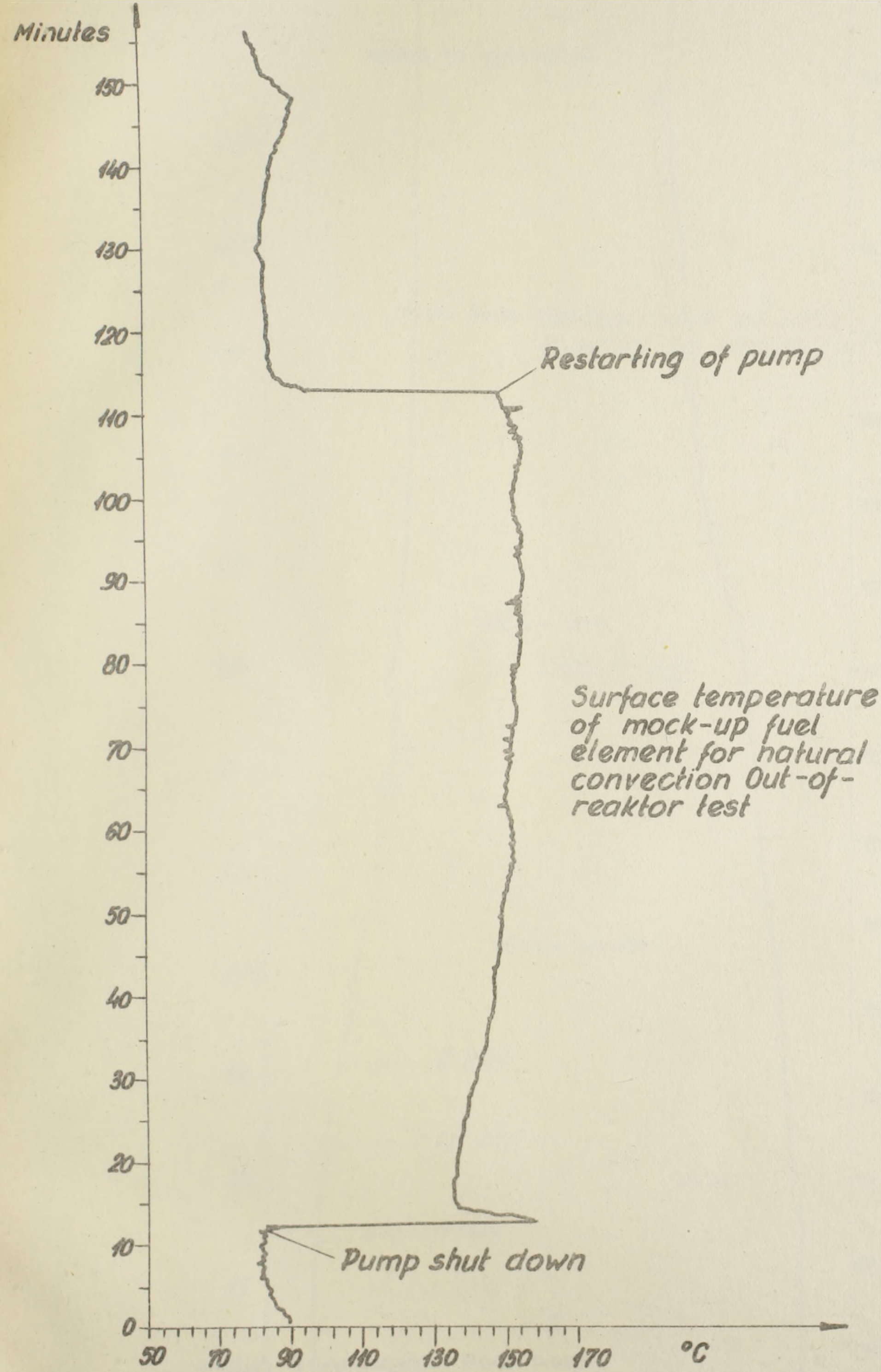
4.

Block diagram of loop control.



Measuring points



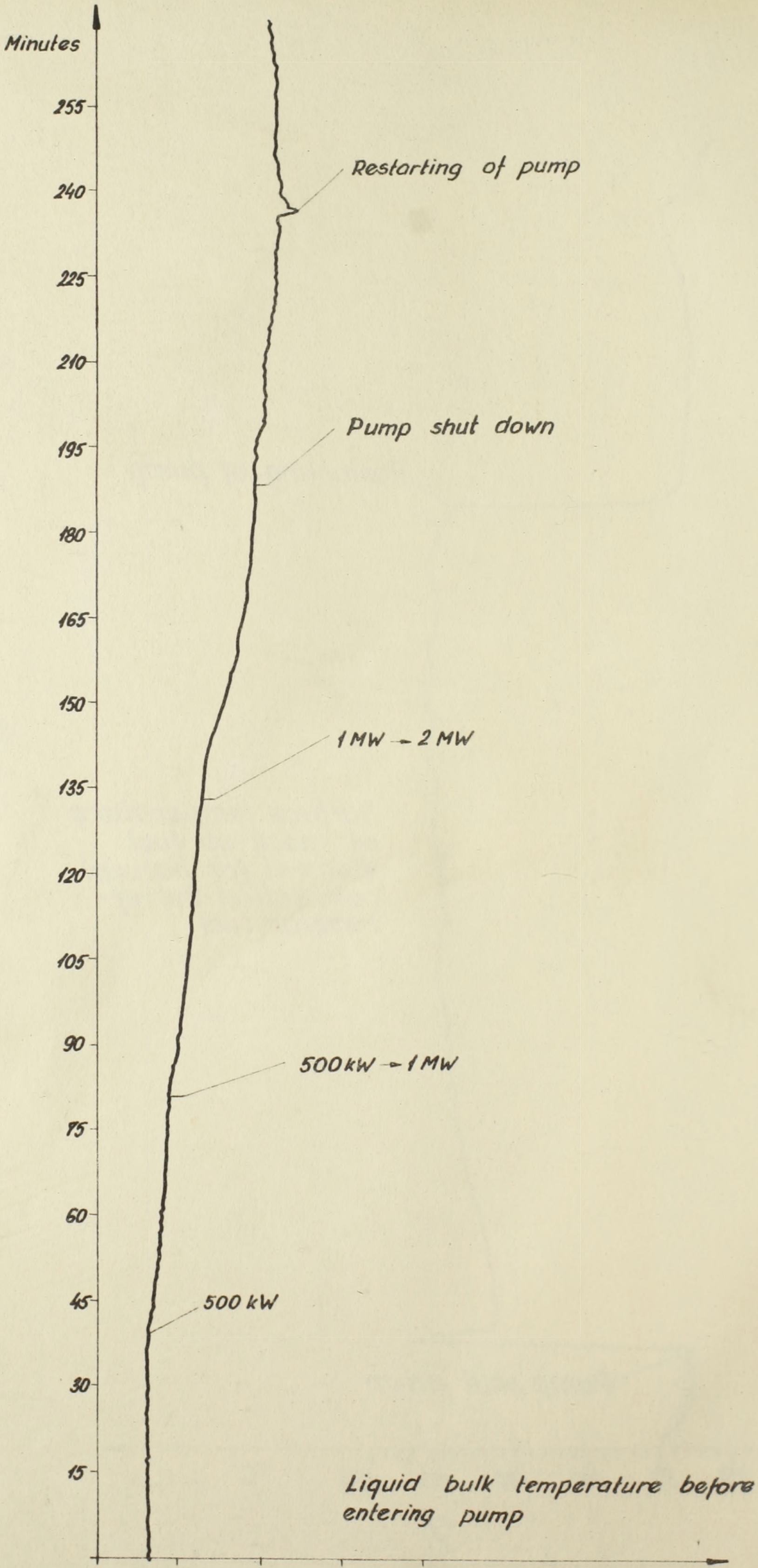


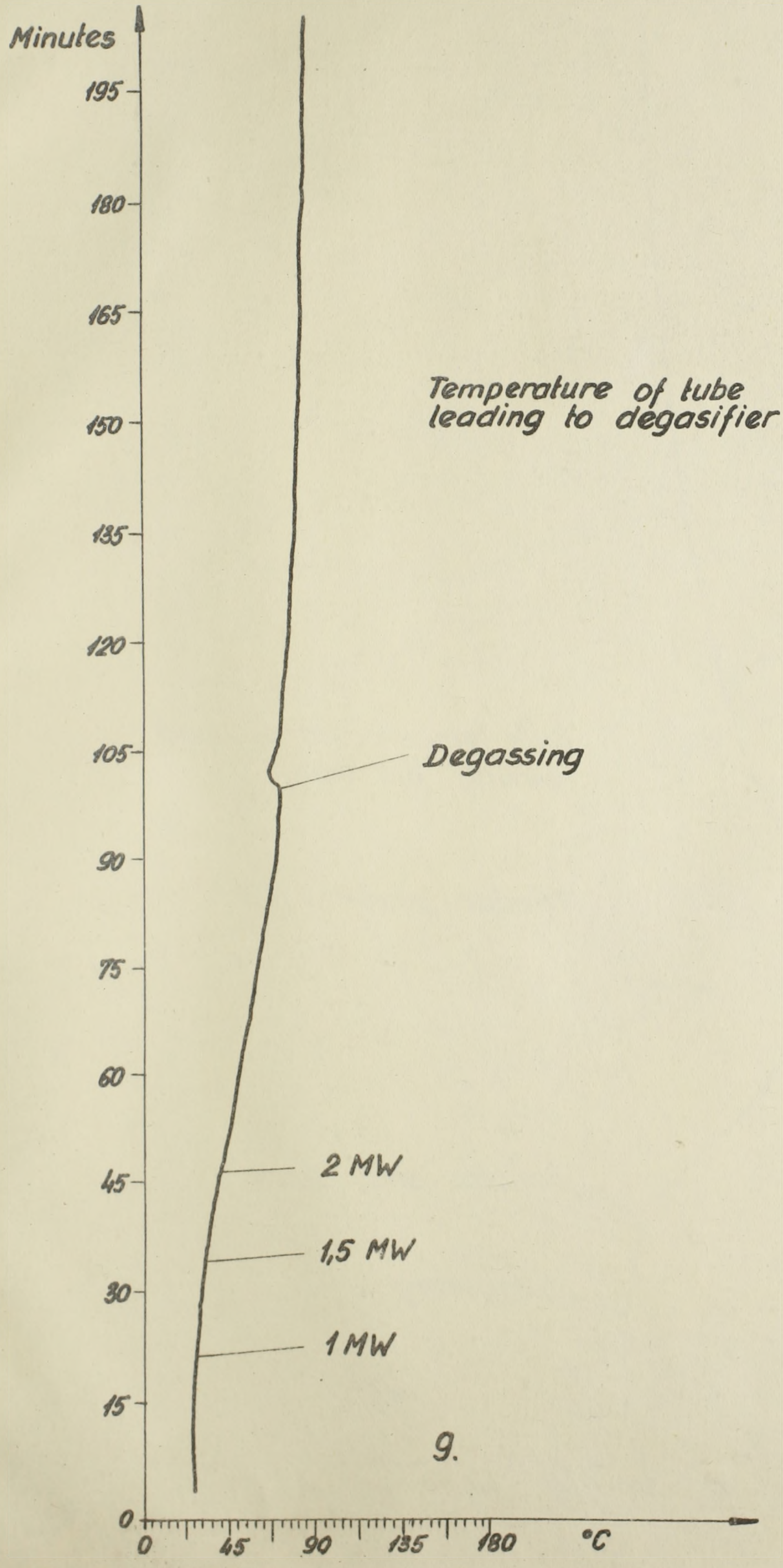
Restarting of pump

Surface temperature of mock-up fuel element for natural convection Out-of-reaktor test

Pump shut down

7.


Minutes
255
240
225
210
195
180
165
150
135
120
105
90
75
60
45
30
15
0
50
100
150
200
°C
Restarting of pump
Pump shut down
1 MW → 2 MW
500 kW → 1 MW
500 kW
Liquid bulk temperature before entering pump


Minutes
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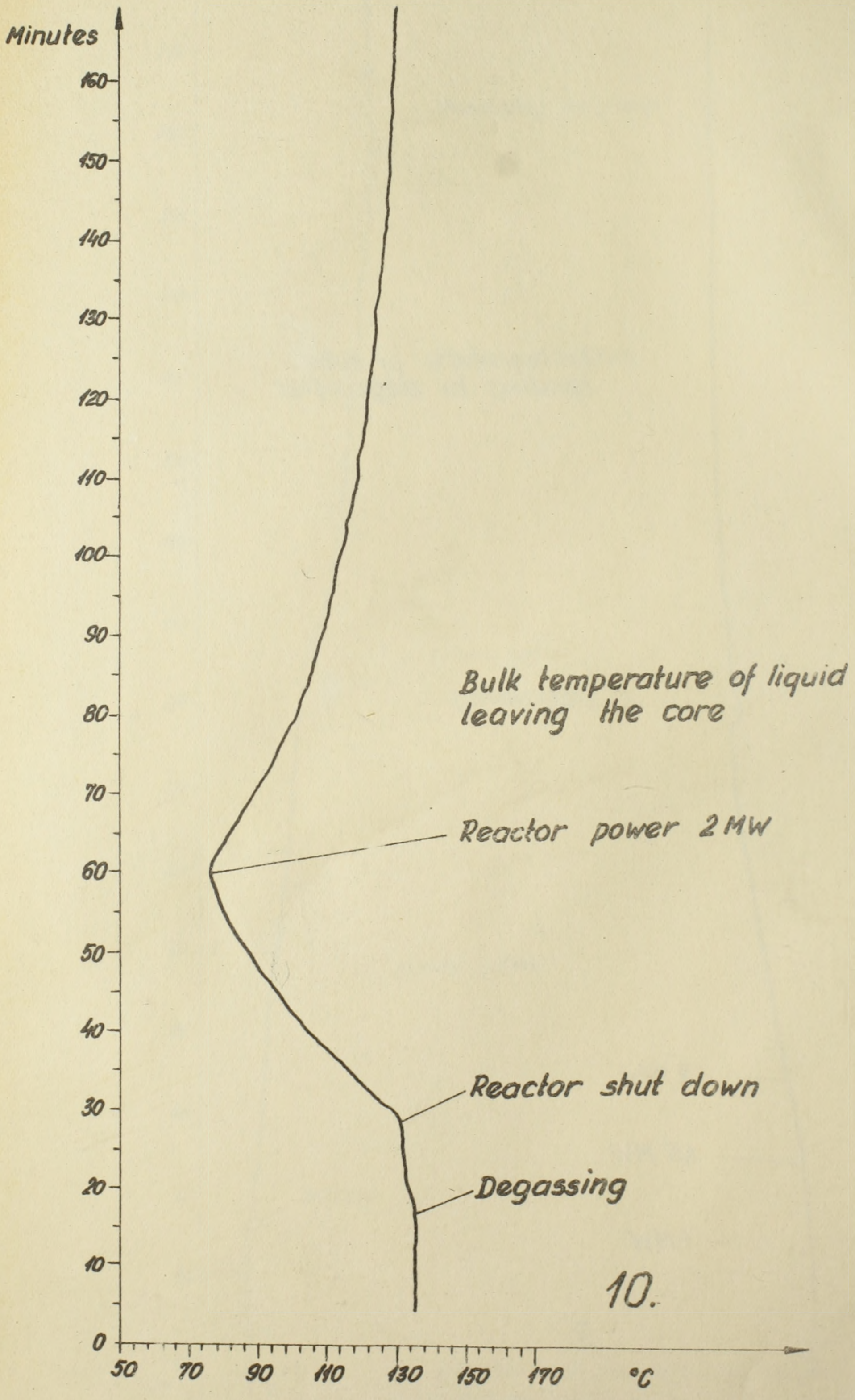
180
165
150
135
120
105
90
75
60
45
30
15
0
0
45
90
135
180
°C
Temperature of tube leading to degasifier
Degassing
2 MW
1,5 MW
1 MW

9.

61752


Minutes
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140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
50
70
90
110
130
150
170
°C
Bulk temperature of liquid leaving the core
Reactor power 2 MW
Reactor shut down
Degassing

10.