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General description of the PACTEL test facility

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ABSTRACT

The PACTEL is a test facility designed to model the thermal-hydraulic behaviours of the Soviet-designed VVER-440 pressurized water reactors currently in use in Finland. These reactors have unique features that differ from other PWR designs. The PACTEL simulates the major components and systems of the reference PWR, making it possible to examine postulated small- and medium-break LOCA’s and operational transients.

The PACTEL is a volume-scaled model (1:305). To ensure that gravitational forces remain equal to those in the reference reactor, the major components and systems in the PACTEL preserve a 1:1 elevation equivalence to the reference reactor. Preserving the elevation equivalence and scaling by volume results in relatively small hydraulic diameters. This report describes some of the affects of the smaller hydraulic diameters on the thermal-hydraulic characteristics of the PACTEL.

The PACTEL steam generator tube diameters and the tubes’ angle-of-inclination are the same as in the reference reactor. Primary-side volume scaling while preserving elevation equivalence results in shorter tubes with double the vertical spacing. This results in oversized secondary-side volumes. This report also discusses the thermal-hydraulic affects of these larger secondary-side volumes.

Assessing thermal-hydraulic computer codes used for the safety analyses of nuclear power plants is the final goal of the PACTEL experiment programmes. This report supplies the physical data on the PACTEL that analysts need to prepare their code models. It describes the PACTEL instrumentation and data acquisition system. The report also lists the experiments conducted prior to publishing and summarises each experiment procedure.

PREFACE

Since 1976, VTT Energy and Lappeenranta University of Technology have co-operated in nuclear reactor thermal hydraulics. During these years, VTT Energy and the Lappeenranta University of Technology have built a series of experiment facilities (REWET-I, -II, -III, VEERA, PACTEL) to simulate Pressurized Water Reactors (PWR's).

The co-operation started with a single pin facility, REWET-I, for rewet studies. The facility included one directly-heated fuel rod simulator in a quartz glass tube, which formed an annular flow channel. Two different rods were available, one with constant power profile and one with cosine profile. The cosine power profile was achieved by varying the thickness of the tube wall. The main object of interest was the effect of different injection modes on rewet of overheated nuclear fuel rods. Also the effect of dissolved nitrogen in the coolant on the rewet was studied.

The REWET-II facility was the next step to the more realistic simulation of VVER-440 reactors. It contained 19 indirectly-heated fuel rod simulators and the main components of the primary loop. The phenomena covered by the REWET-II facility were refill, reflood and rewet phases of the large break Loss-of-Coolant Accidents (LOCA's).

Later, the REWET-II facility was updated by adding one steam generator and a pressurizer. The facility was then renamed REWET-III. The phenomena covered by the facility were extended to natural circulation flow transients.

The VEERA facility was built for experiments simulating soluble neutron poison (boric acid) behaviour in a PWR during long-term cooling period of LOCA's. VEERA was also used for reflood experiments.

The newest facility, the PACTEL (PArallel Channel TEst Loop), is an out-of-pile experiment facility designed to simulate the major components of the primary loop of a commercial PWR during postulated small and medium-size break LOCA's, natural circulation, and operational transients.

To build this series of test facilities would not have been possible without the strong support of the Lappeenranta University of Technology, which offers the infrastructure for experiment research.

Financial support for the construction and operation of the test facilities has been provided by the Ministry of Trade and Industry (KTM), VTT Energy (until 1994 Nuclear Engineering Laboratory of the Technical Research Centre of Finland VTT), and the Lappeenranta University of Technology (LTKK).

CONTENTS

APPENDICES

ABBREVIATIONS

ATWS	Anticipated Transient Without Scram
ECCS	Emergency Core Cooling Systems
ISP	International Standard Problem
IVO	Imatran Voima Oy
KTM	Ministry of Trade and Industry
LTKK	Lappeenranta University of Technology
LOCA	Loss-of-Coolant Accident
PACTEL	Parallel Channel Test Loop
PWR	Pressurized Water Reactor
SBLOCA	Small Break Loss-of-Coolant Accident
STUK	Säteilyturvakeskus, Radiation and Nuclear Safety Authority
VTT	Technical Research Centre of Finland
VVER	Vodo Vodjanyi Energetitseskij Reaktor

1. INTRODUCTION

Since 1976, VTT Energy and the Lappeenranta University of Technology have co-operated in researching nuclear reactor thermal hydraulics. During these years, VTT Energy and the Lappeenranta University of Technology have built a series of experiment facilities (REWET-I, -II, -III /1/ and VEERA /2/) to simulate Pressurized Water Reactors (PWR's). The newest facility, the PACTEL (PArallel Channel TEst Loop), is an out-of-pile experiment facility designed to simulate the major components of the primary loop of a commercial Pressurized Water Reactor during postulated small- and medium-size break Loss-Of-Coolant Accidents (LOCA's), natural circulation, and operational transients.

The reference reactor for the PACTEL is the 6-loop VVER-440-type PWR currently operating in Loviisa, Finland. Reactor manufacturers and research organisations have built similar test facilities in many countries. Some of them have ceased operations. Table 1 presents the scaling factors and other particular characteristics of the PACTEL and some other integral facilities.

Table 1. Comparison of some thermal hydraulic test facilities.

Facility	**Country/Owner**	**Power**	**Pressure**	**Scaling factor**		**Reference reactor**
		(MW)	**(MPa)**	**Volume**	**Height**	
CCTF	Japan/JAERI	10.0	0.6	1:21	1:1	1100 MWe
LSTF	Japan/JAERI	10.0	16.0	1:48	1:1	3400 MWe
LOFT[1]	USA/INEL	50.0	15.5	1:60	1:2	-
BETHSY	France/CENG	3.0	17.2	1:100	1:1	2775 MWt / PWR
PKL	FRG/KWU	1.5	4.0	1:135	1:1	1300 MWe / PWR
PACTEL	***Finland/VTT***	***1.0***	***8.0***	***1:305***	***1:1***	***VVER-440 / PWR***
FLECHT	USA	1.5	0.4	1:327	1:1	-
VEERA	***Finland/VTT***	***0.12***	***0.5***	***1:349***	***1:1***	***VVER-440 / PWR***
SPES	Italy/SIET	9.0	20.0	1:420	1:1	Westinghouse PWR
UMCP	USA/Maryland	0.2	2.1	1:500	1:6.6	B & W PWR
LOBI-Mod 2[1]	Italy/ISPRA	5.4	15.5	1:700	1:1	1300 MWe / PWR
MIST (2X4)	USA/B&W	0.34	15.6	1:840	1:1	-
Semiscale	USA/INEL	2.0	15.0	1:1600	1:1	-
PMK-NVH	Hungary/KFKI	2.0	16.0	1:2070	1:1	VVER-440 / PWR
REWET-III[1]	***Finland/VTT***	***0.09***	***1.0***	***1:2333***	***1:1***	***VVER-440 / PWR***

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[1] Not in operation

The PACTEL facility is suitable for investigating the operating procedures of VVER-type PWR’s in SBLOCA’s and operational transients. This presupposes control systems that are sufficiently similar to the prototype plant. The experiment data base will be used to assess thermal hydraulic computer codes, such as APROS, RELAP5, and CATHARE; particularly for VVER analyses.

This report begins with a current description of the geometry of the PACTEL facility. The previous PACTEL description /3, 4/, published as part of the ISP 33 documentation, described the test facility configuration during the first experimental phase (years 1989 through 1994). Since then, new steam generators, primary circulation pumps, and two individual accumulators were added in 1995. This new report also describes the scaling principles, the typical experiment procedures, and the instrumentation of the PACTEL.

2. FACILITY DESCRIPTION

2.1 General

This chapter summarises the main characteristics and design principles of the PACTEL test facility. Appendix A gives a detailed description of the geometry of different parts of the PACTEL. Reference /5/ describes the design principles of the PACTEL in detail.

The reference reactor of the PACTEL, a VVER-440 PWR in Loviisa, Finland, has certain unique features differing from the other PWR designs. One of these is the number and type of steam generators. The VVER-440 has six primary loops with horizontal steam generators. Due to the horizontal construction of the steam generators, the driving head for the natural circulation in SBLOCA's is rather small. The primary loops have loop seals in both hot and cold legs. The primary coolant pump design is the reason for the cold leg loop seals. The fuel rod bundles are in BWR-like channels and the core is shorter than in most PWR's.

The PACTEL facility simulates the major components and systems of the reference PWR during postulated small- and medium-break LOCA's and operational transients. The facility consists of a primary system, the secondary side of the steam generators, and the Emergency Core Cooling Systems (ECCS). The reactor vessel model consists of a u-tube construction including downcomer, lower plenum, core, and upper plenum. Table 2 summarises the main characteristics of the PACTEL facility and the reference plant. Figure 1 compares the Loviisa reactor and the PACTEL.

Volumetric scaling (1:305) was the basic scaling approach in the PACTEL design. The component elevations of the loop are the same as in the reference reactor. Volumetric scaling requires that all the components and piping volumes have to be equally proportional to the respective volumes of the reference reactor. This scaling ensures that the same relative amount of coolant is available for the energy exchange in both systems and preserves the real time scale of the events.

Precise conservation of the system component heights and elevations is important for SBLOCA and transient simulations. During these transients, the fluid is in a two-phase state, and the flow processes are gravity dominated. Under gravitational forces, the vapour and liquid phases easily separate, and these separation effects can dominate both thermal and hydraulic characteristics of a transient. Because of this, the elevations in the PACTEL facility are the same as in the reference reactor.

The volumes of the components have been scaled down by the ratio of 1:305. The exceptions are caused by the use of standard pipe sizes. The core geometry is the same as in the reference reactor. Figure 2 shows a general view of the PACTEL facility.

Table 2. The PACTEL facility characteristics compared with the Loviisa PWR plant.

	PACTEL	**Loviisa VVER-440**
Reference power plant	VVER-440	-
Volumetric scaling ratio	1:305	-
Scaling factor of component heights and elevations	1:1	-
Number of primary loops	3	6
Maximum heating power / thermal power	1 MW	1 375 MW (1 500 MW)[2]
Number of rods	144	39438
Outer diameter of fuel rod simulators	9.1 mm	9.1 mm
Heated length of fuel rod simulators	2.42 m	2.42 m
Axial power distribution	chopped cosine	cosine
Axial peaking factor	1.4	1.4
Maximum cladding temperature	800 ^{o}C	
Maximum operating pressure	8.0 MPa	12.3 MPa
Maximum operating temperature	300 ^{o}C	300 ^{o}C
Maximum secondary pressure	5.0 MPa	5.0 MPa
Maximum secondary temperature	260 ^{o}C	260 ^{o}C
Feedwater tank pressure	2.5 MPa	2.5 MPa
Feedwater tank temperature	225 ^{o}C	225 ^{o}C
Accumulator pressure	5.5 MPa	5.5 MPa
Low-pressure ECC-water pressure	0.7 MPa	0.7 MPa
High-pressure ECC-water pressure	8.0 MPa	8.0 MPa
ECC-water temperature	30 ^{o}C - 50 ^{o}C	30 ^{o}C - 50 ^{o}C

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[2] New power level after modernisation of the plant

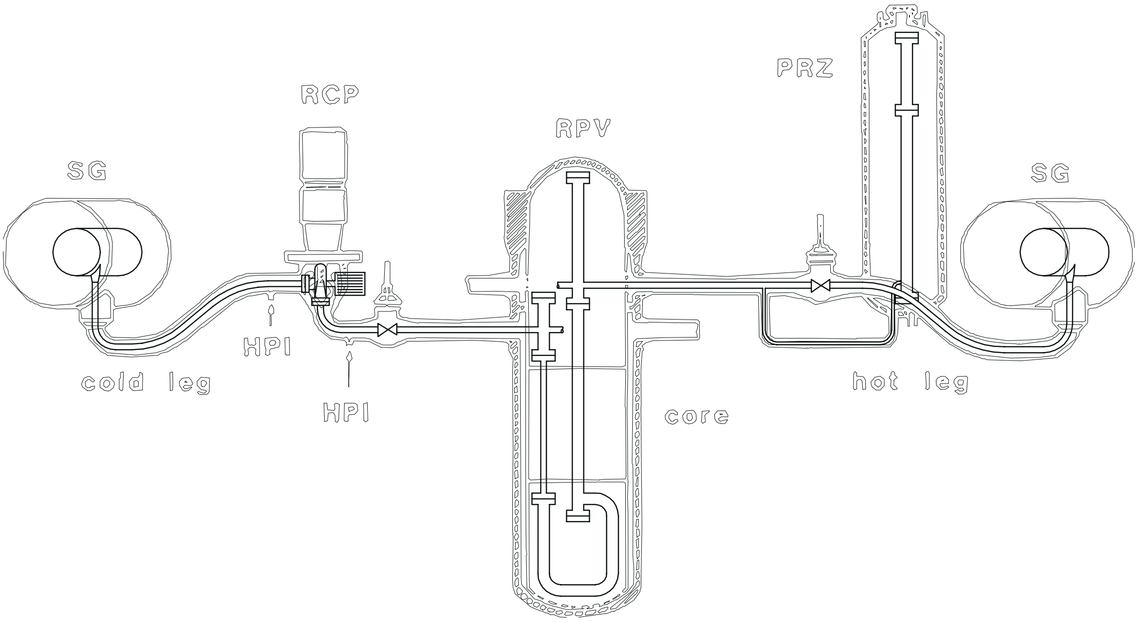

Figure 1. Loviisa VVER-440 and the PACTEL facility.

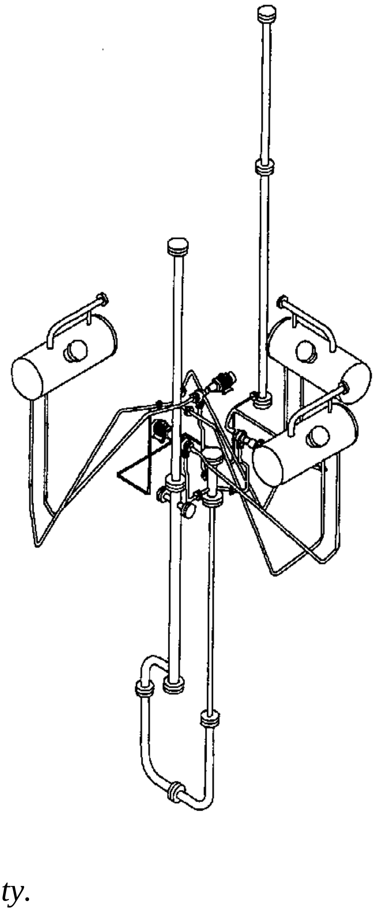

Figure 2. The PACTEL facility.

2.2 Pressure vessel and components

The pressure vessel and other components are made of stainless steel AISI 304 and rated for a pressure of 8.0 MPa and a fluid temperature of 300 ^{o}C. The insulation material of all the parts is mineral wool with an aluminium plate cover. Table A.4 of Appendix A includes data about insulation thickness and the properties of the insulation material in different parts of the facility.

2.2.1 Core

The rod bundle simulating the core consists of 144 electrically-heated fuel rod simulators. The outer diameter of the simulators is 9.1 mm and the thickness of the stainless steel (AISI 316L) cladding is 0.9 mm. The rods are fixed in a triangular grid which has a lattice pitch of 12.2 mm. The rods have a nine-step chopped cosine axial power distribution. The axial peaking factor is 1.4 and the total heated length is 2420 mm. The heated length and the other dimensions of the rods are the same as in the reference reactor. Also the number and construction of the rod spacers are identical with the reference reactor. The heating coils are separated from the stainless steal cladding by magnesium oxide insulation. Six rods use boron nitride insulation for comparison because of its good electrical and thermal properties. In these six rods, the thermocouples are inside the cladding. In other instrumented rods, the thermocouples are on the cladding surface. The fuel rod simulators are in three parallel channels. Each channel has 48 rods. Figure 3 shows the construction of the core. The maximum core power is 1 MW. This corresponds to 22% of the nominal power of the reference reactor. Different power levels can be used in the three separate channels.

2.2.2 Upper plenum, downcomer, and lower plenum

Determination of volumes and elevations of different parts of the loop have been based on the general scaling factors. The upper plenum is made of one tube with three hot leg connections. The downcomer is made of two different parts. The upper part (about 1 m high) has a larger diameter because of the cold leg connections. The lower part (about 5 m high) has the scaled diameter. The lower plenum is made of two separate parts of equal diameter, which together form a u-tube lower plenum. The facility has no bypass from the upper plenum to the downcomer. Both hot and cold leg connections have diffusers preventing direct flow of ECC water from the accumulators or HPIS to the loops.

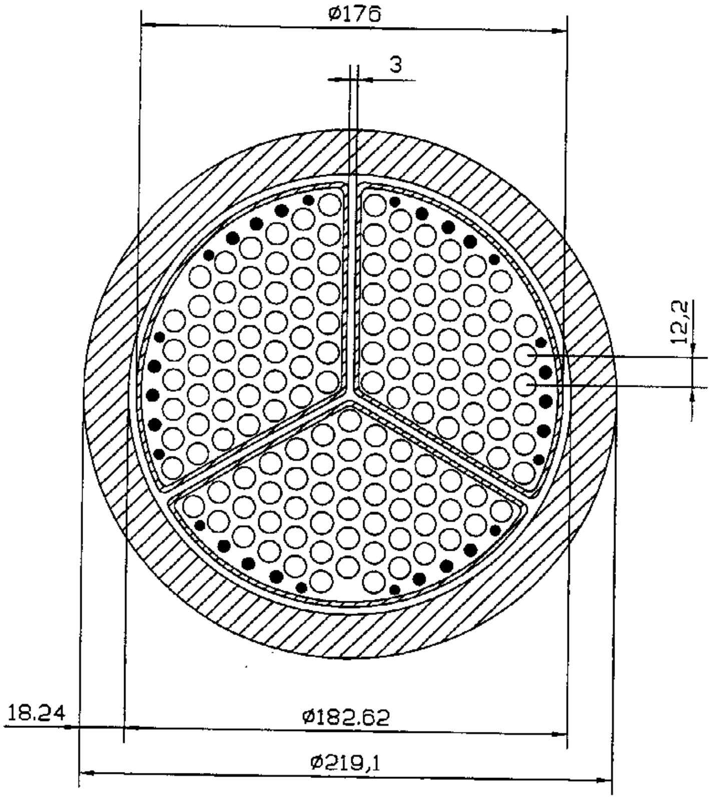

Figure 3. Cross-section of the PACTEL core.

2.2.3 Primary loops and steam generators

The simulation of the six primary loops of the reference reactor includes three separate loops with double capacity. Each of these loops have loop seals and an active horizontal steam generator. The inner diameter of the hot and cold legs is 52.5 mm. The length of the loops is about half of the reference plant to ensure proper separation of phases in the horizontal parts of the loops. All three loops have main circulation pumps. Table 3 presents the main characteristics of the pumps. See also Table A.1 in Appendix A for more information about the pumps.

The steam generators contain 118 heat exchange u-tubes. The average length of the tubes is 2.819 m. The diameter of the tubes (16 x 1,5 mm) is the same as in the reference plant, but the space between the tube rows is doubled to increase height of the steam generator. The heat transfer area of the tube bundles and the primary-side volume of each steam generator is scaled down so that one steam generator in the PACTEL corresponds to two steam generators in the reference plant. Accurate thermal hydraulic simulation of the steam generator is important because, depending on the transient, the steam generators can act as a heat source or as a heat sink. Figure 4 shows a general view of the steam generators.

Table 3. Characteristics of the main circulation pumps of the PACTEL.

Manufacturer	KSB
Type	HPHx 50-200
Rated head	85.38 m
Rated flow	48.37 m^3/h
Rated speed	3 500 rpm
Rated torque	49.44 Nm
Rated power	18.12 kW
Rated efficiency	62.09 %
Rated density	1 000 kg/m^3

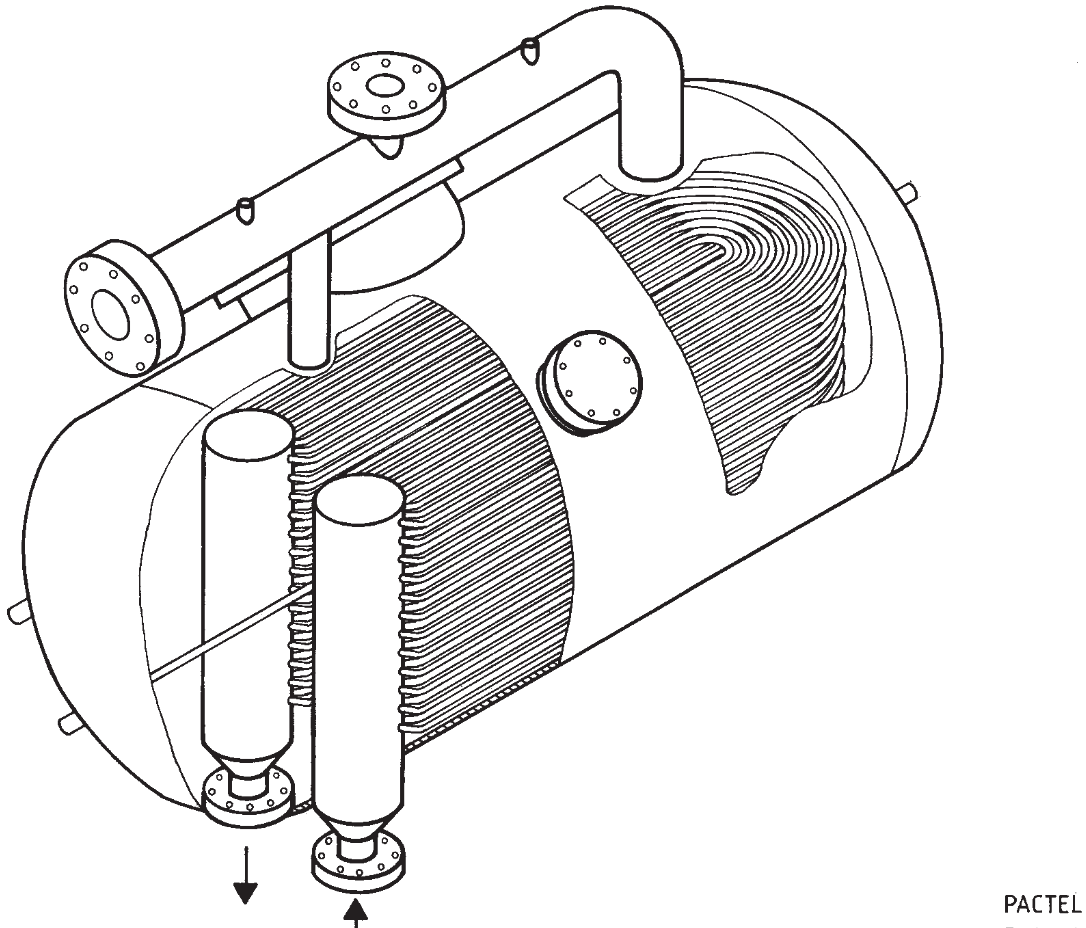

Figure 4. Steam generator of the PACTEL.

2.2.4 Pressurizer

The pressurizer surge line connects the full length pressurizer to the hot leg of Loop 1. The pressurizer has heating and spray systems. It is made of two parts of equal diameter, which are joined with flanges. The total height of the pressurizer is 8.8 m with an inner diameter of 139.7 mm. The length of the pressurizer surge line is 7.77 m. The inside diameter of the line is 27.3 mm.

2.2.5 Emergency core cooling systems

The ECC systems of the PACTEL include high and low pressure pumps and two separate accumulators injecting water to the downcomer and to the upper plenum. The low pressure safety injection system can inject water to the downcomer and to the upper plenum. The high pressure ECC system injects to the cold leg of Loop 1 close to the downcomer. In some of the experiments, the PACTEL accumulators have operated as a passive safety injection system. References /6/, /7/ and /8/ describe the modifications made to the accumulators for the passive safety injection experiments.

2.2.6 Secondary side of the steam generators

On the secondary side, a common steam line connects the three steam generators. From the common steam line, the steam flows to the atmosphere. The secondary side includes separate feed water injection systems for all three steam generators. All steam generators have two separate feed water lines: one above the heat exchange tube bundle, the other in the middle of the bundle. A separate PI-controller controls the pressure in all steam generators. In most of the experiments, the secondary-side control system uses only one controller which controls the pressures in all steam generators through the common steam line.

The fact that the distance between steam generator tube rows is doubled in the PACTEL steam generators leads to an oversized secondary-side volume. The water volume of the secondary side is about three times larger than the volumetrically scaled volume of the secondary side of the two reference steam generators.

2.2.7 Influences of volumetric scaling on the characteristics of the PACTEL

A report titled, “The scaling and design of the PACTEL” based on the work of Riikonen /5/. Hyvärinen /9/ discusses the scaling problems of horizontal steam generators. Volumetric scaling was the main scaling principle in the design of the PACTEL. This scaling principle reduces the volumes and flow areas of different parts of the loop using the selected scaling factor (1:305 for the PACTEL). In addition, a 1:1 scale was used for the heights and elevations in the primary loop.

The selected scaling principle leads to an overestimation of the heat losses to the environment. The main reason is that the ratio of the tube wall area to the tube volume is much larger in the scaled-down facilities than in the reference reactor. In the same manner, the volumetric scaling leads to an overly large ratio of the wall mass to the water volume. To minimise the heat losses, all parts of the PACTEL are well insulated. The magnitude of heat loss greatly depends on the temperature of the primary loop, as discussed in reference /10/. The main source of heat loss in the PACTEL is caused by the cooling of the primary circulation pumps. Reference /10/ gives an estimate of heat losses of the PACTEL without the main circulation pumps. Measurement data from the experiments include information about the primary circulation pumps cooling water flow rate and temperatures. This data is available for estimating the pump heat losses.

All three primary coolant loops of the PACTEL simulate two loops of the reference reactor. Froude scaling, together with volumetric scaling, is the main design principle of the pipe dimensions of the PACTEL hot and cold legs /5/. So, the lengths of the hot and cold legs are about 50% shorter than in the reference reactor. This leads to better simulation of flow regime transitions in the horizontal parts of the loops. The use of volumetric scaling has an effect on the pressure loss distribution around the loop. Reference /5/ includes comparison of pressure loss distribution in the PACTEL (without main circulation pumps) and the Loviisa VVER plant during single phase natural circulation and single phase forced circulation conditions. The pressure loss distribution in the PACTEL corresponds well to the estimated loss distribution of the Loviisa plant.

In the pressurizer, volumetric scaling influences the pressurizer void fraction distribution during blow-down situations. In a large full-scale pressurizer, void fraction profile is non-uniform /11/. In a scaled-down pressurizer, the void fraction profile is uniform /12/. This is important since, in some transients, the pressurizer may accumulate a large mass of water which is not available for core cooling.

The dimensions and inclination of the horizontal steam generator tubes in the PACTEL are the same as in the reference reactor. The same dimension and inclination is important during flow regime transitions from stratified to intermittent flow, as discussed by Hewitt et al. /13/. On the secondary side, volumetric scaling and a doubled distance between tube rows leads to an oversized secondary-side water mass. The secondary-side volume of the PACTEL is about three times larger than the scaled volume of two VVER steam generators. The vertical height of the steam generator tube bundle is also smaller than in the reference reactor.

Hyvärinen /9/ discusses widely the scaling problems of horizontal steam generators during single-phase flow conditions on the primary side and full or reduced secondary-side inventory conditions. Hyvärinen uses a one-dimensional mathematical model for calculating steady-state single-phase flows in primary-side tubes and collectors. His analyses have shown that under natural circulation conditions, flow reverses in the lower part of the tube bundle leading to internal circulation flows. Hyvärinen also discusses the steam generator behaviour under reduced secondary-side inventory conditions, and compares the PACTEL steam generators with other horizontal steam generator designs (real VVER plant and steam generators of PMK test facility). The analyses of Hyvärinen showed that the secondary-side boil-off experiments in scaled down facilities (PACTEL or PMK) do not directly scale up to the reference plant.

3. INSTRUMENTATION AND DATA ACQUISITION SYSTEMS

The figures of Appendix B present the locations of different measurement instruments in the PACTEL. The basic instrumentation in the facility consists of temperature, pressure, pressure difference, and flow transducers. Appendix C presents the naming conventions for the measurement channels. Also included in Appendix C is a full list of the measurement channels with an estimate of measurement accuracy for different instruments.

3.1 Temperature measurements

The cladding temperature measurements of the fuel rod simulators, the fluid temperature measurements, and the structure temperature measurements use K-type (Chromel-Alumel) mineral insulated thermocouples. All the thermocouples are ungrounded. Their outer diameter varies from 0.5 to 3 mm depending on measurement location. All thermocouple cables are routed to the nearest one of six junction boxes. In each junction box, the connections between the thermocouple wire and an ordinary copper wire is made. A standard cable is then used to connect the box to the data acquisition cabinet. The reference temperature of these junctions is established by measuring the air temperature within each junction box with PT100 resistance thermometers (RTD’s).

Reference temperature is measured first and converted into thermocouple voltage using a 3rd degree polynomial. After this, thermocouple voltage is measured. These two voltages are added, and the conversion to degrees Celsius is made with a 6th order polynomial.

3.1.1 Core

In the core section, the cladding temperature of the fuel rod simulators, fluid temperatures in the core, and the structure temperatures are measured. The diameter of the thermocouples is 0.5 mm. Two different methods have been used to measure the cladding temperatures of the rods. In the first method, the thermocouples are spot welded onto the outer surface of the cladding. In the second method, the thermocouples are inside the cladding. There are 15 rods with the first type of measurements and 6 of the second (see Figure 5). There are five thermocouples in each of these rods. Figure 6 shows the different rod types.

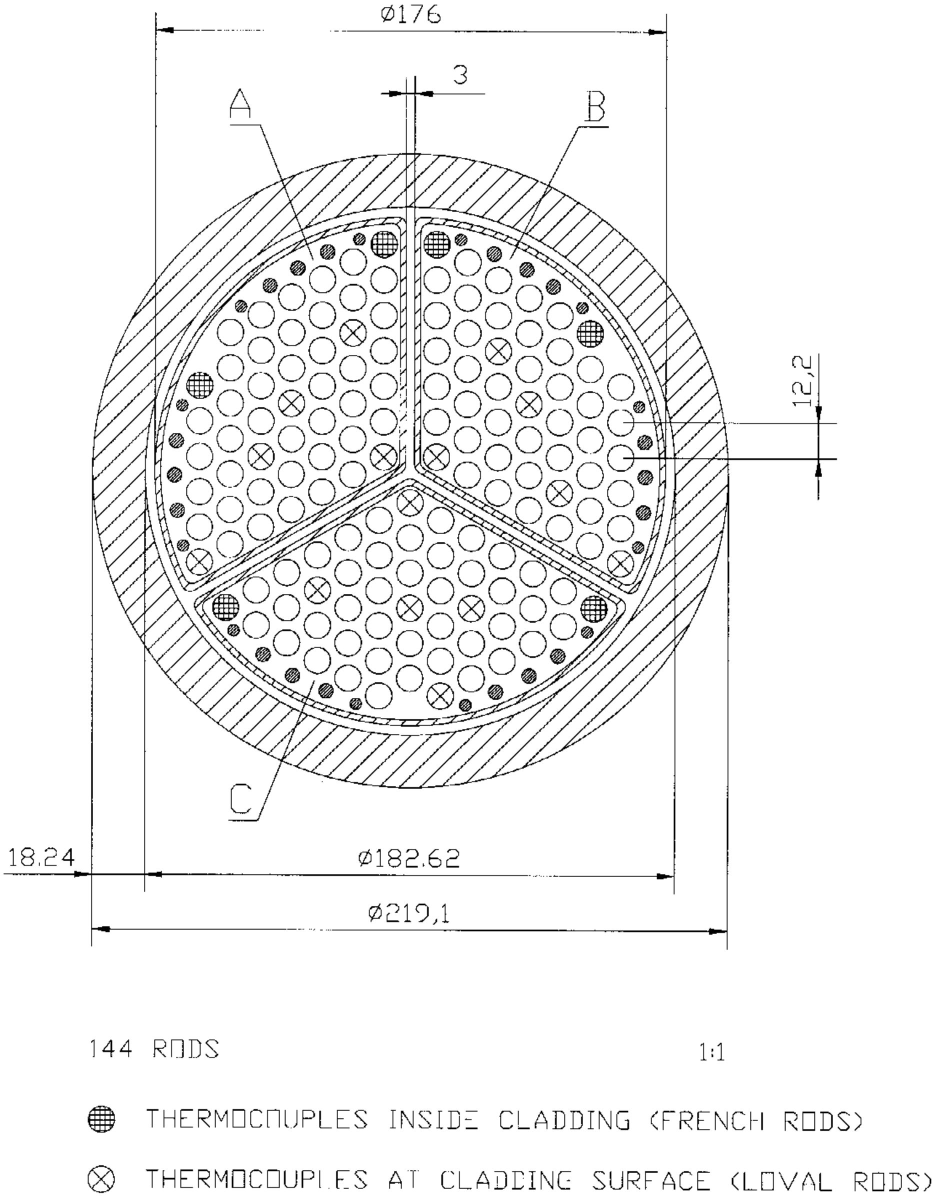

Figure 5. Instrumented rods in the core.

The fluid temperature measurements are arranged so that the junction of the thermocouple is a few millimetres away from the cladding surface, as shown in Figure 6. Thermocouples also measure fluid temperature between the three separate channels in the core. The shroud temperatures are measured with spot welded thermocouples. Table 4 shows the amount and distribution of the thermocouples in the core area. Details of the measurement locations are shown in Appendix B.

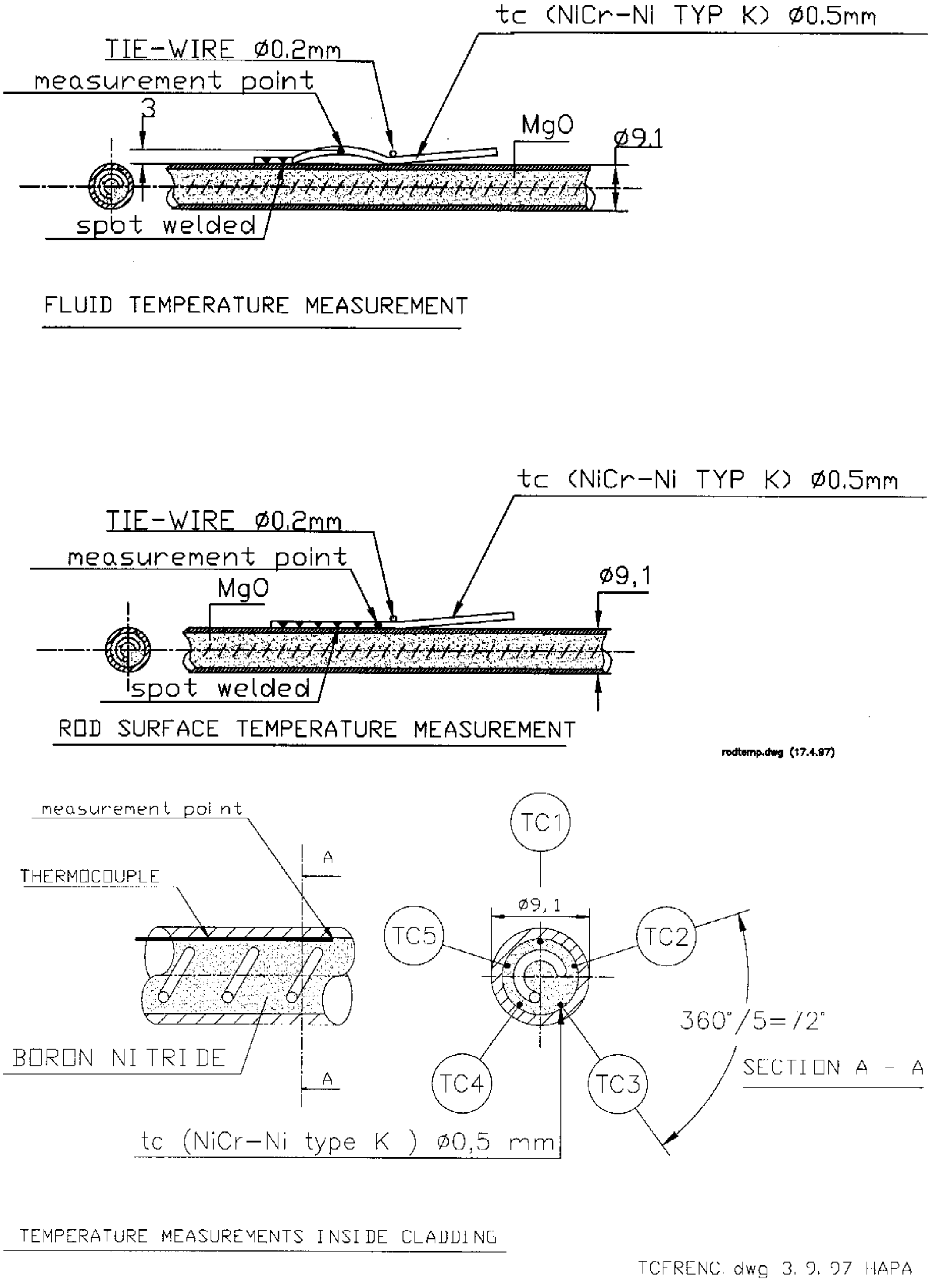

Figure 6. The cladding and fluid temperature measurement methods in the core.

Table 4. Thermocouple measurements in the core.

Measurement	**Number of measurement points**
cladding temperature	105
fluid temperature between rods	15
fluid temperature between shrouds	6
shroud wall temperature	9
total	*135*

3.1.2 Steam generators

There are eight instrumented tubes in each steam generator. All these tubes have six different positions where the temperatures are measured. Each of these positions have at least two thermocouples; one for the primary-side and one for the secondary-side temperature measurements. In addition to these temperature measurements, there are tube wall temperature measurements in steam generators I and II. There are six wall temperature measurements in SG I and three in SG II. The primary- and secondary-side temperatures are obtained with 1.0 mm thermocouples while the tube wall temperatures are measured with 0.5 mm thermocouples. Figure 7 shows how the thermocouples are attached to the tubes. In addition to the measurements at the heat exchange tubes, temperatures of the steam generator outer walls are measured. The structure temperatures are measured with 1.5 mm thermocouples.

3.1.3 Other temperature measurements

Fluid temperatures in the primary loops and in all other locations not mentioned in the two previous chapters are measured with 2.0 mm thermocouples. The positions of the measurements are shown in Appendix B. There are also thermocouples measuring the inner surface temperature of the primary tubes. These temperatures are measured with 1.5 mm thermocouples.

3.2 Differential pressure measurements

There are three different kinds of differential pressure (DP) transducers in the PACTEL. The types are Valmet DIFF-EL, Fuji FHC, and Siemens Teleperm 7MF13 /3, 4, 5/. Valmet has a piezoresistive sensor, and the others have a diaphragm mechanism with capacitative pick-up. Table 5 shows the number of DP measurements of different types. The differential pressure transducers are also used to determine the collapsed level in the secondary side of the steam generators and the upper plenum, as well as the downcomer in the primary side.

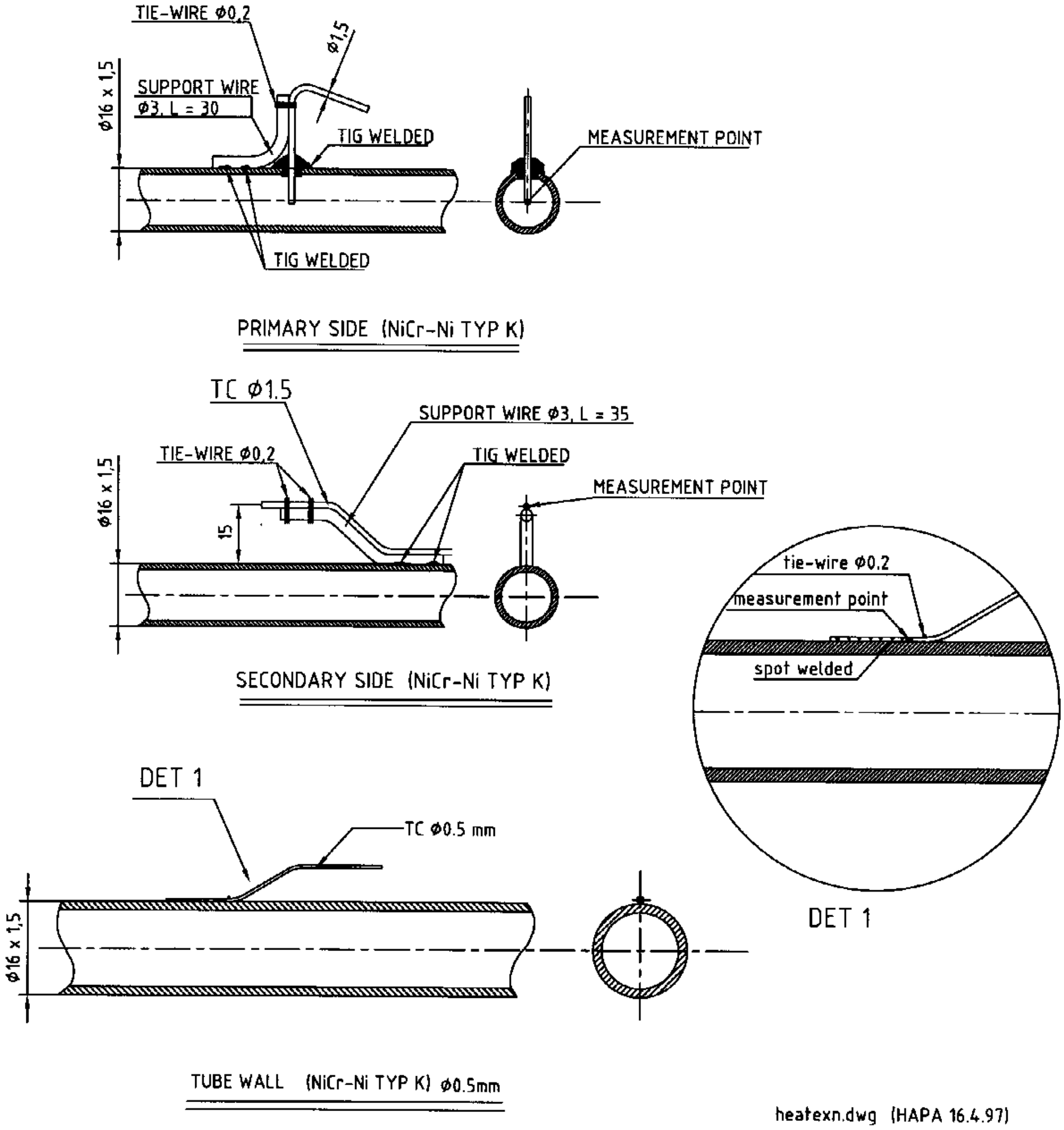

Figure 7. The three different temperature measurement methods for the steam generator tubes.

Table 5. The number of differential pressure transducers.

Type	**Number**
Valmet	26
Fuji	12
Siemens	5
total	*43*

3.3 Pressure measurements

The pressure transducers used in the PACTEL are Valmet PRESS-EL and Fuji FHG types. The number of Valmet transducers is four and the number of Fuji is two. There are two transducers in the primary side; in the upper plenum and in the top of the pressurizer. The secondary-side pressures are measured in all steam generators and in the common steam line.

3.4 Flow meters

Vortex flow meters are used to measure primary flow to all three steam generators, with a flow meter installed in each cold leg. In the downcomer, there is a venturi nozzle that measures the combined flow of the three loops. The measuring range of the vortex meters and venturi nozzle is 0.29 - 11.72 kg/s (liquid temperature 300 °C, pressure 8.1 MPa) and 0.3 - 3.0 kg/s, respectively. The pressure drop of the vortex flow meters is 58.1 kPa (liquid temperature 300 °C, pressure 8.1 MPa, mass flow rate 9.75 kg/s), and the pressure drop of the venturi nozzle is 1.45 kPa (liquid temperature 295 °C, pressure 8.1 MPa, mass flow rate 2.99 kg/s). The break flow for LOCA experiments is measured indirectly using a large condensate tank. The flow rate is determined from the level measurements of the tank.

Electromagnetic flow meters are used to measure the flow of ECC water and feed water to the steam generators. There is one flow meter in both accumulator injection lines. There are three flow meters measuring the feed water flow to the steam generators. All these electromagnetic flow rates can be used to measure the integrated flow. Also included is a steam flow rate measurement from each steam generator using vortexes. Table 6 shows the number and type of different flow meters in the PACTEL.

Table 6. Type and number of different flow meters in the PACTEL.

Type	**Emergency Core Cooling Systems**		**Steam Generator Feedwater**	**Cold Leg**	**Downcomer**	**Secondary Steam**	**Total**
	High Pressure Injection	Low Pressure & Accumulator Injection					
magnetic	1	2	3				**6**
nozzle					1		**1**
vortex				3		3	**6**
TOTAL	**1**	**2**	**3**	**3**	**1**	**3**	**13**

3.5 Heating power

Power supplied to the three core sections is controlled individually. The power output of each section is measured through its power controller. The power controller is an AEG Thyrotak MTL-1065F. Measurement of total core power is also possible using measured energy consumption during the experiments.

3.6 Data acquisition system

3.6.1 General

This chapter describes the PACTEL facility data acquisition system (a combination of a data acquisition unit and a computer). The Hewlett-Packard (HP) 3852A data acquisition unit is used together with an HP VECTRA XU 6/200 personal computer to record experiment results. The two devices are connected using an IEEE-488 bus (also known as HB-IB or GPIB). The computer has a Microsoft Windows NT 4.0 operating system, and the data acquisition programs have been developed using the HP VEE program development language. Figure 8 shows a schematic diagram of the PACTEL data acquisition system.

3.6.2 Data acquisition unit HP 3852A

The data acquisition unit consists of a mainframe and three extenders (HP 3853). The mainframe has eight slots whereas each extender has ten slots. The extenders increase the number of slots in the data logger, but the extender units cannot be used as independent measurement devices. Accessory cards used in the slots determine the configuration and performance of the data acquisition unit. It is possible to use a variety of different voltmeters and multiplexers, but the basic procedure to measure the transducer signals is always the same. A voltmeter measures the multiplexer channels in sequence and stores the results in the memory of a mainframe, which sends the results further to the computer. Table 7 shows the current configuration of the data acquisition devices.

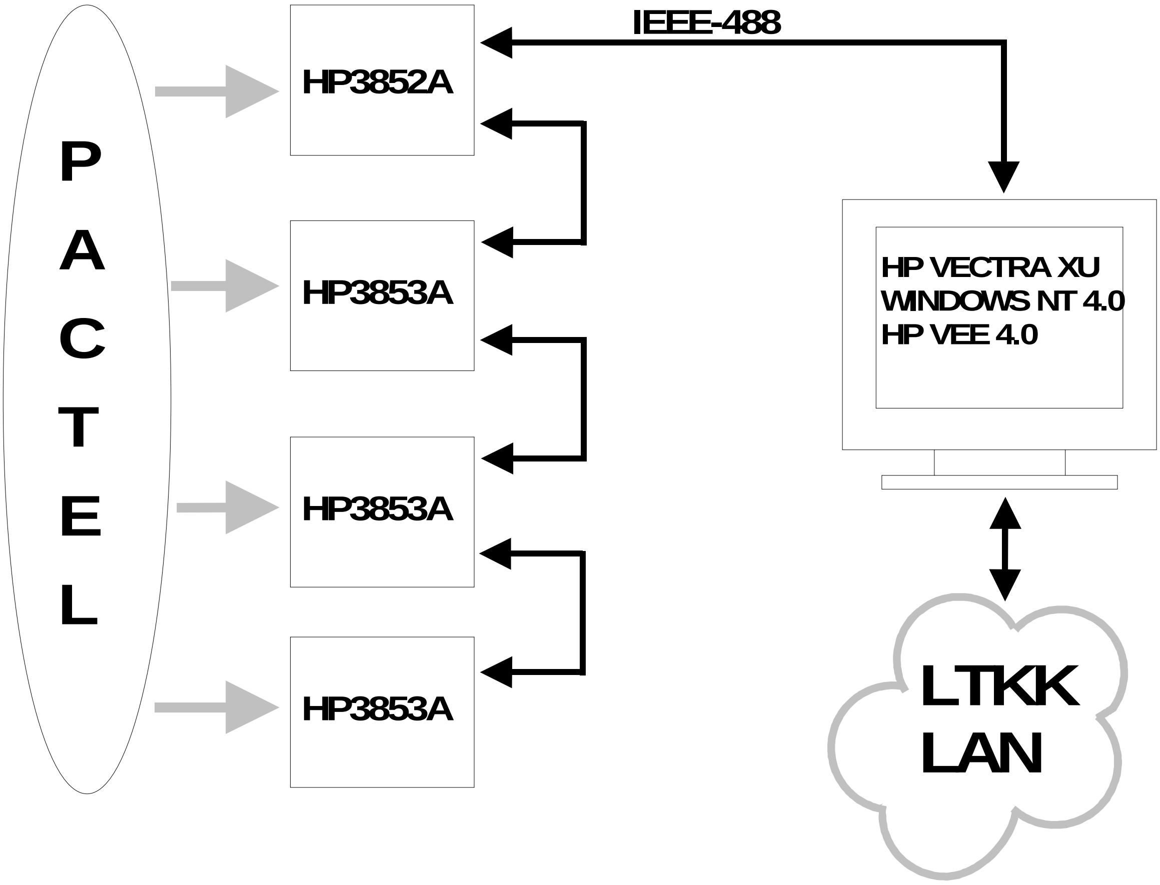

Figure 8. Schematic diagram of the PACTEL data acquisition system.

Table 7. Configuration of the data acquisition unit and the extenders.

Slot	Mainframe	Extender #1	Extender #2	Extender #3
0	HP 44701A	HP 44711A	HP 44711A	Empty
1	HP 44710A	HP 44711A	HP 44711A	Empty
2	HP 44710A	HP 44711A	HP 44711A	HP 44713A
3	HP 44710A	HP 44711A	HP 44711A	HP 44713A
4	HP 44710A	HP 44711A	HP 44711A	HP 44713A
5	HP 44710A	HP 44711A	HP 44711A	HP 44713A
6	HP 44709A	HP 44711A	HP 44711A	HP 44713A
7	HP 44709A	HP 44711A	HP 44711A	HP 44713A
8	Not available	HP 44702B	HP 44702B	HP 44704B
9	Not available	HP 44702B	HP 44702B	HP 44704B

In most of the experiments, an integrating digital voltmeter (HP 44701A) has been used to measure all the channels. It is possible to reach a scanning speed of 1 Hz or less with the integrating voltmeter. This is sufficient for steady state tests or slow transients but some experiments require a faster scanning speed. In experiments where faster scanning is needed, high speed voltmeters (HP 44702 B or HP 44704 B) have been used.

Table 8 presents a short description of the data acquisition cards used in the PACTEL.

Table 8. Description of the data acquisition cards.

Card	Description
HP 44701A	Integrating digital voltmeter
HP 44702B	High speed digital voltmeter (13 bit A/D converter)
HP 44704B	High speed digital voltmeter (16 bit A/D converter)
HP 44709A	20 channel FET multiplexer
HP 44710A	20 channel FET multiplexer
HP 44711A	24 channel high speed FET multiplexer
HP 44713A	24 channel high speed FET multiplexer with (50 Hz filter)

3.7 Process control system

A process control system for the PACTEL loop consists of a Siemens Simatic S7-300 programmable controller, which is connected to a personal computer. The communication between the computer and the programmable controller is carried out using Multi-Point Interface cable. The measurement transducers necessary to control the test facility are wired to the Simatic S7-300 input cards. So, the quantity of inputs is much smaller than in the data acquisition unit. The transducers with 4 - 20 mA output signal that are wired to the programmable controller are connected to the data acquisition unit as well. This parallel wiring has small effect on the accuracy of the measurement transducers since the impedance of both measurement systems is very high. Thermocouples connected to the process controller device are independent of the data acquisition system.

The programmable controller is comprised of modules. If necessary, modules can be added to the controller module racks. The quantity of inputs and outputs in the Simatic S7-300 programmable controller in the current configuration is presented in Table 9.

Table 9. Quantity of inputs and outputs of the Simatic S7-300 programmable controller.

Connection type	**Quantity**
Analog input	44
Analog output	17
Digital input	20
Digital output	32

Two computer programs are used for developing control software for the PACTEL: The Step 7 programming language which is used to make the control programs and WinCC which is used to program the man machine interface for the PACTEL experiments. Step 7 runs in the Microsoft Windows 95 operating system whereas the WinCC program runs in Microsoft Windows NT 4.0 operating system.

During the experiments, the operators of the PACTEL use the process control system to control the system pressure in the primary and secondary sides, core power, feedwater and ECC water flow rates to the loop, and main circulation pump speed. The operators can also open and close valves through the control system. The number and type of controls needed in an experiment strongly depends on the type of experiment. In slow transients and steady-state measurements, manual control systems can be used. In faster transients, such as large SBLOCA's, manual control systems are too slow and pre-programmed controls have to be used.

4. EXPERIMENT PROCEDURE

PACTEL experiments can run with either one, two, or three loops in operation. Typical examples of the experiments with one loop are studies of hot leg loop seal behaviour in small break LOCA's. During construction the new horizontal steam generators, some experiments were run with two loops in operation. An example of a two loop experiment is the passive safety injection experiment GDE-11. This experiment used two loops with the older steam generators. The third loop had already been equipped with the newer steam generator design.

Experiment procedure strongly depends on the type of experiment and the loop configuration. Preparation for the experiments normally begins with calibration and testing of the instrumentation. The experiment procedures are usually tested in pre-test calculations for each test with large thermal hydraulic system codes, such as APROS or RELAP.

After the pre-test calculations, the responsible engineer writes the test descriptions in a test specification report and fills out the test procedure forms. The PACTEL operators follow the procedures detailed on the forms during test execution. Typically, when preparing for an experiment, the PACTEL operators fill the primary and secondary systems with water and heat the loop to the desired initial conditions. After reaching steady state, it is maintained for about one hour before beginning the measurements. The measurement data collection begins normally with a steady-state period that is typically 1 000 seconds long. During the steady-state phase, the primary circulation pumps run, and the primary loop flow is single-phase forced circulation. The pressurizer heaters control automatically primary pressure, and the secondary-side control valve, the secondary-side pressure. The operators keep the secondary-side liquid inventory constant during the experiment manually running the feed water pumps.

The transient begins after the 1 000 second period of steady-state measurement. A typical transient initiator is the opening of the break valve (LOCA experiments). During test execution, the operators follow its progress by watching the instruments' output through a CRT monitor. Figure 9 shows the main screen display of the data acquisition system.

The experiments are terminated if the core heats up, or according to the test specifications. After the experiments, the responsible engineer converts the data to engineering units and examines the data to identify possible failed measurements. NPA - program can be used as a visualisation tool to analyse experiment results. See Figure 10 for the main mask of NPA. It is also possible to use NPA on-line to visualise experiment results during the experiments.

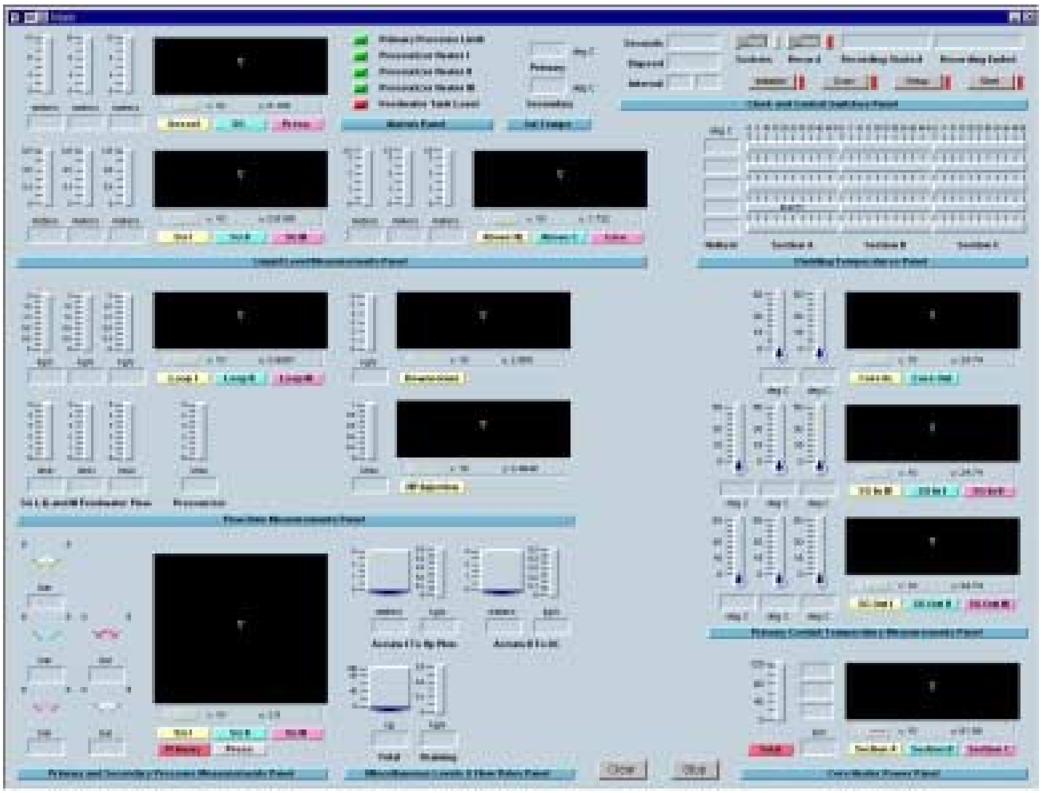

Figure 9. The main screen of the data acquisition system.

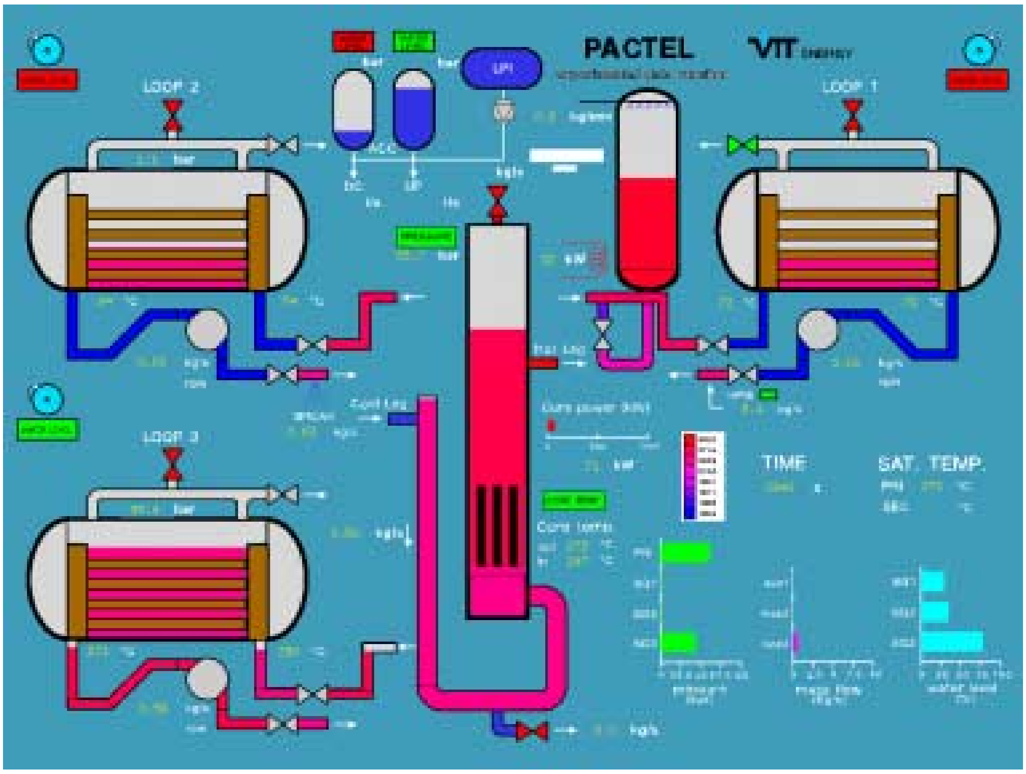

Figure 10. NPA main mask of the PACTEL.

After test data processing and quality checking, the experiment results are published in Quick-Look Reports and Experiment Data Reports. See Table 10 for a list of PACTEL experiments performed by December 19, 1997.

Table 10. List of PACTEL experiments conducted by January 1998.

TEST TYPE	**CODE**	**Number of Loops**	**ECC systems used**	**Break Location and Size (CL=cold leg, HL=hot leg**	**Type of SG**
Natural circulation	NC01-05	1	-	-	old
	NC06-07	3	-	-	old
Depressurisation of Primary System	CPR01-04, CPR11-12	3	Accumulatorss	Pressurizer top	old
ISP-33	ITE01-10	3	-	Lower plenum	old
SBLOCA	SBL02-07	3	-	CL,1 - 5.2 mm	old
	SBL08-09	1	-	CL, 1 mm	old
	SBL20-22	1	-	CL, 1 mm	new
	SBL30	3	-	CL, 1 mm	new
	SBL31	3	ACC	CL, 2.5 mm	new
	SBL32	3	ACC, HPI	CL, 2.8 mm	new
	SBL33	3	ACC, HPI	CL, 3.5 mm	new
	SBL40	3	DC-ACC	CL, 3.5 mm	new
Loss of Secondary-side Feed Water	LOF01	1	-	-	old
	LOF02-04	3	-	-	old
	LOF10	1	-	-	new
Compensated SBLOCA	CMP01-05	1	CL HPI	HL, 1 - 2.5 mm	old
	CMP06-11	3	CL HPI	HL, 2 - 2.5 mm	old
SBLOCA with Inclined Steam Generator Tubes	SBL10-12	1		CL, 1 mm	old
Gravity Driven ECC	GDE01-05	3	CMT	HL, 2 - 6 mm	old
	GDE11-14	2	CMT	CL, 2 - 4 mm	old
	GDE21-25	3	CMT	CL,1 - 5 mm	new
	GDE31	3	CMT	CL, 3.5 mm	new
	GDE32	3	CMT	HL, 3.5 mm	new
	GDE33	3	CMT	CL, 3.5 mm	new
	GDE34	3	CMT	CL, 3.5 mm	new
	GDE35	3	CMT	CL, 3.5 mm	new
	GDE41-GDE-45	3	CMT	CL, 1-3.5 mm	new
Hot Leg CCFL	LSR01-02	1			old
	LSR10	1			new
	LSR20-21	1			new
Primary to Secondary Leakage	PSL01	2	-	1 SG Tube	old
	PSL02-04	2	-	5 SG Tubes	old
	PSL5-7	3	ACC, HPI, LPI	5 SG tubes	3 new
Steam generator tests (IVO)	SG01-05	1	-	-	new
Stepwise inventory reduction test	SIR01-02	3	-	-	old
	SIR11	1	-	-	new
Natural circulation tests in low primary pressure	SIR20-23	1	-	-	new
ATWS-experiments	ATWS01	1	-	inventory reduced in steps	new
	ATWS02	1	-		new
	ATWS03	3	-		new
	ATWS04	1	-	CL, 1 mm	new
	ATWS06	3	-	Pressurizer top	new
SG Tubes Heat Stress Tests (IVO)	HPR01-13	3	-	-	2 old and 1 new
SG Experiments (STUK)	HSG01	1	-	-	new
	HSG02	3	-	-	new
	HSG03	2	-	-	new

5. DISCUSSION AND CONCLUSIONS

VTT Energy and the Lappeenranta University of Technology have successfully run more than 100 experiments with the PACTEL experiment loop. A large number of the experiments have been a part of the nationally funded research programmes YKÄ and RETU. Some of the experiments have been funded by the Radiation and Nuclear Safety Authority (STUK), the European Commission, and the Finish power company IVO.

The experiments have provided valuable information about the natural circulation characteristics of the VVER-type PWR, behaviour of horizontal steam generators in transients and accidents, and performance of passive safety injection systems in LOCA's. The experiment data has been used for validation of the Finnish APROS code, as a Finnish contribution to some international research programmes, and directly at the Loviisa power plant to verify some design modifications to the horizontal steam generators.

The next experiment phase of the publicly funded research programme in the PACTEL includes additional simulations of ATWS transients and studies of influences of non-condensable gases on the natural circulation characteristics of the VVER reactors. Some proposals have been made for further passive safety injection experiments, for example, to simulate Russian VVER-640 design or to use the PACTEL in some research-oriented TACIS/PHARE projects. The PACTEL has been in operation almost 10 years now. In 1997, PACTEL operators replaced the old data acquisition and process control systems. The next modification will be to replace the existing fuel rod simulators with new ones during 1998.

ACKNOWLEDGEMENTS

The construction and operation of the PACTEL test facility have been financially supported by the Ministry of Trade and Industry (KTM), VTT Energy (until 1994 Nuclear Engineering Laboratory of the Technical Research Centre of Finland (VTT)) and the Lappeenranta University of Technology (LTKK).

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Appendix A Geometry of PACTEL facility

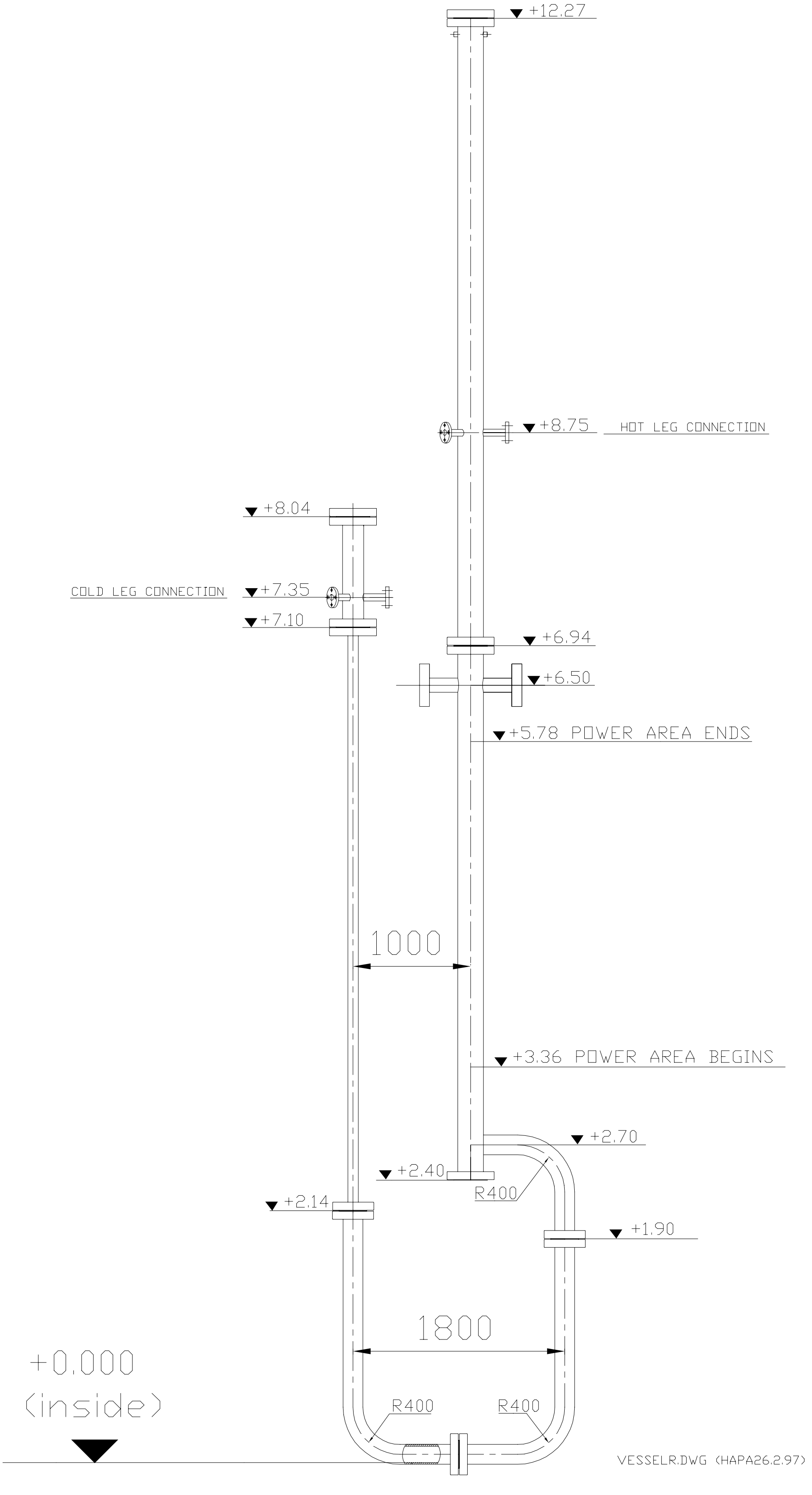
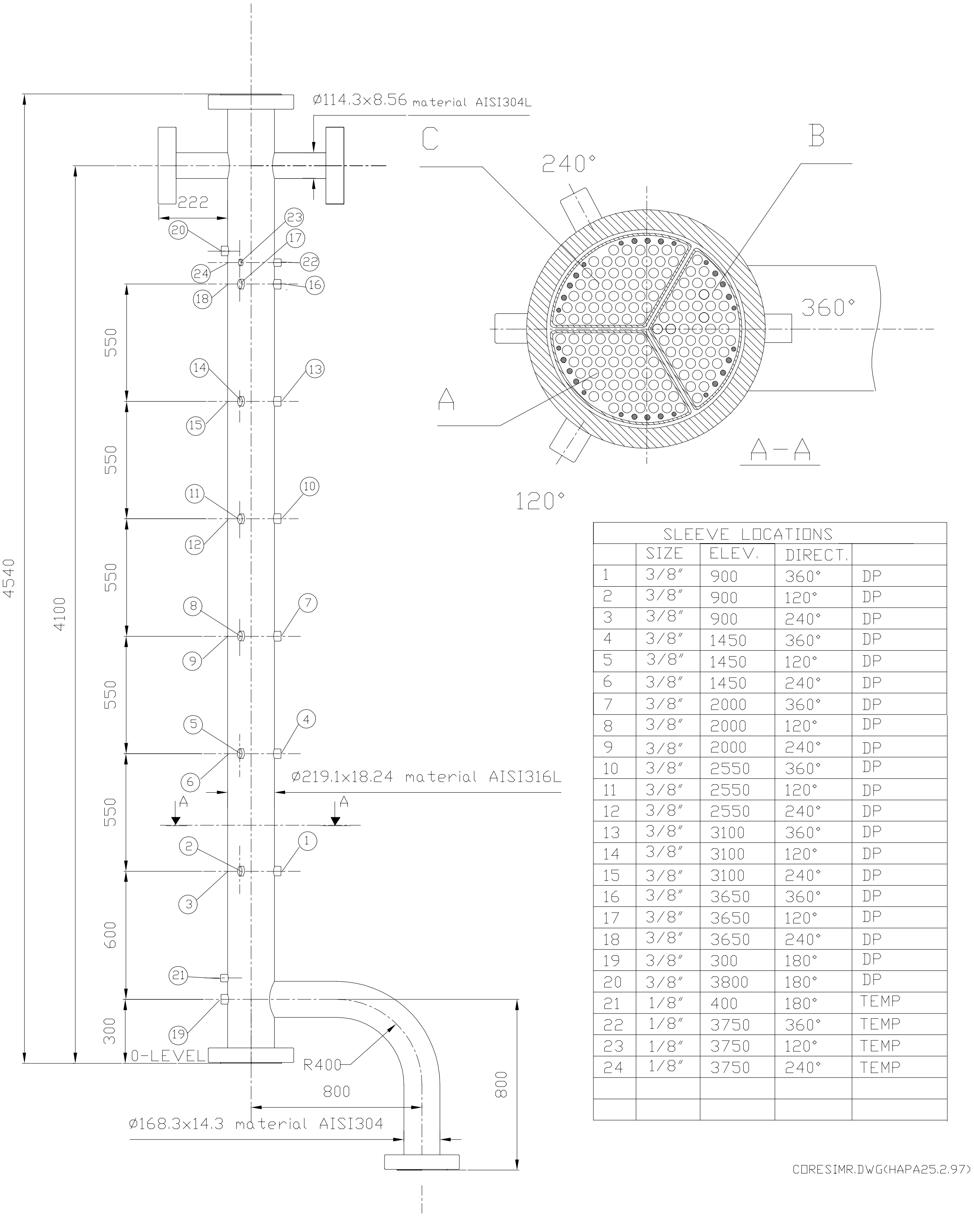


Figure A. 1. The pressure vessel of the PACTEL facility. The elevations are from the inner surface of the bottom.



SLEEVE LOCATIONS

	SIZE	ELEV.	DIRECT.	
1	3/8"	900	360°	DP
2	3/8"	900	120°	DP
3	3/8"	900	240°	DP
4	3/8"	1450	360°	DP
5	3/8"	1450	120°	DP
6	3/8"	1450	240°	DP
7	3/8"	2000	360°	DP
8	3/8"	2000	120°	DP
9	3/8"	2000	240°	DP
10	3/8"	2550	360°	DP
11	3/8"	2550	120°	DP
12	3/8"	2550	240°	DP
13	3/8"	3100	360°	DP
14	3/8"	3100	120°	DP
15	3/8"	3100	240°	DP
16	3/8"	3650	360°	DP
17	3/8"	3650	120°	DP
18	3/8"	3650	240°	DP
19	3/8"	300	180°	DP
20	3/8"	3800	180°	DP
21	1/8"	400	180°	TEMP
22	1/8"	3750	360°	TEMP
23	1/8"	3750	120°	TEMP
24	1/8"	3750	240°	TEMP

Figure A. 2. The core section. Locations of differential pressure and temperature measurements.

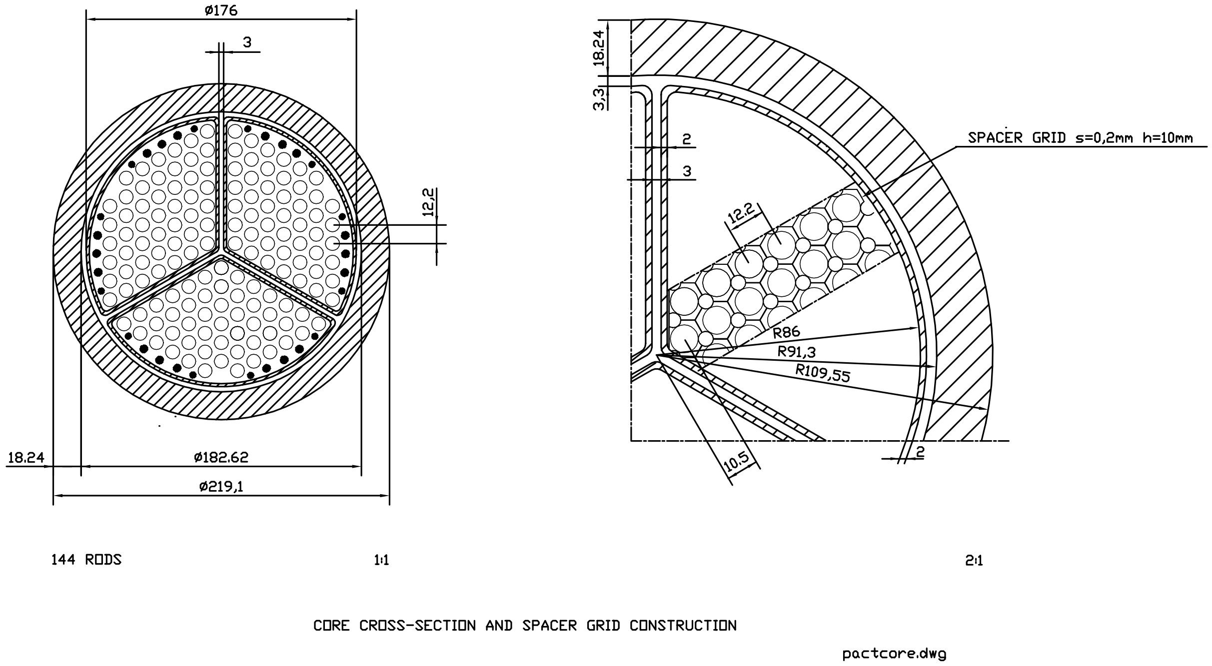


Figure A. 3. Core cross-section and spacer grid construction.

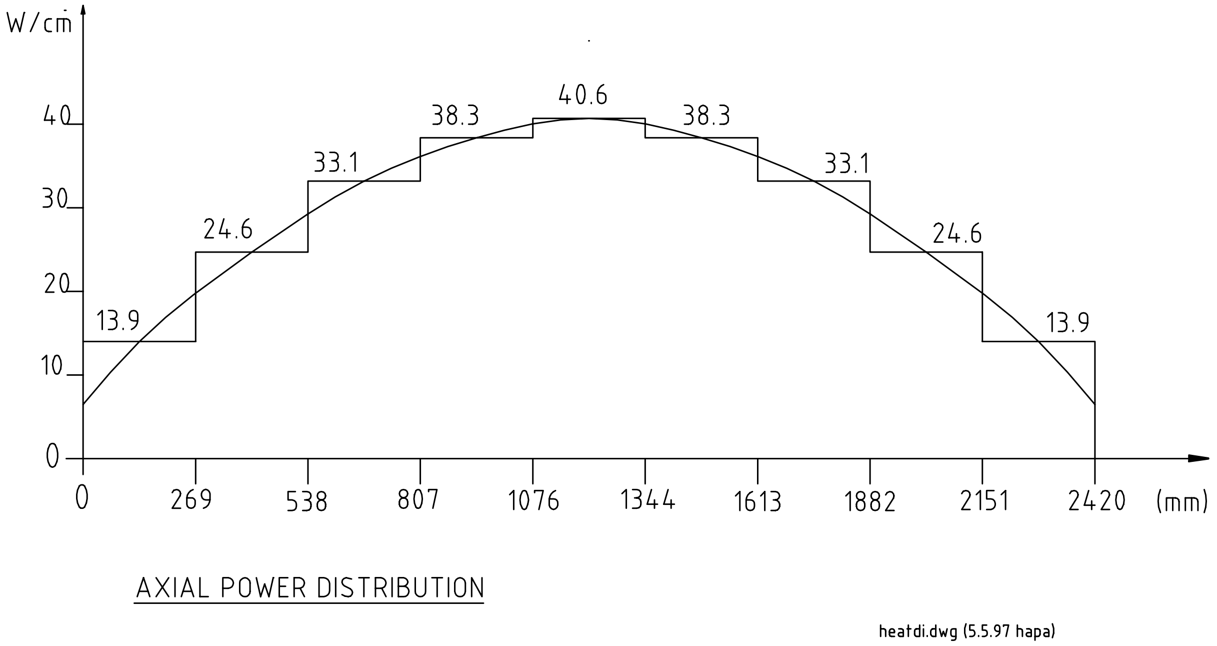
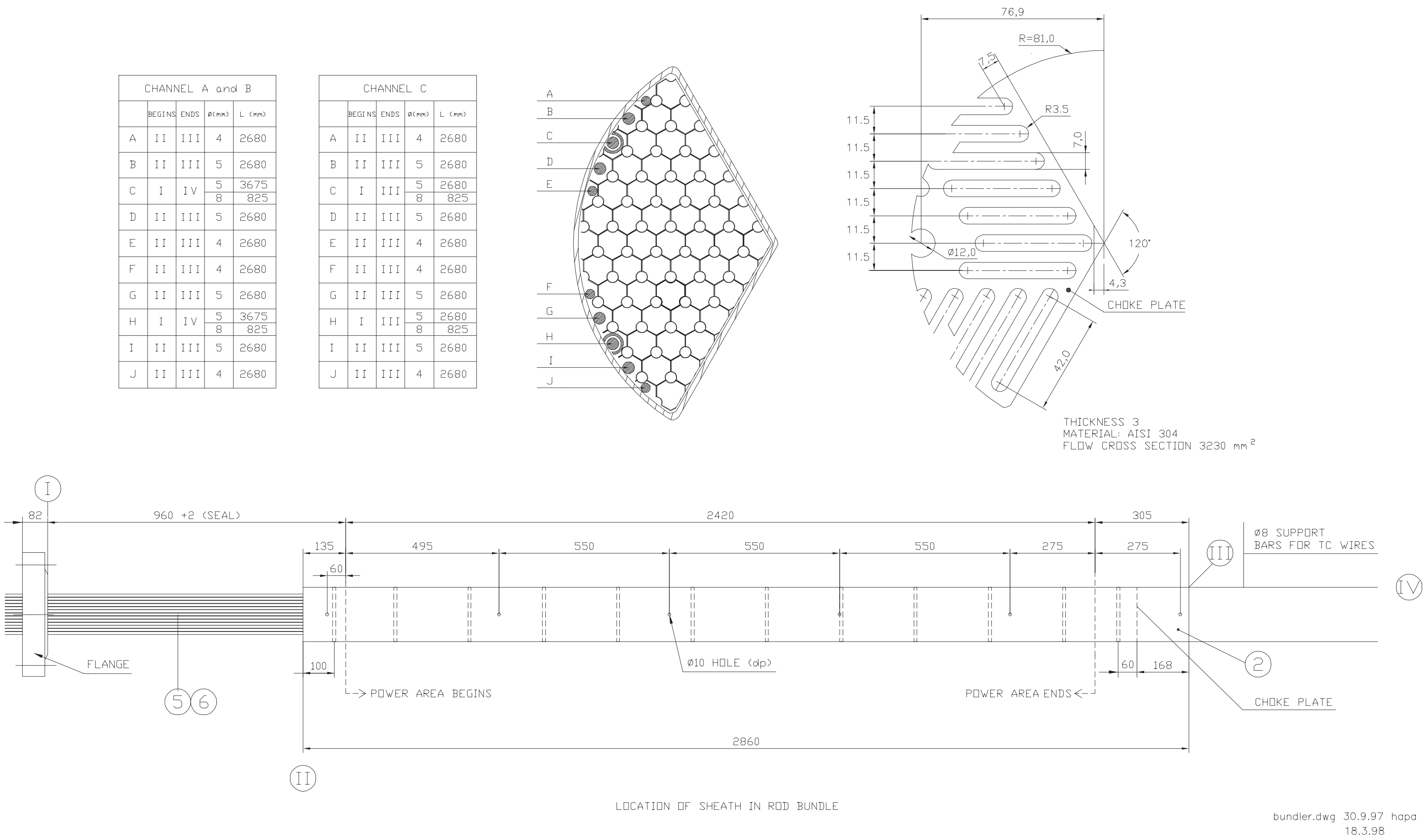


Figure A. 4. Axial power distribution in the core.



CHANNEL A and B				
	BEGINS	ENDS	Ø(mm)	L (mm)
A	II	III	4	2680
B	II	III	5	2680
C	I	IV	5 8	3675 825
D	II	III	5	2680
E	II	III	4	2680
F	II	III	4	2680
G	II	III	5	2680
H	I	IV	5 8	3675 825
I	II	III	5	2680
J	II	III	4	2680

CHANNEL C				
	BEGINS	ENDS	Ø(mm)	L (mm)
A	II	III	4	2680
B	II	III	5	2680
C	I	III	5 8	2680 825
D	II	III	5	2680
E	II	III	4	2680
F	II	III	4	2680
G	II	III	5	2680
H	I	III	5 8	2680 825
I	II	III	5	2680
J	II	III	4	2680

Figure A. 5. PACTEL rod bundle construction. Dimensions and positions of steel rods (A, B, C, D, E, F, G, H and J) in the core.

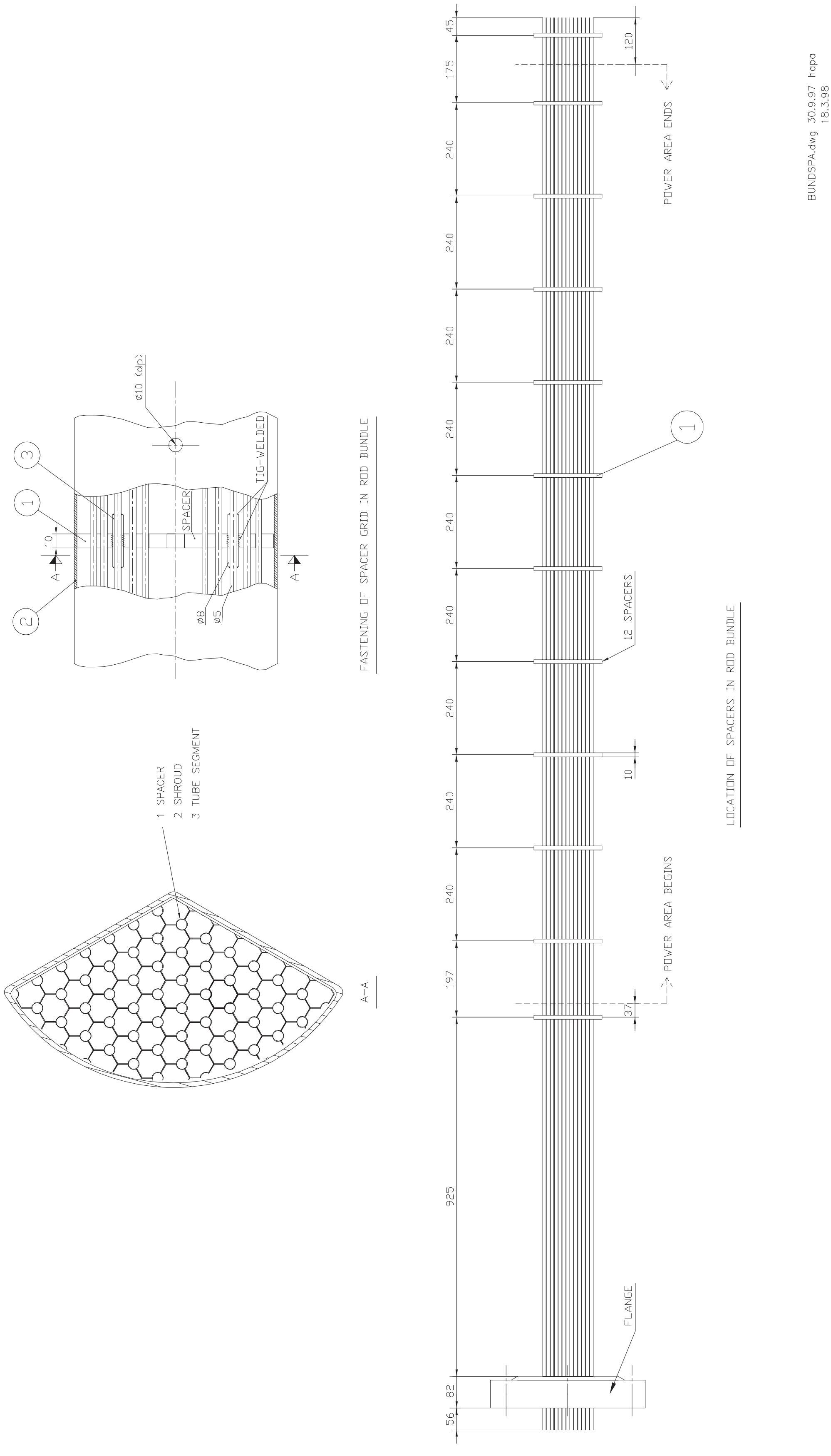


Figure A. 6. Location of spacers in the rod bundle.

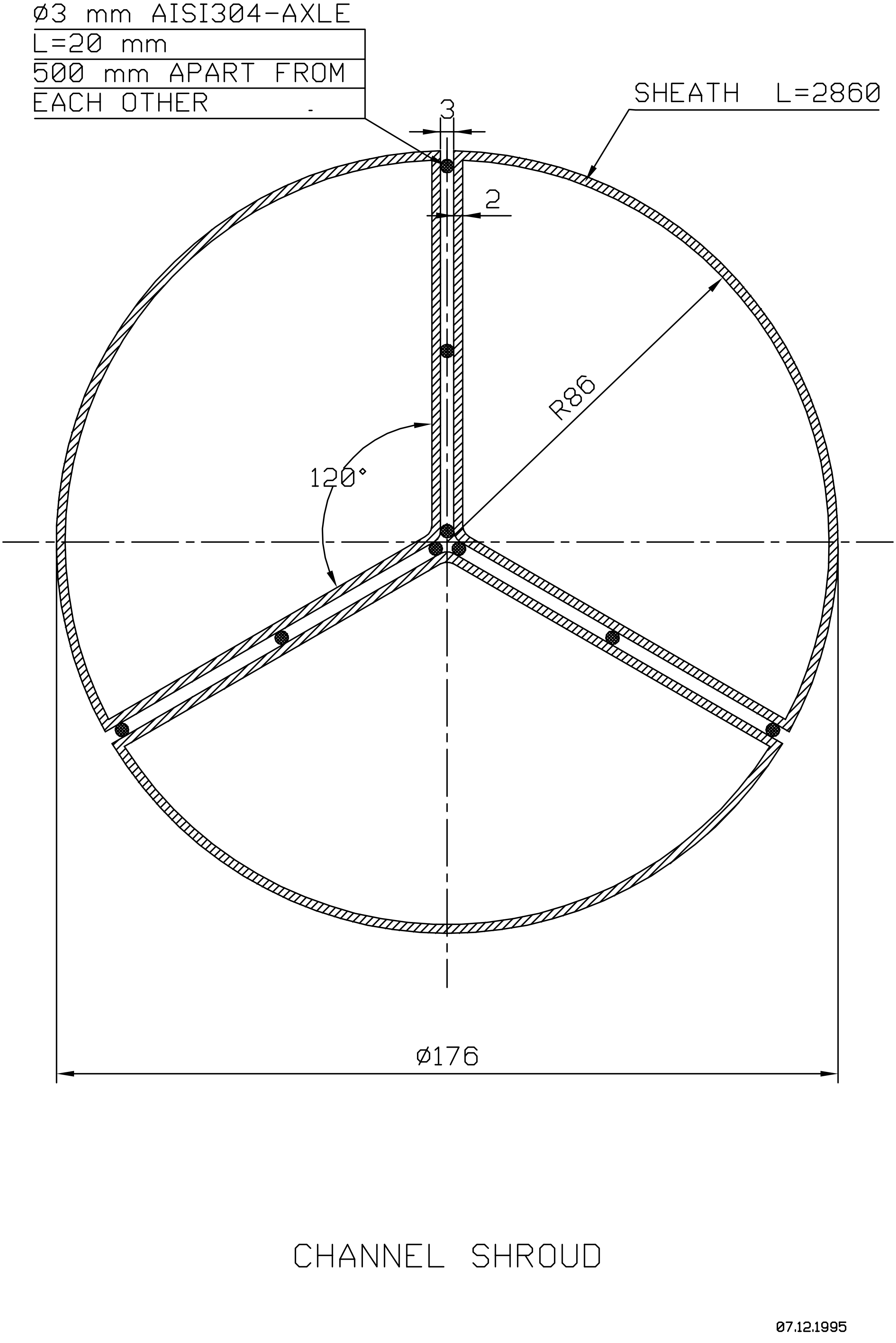


Figure A. 7. Construction of the channel shroud at the core.

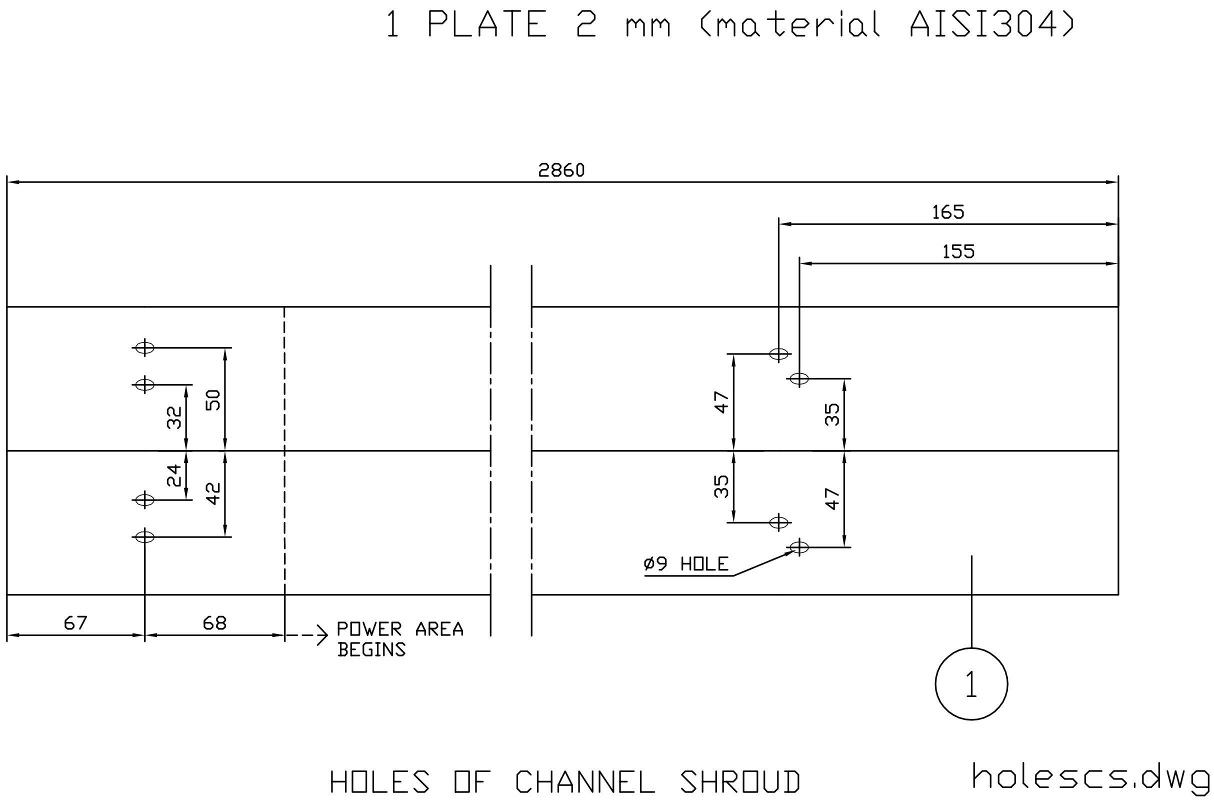
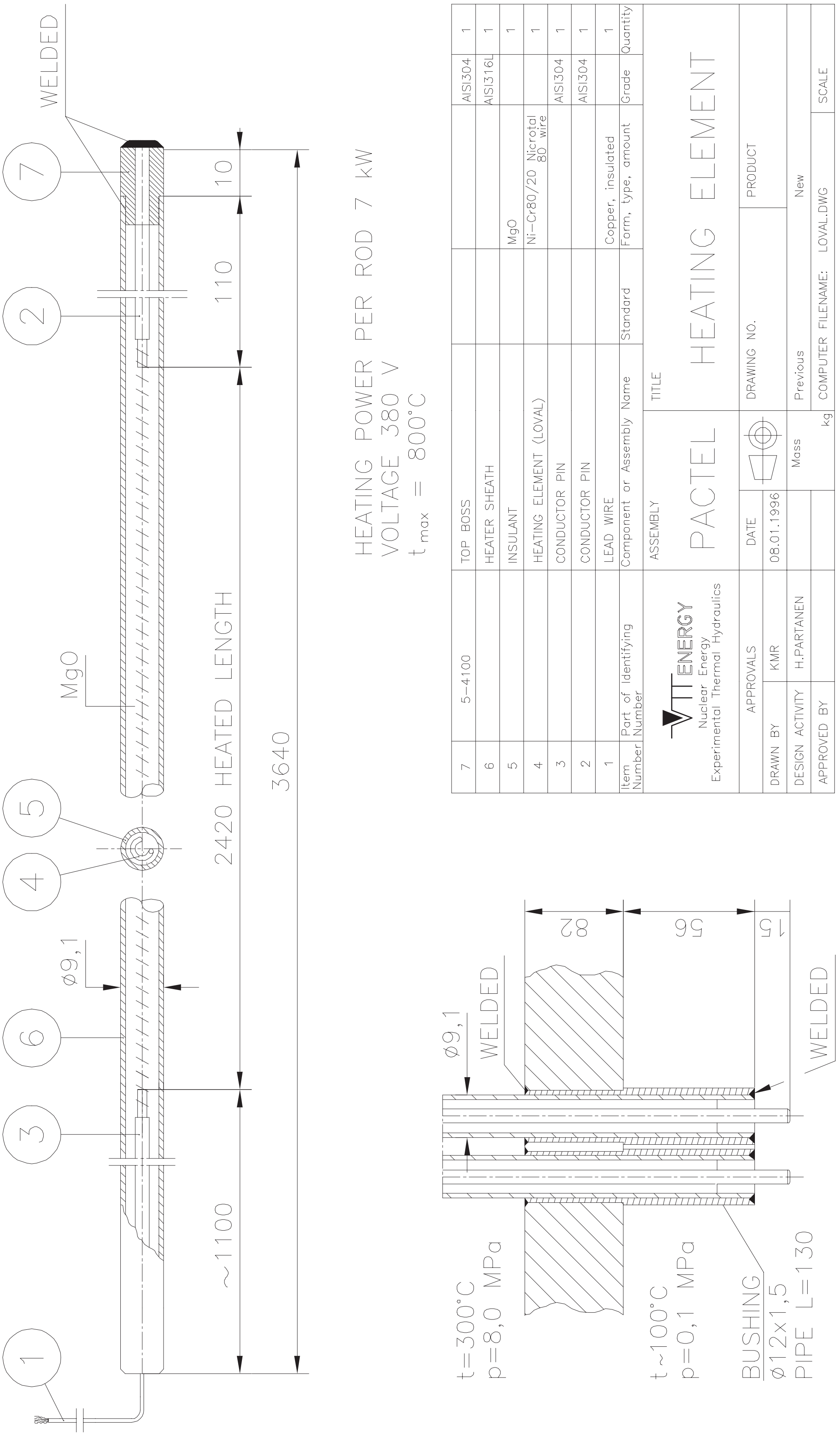
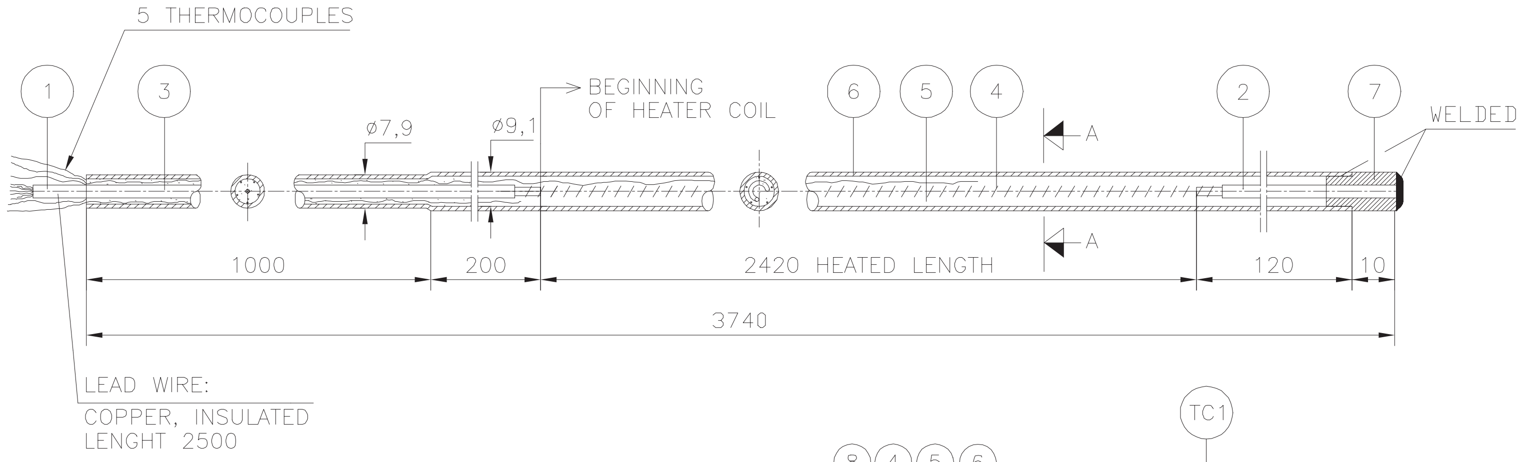


Figure A. 8. Location of the holes at the channel shroud.



Item Number	Part of Identifying Number	Component or Assembly Name	Standard	Form, type, amount	Grade	Quantity
7	5–4100	TOP BOSS			AISI304	1
6		HEATER SHEATH			AISI316L	1
5		INSULANT		MgO		1
4		HEATING ELEMENT (LOVAL)		Ni–Cr80/20 Nicrotal 80 wire		1
3		CONDUCTOR PIN			AISI304	1
2		CONDUCTOR PIN			AISI304	1
1		LEAD WIRE		Copper, insulated		1

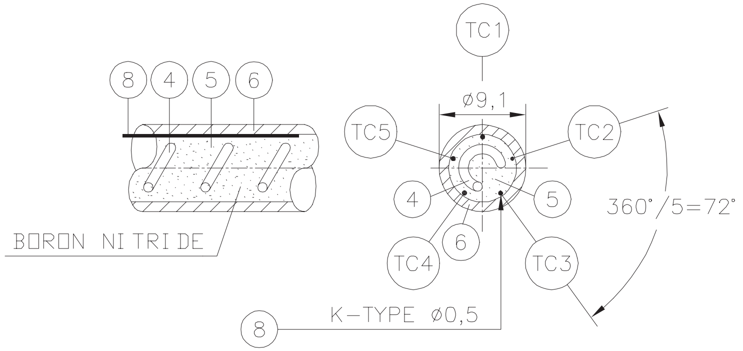
Figure A. 9. Fuel rod simulators (thermocouples welded on the cladding).



THERMOCOUPLE LOCATIONS FROM THE BEGINNING OF THE HEATER COIL.

MEATER TYPE \ THERMOCOUPLE LOCATIONS	TC1	TC2	TC3	TC4	TC5
TYPE 1	134	672	1210	1748	2286
TYPE 2	403	941	1210	1479	2017

HEATING POWER PER ROD	7 kW
OPERATING VOLTAGE	380 V
HEATED LENGHT	2420 mm
OUTER DIAMETER	Ø9,1 mm (Ø7,9 mm)
AXIAL POWER DISTRIPUTION	CHOPPED COSINE
AXIAL PEAKING FACTOR	1,4
AVE. LINEAR HEATING POWER	28,9 W/cm
MAX. SURFACE TEMP OF ROD	800° C
SYSTEM PRESSURE	0,1-8,0 MPa
COOLANT TEMPERATURE	20-105° C
INSULANT	BORON NITRIDE

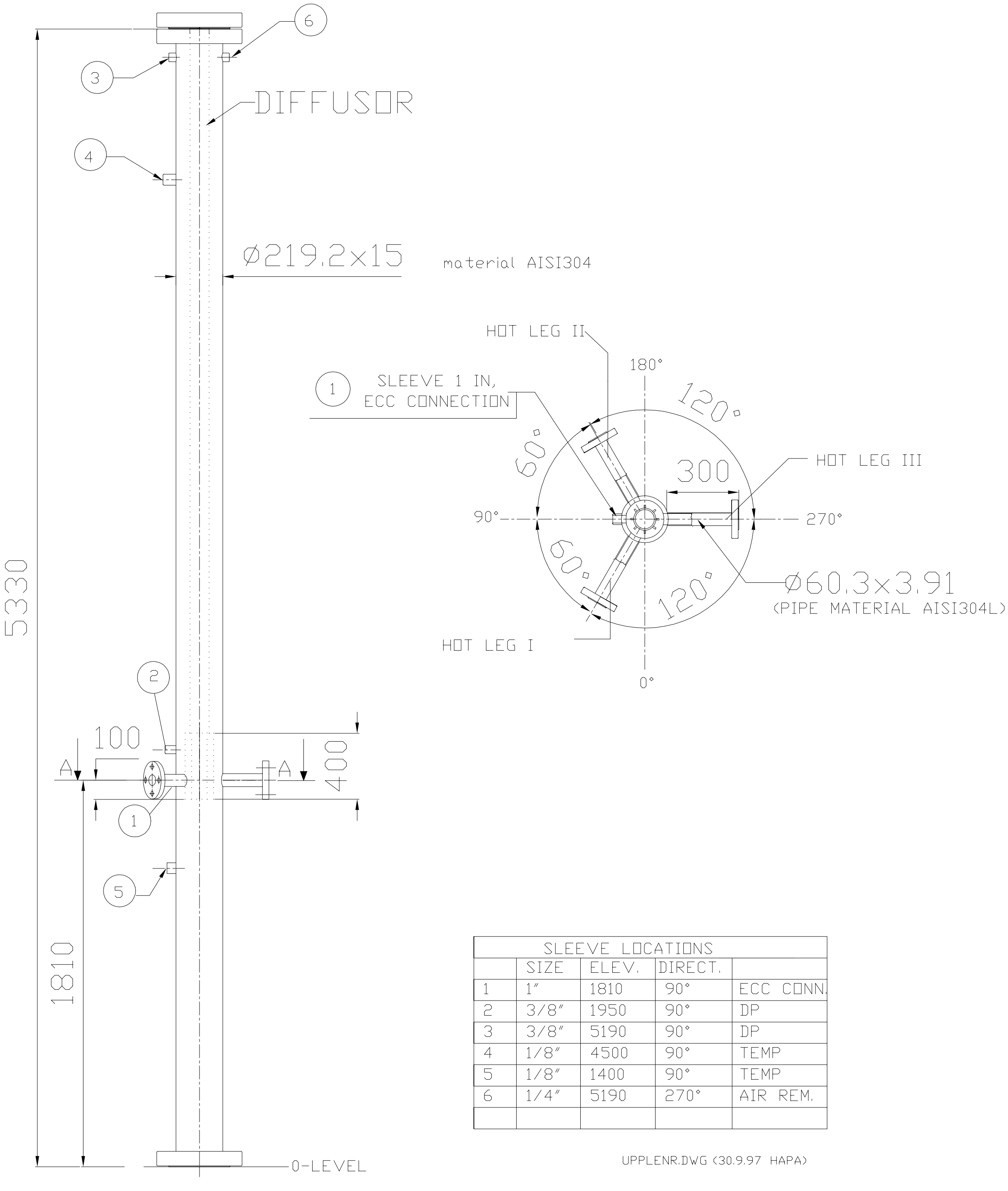


SECTION A - A

Item Number	Part of Identifying Number	Component or Assembly Name	Standard	Form, type, amount	Grade	Quantity
8		MINERAL INSULARED THERMOCOUPLE		K-type Ni-Cr-Fe alloy		5
7		TOP BOSS			AISI304	1
6		HEATER SHEATH			AISI316L	1
5		INSULANT		Boron nitride		1
4		HEATING ELEMENT				1
3		CONDUCTOR PIN			AISI304 orNi	1
2		CONDUCTOR PIN			AISI304 orNi	1
1		LEAD WIRE		Copper, insulated		1

VTT ENERGY Nuclear Energy Experimental Thermal Hydraulics	ASSEMBLY PACTEL	TITLE FUEL ROD SIMULATOR / FRANCE		
APPROVALS	DATE		DRAWING NO.	PRODUCT
DRAWN BY	KMR	08.01.1996	Previous 5-1097	New
DESIGN ACTIVITY	H.PARTANEN	Mass kg	COMPUTER FILENAME: FRENCH.DWG	SCALE
APPROVED BY				

Figure A. 10. Fuel rod simulators (thermocouples inside the cladding).



SLEEVE LOCATIONS

	SIZE	ELEV.	DIRECT.	
1	1″	1810	90°	ECC CONN.
2	3/8″	1950	90°	DP
3	3/8″	5190	90°	DP
4	1/8″	4500	90°	TEMP
5	1/8″	1400	90°	TEMP
6	1/4″	5190	270°	AIR REM.

Figure A. 11. Upper plenum with hot leg connections.

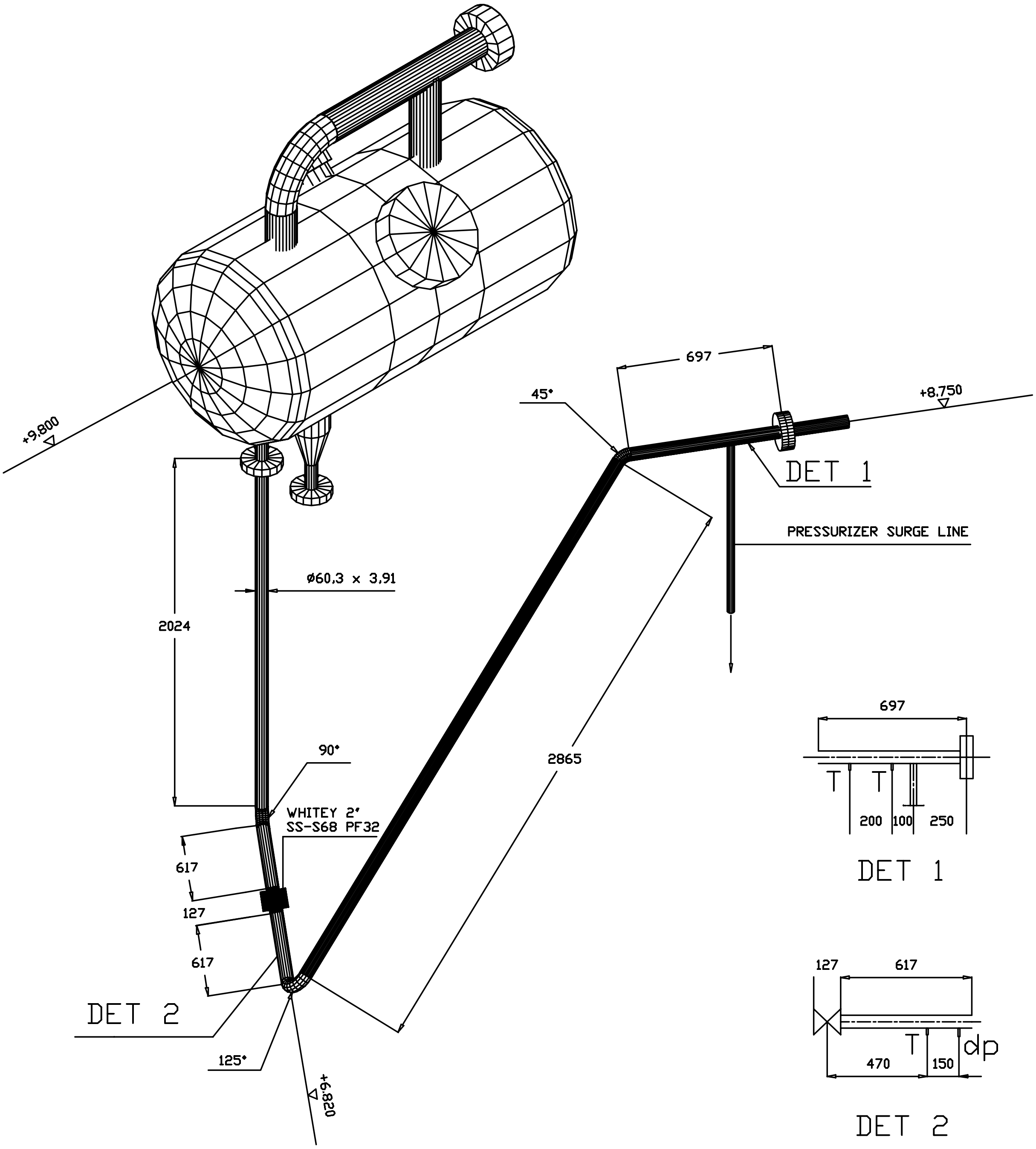


Figure A. 12. Loop 1 hot leg.

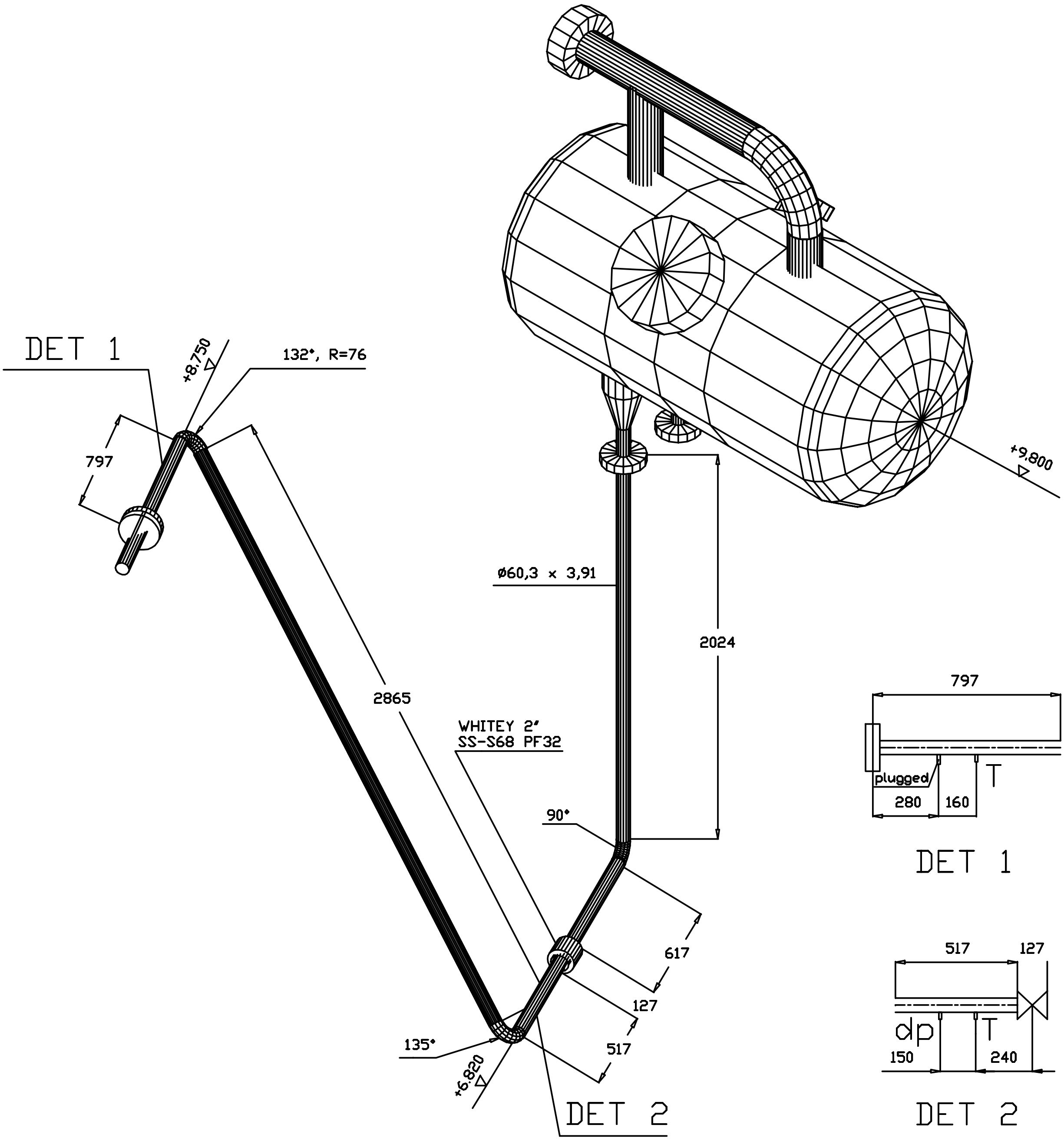


Figure A. 13. Loop 2 hot leg.

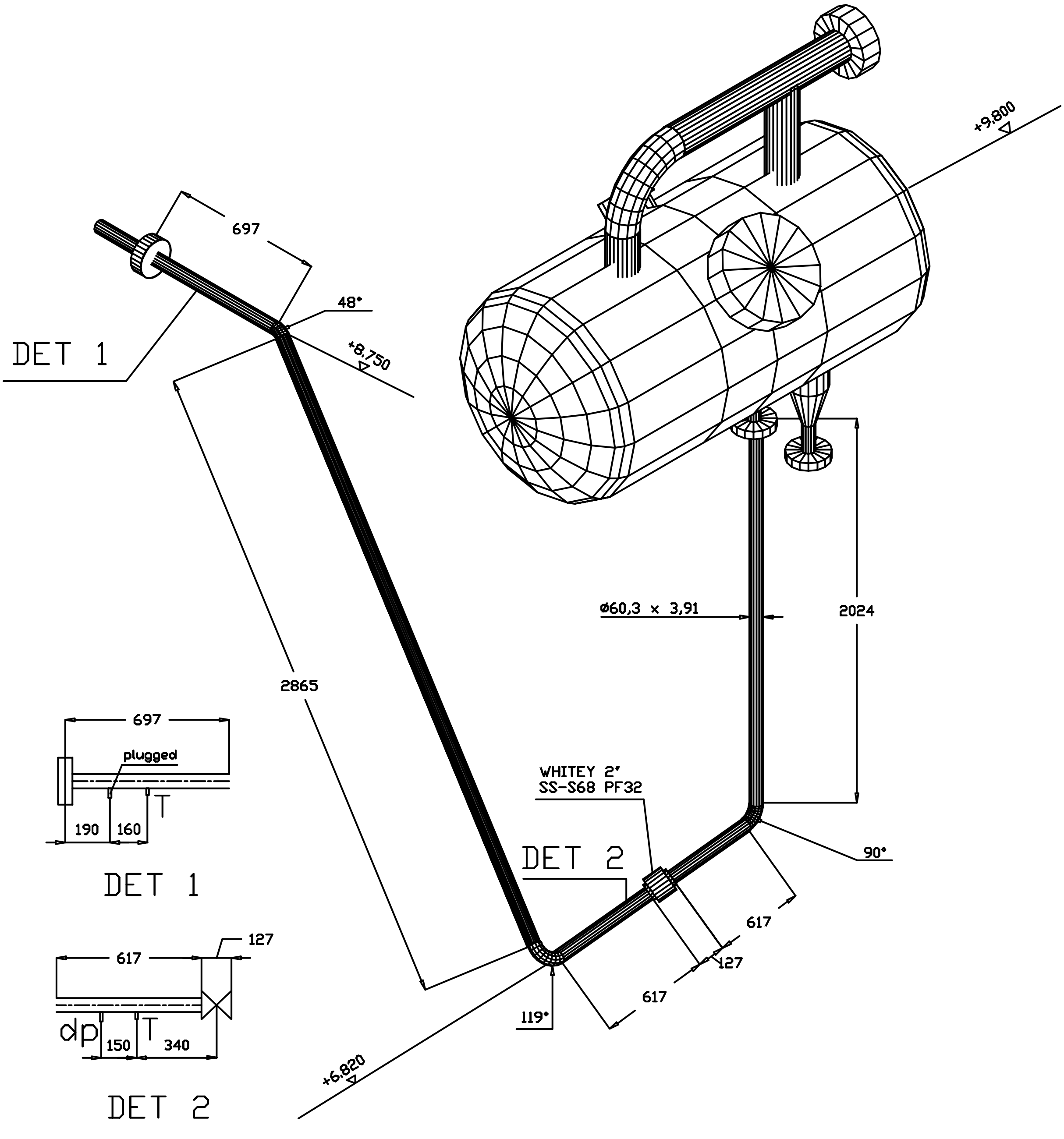


Figure A. 14. Loop 3 hot leg.

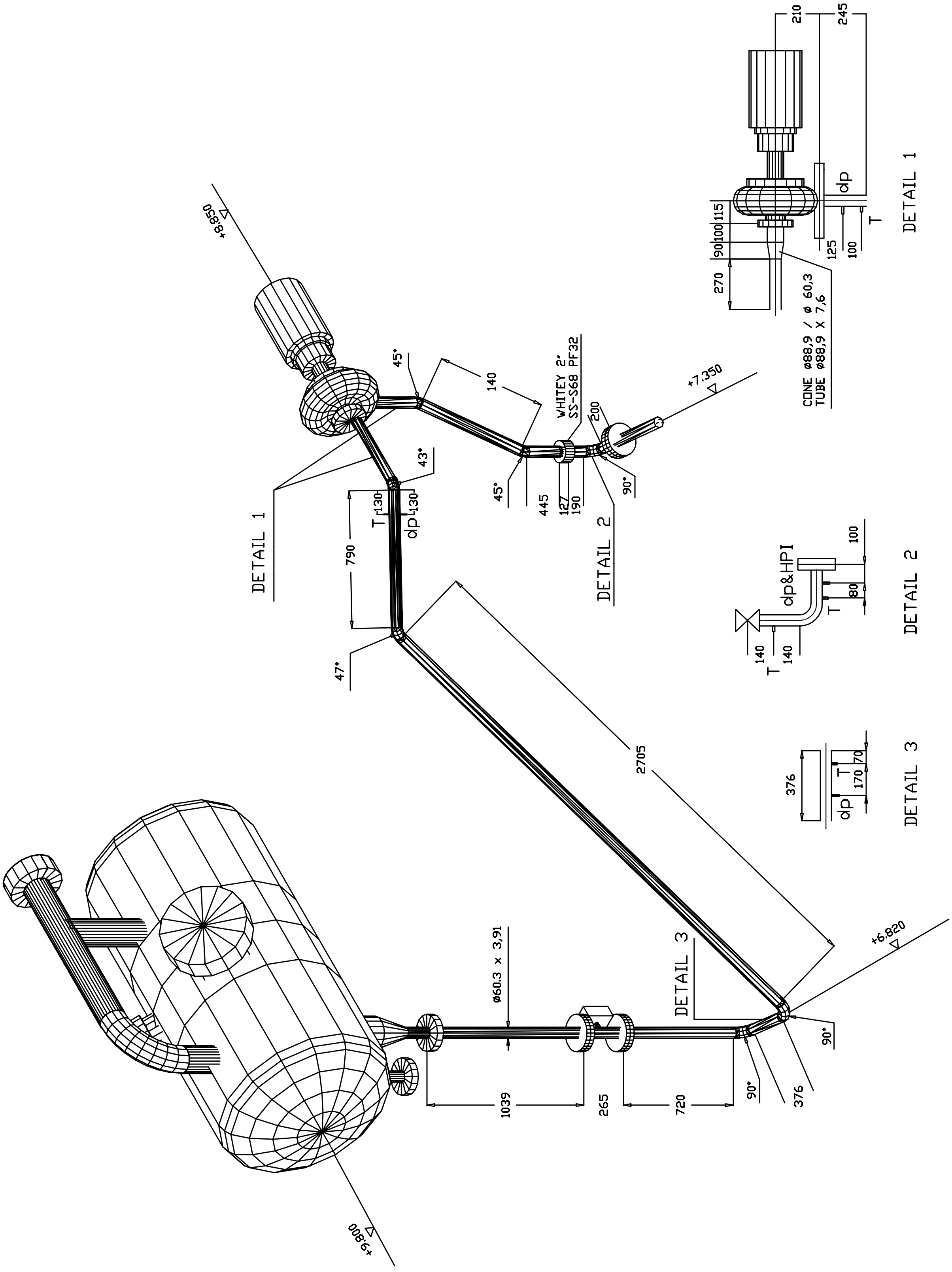


Figure A. 15. Loop 1 cold leg.

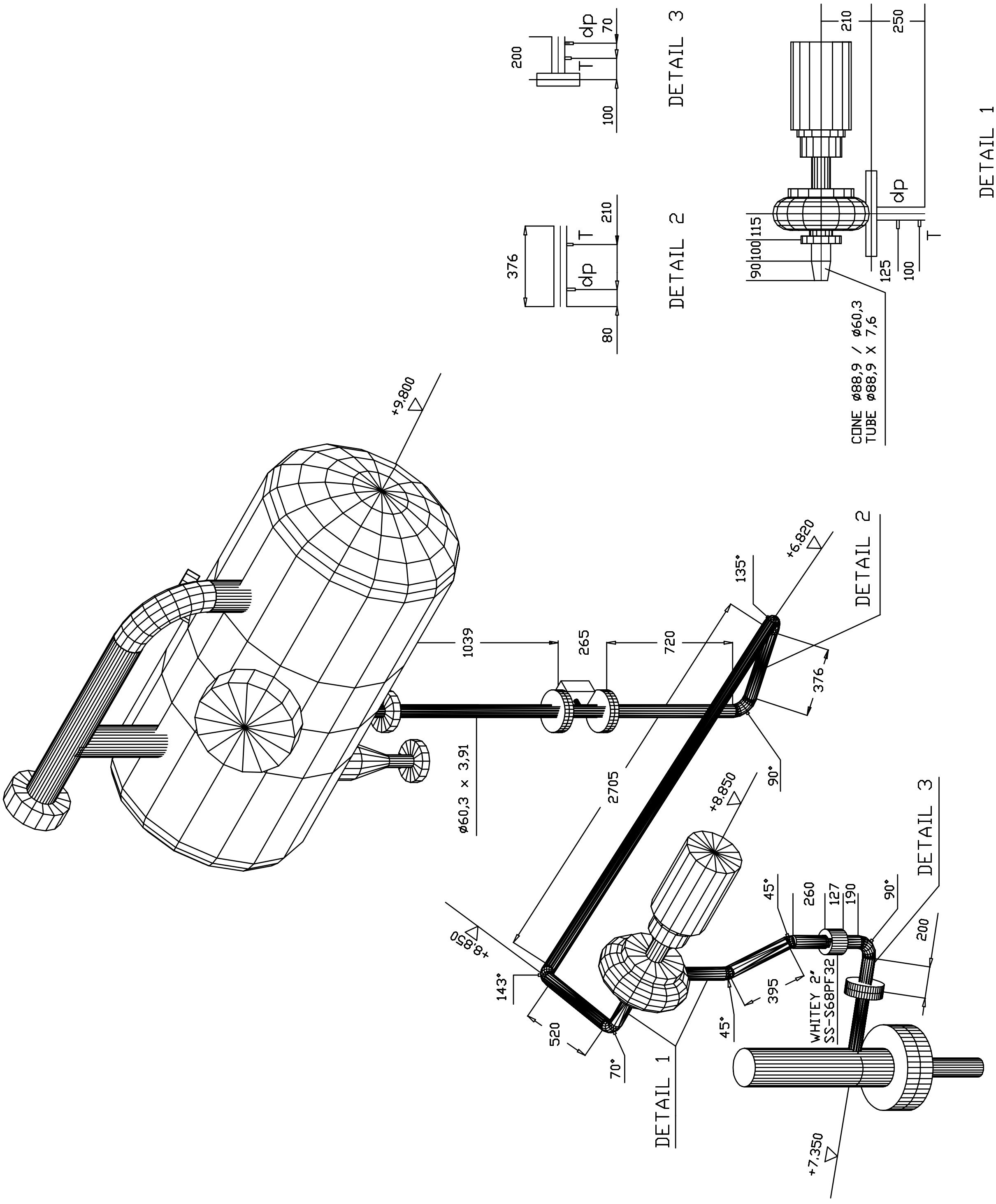


Figure A. 16. Loop 2 cold leg.

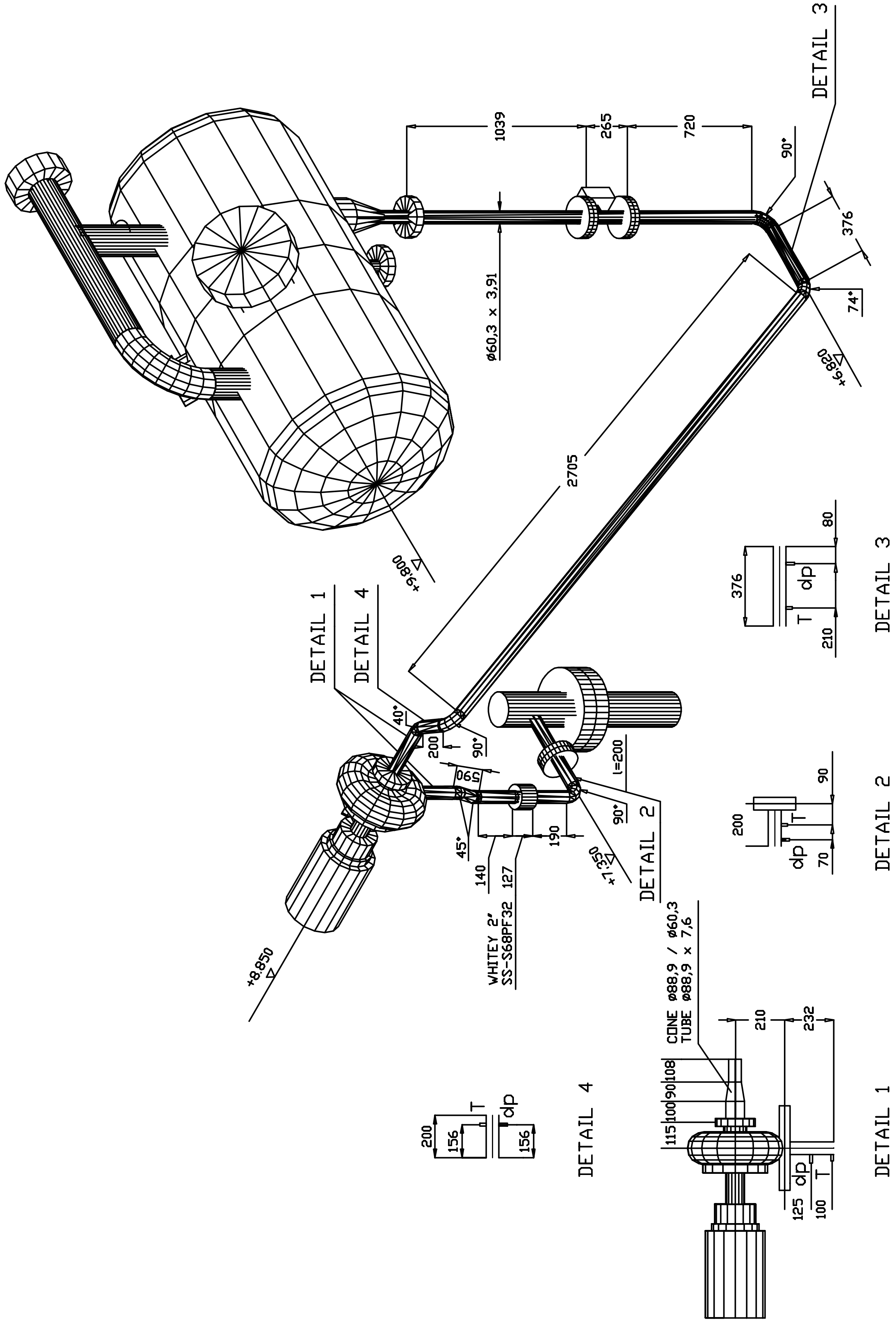


Figure A. 17. Loop 3 cold leg.

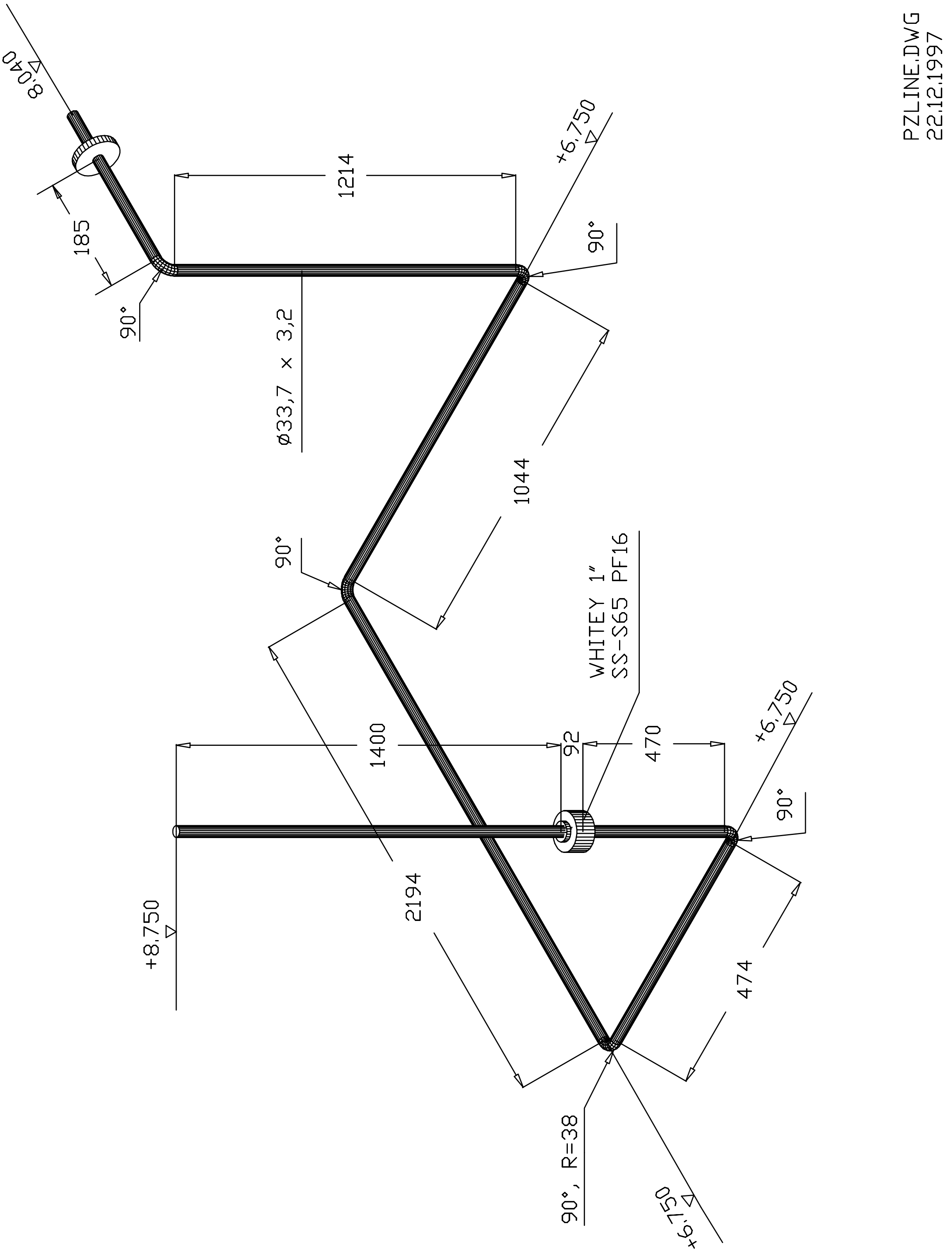


Figure A. 18. Pressurizer surge line.

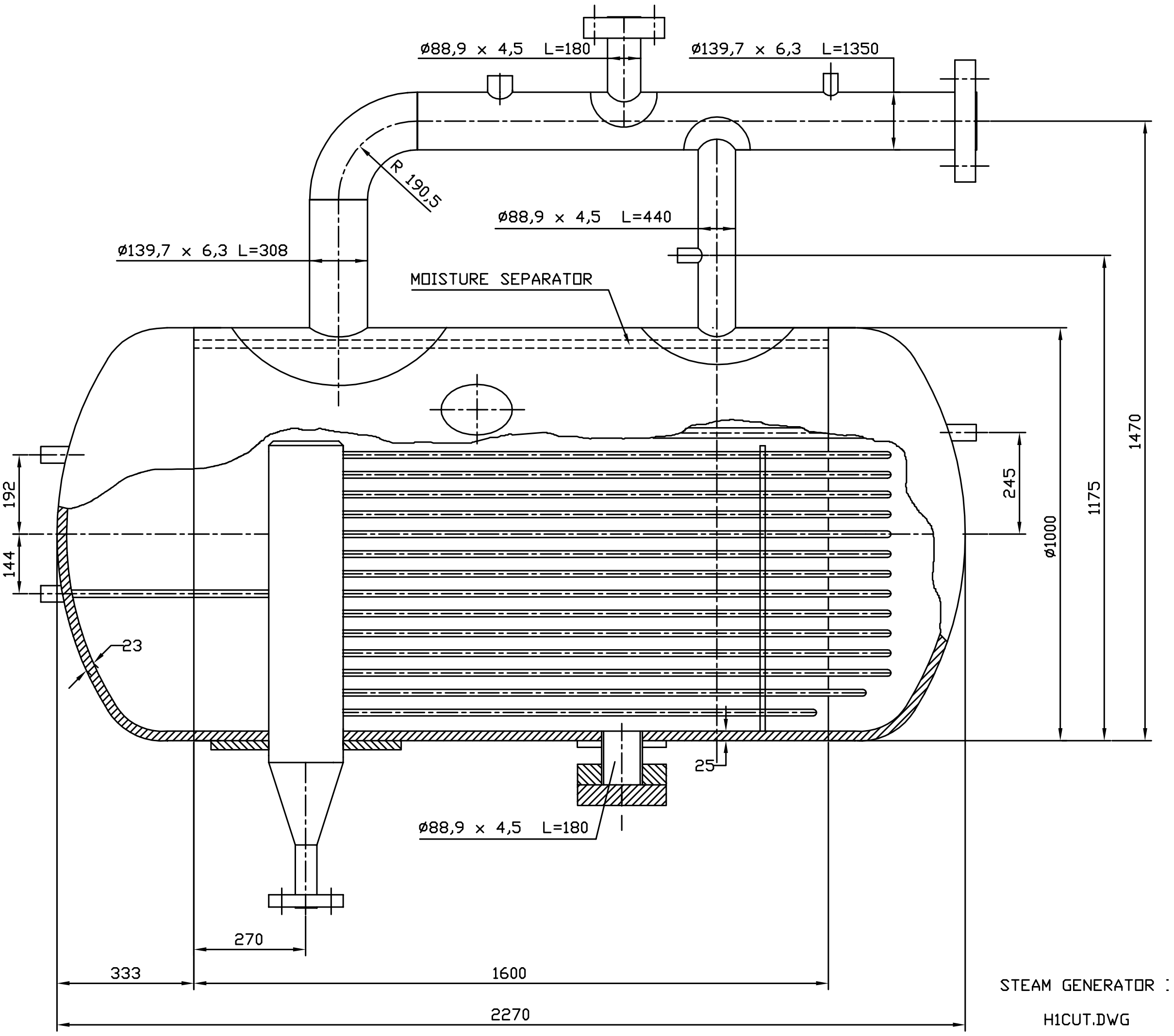


Figure A. 19. Steam generator construction. Loop 1.

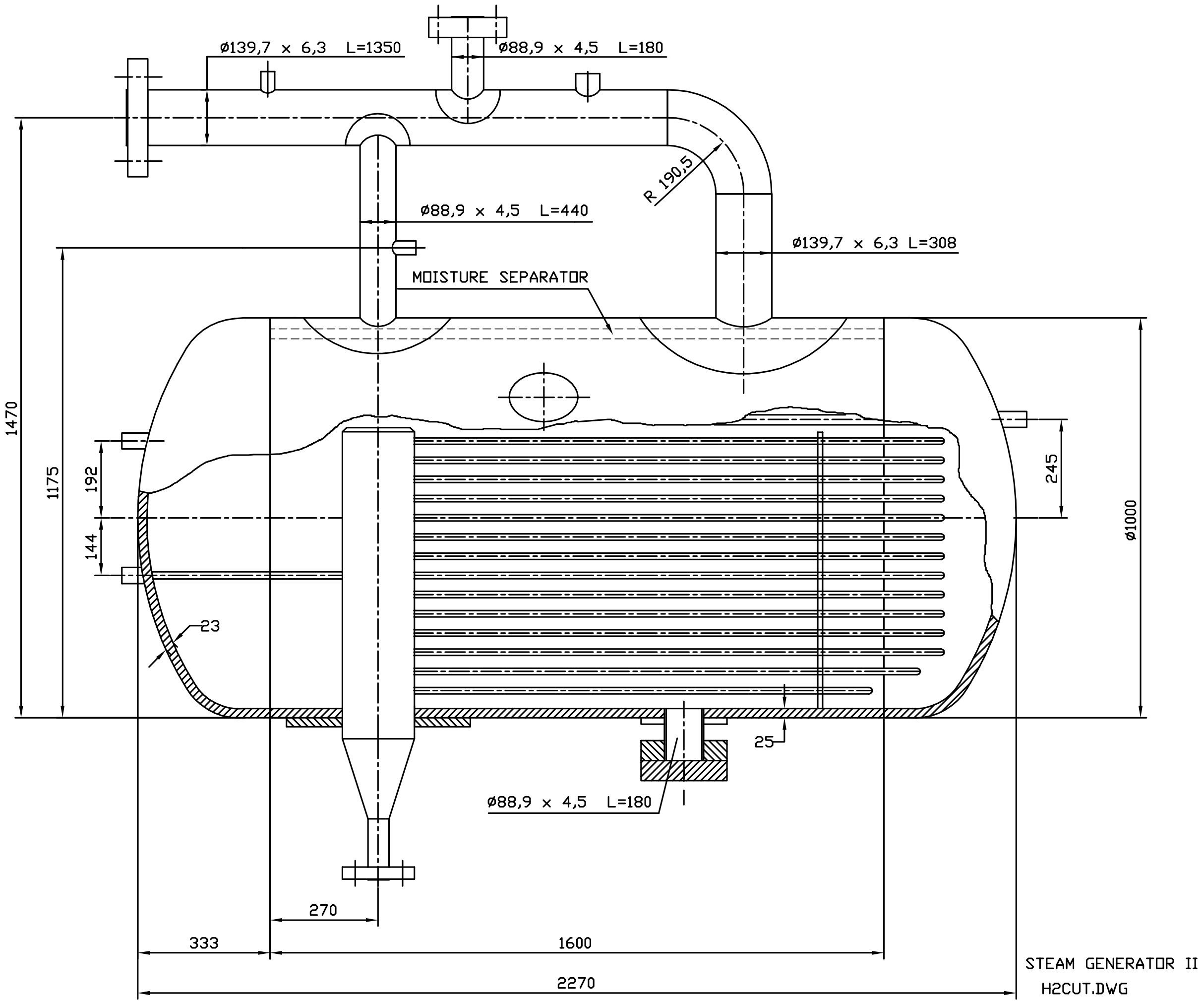


Figure A. 20. Steam generator construction. Loop 2.

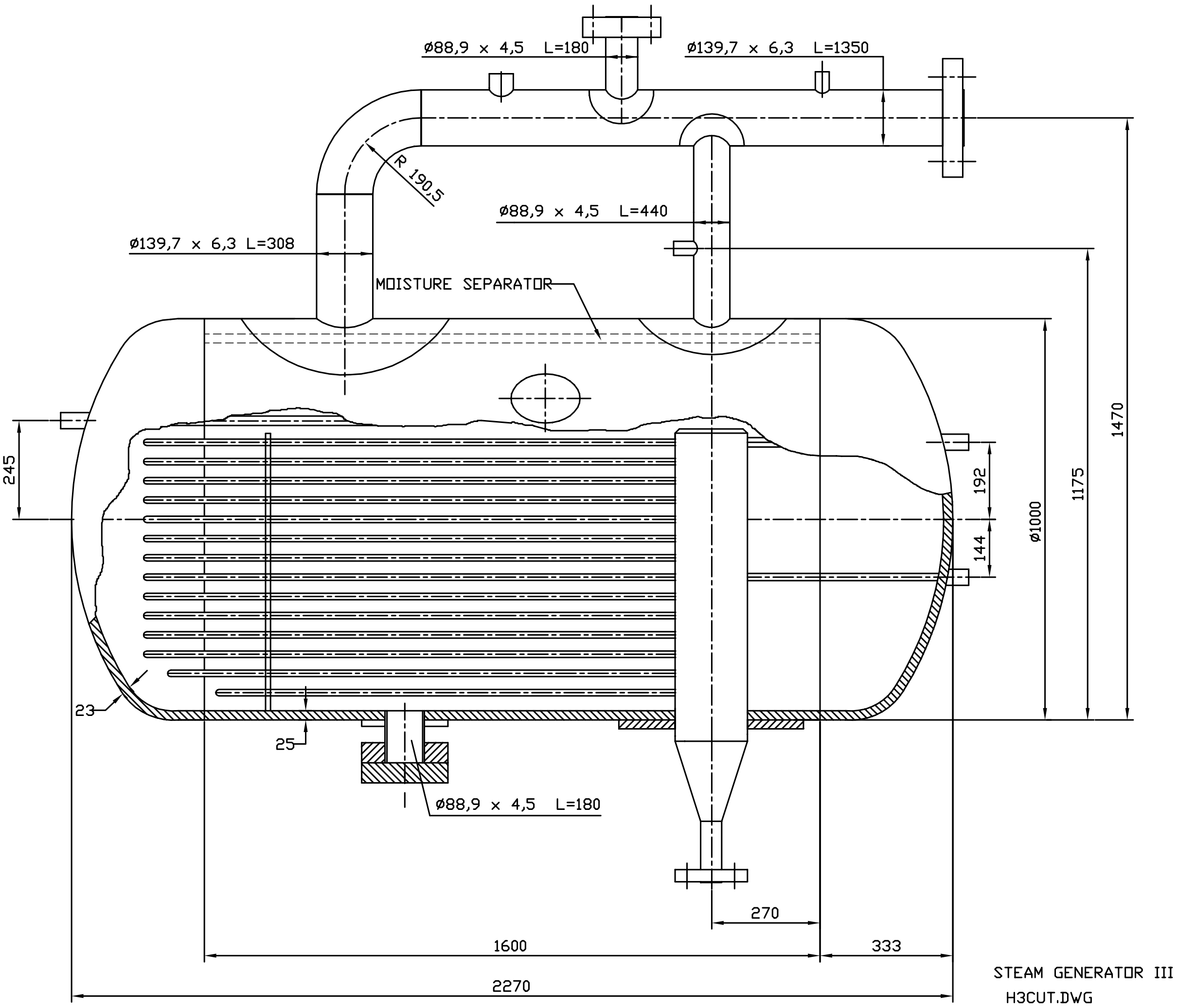


Figure A. 21. Steam generator construction. Loop 3.

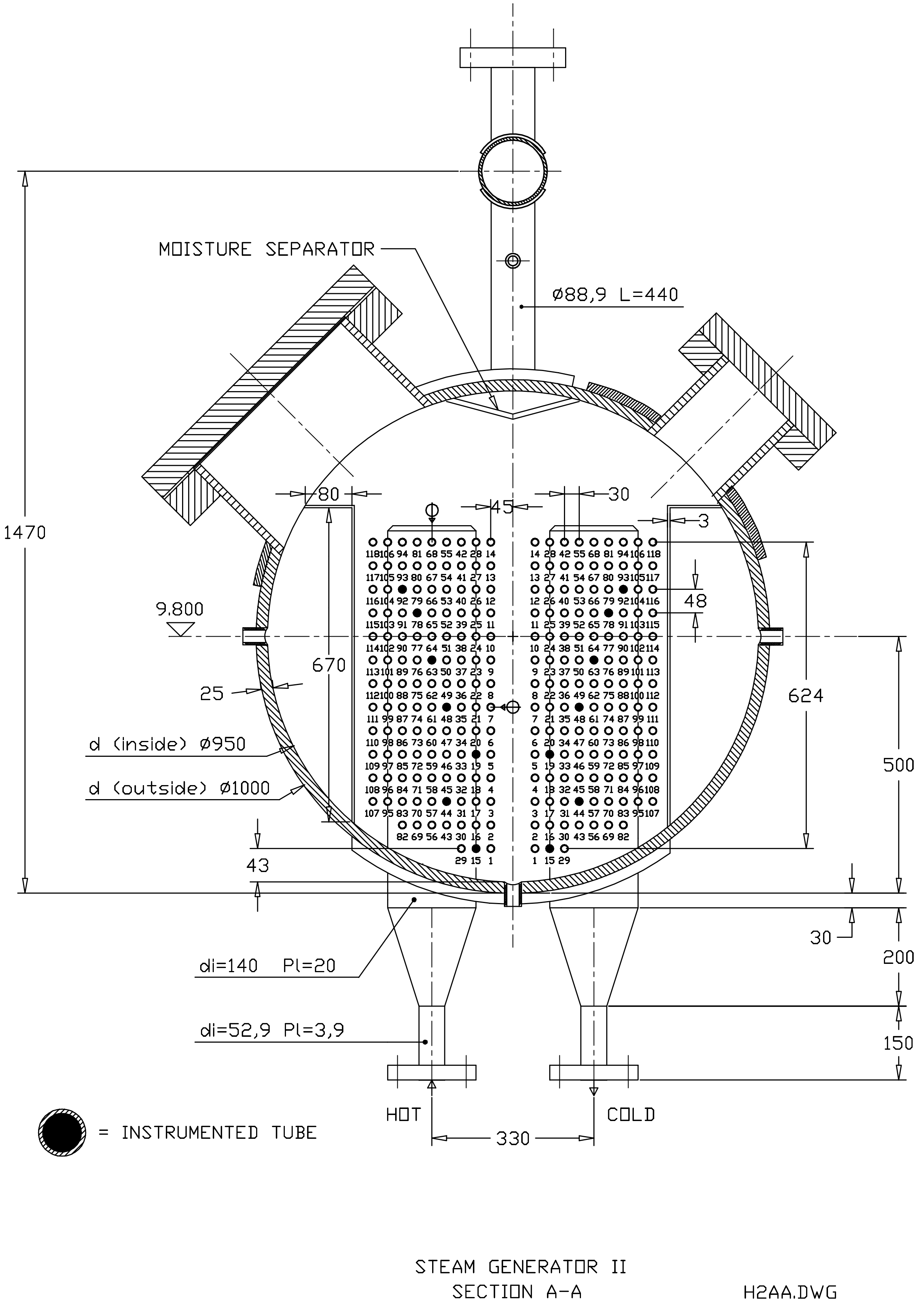


Figure A. 22. Cross section of the steam generator. Loop 1.

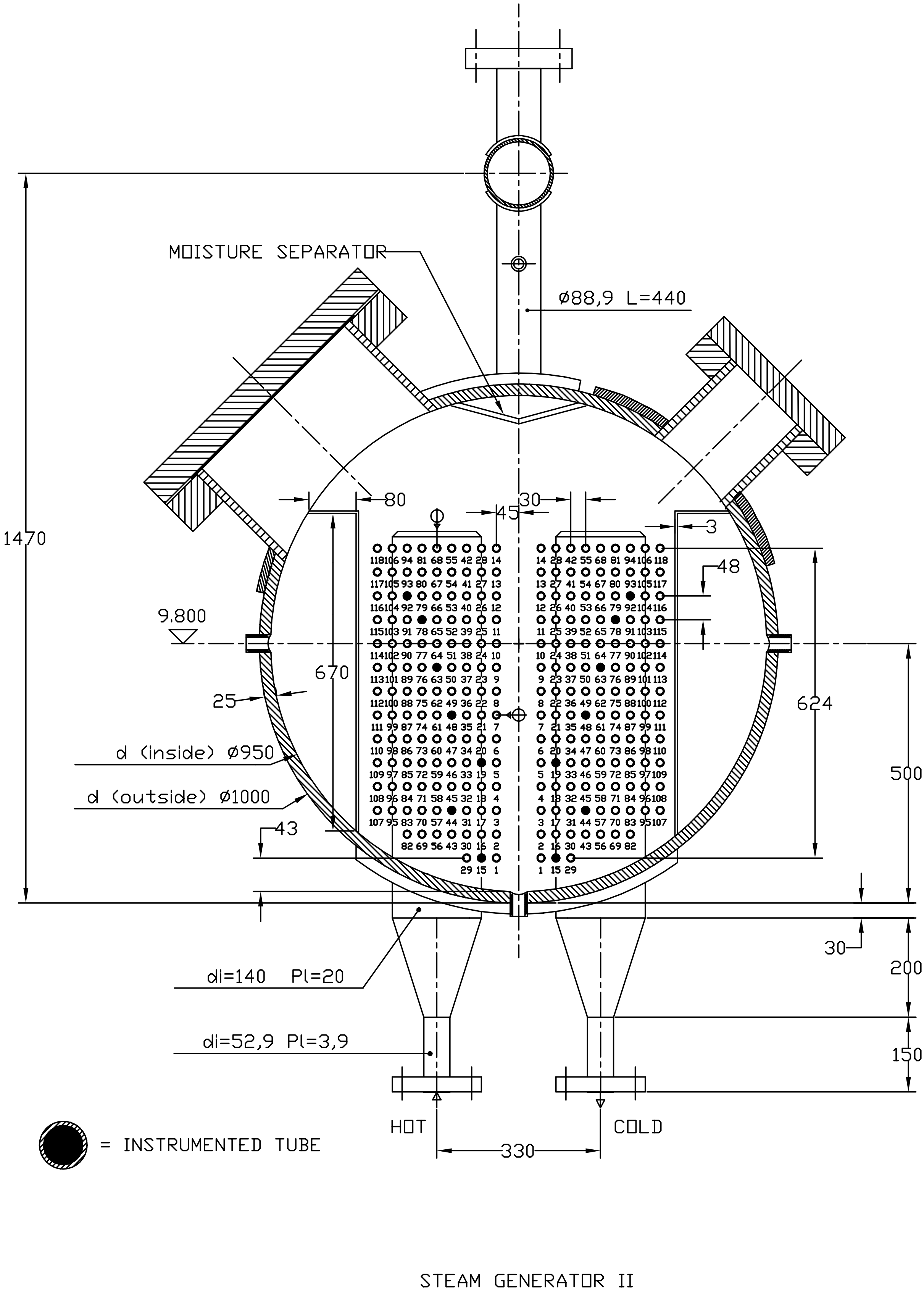


Figure A. 23. Cross section of the steam generator. Loop 2.

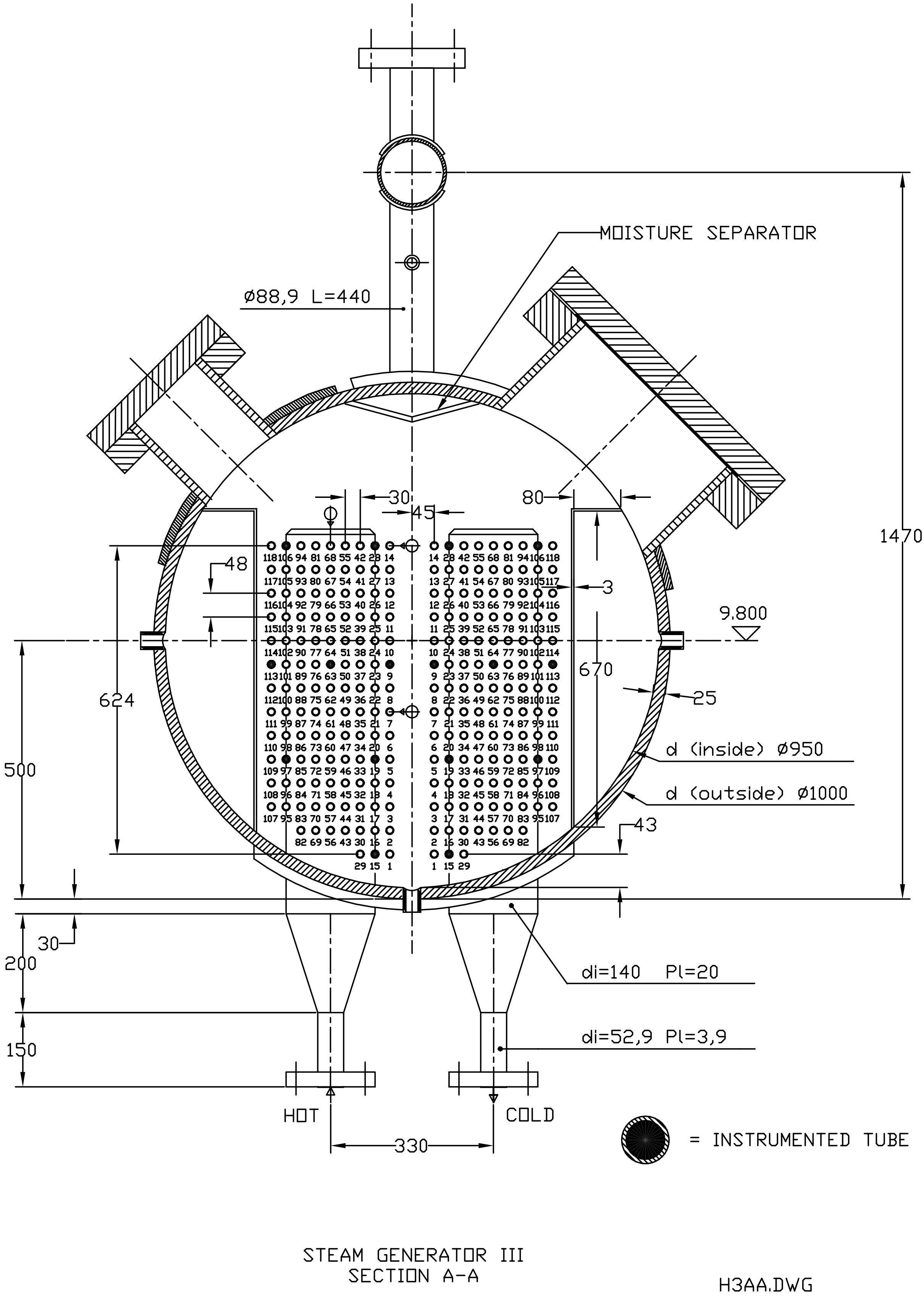


Figure A. 24. Cross section of the steam generator. Loop 3.

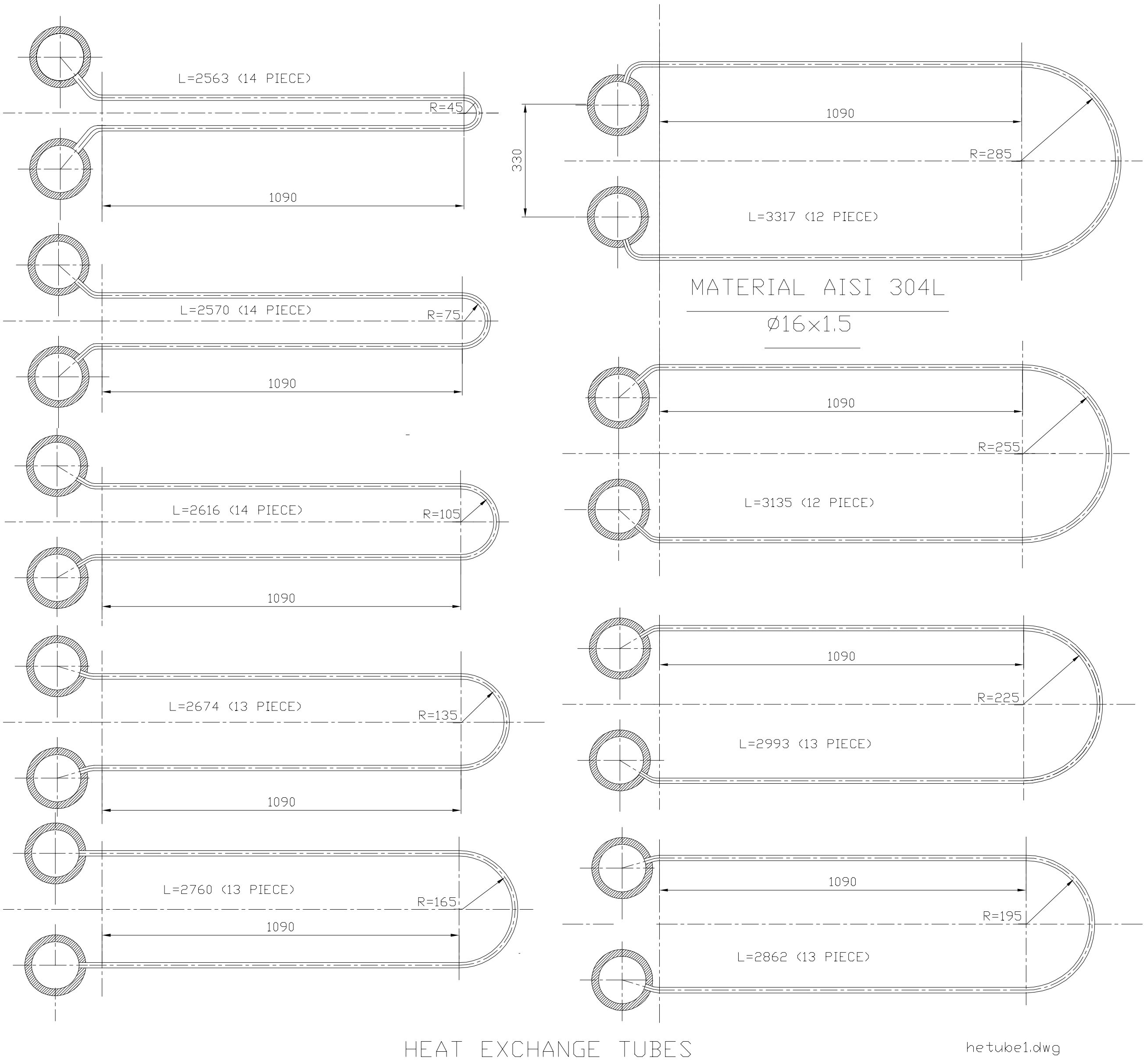


Figure A. 25. Heat exchange tubes of the steam generators.

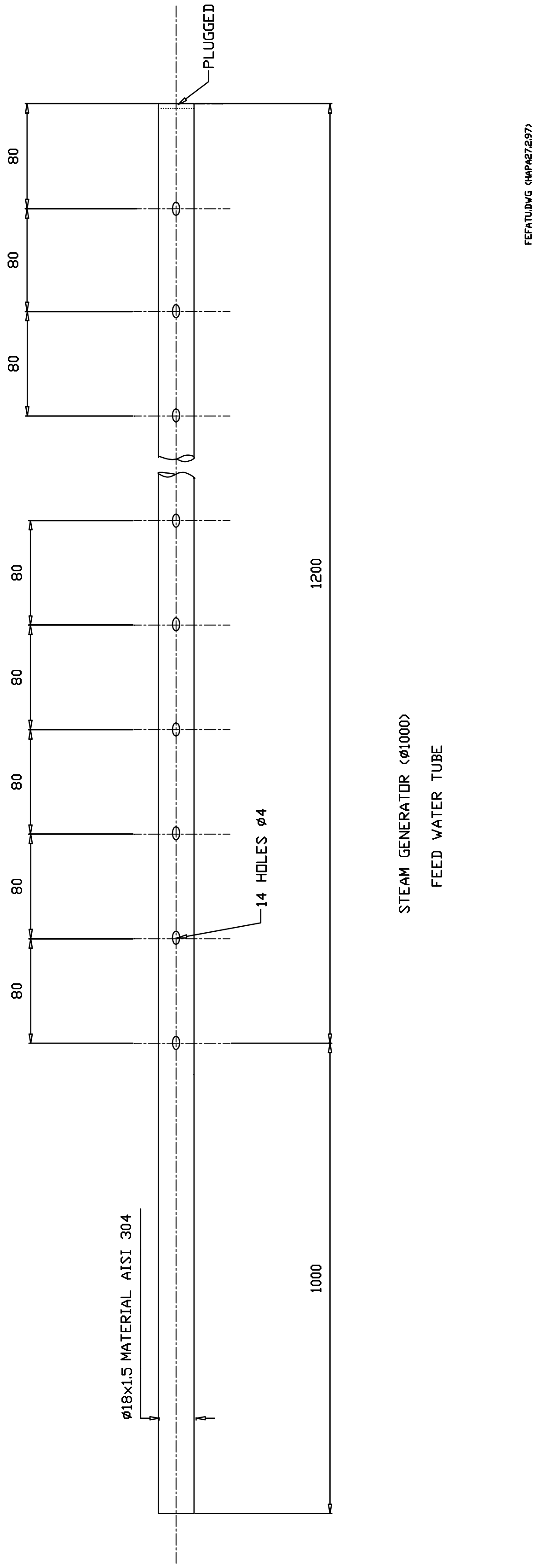


Figure A. 26. Steam generator feed water tube.

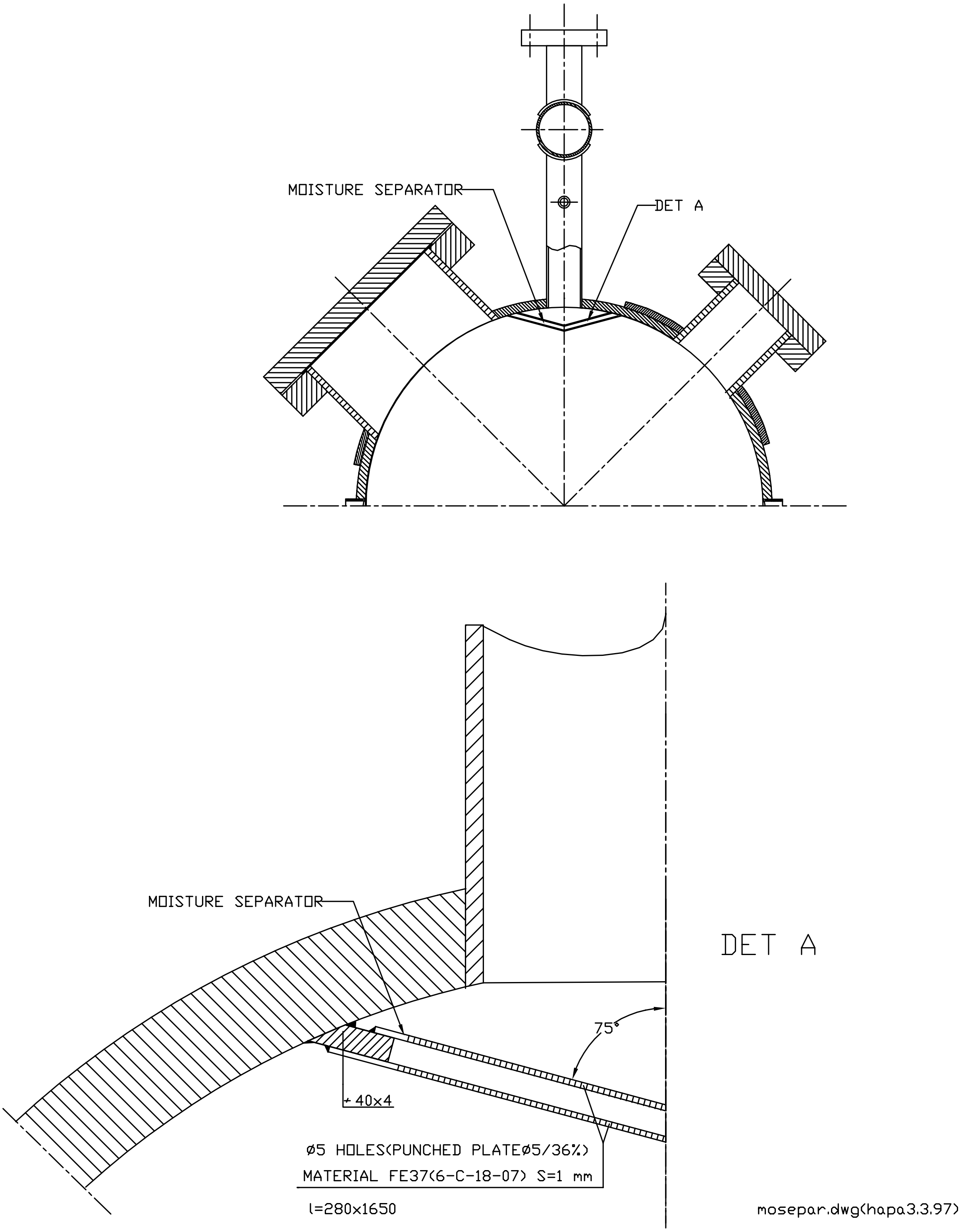
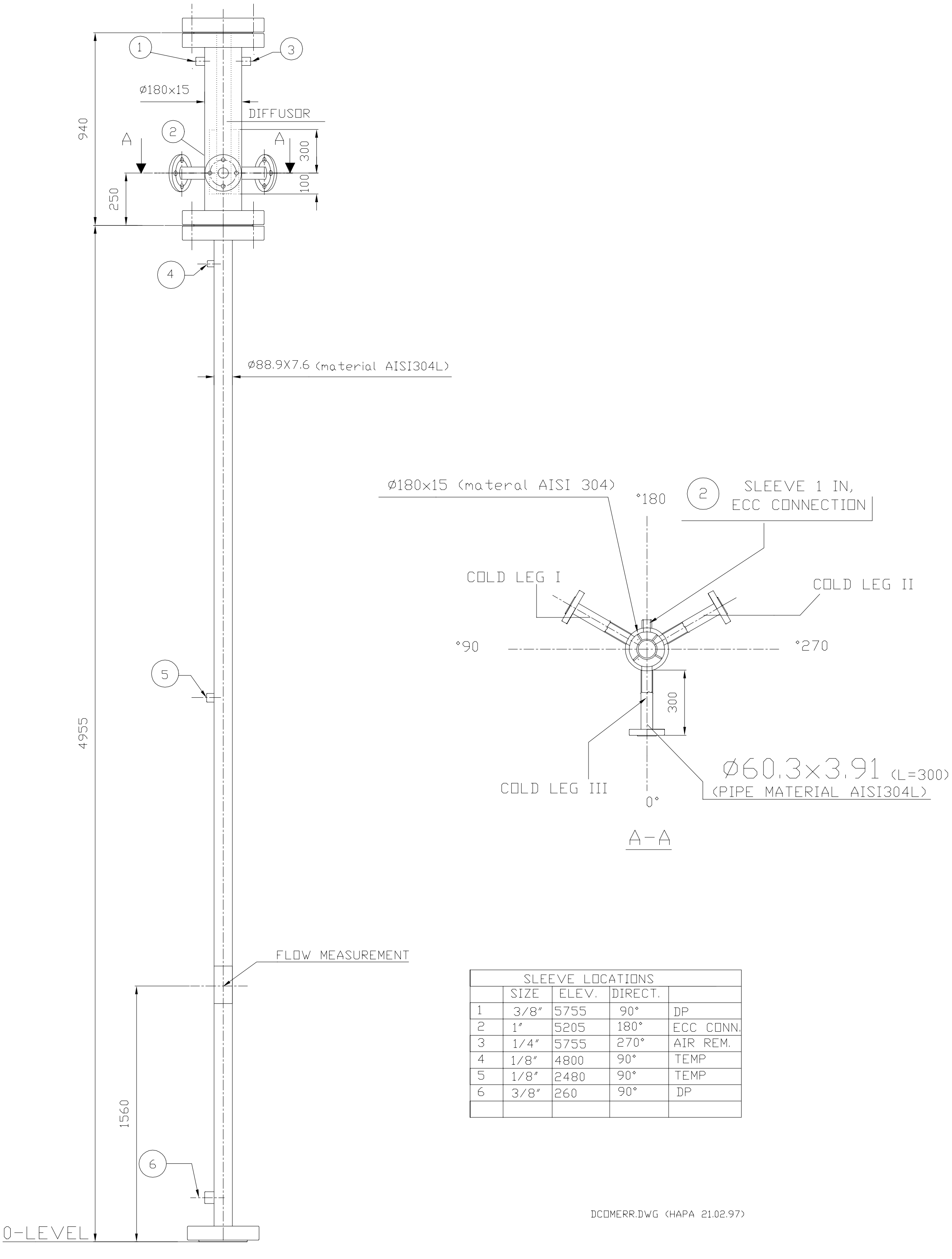


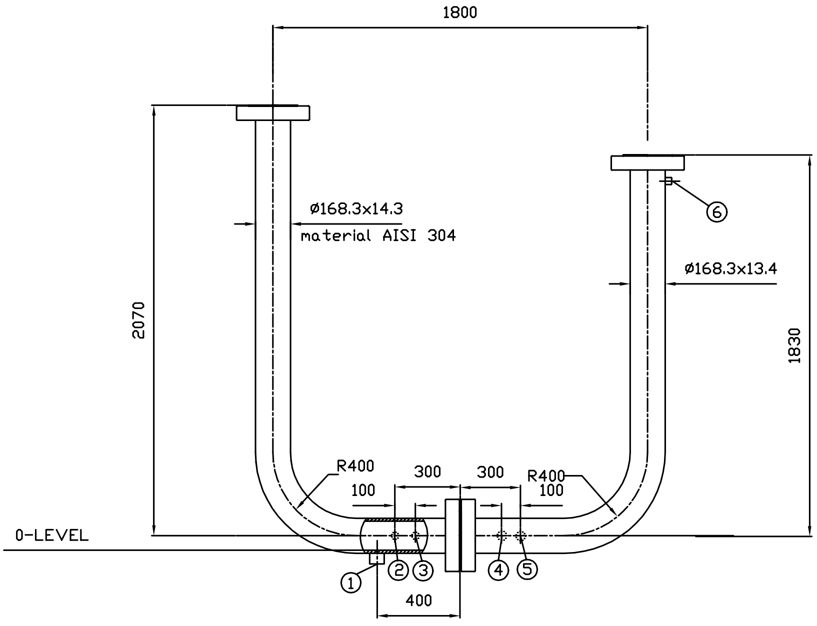
Figure A. 27. Moisture separator of the steam generator.



SLEEVE LOCATIONS

	SIZE	ELEV.	DIRECT.	
1	3/8″	5755	90°	DP
2	1″	5205	180°	ECC CONN.
3	1/4″	5755	270°	AIR REM.
4	1/8″	4800	90°	TEMP
5	1/8″	2480	90°	TEMP
6	3/8″	260	90°	DP

Figure A. 28. Downcomer with cold leg connections.



SLEEVE LOCATIONS				
	SIZE	ELEV.		
1	1"	0		draining
2	3/8"	70		DP
3	3/8"	70		DP
4	1/8"	70		TEMP
5	3/8"	70		DP
6	1/8"	1770		TEMP

LBLENUM.DWG(HAPA 24.2.97)

Figure A. 29. Lower plenum.

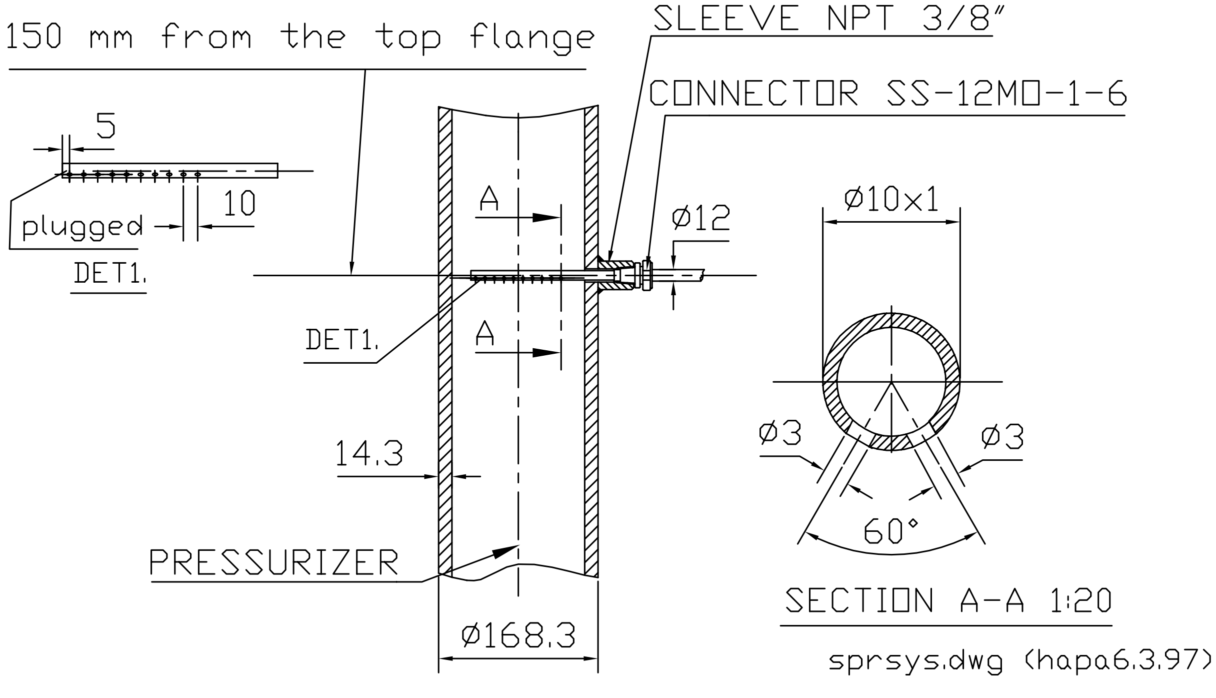
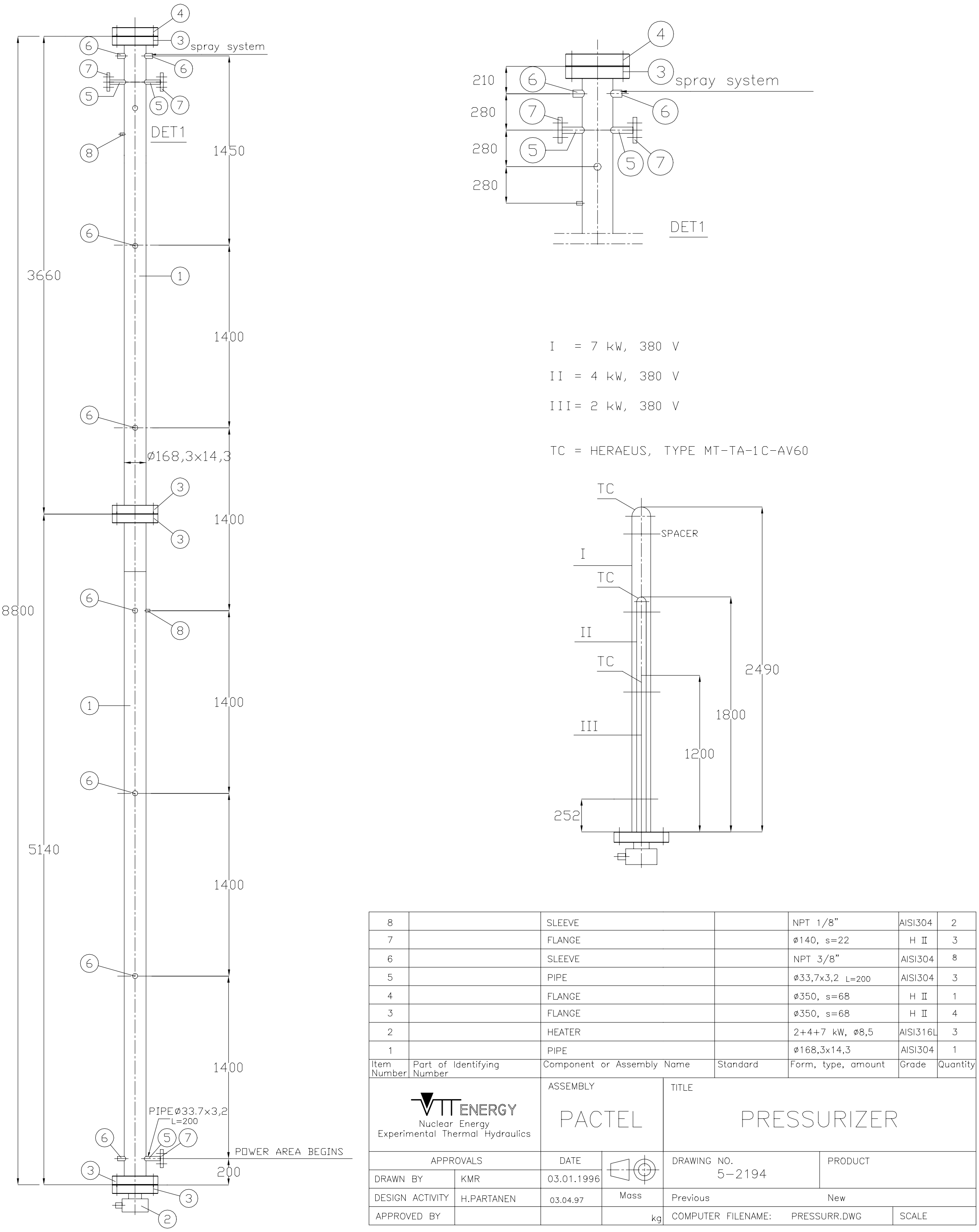


Figure A. 30. Pressurizer spray nozzle.



Item Number	Part of Identifying Number	Component or Assembly Name	Standard	Form, type, amount	Grade	Quantity
8		SLEEVE		NPT 1/8"	AISI304	2
7		FLANGE		ø140, s=22	H II	3
6		SLEEVE		NPT 3/8"	AISI304	8
5		PIPE		ø33,7x3,2 L=200	AISI304	3
4		FLANGE		ø350, s=68	H II	1
3		FLANGE		ø350, s=68	H II	4
2		HEATER		2+4+7 kW, ø8,5	AISI316L	3
1		PIPE		ø168,3x14,3	AISI304	1

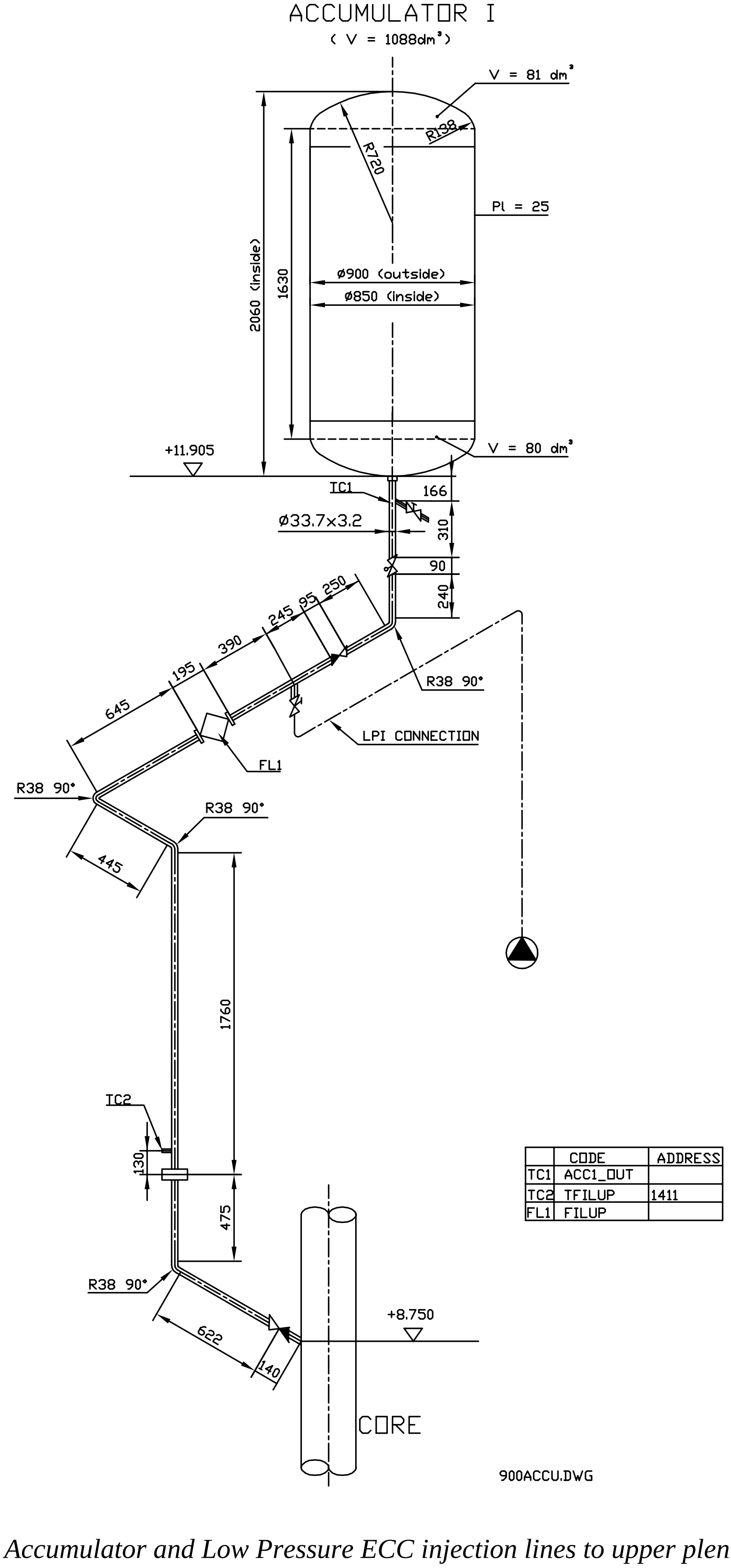
VTT ENERGY
Nuclear Energy
Experimental Thermal Hydraulics

ASSEMBLY
PACTEL

TITLE
PRESSURIZER

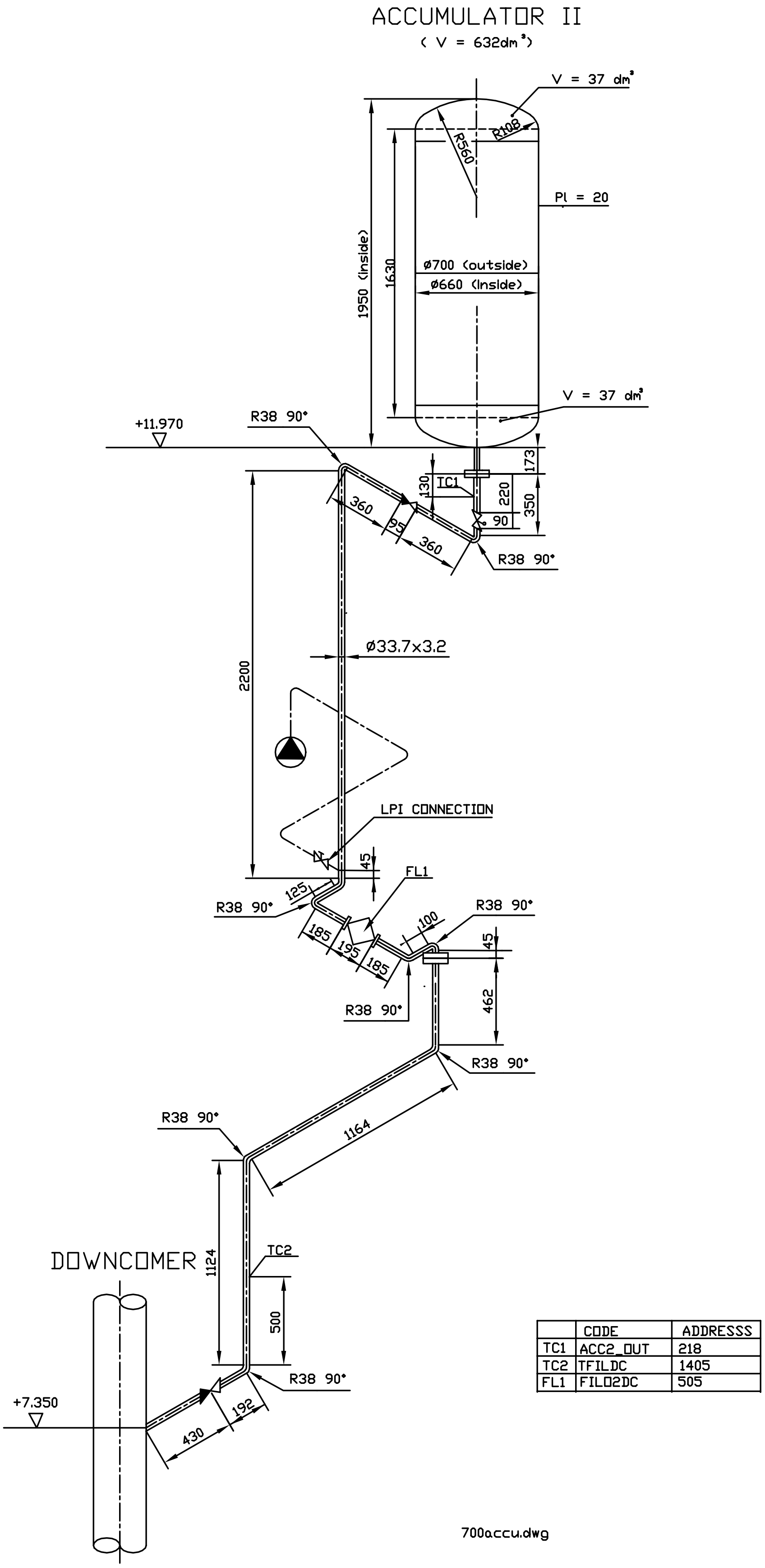
APPROVALS		DATE		DRAWING NO. 5-2194	PRODUCT
DRAWN BY	KMR	03.01.1996			
DESIGN ACTIVITY	H.PARTANEN	03.04.97	Mass	Previous	New
APPROVED BY			kg	COMPUTER FILENAME: PRESSURR.DWG	SCALE

Figure A. 31. Pressurizer with heaters.



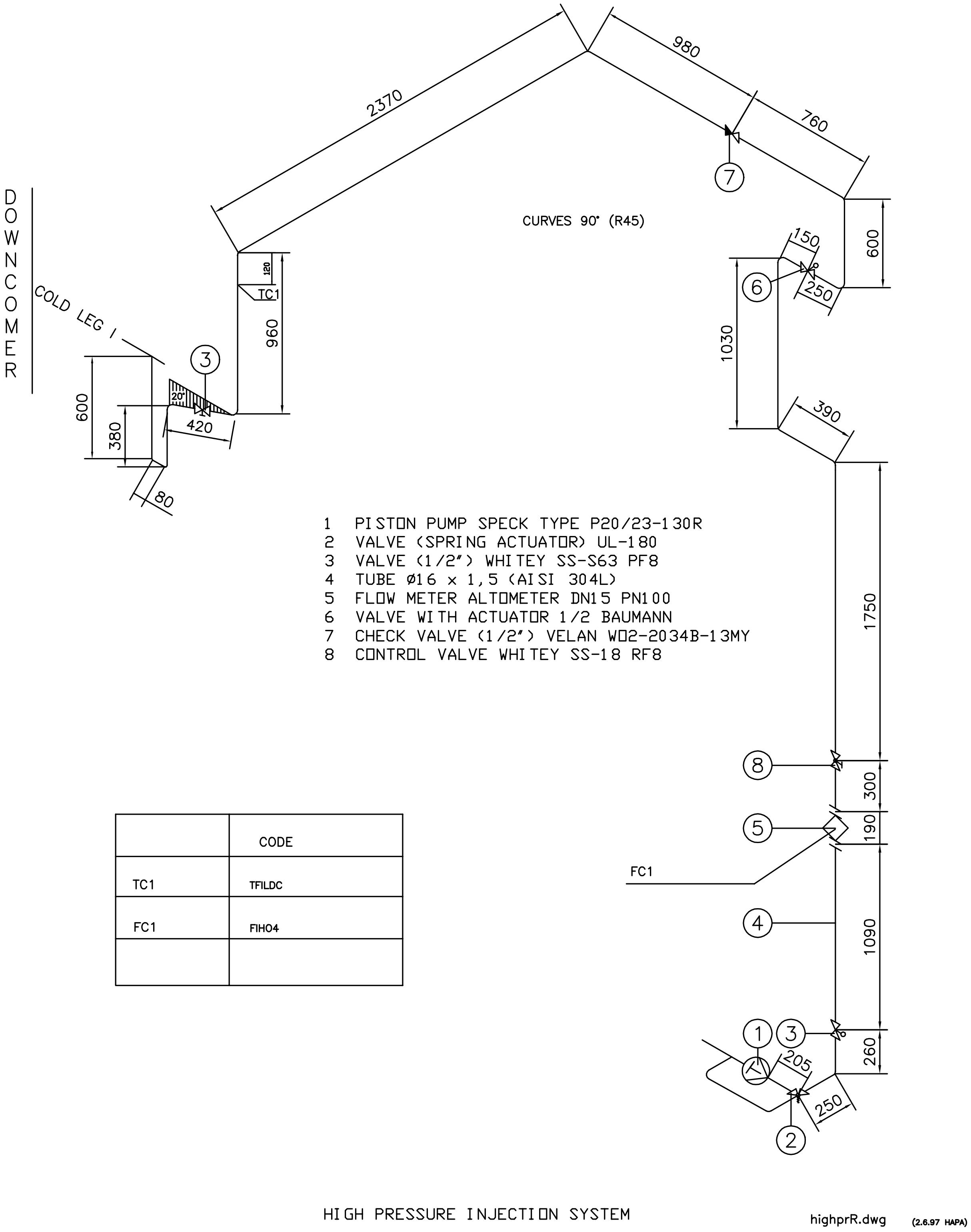
	CODE	ADDRESS
TC1	ACC1_OUT	
TC2	TFILUP	1411
FL1	FILUP	

Figure A. 32. Accumulator and Low Pressure ECC injection lines to upper plenum.



	CODE	ADDRESSS
TC1	ACC2_OUT	218
TC2	TFILDC	1405
FL1	FIL02DC	505

Figure A. 33. Accumulator and Low Pressure ECC injection lines to downcomer.



1 PISTON PUMP SPECK TYPE P20/23-130R
2 VALVE (SPRING ACTUATOR) UL-180
3 VALVE (1/2") WHITEY SS-S63 PF8
4 TUBE Ø16 x 1,5 (AISI 304L)
5 FLOW METER ALTOMETER DN15 PN100
6 VALVE WITH ACTUATOR 1/2 BAUMANN
7 CHECK VALVE (1/2") VELAN W02-2034B-13MY
8 CONTROL VALVE WHITEY SS-18 RF8

	CODE
TC1	TFILDC
FC1	FIHO4

Figure A. 34. High pressure injection system.

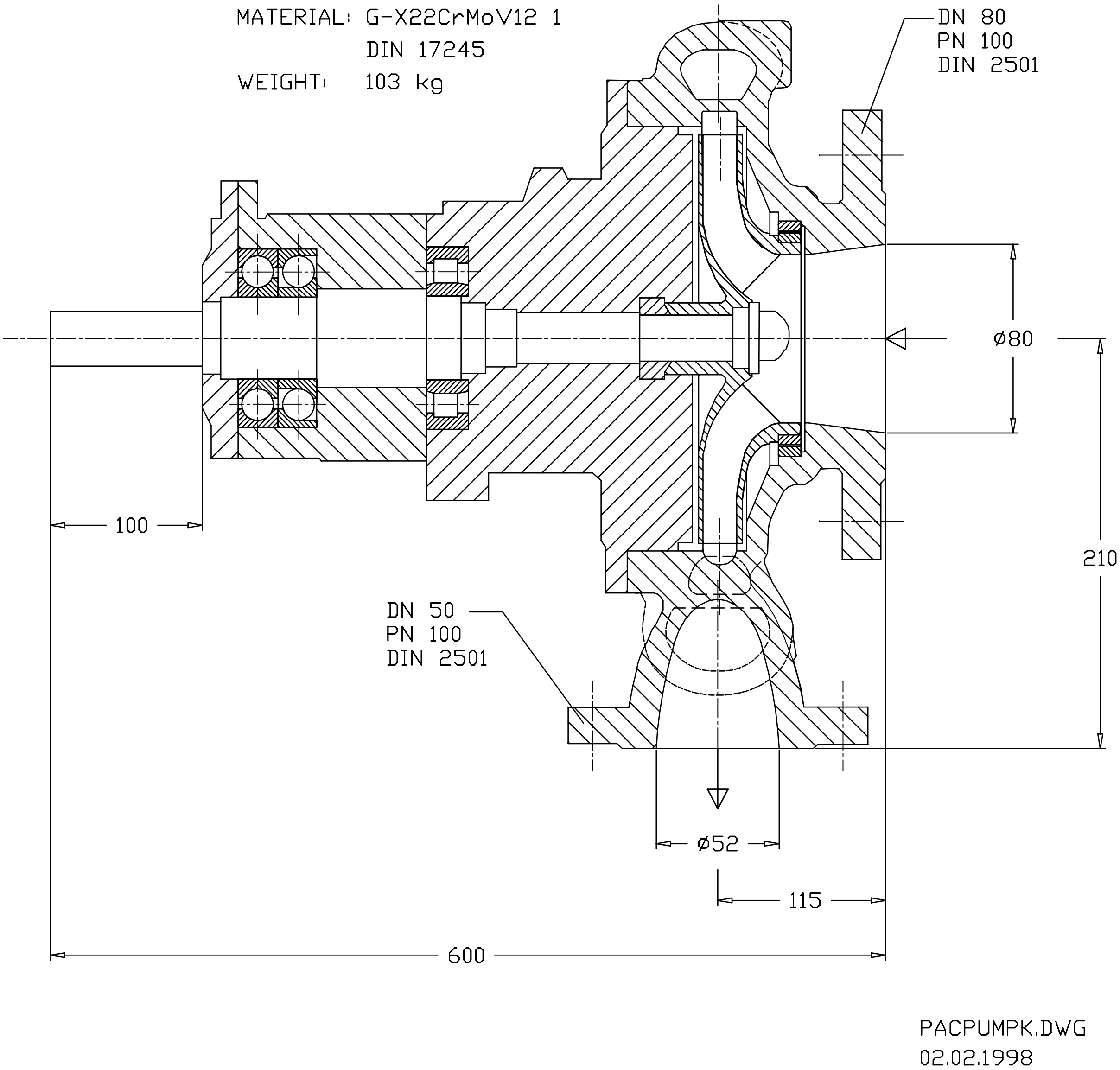
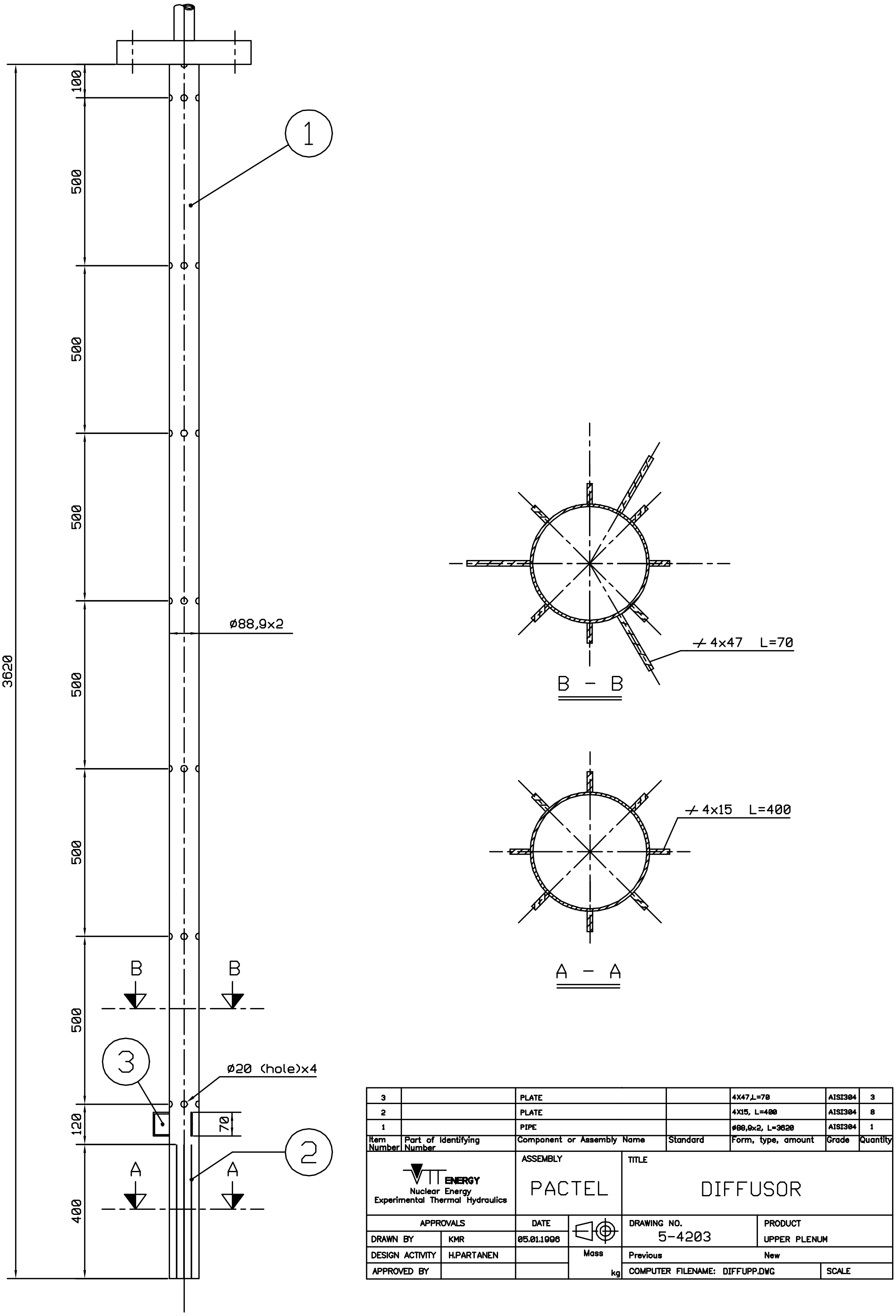


Figure A. 35. Main circulation pump.



Item Number	Part of Identifying Number	Component or Assembly Name	Standard	Form, type, amount	Grade	Quantity
3		PLATE		4X47,L=70	AISI304	3
2		PLATE		4X15, L=400	AISI304	8
1		PIPE		ø88,9x2, L=3620	AISI304	1

VTT ENERGY
Nuclear Energy
Experimental Thermal Hydraulics

ASSEMBLY PACTEL

TITLE DIFFUSOR

APPROVALS		DATE	
DRAWN BY	KMR	05.01.1996	
DESIGN ACTIVITY	H.PARTANEN		Mass
APPROVED BY			kg

DRAWING NO. 5-4203

PRODUCT UPPER PLENUM

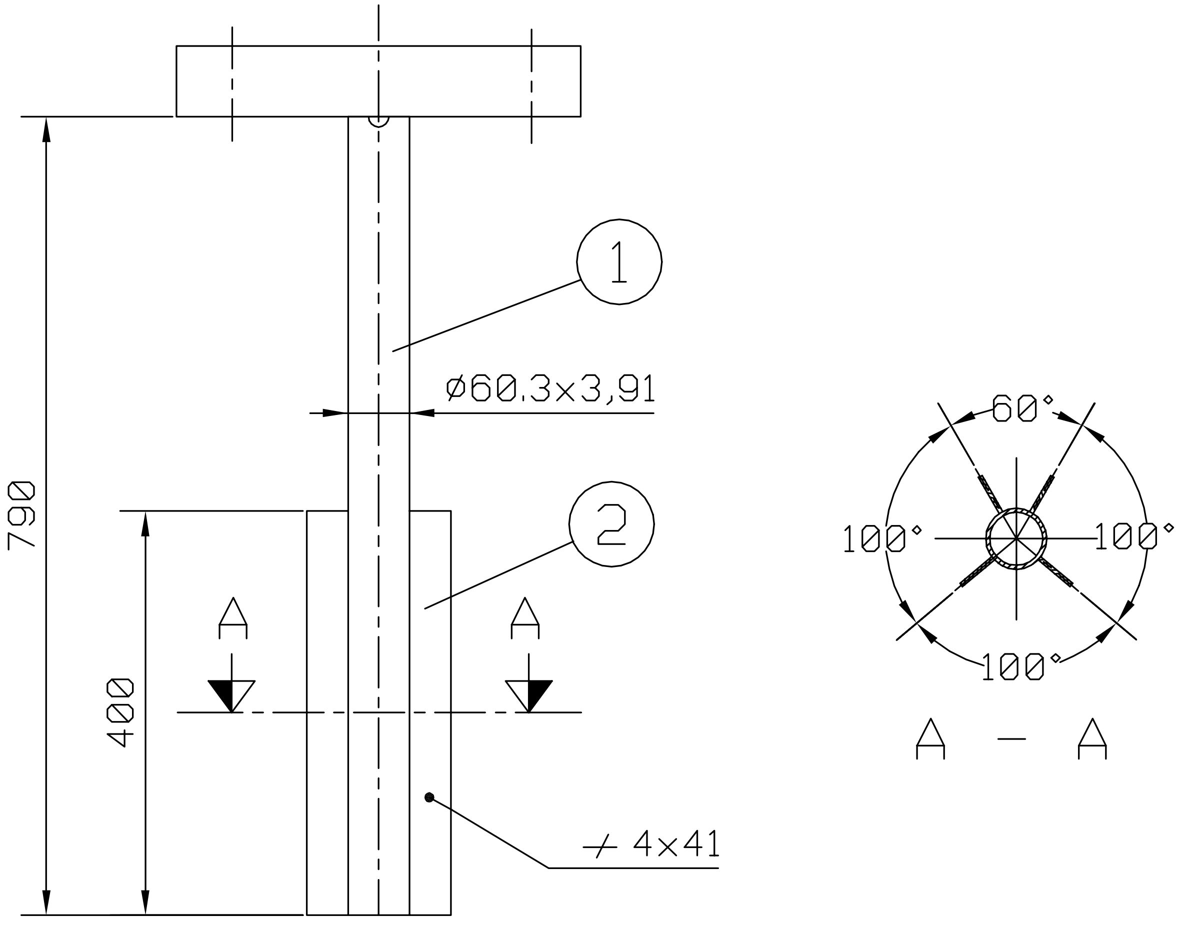
Previous

New

COMPUTER FILENAME: DIFFUPP.DWG

SCALE

Figure A. 36. Upper plenum diffusor.



2		PLATE		PL 4x41, L=400	AISI304	4
1		PIPE		∅60,3x3,91, L=790	AISI304	1
Item Number	Part of Identifying Number	Component or Assembly Name	Standard	Form, type, amount	Grade	Quantity

VTT ENERGY Nuclear Energy Experimental Thermal Hydraulics		ASSEMBLY PACTEL	TITLE DIFFUSOR	
APPROVALS		DATE	DRAWING NO.	PRODUCT DOWNCOMER
DRAWN BY	KMR	19.12.1995		
DESIGN ACTIVITY	H.PARTANEN		Mass	Previous	New
APPROVED BY			kg	COMPUTER FILENAME: DIFFDOWN.PLT	SCALE

Figure A. 37. Downcomer diffusor.

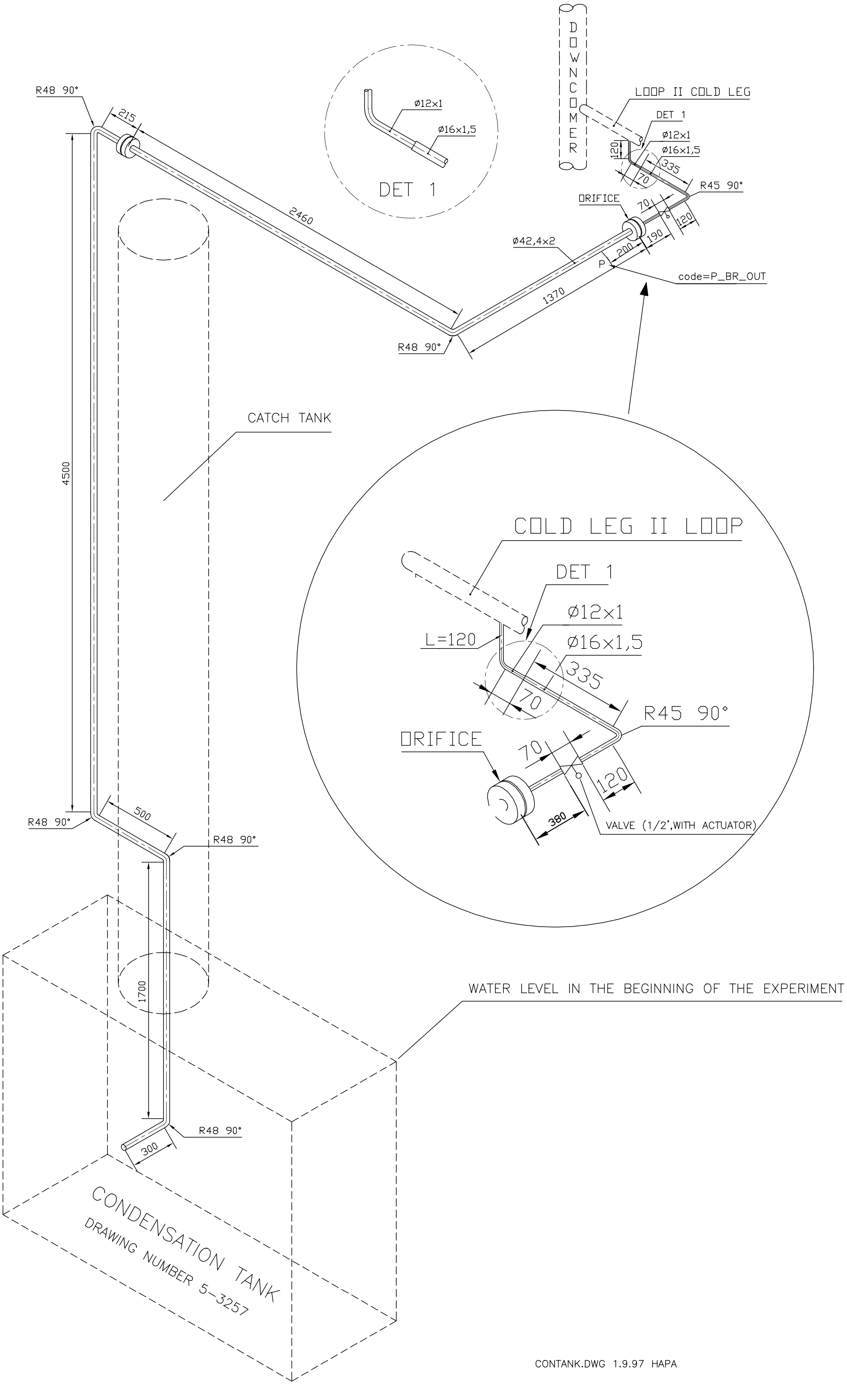


Figure A. 38. Break flow measurement system.

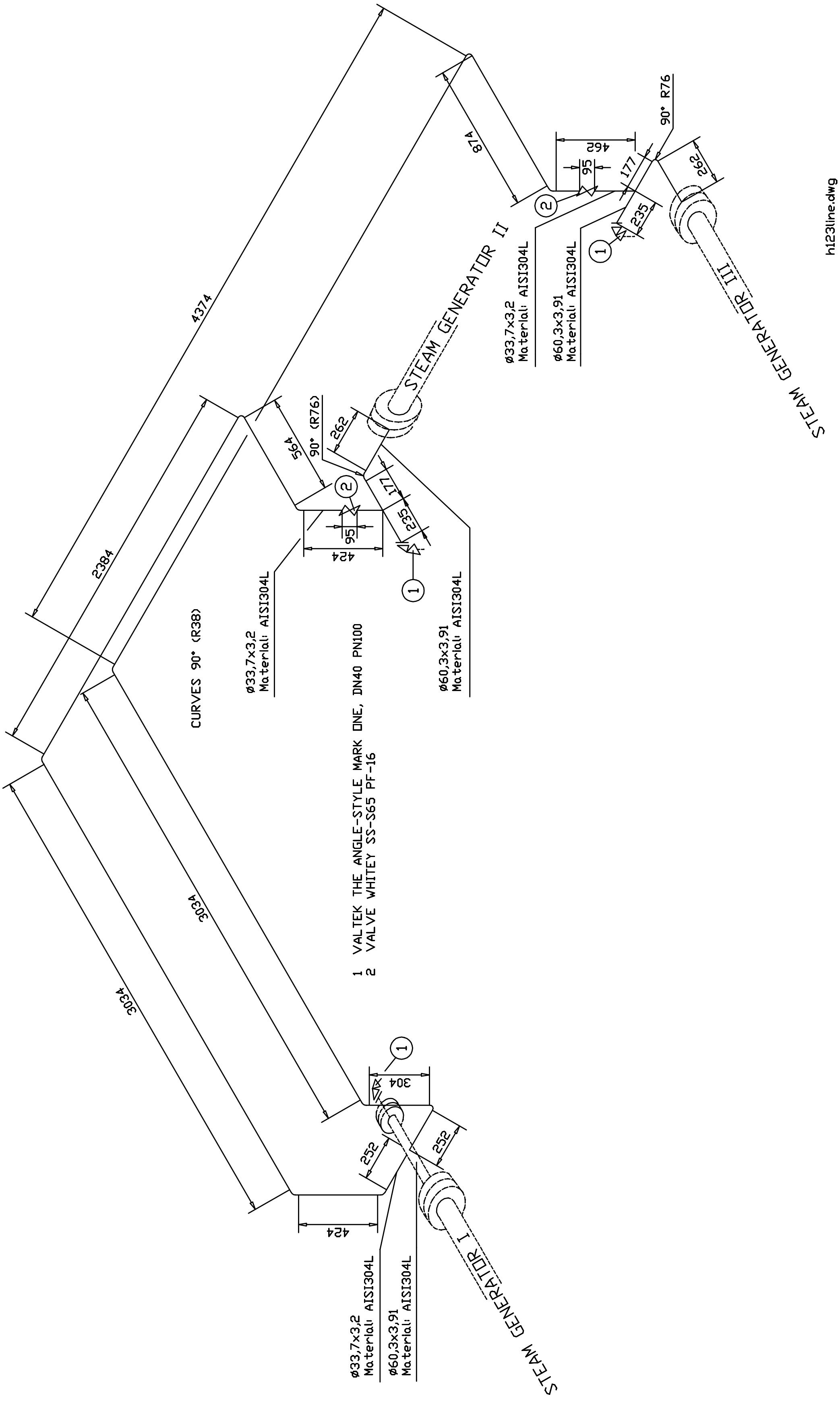
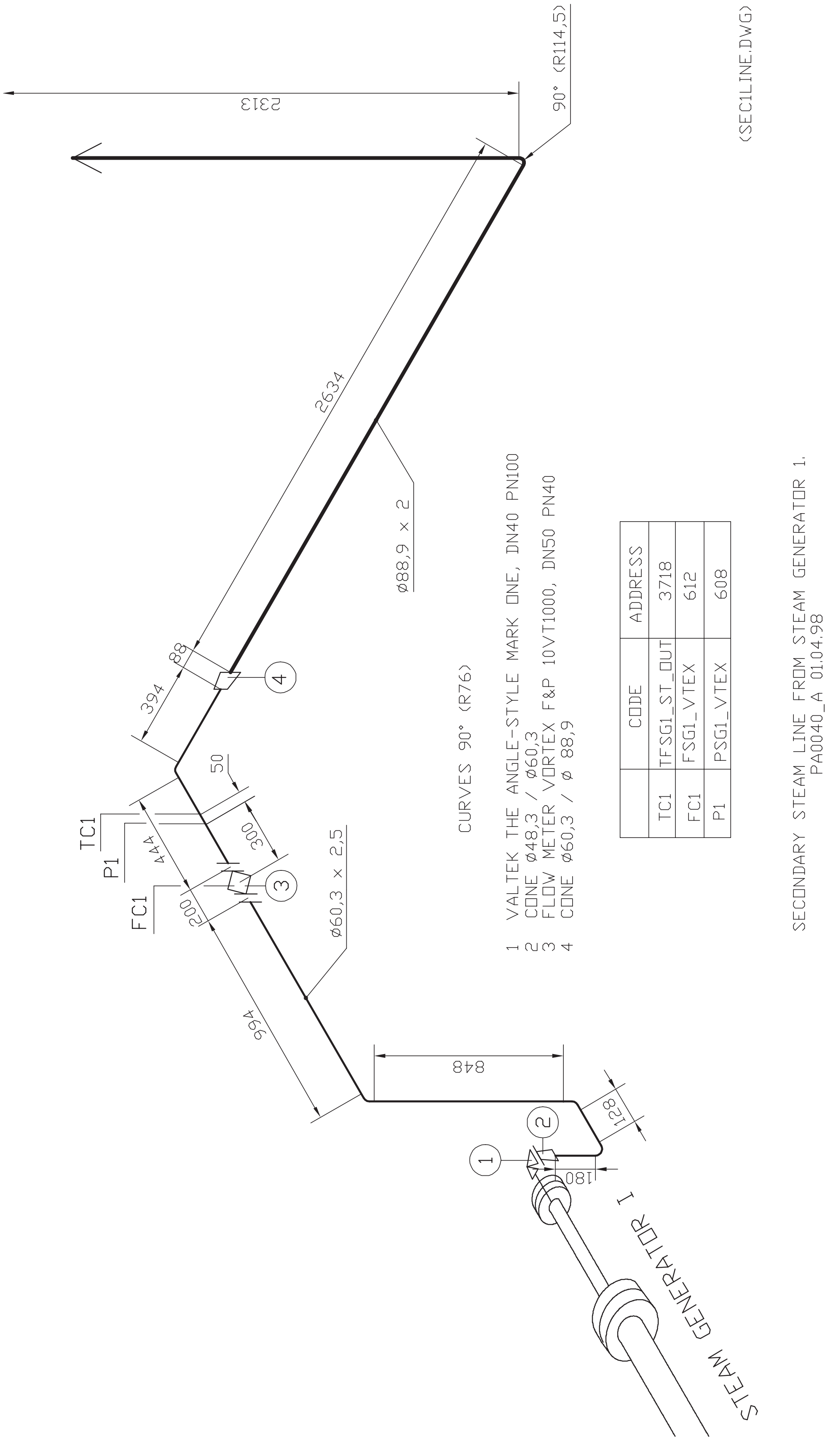


Figure A. 39. Secondary steam line (common line).



CURVES 90° (R76)

1 VALTEK THE ANGLE-STYLE MARK ONE, DN40 PN100
2 CONE ⌀48,3 / ⌀60,3
3 FLOW METER VORTEX F&P 10VT1000, DN50 PN40
4 CONE ⌀60,3 / ⌀ 88,9

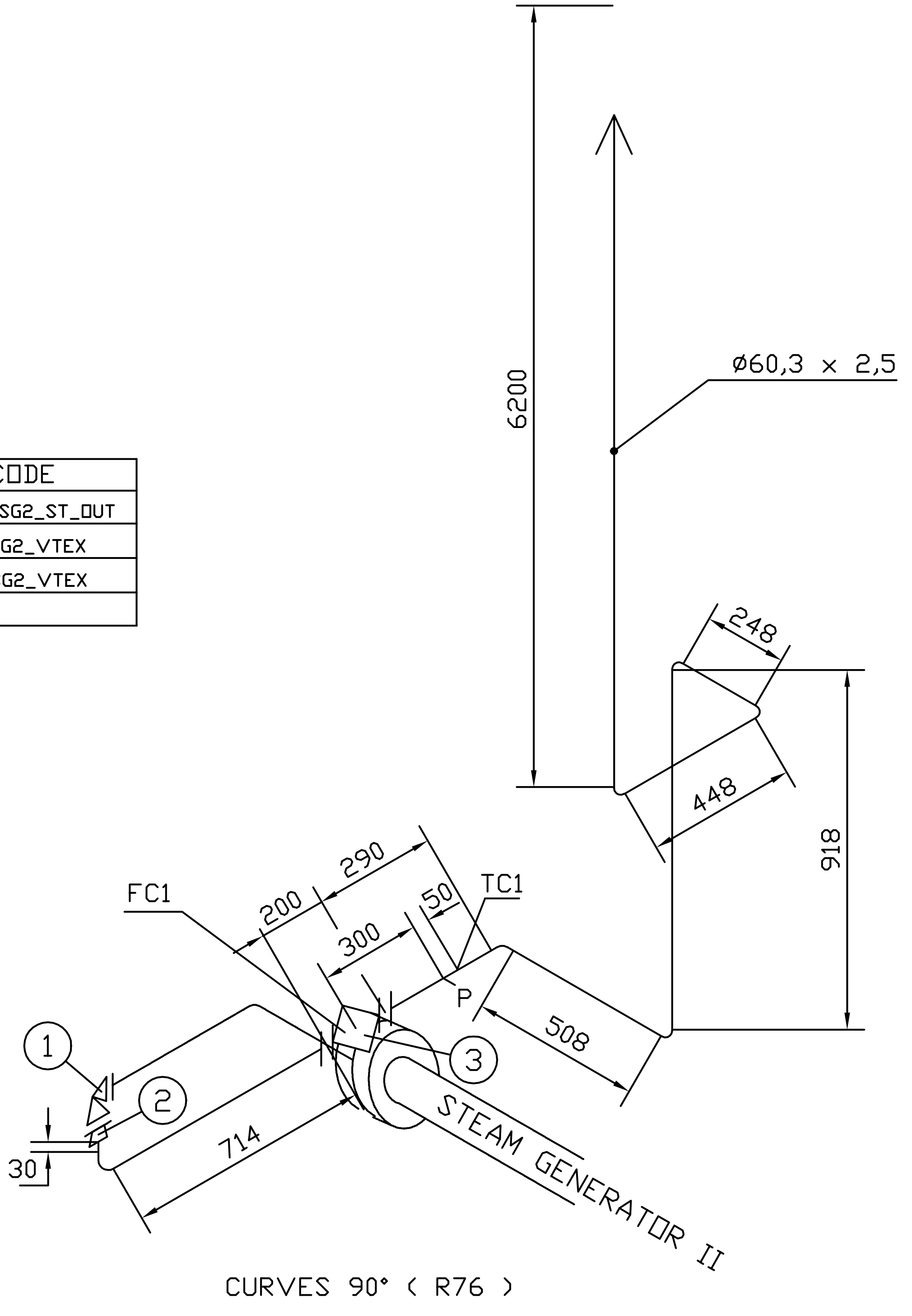
	CODE	ADDRESS
TC1	TFSG1_ST_OUT	3718
FC1	FSG1_VTEX	612
P1	PSG1_VTEX	608

SECONDARY STEAM LINE FROM STEAM GENERATOR 1.
PA0040_A 01.04.98

(SEC1LINE.DWG)

Figure A. 40. Secondary steam line from steam generator 1.

	CODE
TC1	TFSG2_ST_OUT
FC1	FSG2_VTEX
P	PSG2_VTEX

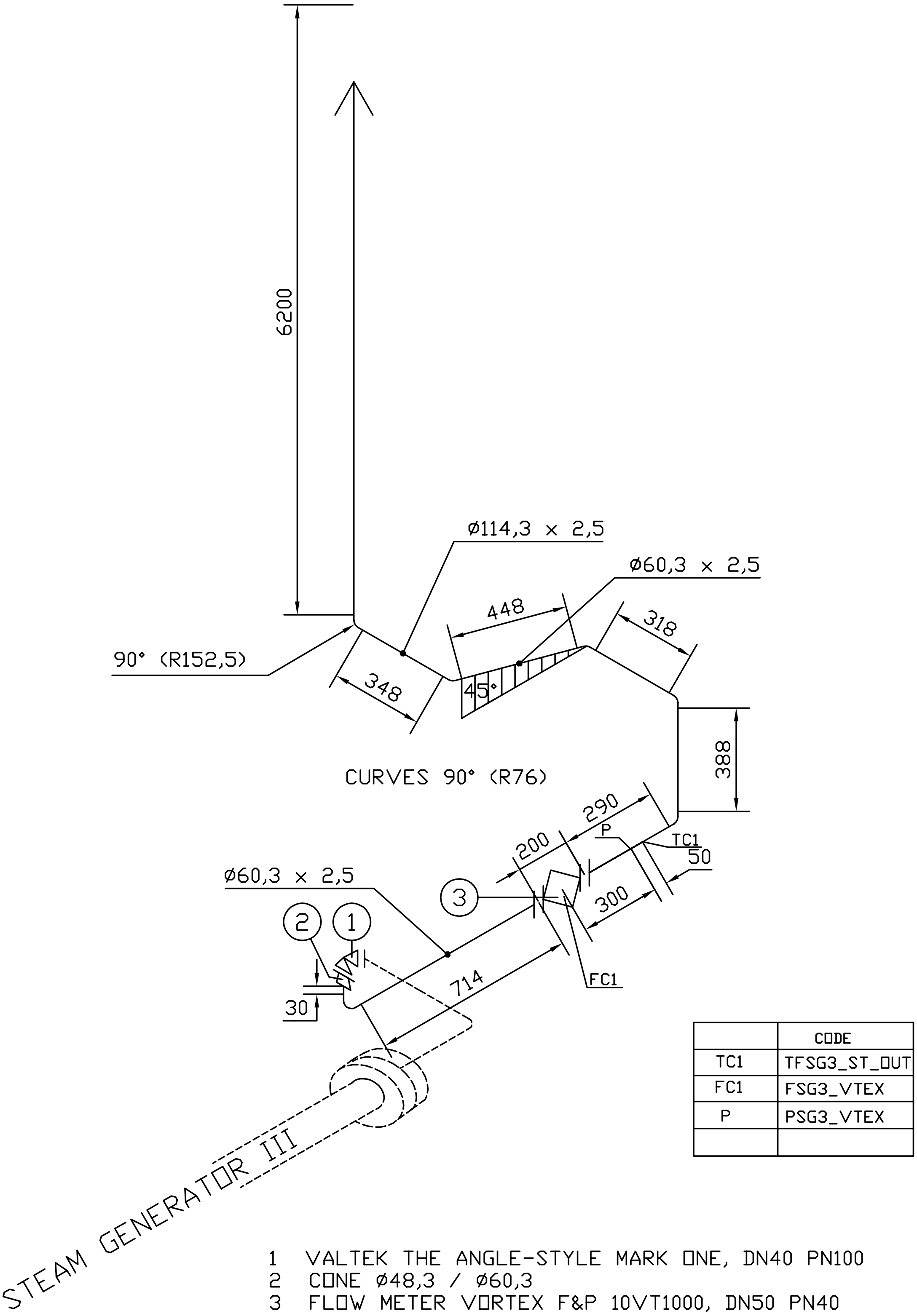


CURVES 90° (R76)

1 VALTEK THE ANGLE-STYLE MARK ONE, DN40 PN100
2 CONE Ø48,3 / Ø60,3
3 FLOW METER VORTEX F&P 10VT1000, DN50 PN40

sec2lR.dwg 30.5.97 HAPA

Figure A. 41 Secondary steam line from steam generator 2.



	CODE
TC1	TFSG3_ST_OUT
FC1	FSG3_VTEX
P	PSG3_VTEX

1 VALTEK THE ANGLE-STYLE MARK ONE, DN40 PN100
2 CONE Ø48,3 / Ø60,3
3 FLOW METER VORTEX F&P 10VT1000, DN50 PN40

sec3lR.dwg 2.10..97 HAPA

Figure A. 42. Secondary steam line from steam generator 3.

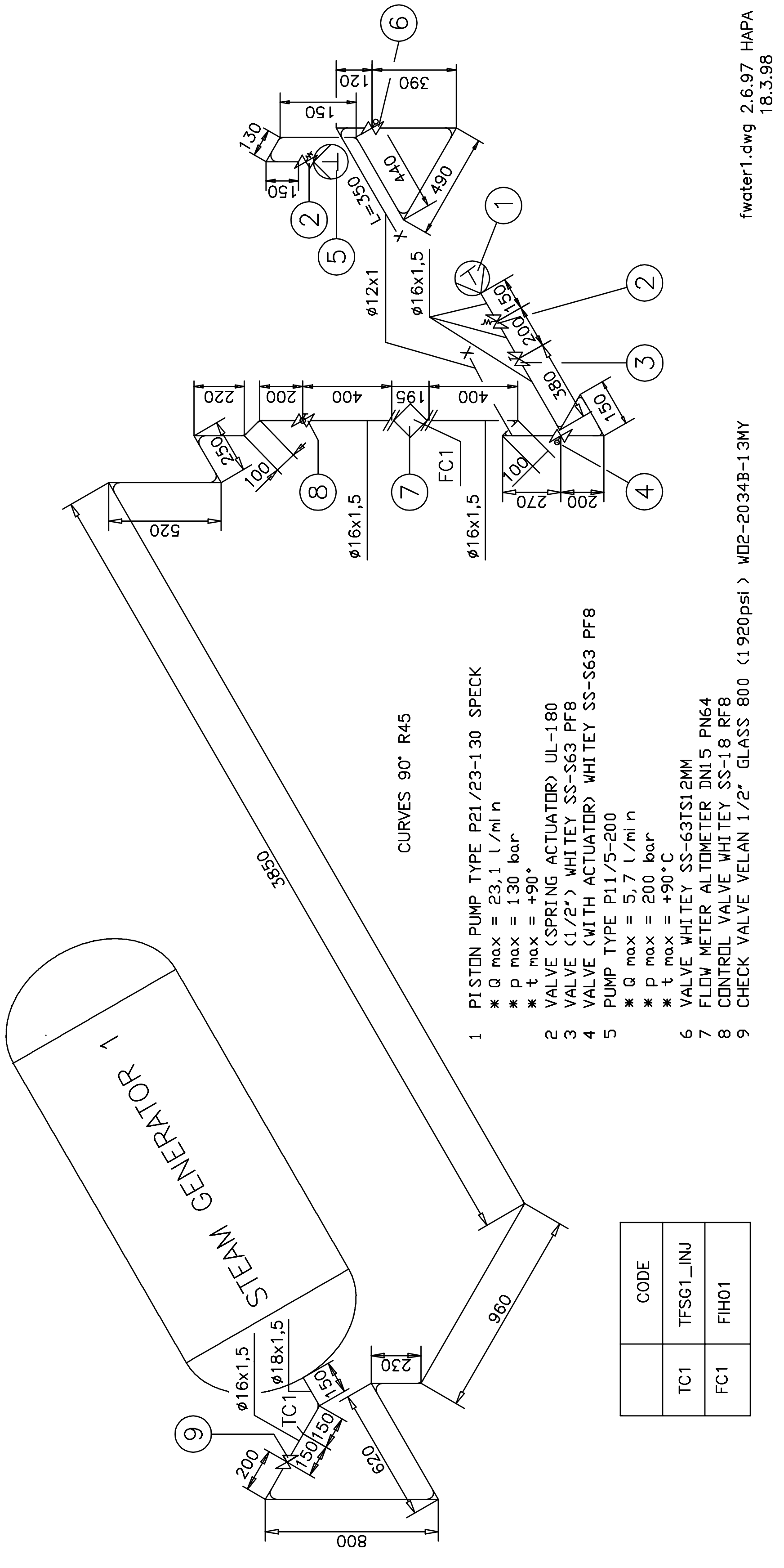
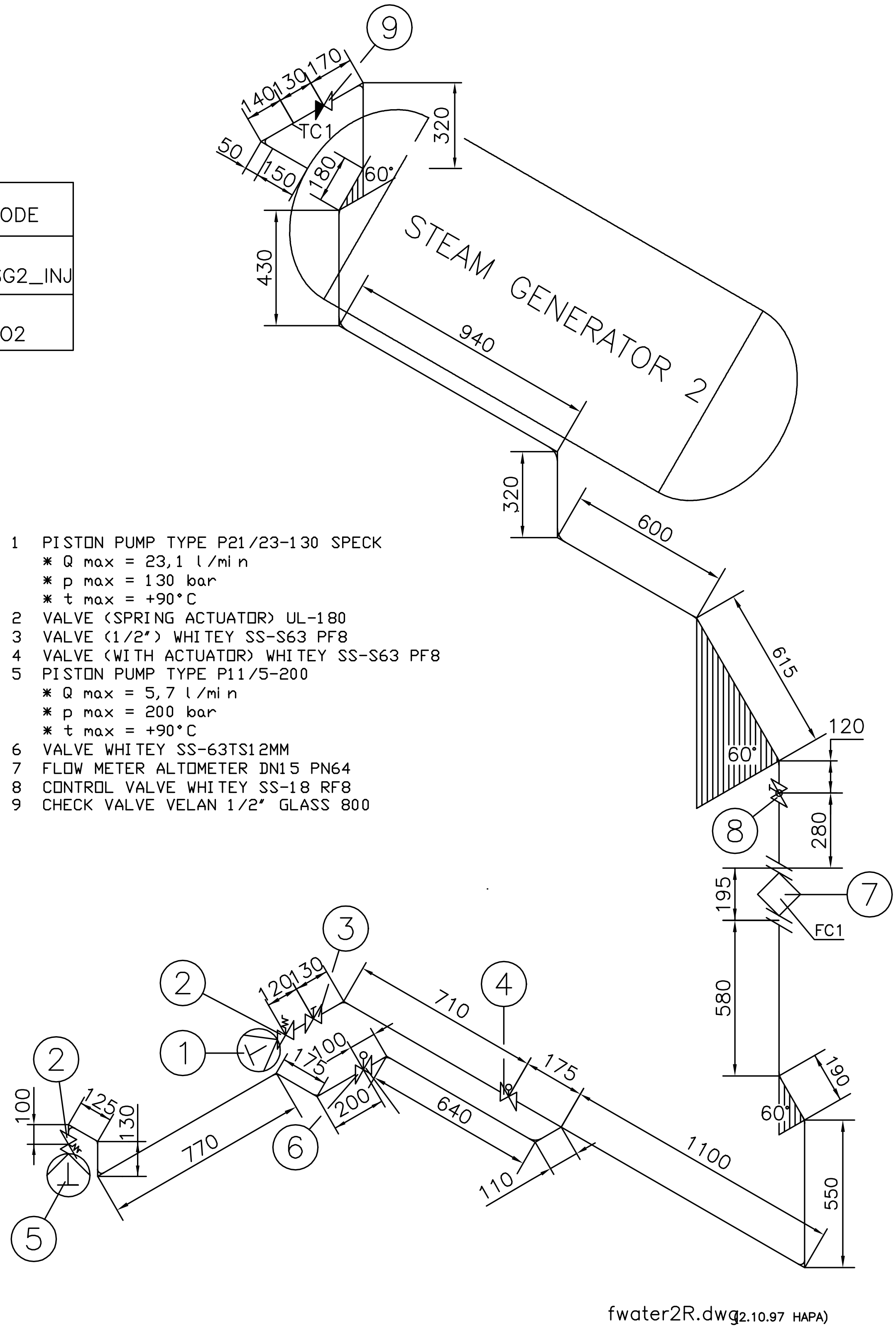


Figure A. 43. Feed water system of steam generator 1.

	CODE
TC1	TFSG2_INJ
FC1	FIHO2

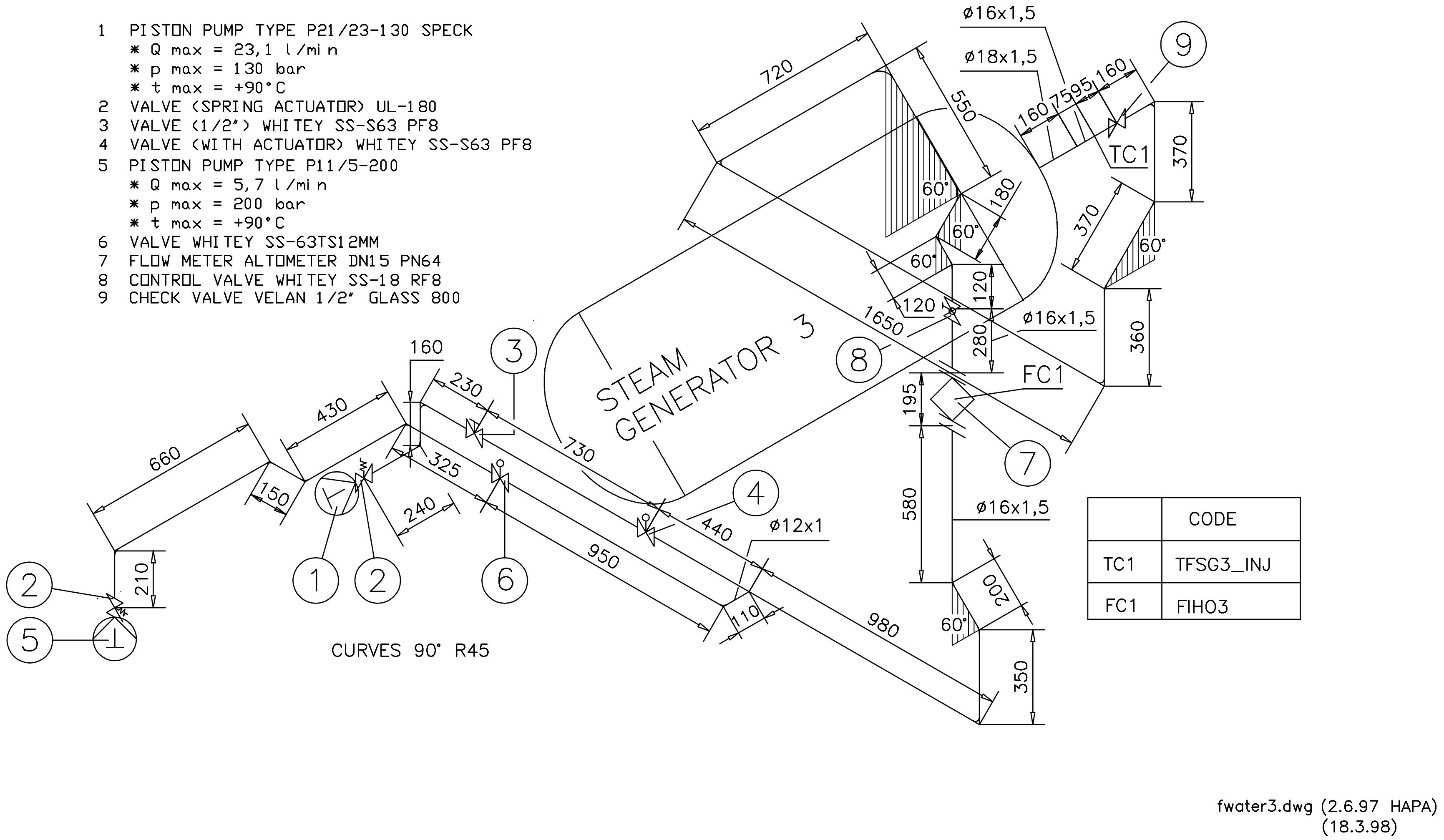


1 PISTON PUMP TYPE P21/23-130 SPECK
- ∗ Q max = 23,1 l/min
- ∗ p max = 130 bar
- ∗ t max = +90°C

2 VALVE (SPRING ACTUATOR) UL-180
3 VALVE (1/2") WHITEY SS-S63 PF8
4 VALVE (WITH ACTUATOR) WHITEY SS-S63 PF8
5 PISTON PUMP TYPE P11/5-200
- ∗ Q max = 5,7 l/min
- ∗ p max = 200 bar
- ∗ t max = +90°C

6 VALVE WHITEY SS-63TS12MM
7 FLOW METER ALTOMETER DN15 PN64
8 CONTROL VALVE WHITEY SS-18 RF8
9 CHECK VALVE VELAN 1/2" GLASS 800

Figure A. 44. Feed water system of steam generator 2.



	CODE
TC1	TFSG3_INJ
FC1	FIH03

Figure A. 45. Feed water system of steam generator 3.

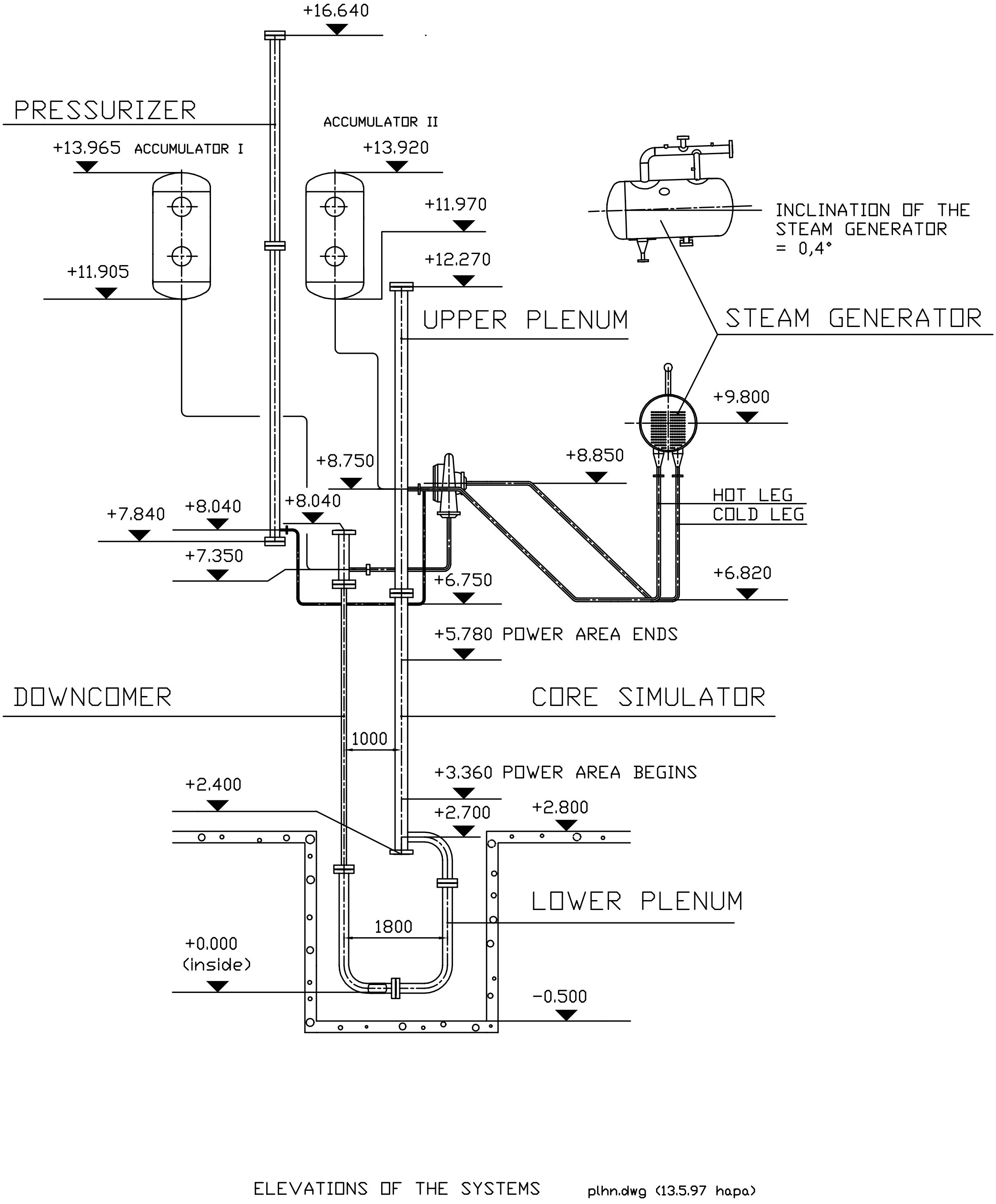


Figure A. 46. Elevations of the systems.

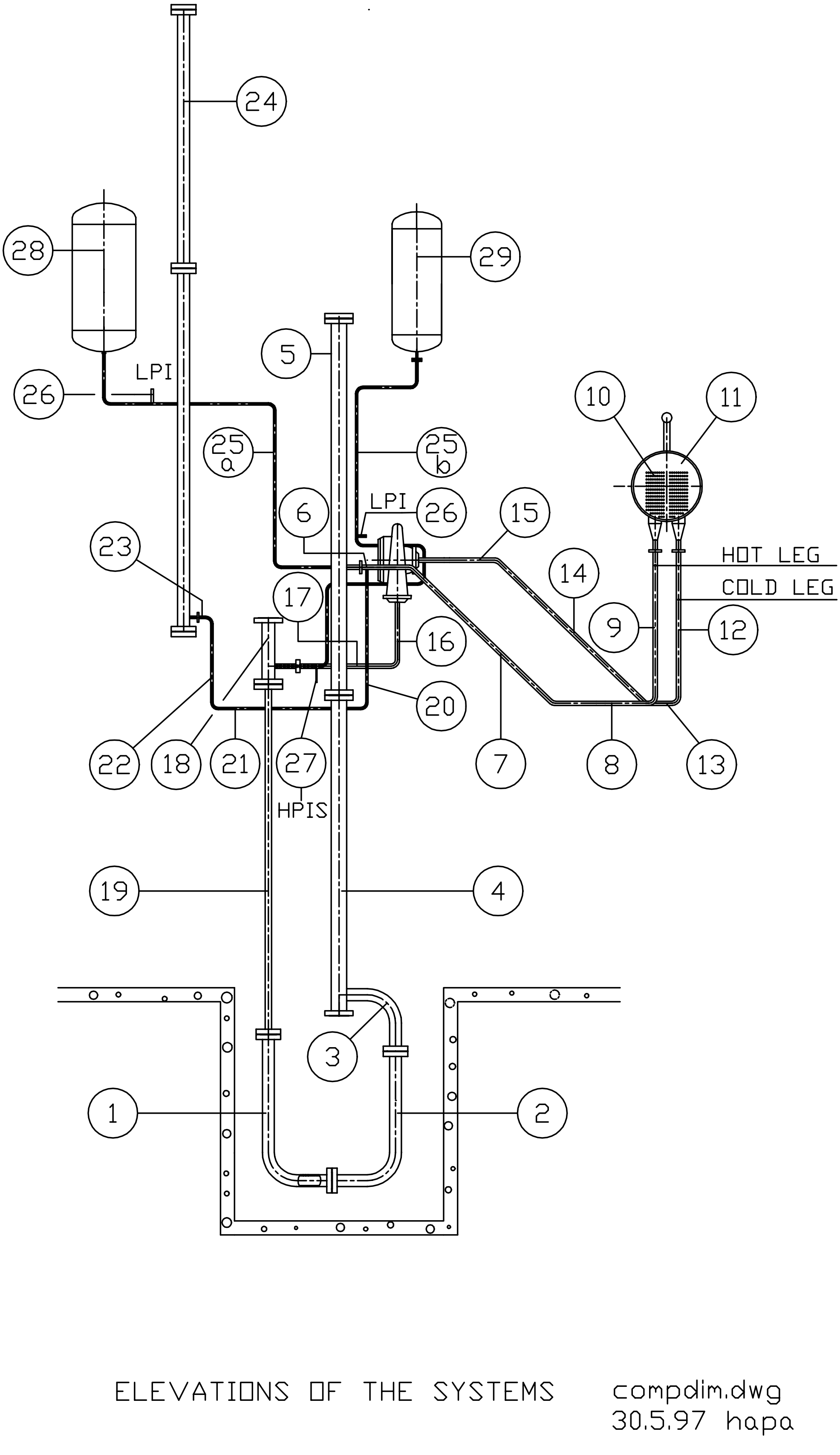
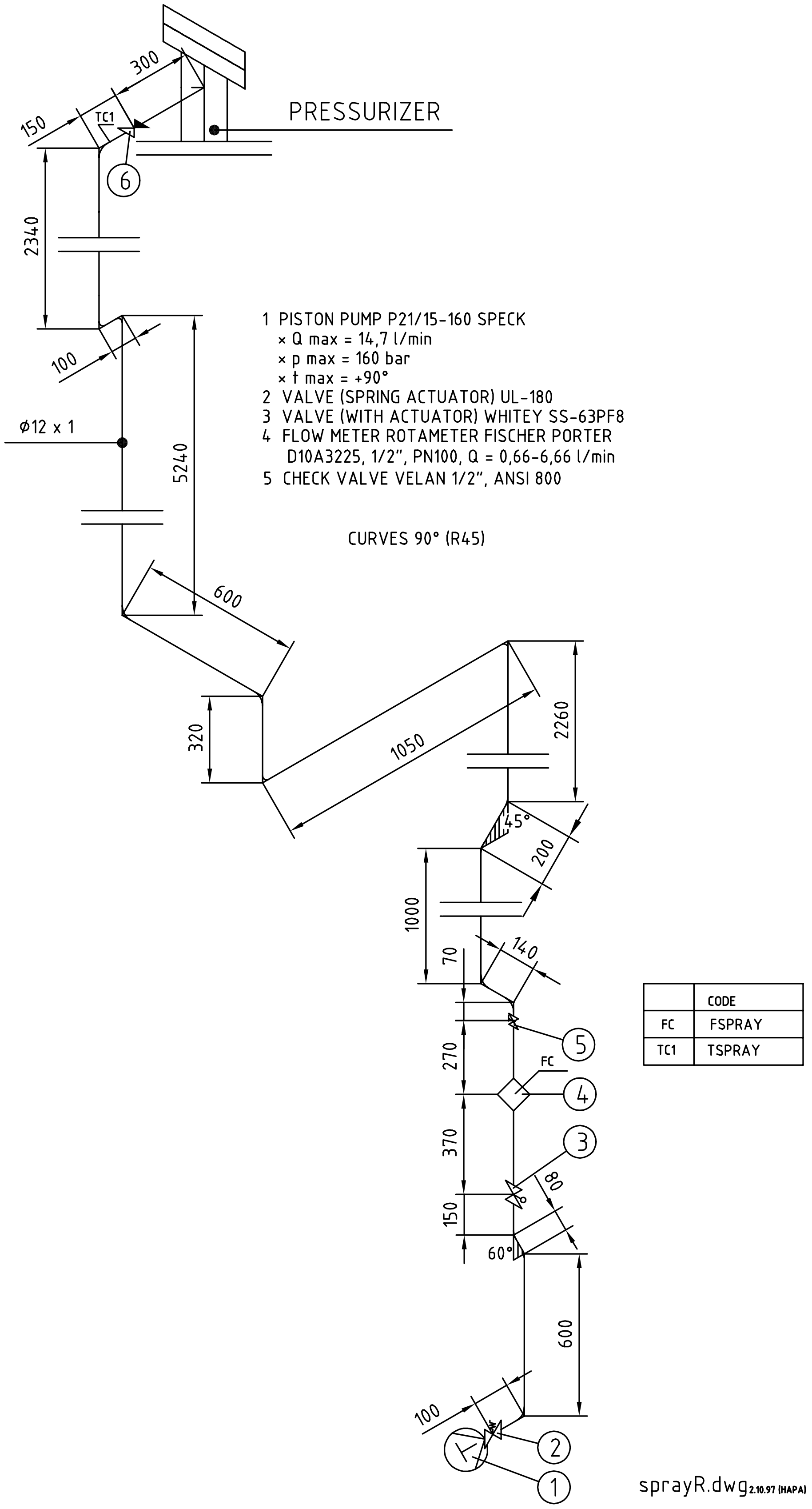


Figure A. 47. Components of PACTEL loop. See Table A.3 for components volumes and flow areas.



1 PISTON PUMP P21/15-160 SPECK
× Q max = 14,7 l/min
× p max = 160 bar
× t max = +90°
2 VALVE (SPRING ACTUATOR) UL-180
3 VALVE (WITH ACTUATOR) WHITEY SS-63PF8
4 FLOW METER ROTAMETER FISCHER PORTER D10A3225, 1/2", PN100, Q = 0,66-6,66 l/min
5 CHECK VALVE VELAN 1/2", ANSI 800

CURVES 90° (R45)

	CODE
FC	FSPRAY
TC1	TSPRAY

sprayR.dwg 2.10.97 (HAPA)

Figure A. 48. Pressurizer spray system.

Table A.1. Characteristics of the main circulation pump.

rotation speed	**volumetric flow**	**head**	**powewr**	**efficiency**	**torque**	**density**
n (rpm)	**Q (m^3/h)**	**H (m)**	**P (kW)**	**η (%)**	**M (Nm)**	**ρ (kg/m^3)**
1500	0.00	15.97	1.35	0.00	8.59	1000
1500	12.47	16.06	1.70	32.02	10.82	1000
1500	23.49	15.55	2.08	47.81	13.24	1000
1500	36.35	13.90	2.41	57.08	15.34	1000
1500	54.81	8.89	2.80	47.41	17.83	1000
3500	0.0	87.56	10.03	0.00	27.37	1000
3500	25.34	87.45	14.17	42.60	38.66	1000
3500	48.37	85.38	18.12	62.09	49.44	1000
3500	72.01	79.84	22.55	69.45	61.52	1000
3500	89.72	71.99	25.04	70.27	68.32	1000

Table A.2. Component dimensions (see fig. A.47 for components).

COMPONENT	**DIMENSIONS (mm)**			**COMMENTS**
	Size	d_i	Length	
1.Lower plenum	Ø168.3x14.3	139.7	2798	Bends: 1x90^{O},r=400
2.Lower plenum	Ø168.3x14.3	139.7	2558	Bends: 1x90^{O},r=400
3.Lower plenum	Ø168.3x14.3	139.7	1338	Bends: 1x90^{O},r=400
4.Core	Ø219.1x18.2	182.7	4540	
5.Upper plenum	Ø219.1x15	189.1	5330	
6.Hot leg I	Ø60.3x3.9	52.5	1012	
Hot leg II	Ø60.3x3.9	52.5	1112	
Hot leg III	Ø60.3x3.9	52.5	1012	
7.Hot leg I	Ø60.3x3.9	52.5	3090	Bends: 1x45^{O},1x125^{O},r=76
Hot leg II	Ø60.3x3.9	52.5	3219	Bends: 1x132^{O},1x135^{O},r=76
Hot leg III	Ø60.3x3.9	52.5	3087	Bends: 1x48^{O},1x119^{O},r=76
8.Hot leg I	Ø60.3x3.9	52.5	1361	Including valve
Hot leg II	Ø60.3x3.9	52.5	1261	Including valve
Hot leg III	Ø60.3x3.9	52.5	1361	Including valve
9.Hot leg I	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
Hot leg II	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
Hot leg III	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
10.SG I,II,III tubes	Ø16.0x1.5	13.0	2521	14 U-tubes,r=45
SG I,II,III tubes	Ø16.0x1.5	13.0	2528	14 U-tubes,r=75
SG I,II,III tubes	Ø16.0x1.5	13.0	2574	14 U-tubes,r=105
SG I,II,III tubes	Ø16,0x1.5	13.0	2632	13 U-tubes,r=135
SG I,II,III tubes	Ø16,0x1.5	13.0	2718	13 U-tubes,r=165
SG I,II,III tubes	Ø16,0x1.5	13.0	2821	13 U-tubes,r=195
SG I,II,III tubes	Ø16,0x1.5	13.0	2951	13 U-tubes,r=225
SG I,II,III tubes	Ø16,0x1.5	13.0	3093	12 U-tubes,r=255
SG I,II,III tubes	Ø16,0x1.5	13.0	3275	12 U-tubes,r=285
11.SG I,II,III shell	Ø1000x25	950.0	1600	
SG I,II,III endings	Ø1000x23	954.0	333	Ellipsoid
SG I,II,III collectors	Ø180x20	140.0	737	
	-	-	200	Reducer 6" -> 2"
	Ø60.3x3.9	52.5	150	
12.Cold leg I	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
Cold leg II	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
Cold leg III	Ø60.3x3.9	52.5	2143	Bends: 1x90^{O},r=76
13.Cold leg I	Ø60.3x3.9	52.5	376	
Cold leg II	Ø60.3x3.9	52.5	376	
Cold leg III	Ø60.3x3.9	52.5	376	
14.Cold leg I	Ø60.3x3.9	52.5	2887	Bends: 1x90^{O},1x47^{O},r=76
Cold leg II	Ø60.3x3.9	52.5	3074	Bends: 1x135^{O},1x143^{O},r=76
Cold leg III	Ø60.3x3.9	52.5	2923	Bends: 1x74^{O},1x90^{O},r=76
15.Cold leg I	Ø60.3x3.9	52.5	1307	Bends: 1x43^{O},r=76
Cold leg II	Ø60.3x3.9	52.5	803	Bends: 1x70^{O},r=76
Cold leg III	Ø60.3x3.9	52.5	551	Bends: 1x40^{O},r=76
16.Cold leg I	Ø60.3x3.9	52.5	1385	Bends: 2x45^{O},1x90^{O}, r=76,including valve, excluding pump
Cold leg II	Ø60.3x3.9	52.5	1460	Bends: 2x45^{O},1x90^{O}r=76,including valve, excluding pump
Cold leg III	Ø60.3x3.9	52.5	1517	Bends: 2x45^{O},1x90^{O}r=76,including valve, excluding pump
17.Cold leg I	Ø60.3x3.9	52.5	515	
Cold leg II	Ø60.3x3.9	52.5	515	
Cold leg III	Ø60.3x3.9	52.5	515	
18.Downcomer	Ø180.0x15.0	150.0	940	
19.Downcomer	Ø88.9x7.6	73.7	4960	
20.Pressurizer line	Ø33.7x3.2	27.3	1992	Bends: 1x90^{O},r=38
21.Pressurizer line	Ø33.7x3.2	27.3	3832	Bends: 2x90^{O},r=38
22.Pressurizer line	Ø33.7x3.2	27.3	1334	Bends: 2x90^{O},r=38
23.Pressurizer line	Ø33.7x3.2	27.3	349	
24.Pressurizer	Ø168.3x14.3	139.7	8800	
25a Accumulator line	Ø33.7x3.2	27.3	6347	Upper plenum injection Bends: 4x90^{O},r=38
25b Accumulator line	Ø33.7x3.2	27.3	8377	Downcomer injection Bends: 9x90^{O},r=38
26.LPIS line	Ø33.7x3.2	27.3		
27.HPIS line	Ø16.0x1.5	13.0		

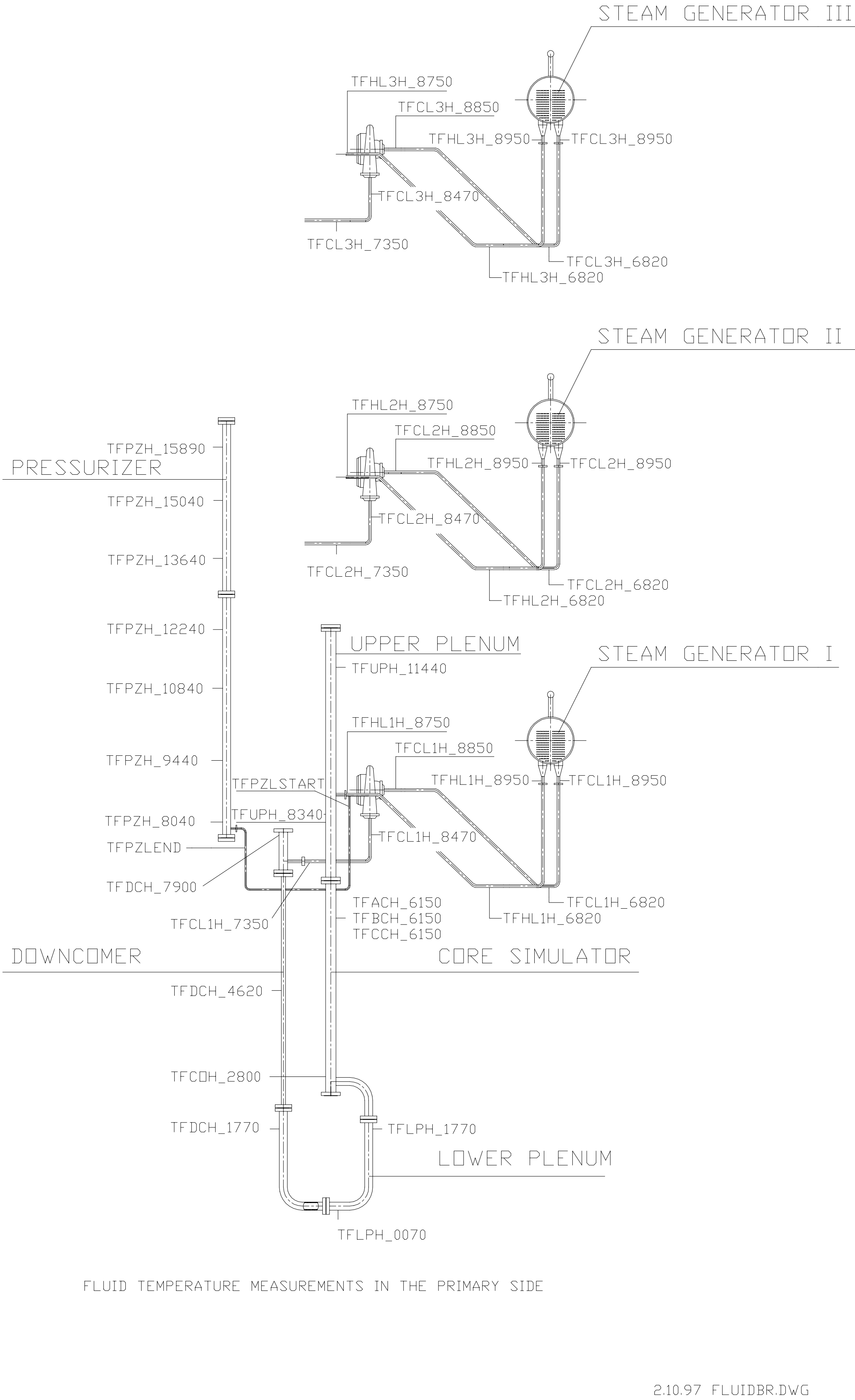
Table A.3. Component volumes and flow areas (see fig. A.47 for components).

COMPONENT	**VOLUME [L]**	**FLOW AREA [cm^2]**
Lower plenum (1-3)	102.6	153.3
Core, lower part (4)	15.5	-
Core, power area (3 channels + bypass) (4)	34.6	-
Core, upper part (4)	32.5	-
Upper plenum (5)	147.5	-
Hot leg I (6-9)	16.4	21.6
Cold leg I (12-17)	18.8	21.6
Hot leg II (6-9)	16.7	21.6
Cold leg II (12-17)	18.3	21.6
Hot leg III (6-9)	16.4	21.6
Cold leg III (12-17)	17.6	21.6
Downcomer, top (18)	15.8	176.7
Downcomer (19)	21.2	42.7
Pressurizer line (20-23)	4.5	5.9
Pressurizer (24)	133.5	153.3
Steam generators, primary side	69.9	-
Steam generators, secondary side (steam collectors included)	1 378	-
Connection line, SG2->SG1 (28)		5.9
Connection line, SG3->SG1 (29)		5.9
Primary Circulation Pump	1.9	-
PRIMARY SIDE	827	-
SECONDARY SIDE	4 135	-

Table A.4. Component insulation (see fig. A.47 for components).

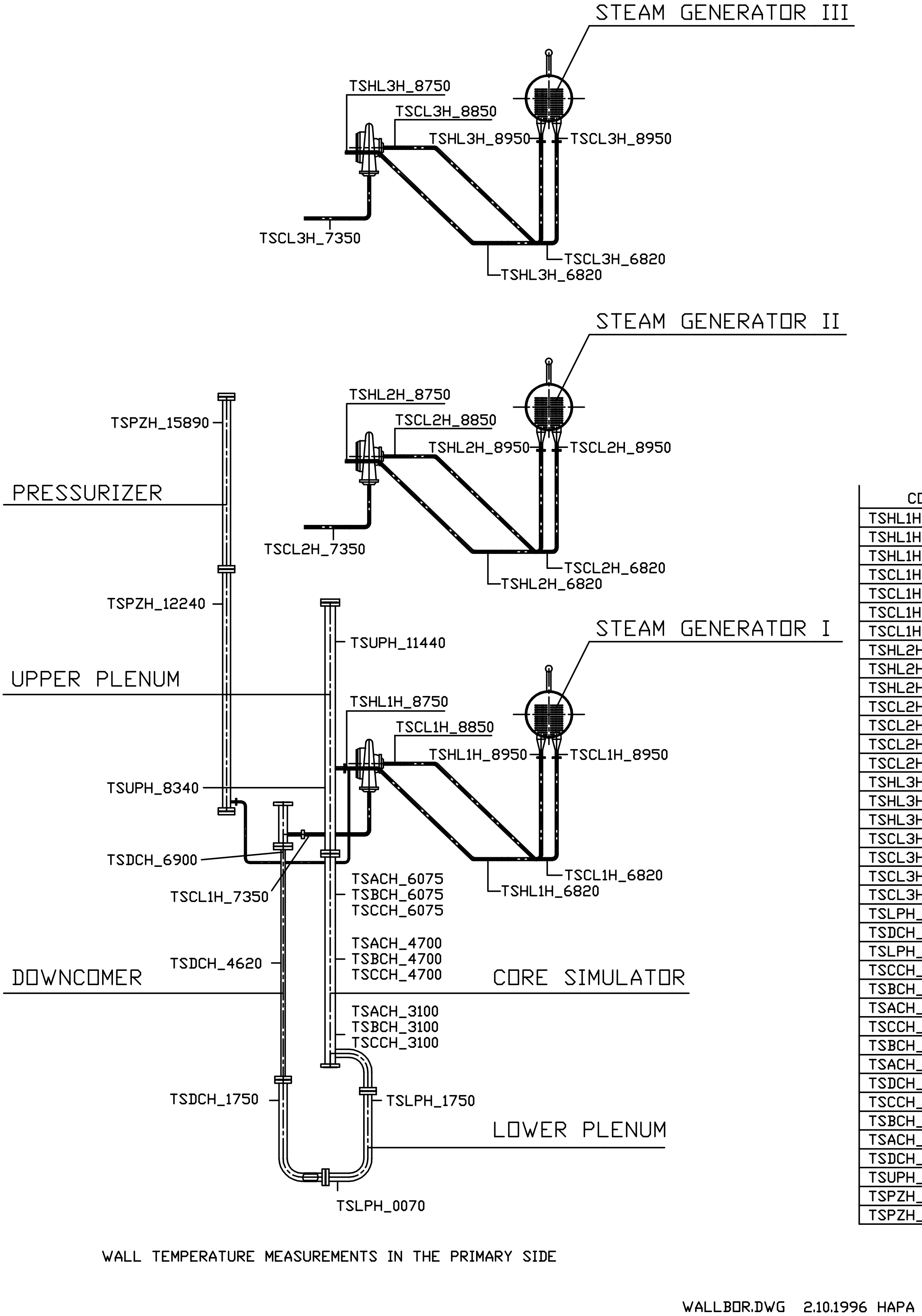
COMPONENT	**Insulation**			
	Material	Thickness (mm)	Material	Thickness (mm)
Core (4)	Mineral wool	100	Aluminum	0.7
Upper plenum (5)	Mineral wool	100	Aluminum	0.7
Hot leg (6-9)	Mineral wool	60	Aluminum	0.7
Steam generators (10 -11)	Mineral wool	100	Aluminum	0.7
Cold legs (12 - 17)	Mineral wool	60	Aluminum	0.7
Downcomer (18 - 19)	Mineral wool	100	Aluminum	0.7
Lower plenum (1 - 3)	Mineral wool	100	Aluminum	0.7
Accumulator line	Mineral wool	30	Aluminum	0.7
Pressurizer surge line	Mineral wool	30	Aluminum	0.7
Accumulator	Mineral wool	60	Aluminum	0.7
Pressurizer (24)	Mineral wool	100	Aluminum	0.7
SG connection lines	Mineral wool	30	Aluminum	0.7

Appendix B Location of measurement instrumentation in the PACTEL facility



CODE
TFHL1H_8750
TFHL1H_6820
TFHL1H_8950
TFCL1H_8950
TFCL1H_6820
TFCL1H_8850
TFCL1H_8470
TFCL1H_7350
TFHL2H_8750
TFHL2H_6820
TFHL2H_8950
TFCL2H_8950
TFCL2H_6820
TFCL2H_8850
TFCL2H_8470
TFCL2H_7350
TFHL3H_8750
TFHL3H_6820
TFHL3H_8950
TFCL3H_8950
TFCL3H_6820
TFCL3H_8850
TFCL3H_8470
TFCL3H_7350
TFLPH_0070
TFLPH_1770
TFDCH_1770
TFCON_2800
TFDCH_4620
TFCCH_6150
TFBCH_6150
TFACH_6150
TFDCH_7900
TFUOH_8340
TFUPH_11440
TFPZLSTART
TFPZLEND
TFPZH_8040
TFPZH_9440
TFPZH_10840
TFPZH_12240
TFPZH_13640
TFPZH_15040
TFPZH_15890

Figure B. 1. Fluid temperature measurements in the primary side.



CODE
TSHL1H_8750
TSHL1H_6820
TSHL1H_8950
TSCL1H_8950
TSCL1H_6820
TSCL1H_8850
TSCL1H_7350
TSHL2H_8750
TSHL2H-6820
TSHL2H_8950
TSCL2H_8950
TSCL2H_6820
TSCL2H_8850
TSCL2H_7350
TSHL3H_8750
TSHL3H_6820
TSHL3H_8950
TSCL3H_8950
TSCL3H_6820
TSCL3H_8850
TSCL3H_7350
TSLPH_0070
TSDCH_1750
TSLPH_1750
TSCCH_3100
TSBCH_3100
TSACH_3100
TSCCH_4700
TSBCH_4700
TSACH_4700
TSDCH_4620
TSCCH_6075
TSBCH_6075
TSACH_6075
TSDCH_6900
TSUPH_8340
TSPZH_12240
TSPZH_15890

Figure B. 2. Wall temperature measurements in the primary side.

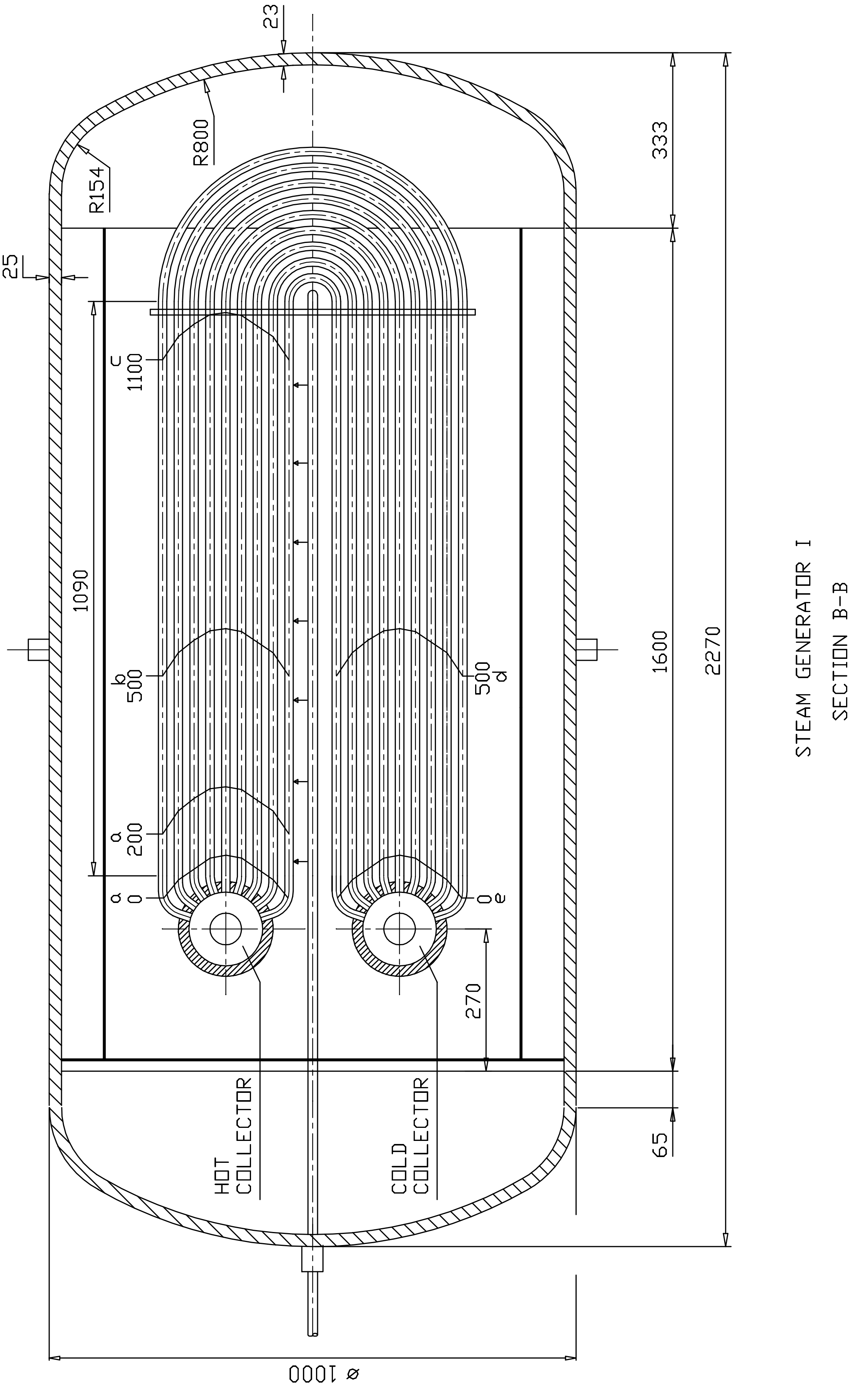


Figure B. 3. Temperature measurement positions in the steam generator of loop 1.

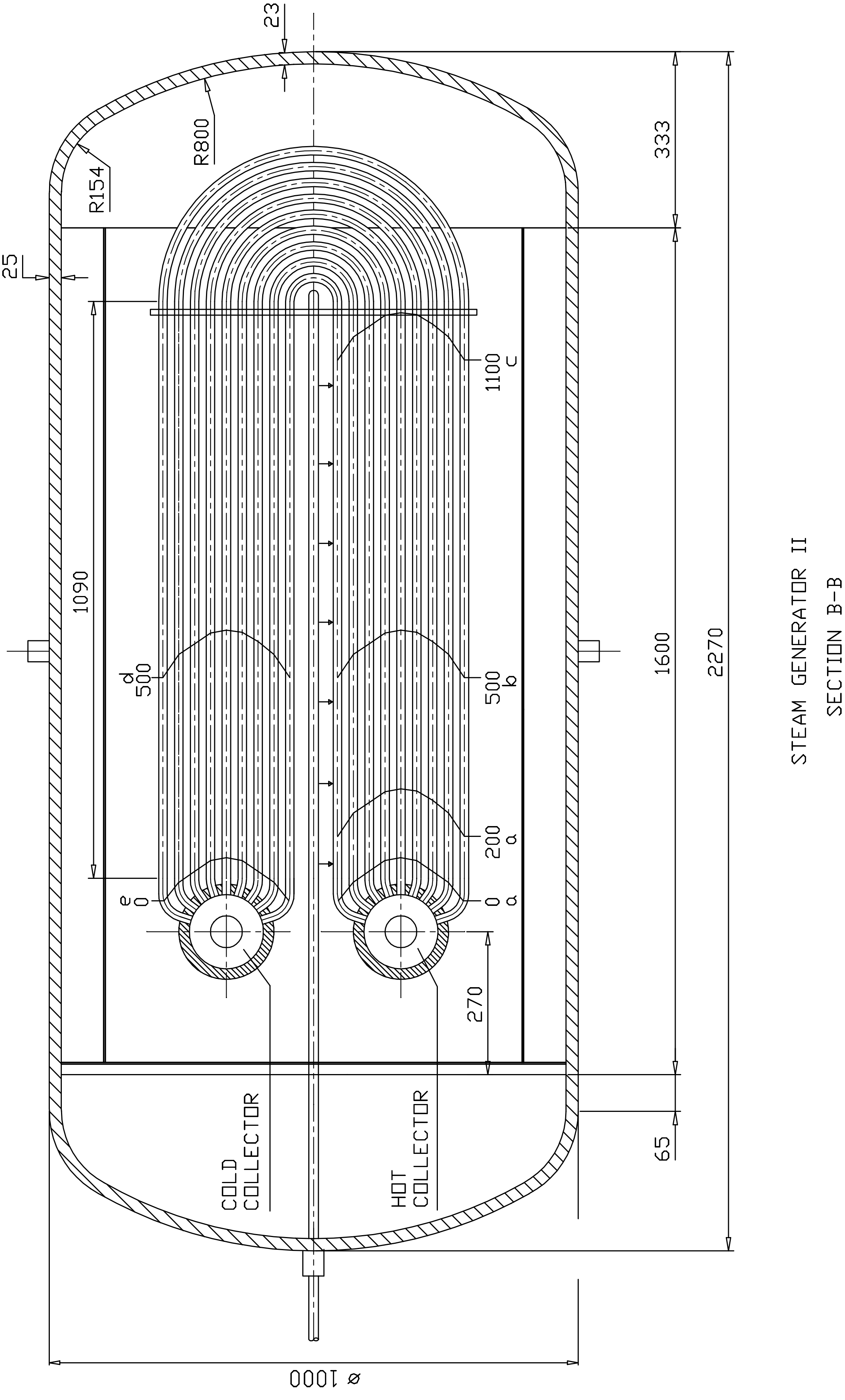


Figure B. 4. Temperature measurement positions in the steam generator of loop 2.

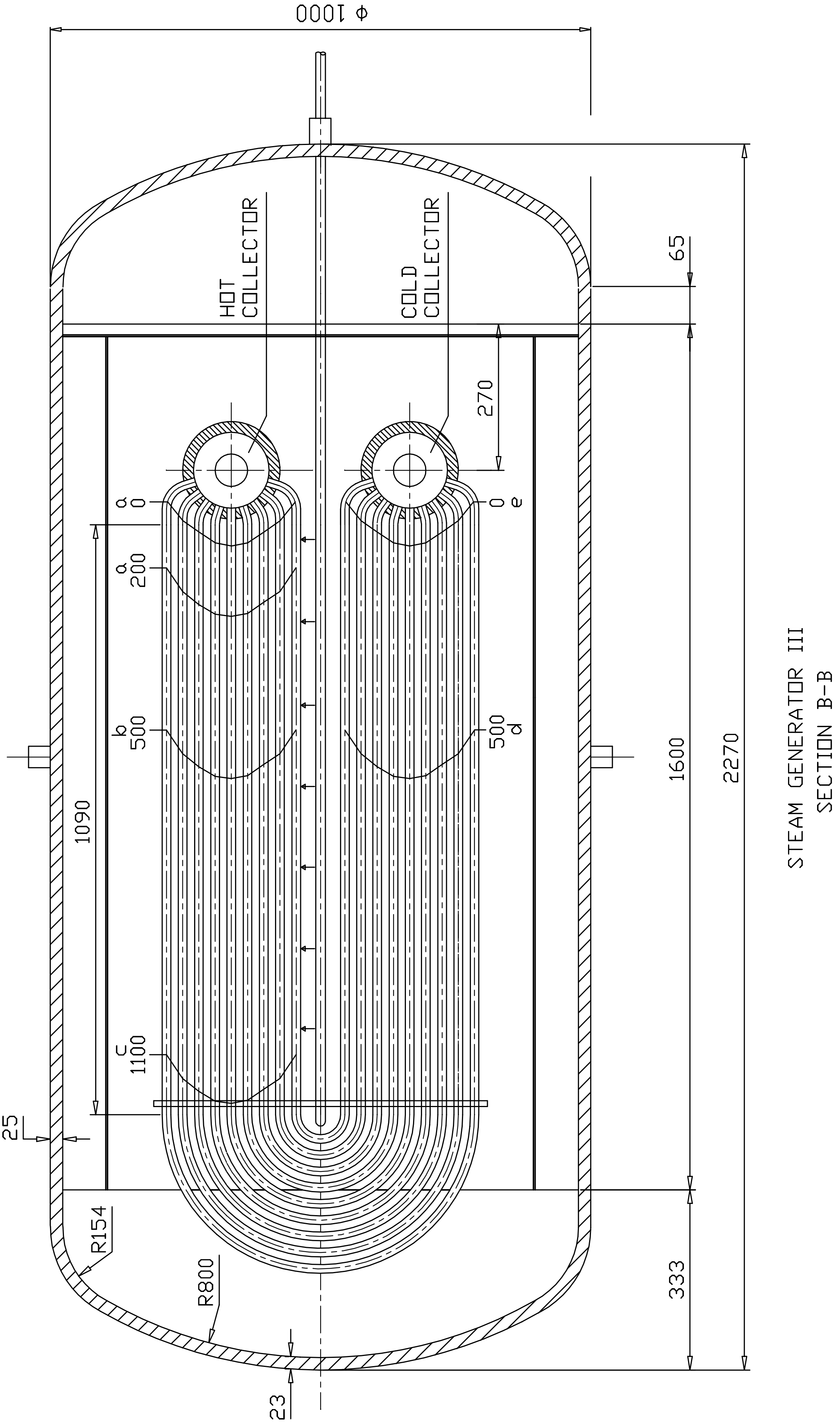


Figure B. 5. Temperature measurement positions in the steam generator of loop 3.

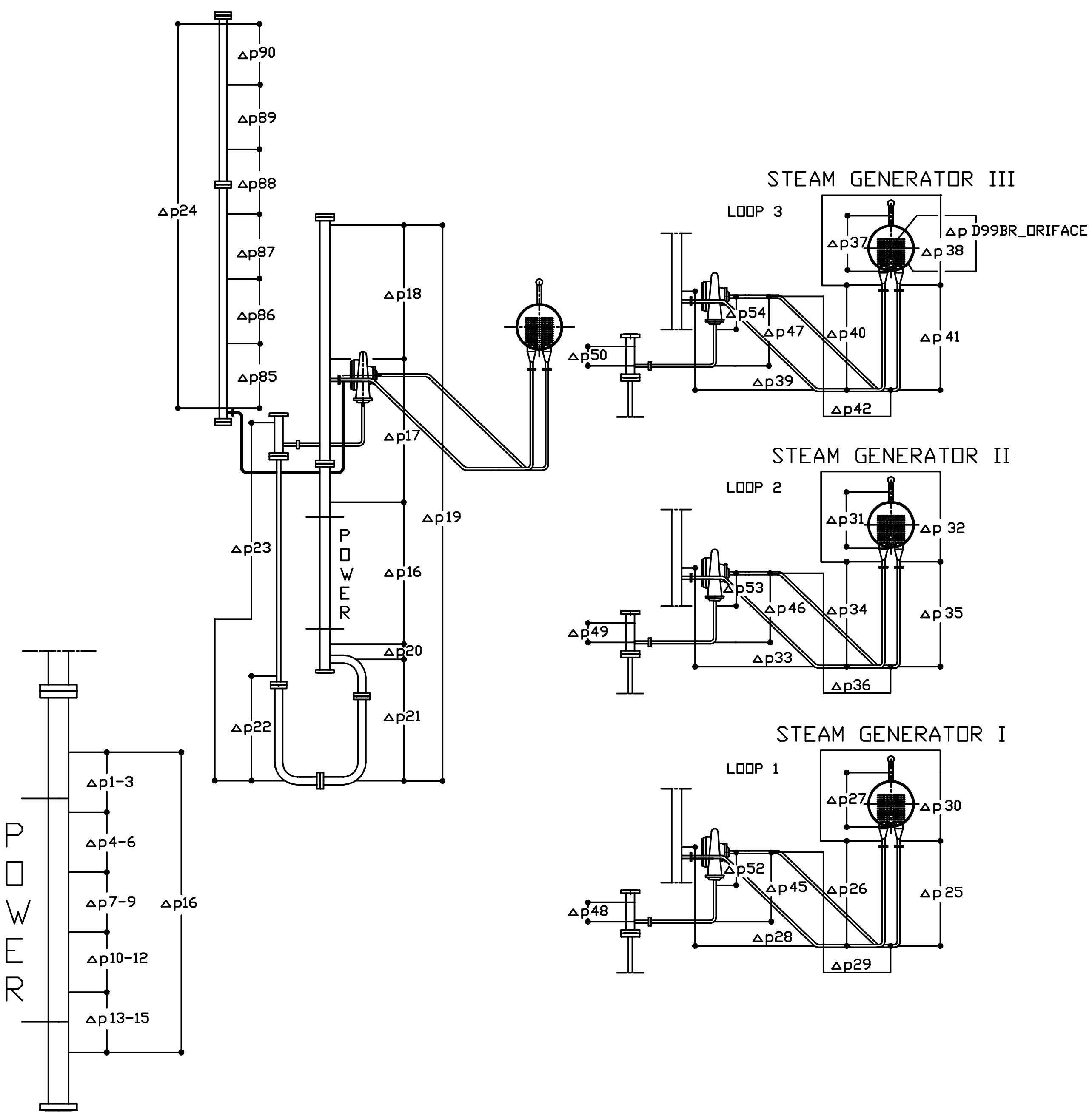
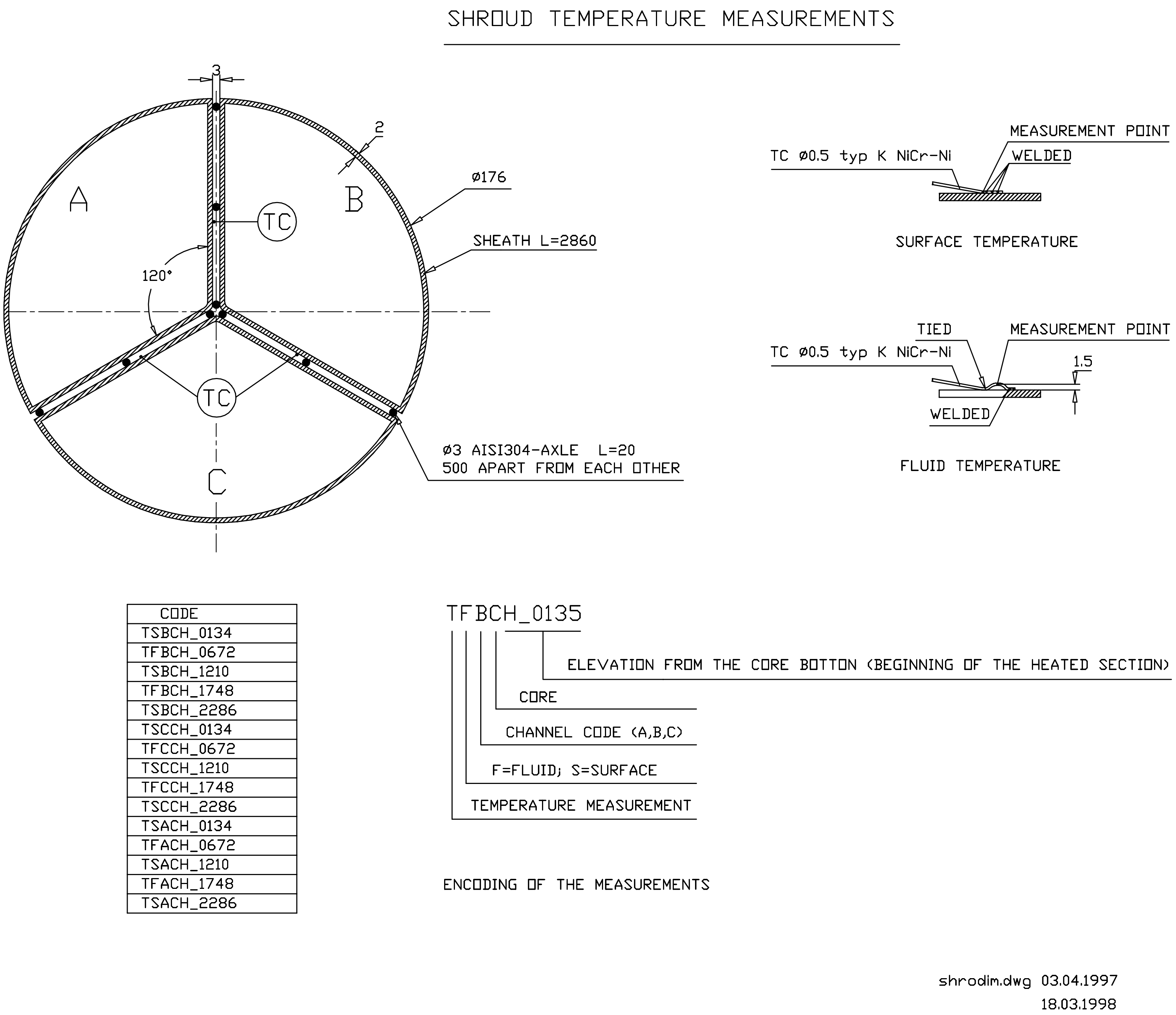


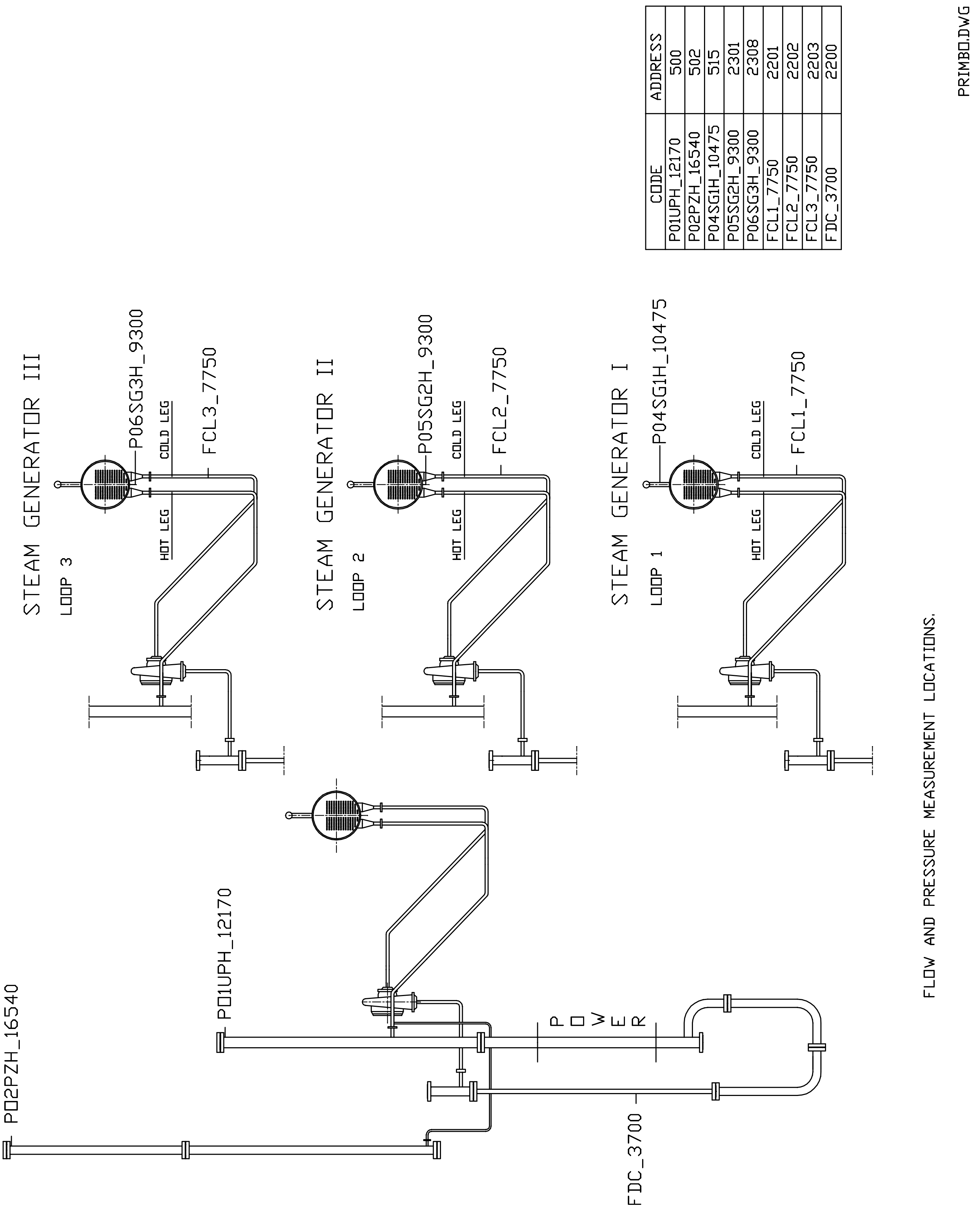
Figure B. 6. Pressure difference measurements.

ΔP	CODE	ADDRESS
1	D01AC_6050AC_5500	1703
2	D02BC_6050BC_5500	1704
3	D03CC_6050CC_5500	1705
4	D04AC_5500AC_4950	1706
5	D05BC_5500BC_4950	1707
6	D06CC_5500CC_4950	1708
7	D07AC_4950AC_4400	1709
8	D08BC_4950BC_4400	1710
9	D09CC_4950CC_4400	1711
10	D10AC_4400AC_3850	1712
11	D11BC_4400BC_3850	1713
12	D12CC_4400CC_3850	1714
13	D13AC_3850AC_3300	1715
14	D14BC_3850BC_3300	1716
15	D15CC_3850CC_3300	1717
16	D16C0_6050C0_3300	1701
17	D17UP_8890UP_6050	506
18	D18UP_12130UP_8890	513
19	D19UP_12130LP_0070	1700
20	D20CO_3300LP_2700	1720
21	D21LP_2700LP_0070	1721
22	D22DC_2400LP_0070	1722
23	D23DC_7900LP_0070	1702
24	D24PZ_16490PZ_8040	501
25	D25HL1_8950HL1_6790	1718
26	D26CL1_8950CL1_6790	1719
27	D27SG1	514
28	D28UP_8890HL1-6790	508
29	D29CL1_8820CL1_6790	509
30	D30HL1-8950CL1_8950	512
31	D31SG2	2300
32	D32HL2_8950CL2_8950	2302
33	D33UP_8890HL2_6790	2303
34	D34HL2_8950HL2_6790	2304
35	D35CL2_8950CL2_6790	2305
36	D36CL2_8820CL2_6790	2306
37	D37SG3	2309
38	D38HL3_8950CL3_8950	2310
39	D39UP_8890HL3_6790	2311
40	D40HL3_8950HL3_6790	2312
41	D41CL3_8950CL3_6790	2313
42	D42CL3_8820CL3_6790	2314
43	D43ACC1	2204
44	D44ACC2	605
45	D45CL1_8820CL1_7320	604
46	D46CL2_8820CL2_7320	2315
47	D47CL3_8820CL3_7320	2307
48	D48DC_7900CL1_7320	601
49	D49DC_7900CL2_7320	602
50	D50DC_7900CL3_7320	603
51	D51CND_TNK	1123
52	D52CL1_8820CL1_8500	2209
53	D53CL2_8820CL2_8500	2210
54	D54CL3_8820CL3_8500	2211
85	D85PZ_9440PZ_8040	3417
86	D86PZ_10840PZ_9440	3416
87	D87PZ_12240PZ_10840	3415
88	D88PZ_13640PZ_12240	3414
89	D89PZ_15040PZ_13640	3413
90	D90PZ_16490PZ_15040	3412
99	D99BR_ORIFASE	611



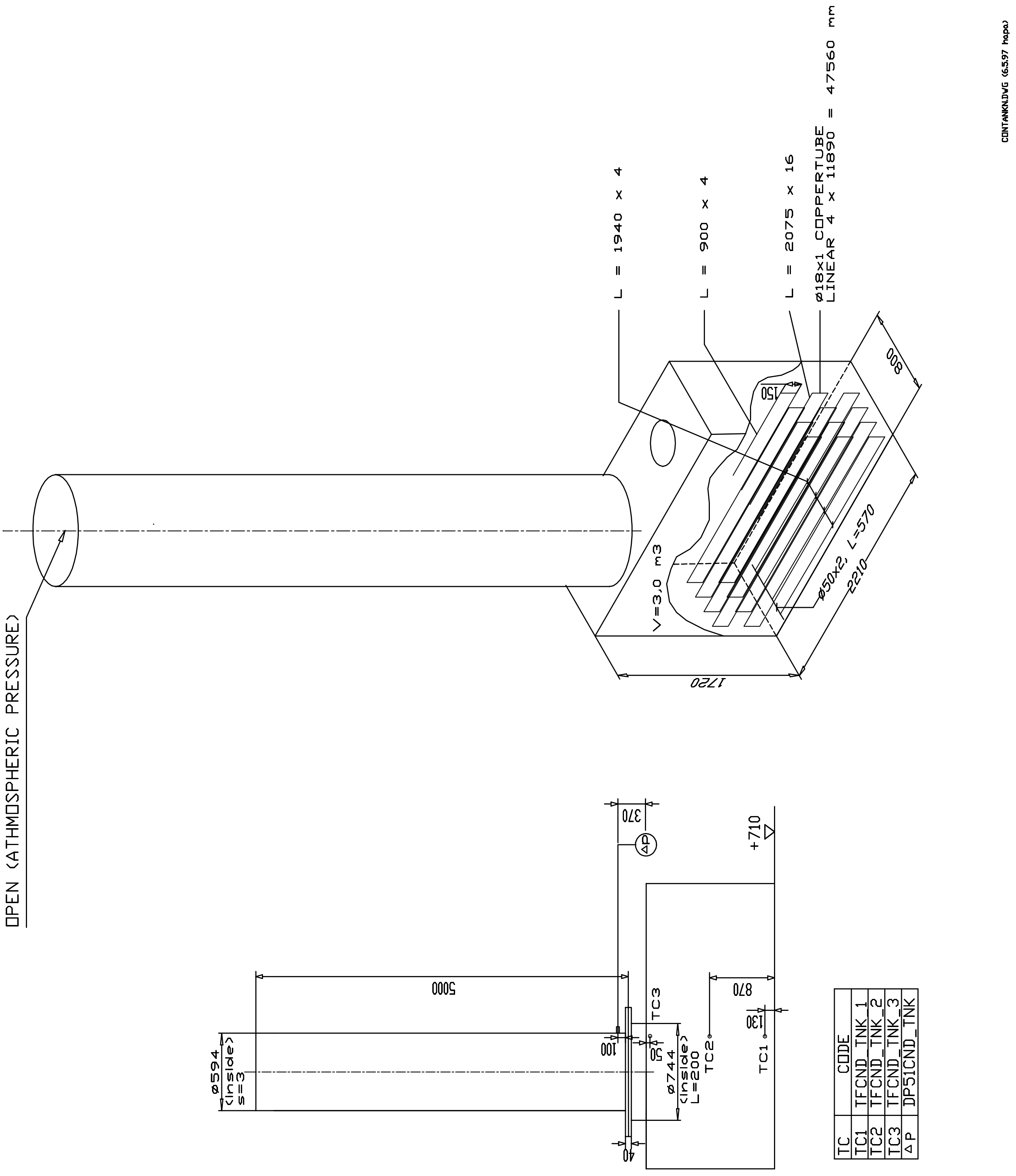
CODE
TSBCH_0134
TFBCH_0672
TSBCH_1210
TFBCH_1748
TSBCH_2286
TSCCH_0134
TFCCH_0672
TSCCH_1210
TFCCH_1748
TSCCH_2286
TSACH_0134
TFACH_0672
TSACH_1210
TFACH_1748
TSACH_2286

Figure B. 7. Shroud temperature measurements.



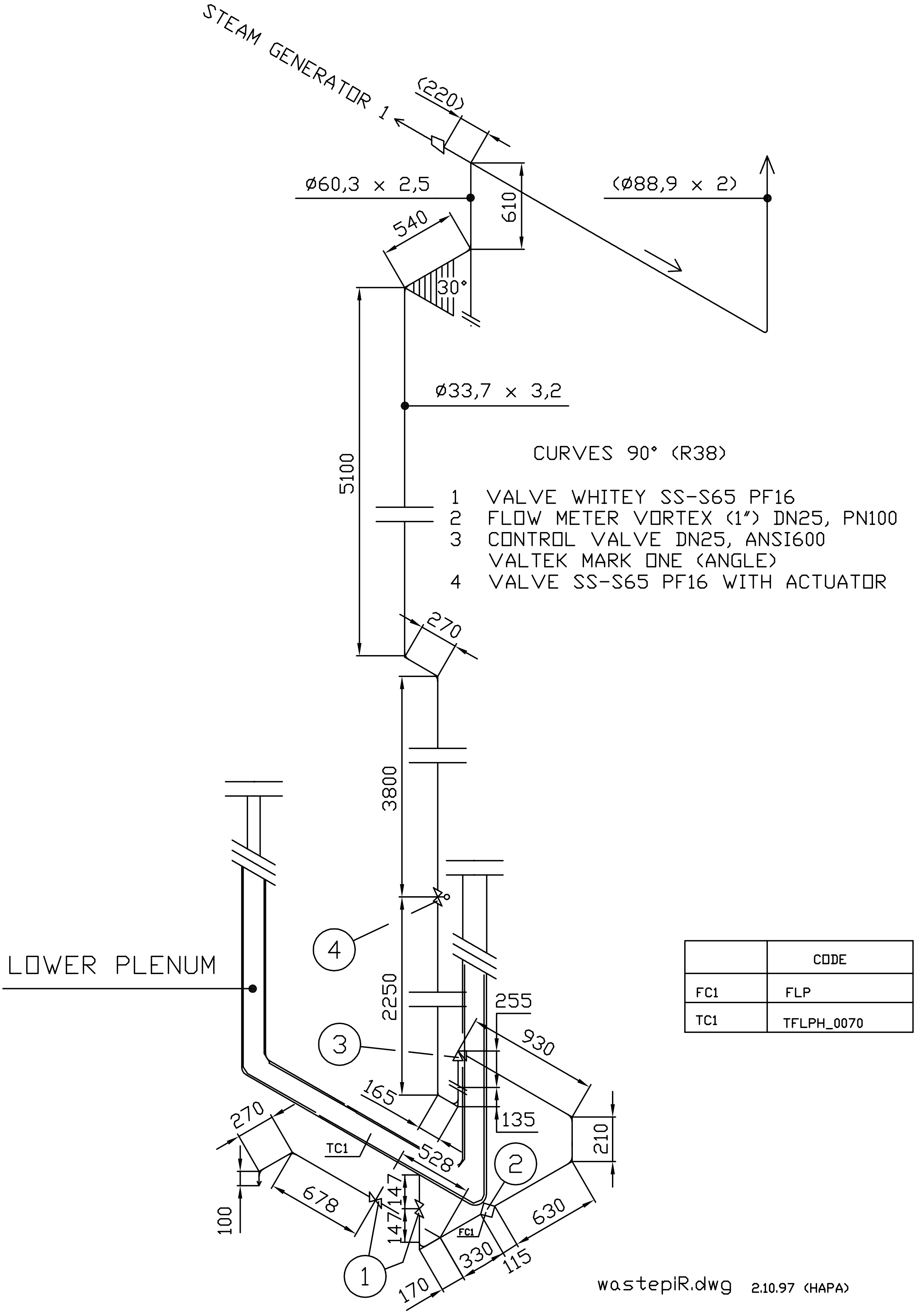
CODE	ADDRESS
P01UPH_12170	500
P02PZH_16540	502
P04SG1H_10475	515
P05SG2H_9300	2301
P06SG3H_9300	2308
FCL1_7750	2201
FCL2_7750	2202
FCL3_7750	2203
FDC_3700	2200

Figure B. 8. Flow and pressure measurement locations.



TC	CODE
TC1	TFCND_TNK_1
TC2	TFCND_TNK_2
TC3	TFCND_TNK_3
ΔP	DP51CND_TNK

Figure B. 9. Break flow measurement system.

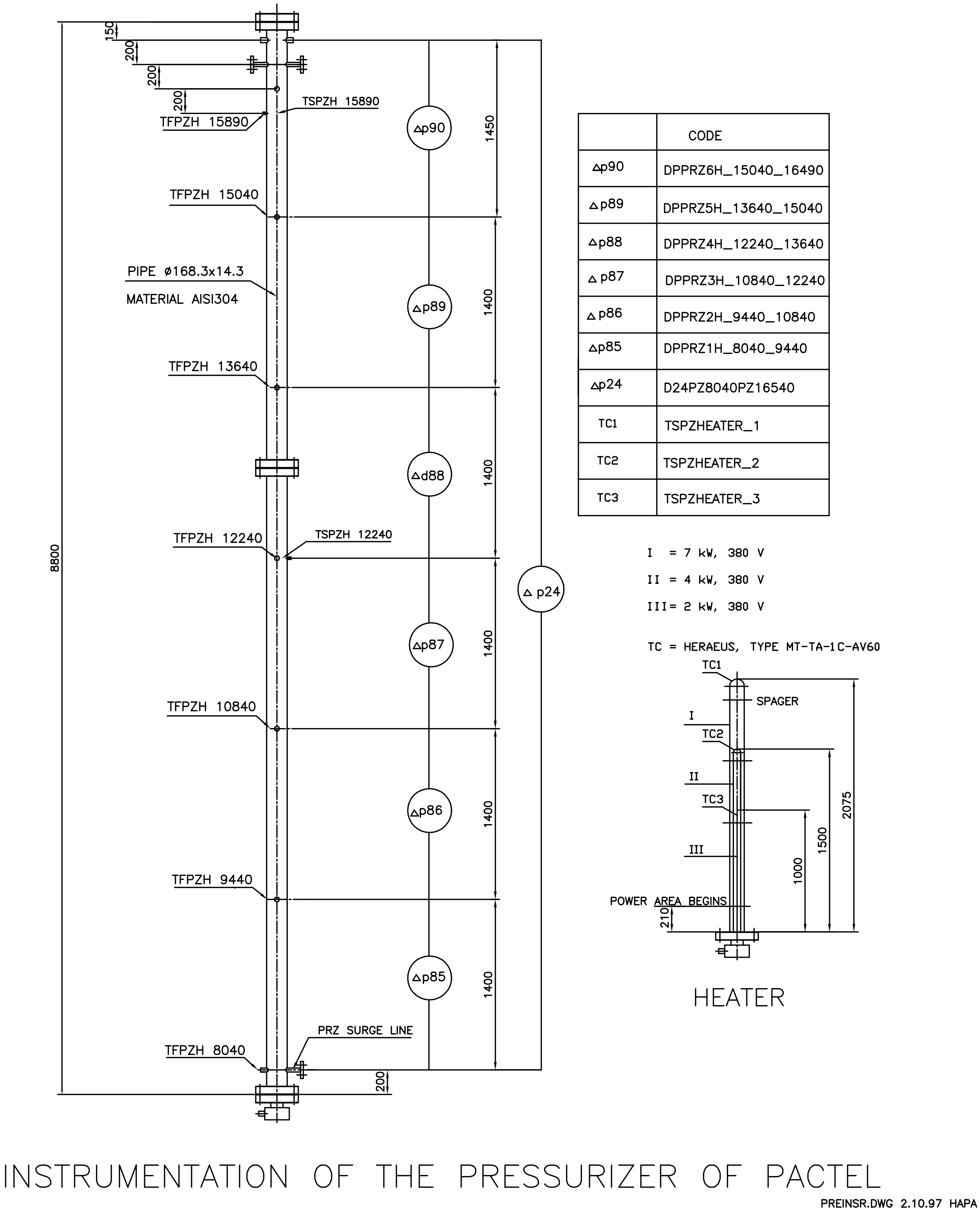


CURVES 90° (R38)

1 VALVE WHITEY SS-S65 PF16
2 FLOW METER VORTEX (1") DN25, PN100
3 CONTROL VALVE DN25, ANSI600
VALTEK MARK ONE (ANGLE)
4 VALVE SS-S65 PF16 WITH ACTUATOR

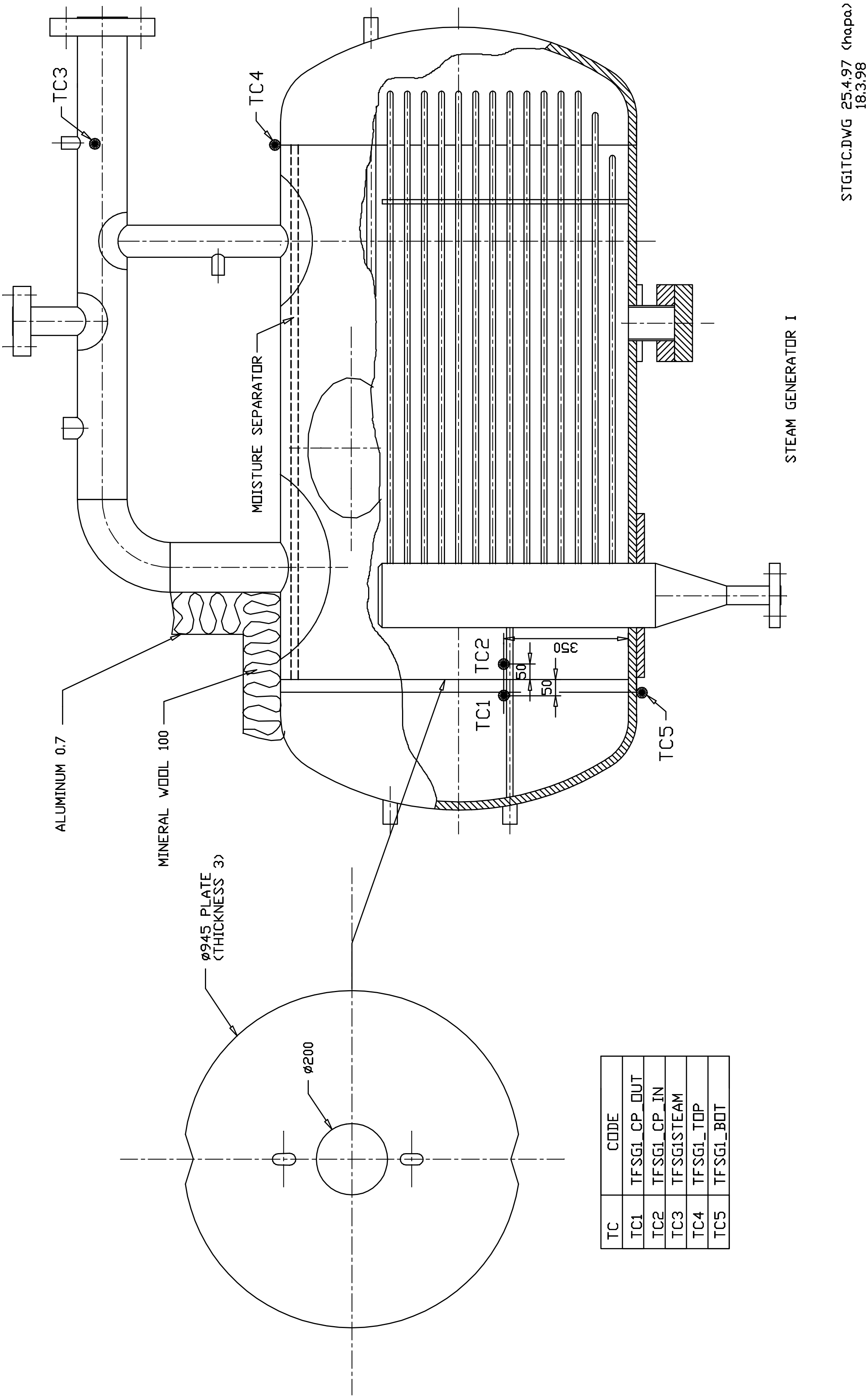
	CODE
FC1	FLP
TC1	TFLPH_0070

Figure B. 10. Drainage flow measurement system.



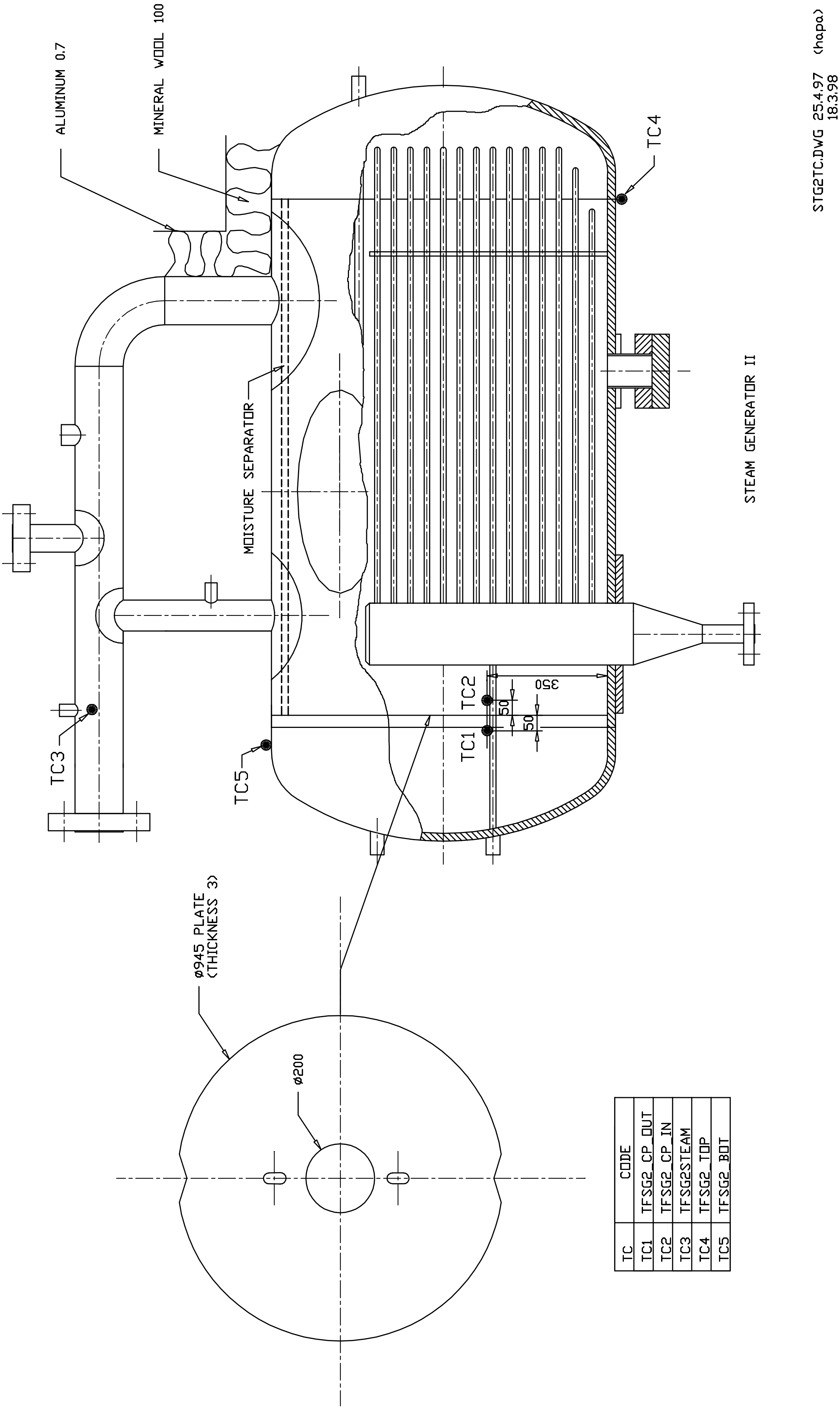
	CODE
Δp90	DPPRZ6H_15040_16490
Δp89	DPPRZ5H_13640_15040
Δp88	DPPRZ4H_12240_13640
Δ p87	DPPRZ3H_10840_12240
Δ p86	DPPRZ2H_9440_10840
Δp85	DPPRZ1H_8040_9440
Δp24	D24PZ8040PZ16540
TC1	TSPZHEATER_1
TC2	TSPZHEATER_2
TC3	TSPZHEATER_3

Figure B. 11. Instrumentation of the pressurizer.



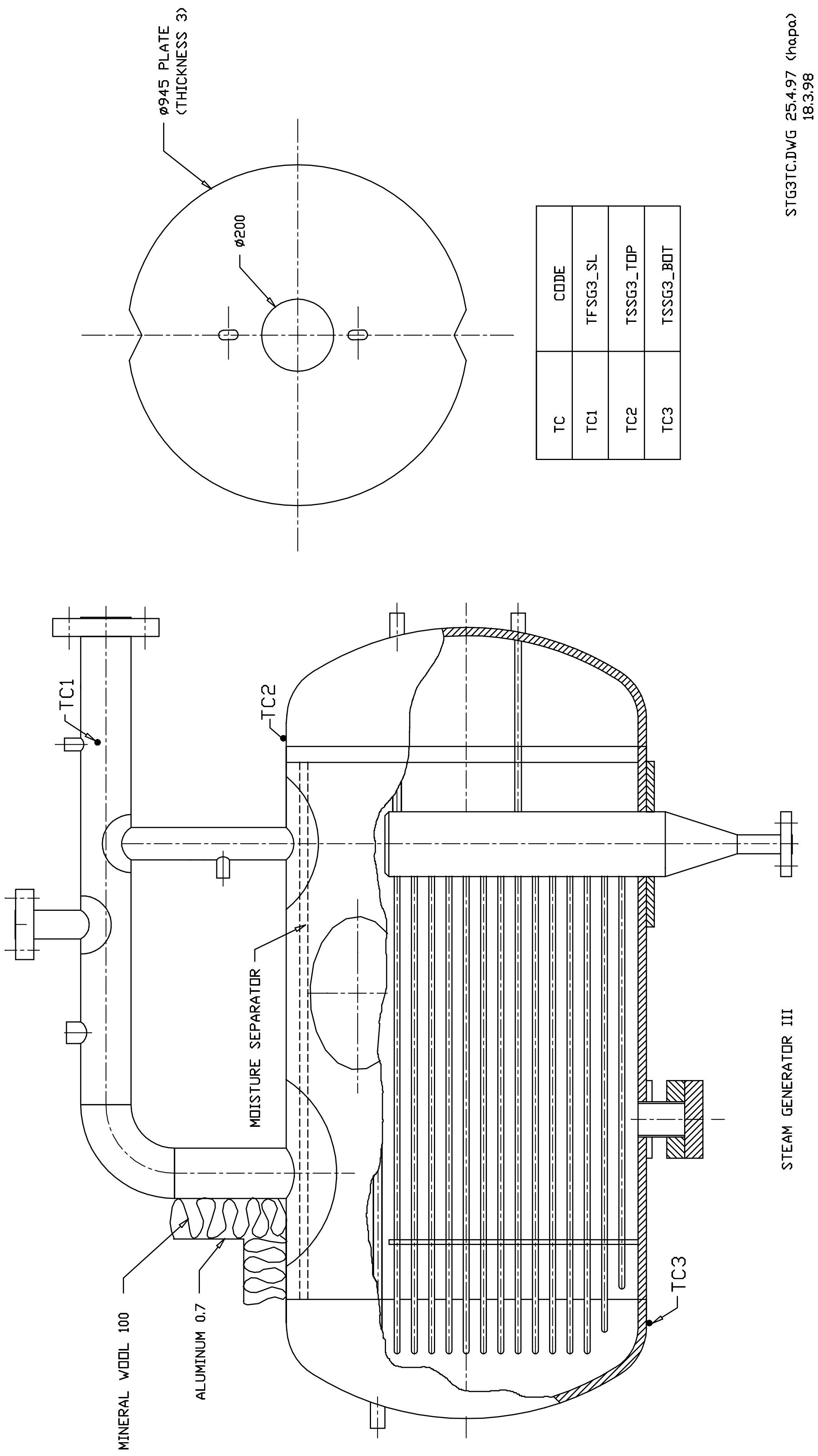
TC	CODE
TC1	TFSG1_CP_OUT
TC2	TFSG1_CP_IN
TC3	TFSG1STEAM
TC4	TFSG1_TOP
TC5	TFSG1_BOT

Figure B. 12. Position of the thermocouples measuring structure temperatures in the steam generator 1.



TC	CODE
TC1	TFSG2_CP_OUT
TC2	TFSG2_CP_IN
TC3	TFSG2STEAM
TC4	TFSG2_TOP
TC5	TFSG2_BOT

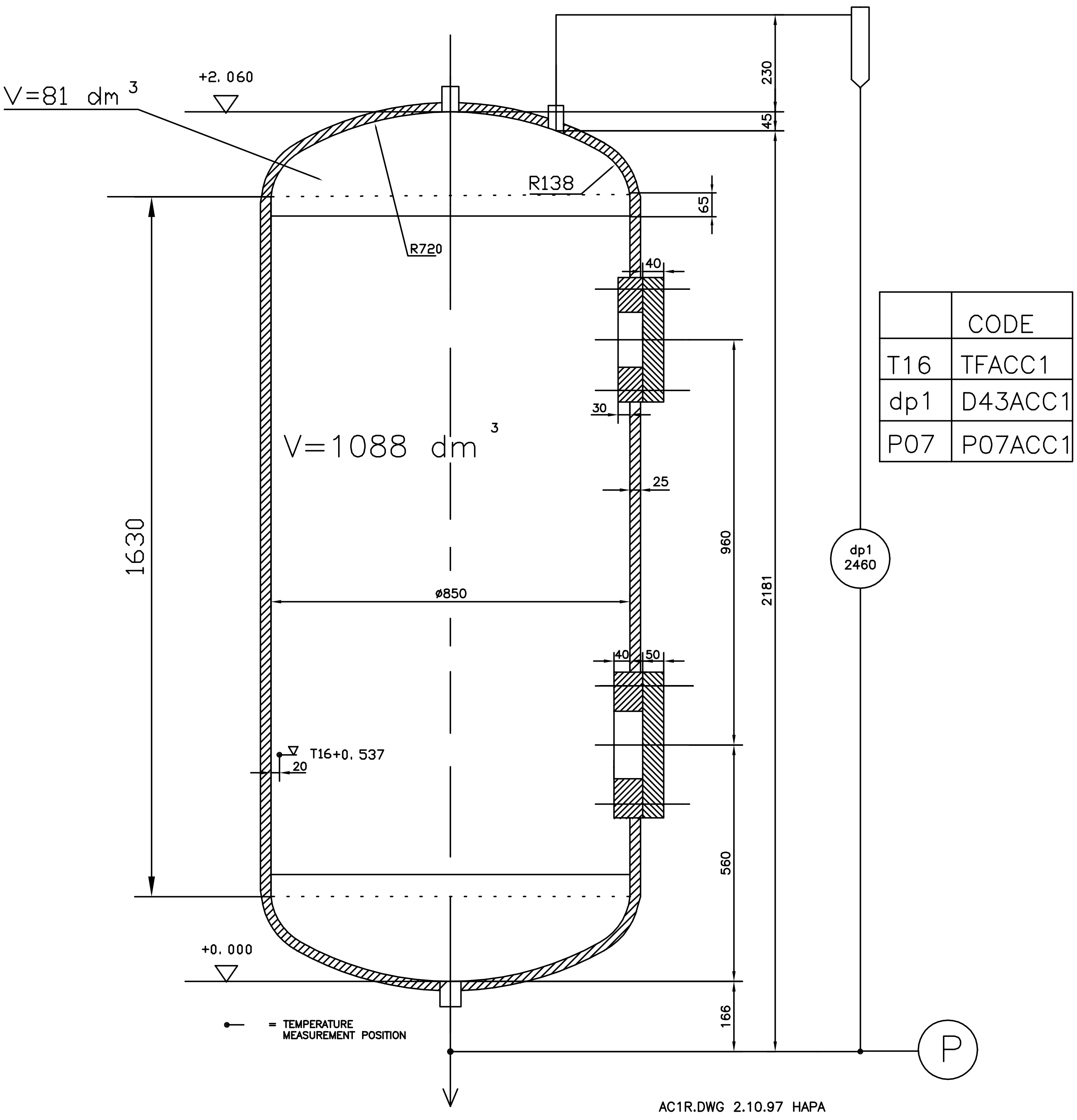
Figure B. 13. Position of the thermocouples measuring structure temperatures in the steam generator 2.



TC	CODE
TC1	TFSG3_SL
TC2	TSSG3_TOP
TC3	TSSG3_BOT

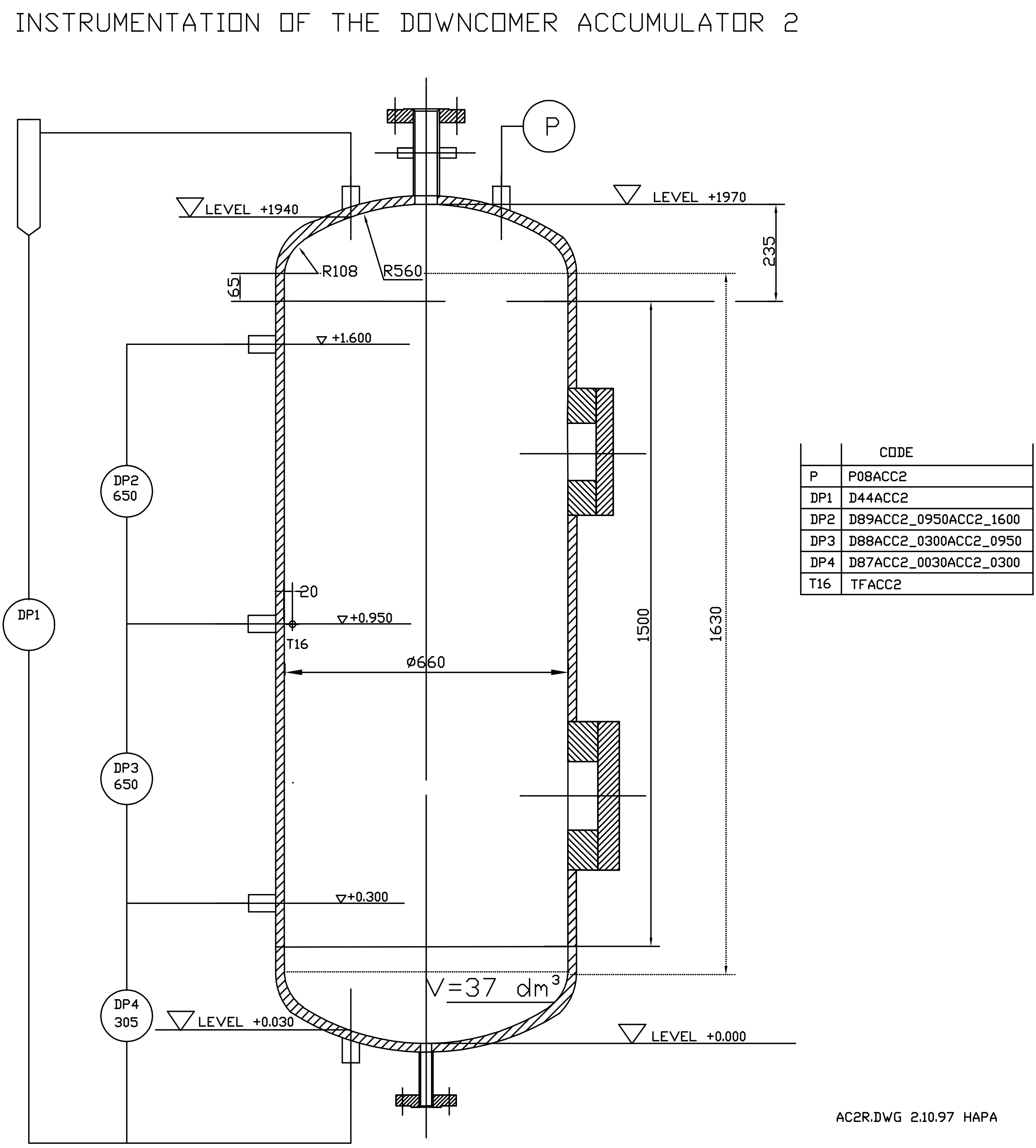
Figure B. 14. Position of the thermocouples measuring structure temperatures in the steam generator 3.

INSTRUMENTATION OF THE UPPER PLENUM ACCUMULATOR 1



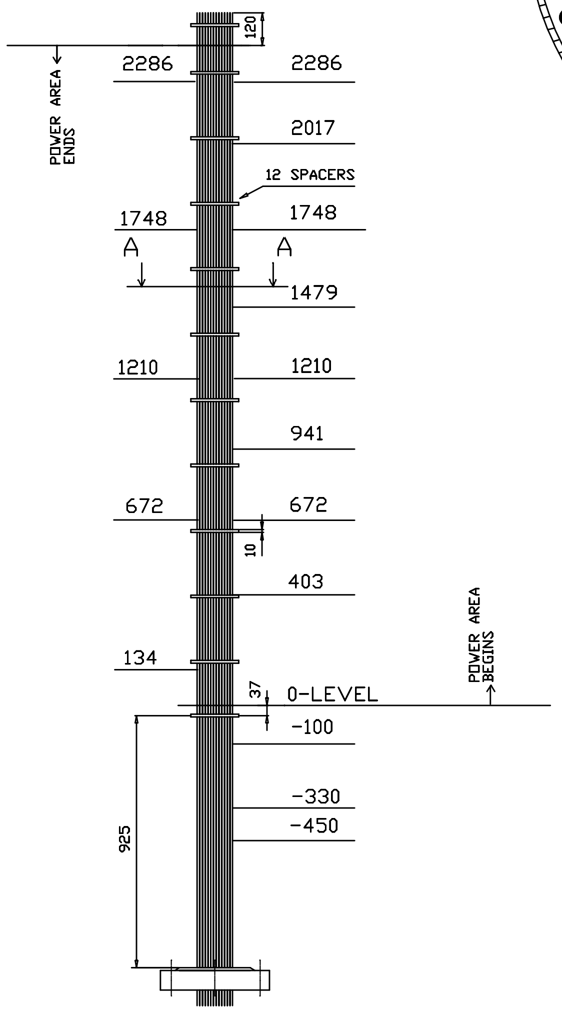
	CODE
T16	TFACC1
dp1	D43ACC1
P07	P07ACC1

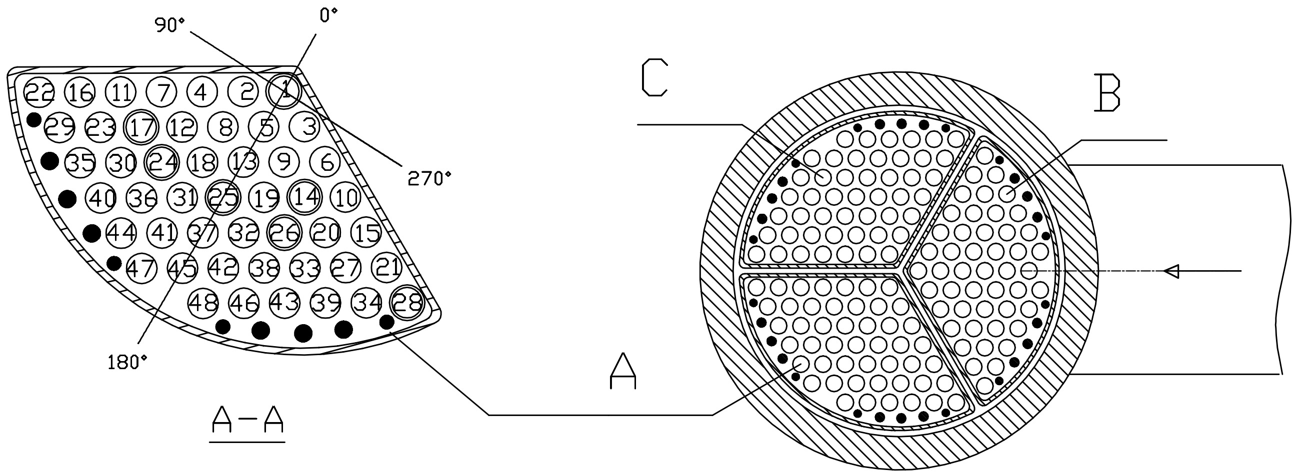
Figure B. 15. Instrumentation of the upper plenum accumulator.



	CODE
P	P08ACC2
DP1	D44ACC2
DP2	D89ACC2_0950ACC2_1600
DP3	D88ACC2_0300ACC2_0950
DP4	D87ACC2_0030ACC2_0300
T16	TFACC2

Figure B. 16. Instrumentation of the downcomer accumulator.





CODE	HORIZONTAL ANGLE
TCAC01H-450	150°
TCAC01H_672	75°
TCAC01H_1210	0°
TCAC01H_1748	285°
TCAC01H_2286	210°
TCAC17H-0100	150°
TCAC17H_0941	75°
TCAC17H_1210	0°
TCAC17H_1479	285°
TCAC17H_2017	210°
TCAC25H-0330	150°
TCAC25H_0672	75°
TCAC25H_1210	0°
TCAC25H_1748	285°
TCAC25H_2286	210°
TCAC26H_0403	150°
TCAC26H_0941	75°
TCAC26H_1210	0°
TCAC26H_1479	285°
TCAC26H_2017	210°
TCAC28H_0134	150°
TCAC28H_0672	75°
TCAC28H_1210	0°
TCAC28H_1748	285°
TCAC28H_2286	210°

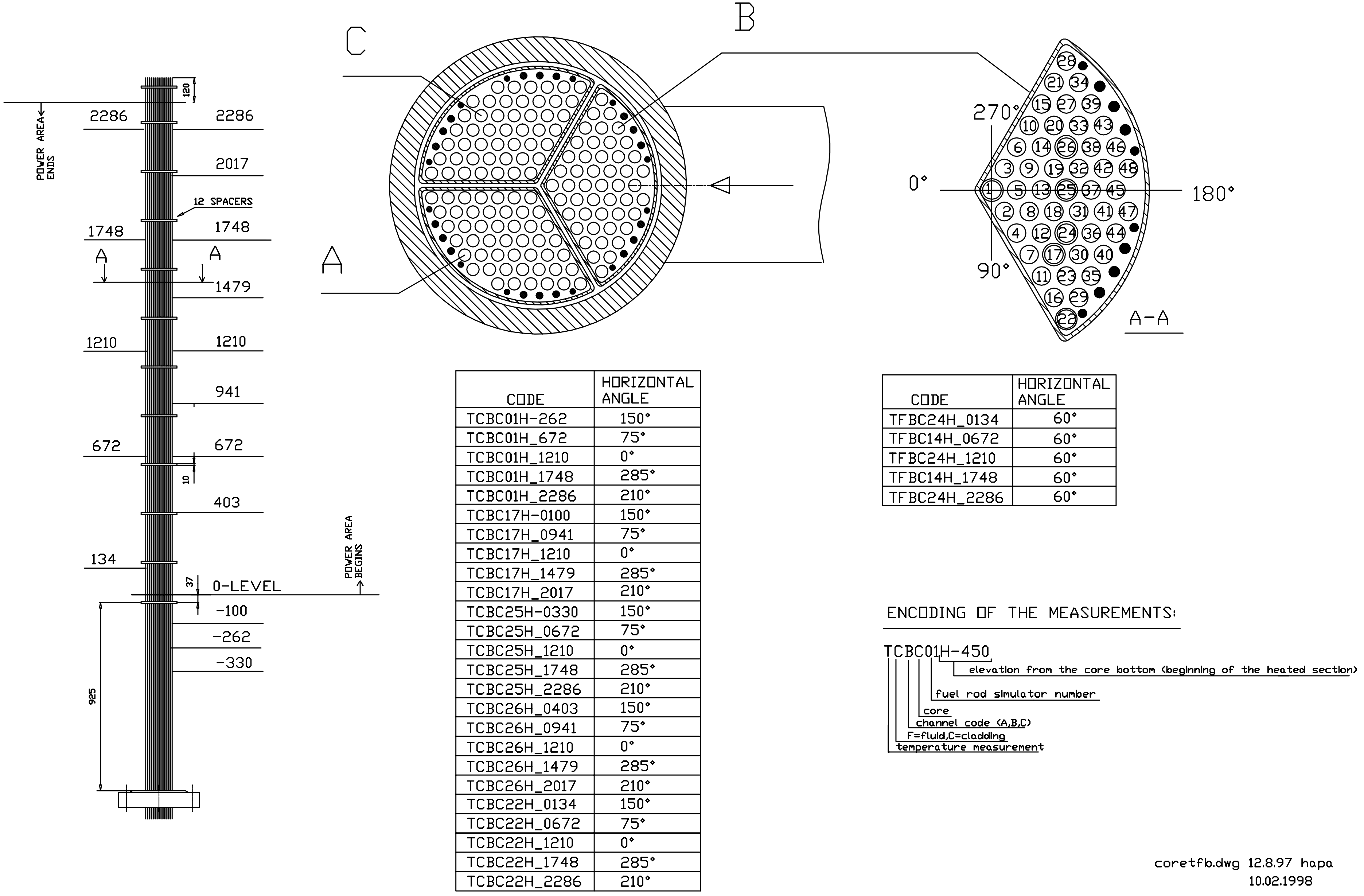
CODE	HORIZONTAL ANGLE
TFAC24H_0134	60°
TFAC14H_0672	60°
TFAC24H_1210	60°
TFAC14H_1748	60°
TFAC24H_2286	60°

ENCODING OF THE MEASUREMENTS:

TCAC01H-450
- elevation from the core bottom (beginning of the heated section)
- fuel rod simulator number
- core
- channel code (A,B,C)
- F=fluid,C=cladding
- temperature measurement

coretfa.dwg 12.8.97 hapa
10.02.1998

Figure B. 17. Temperature measurements in the core. Water and rod surface temperature measurements in the Channel A.



CODE	HORIZONTAL ANGLE
TCBC01H-262	150°
TCBC01H_672	75°
TCBC01H_1210	0°
TCBC01H_1748	285°
TCBC01H_2286	210°
TCBC17H-0100	150°
TCBC17H_0941	75°
TCBC17H_1210	0°
TCBC17H_1479	285°
TCBC17H_2017	210°
TCBC25H-0330	150°
TCBC25H_0672	75°
TCBC25H_1210	0°
TCBC25H_1748	285°
TCBC25H_2286	210°
TCBC26H_0403	150°
TCBC26H_0941	75°
TCBC26H_1210	0°
TCBC26H_1479	285°
TCBC26H_2017	210°
TCBC22H_0134	150°
TCBC22H_0672	75°
TCBC22H_1210	0°
TCBC22H_1748	285°
TCBC22H_2286	210°

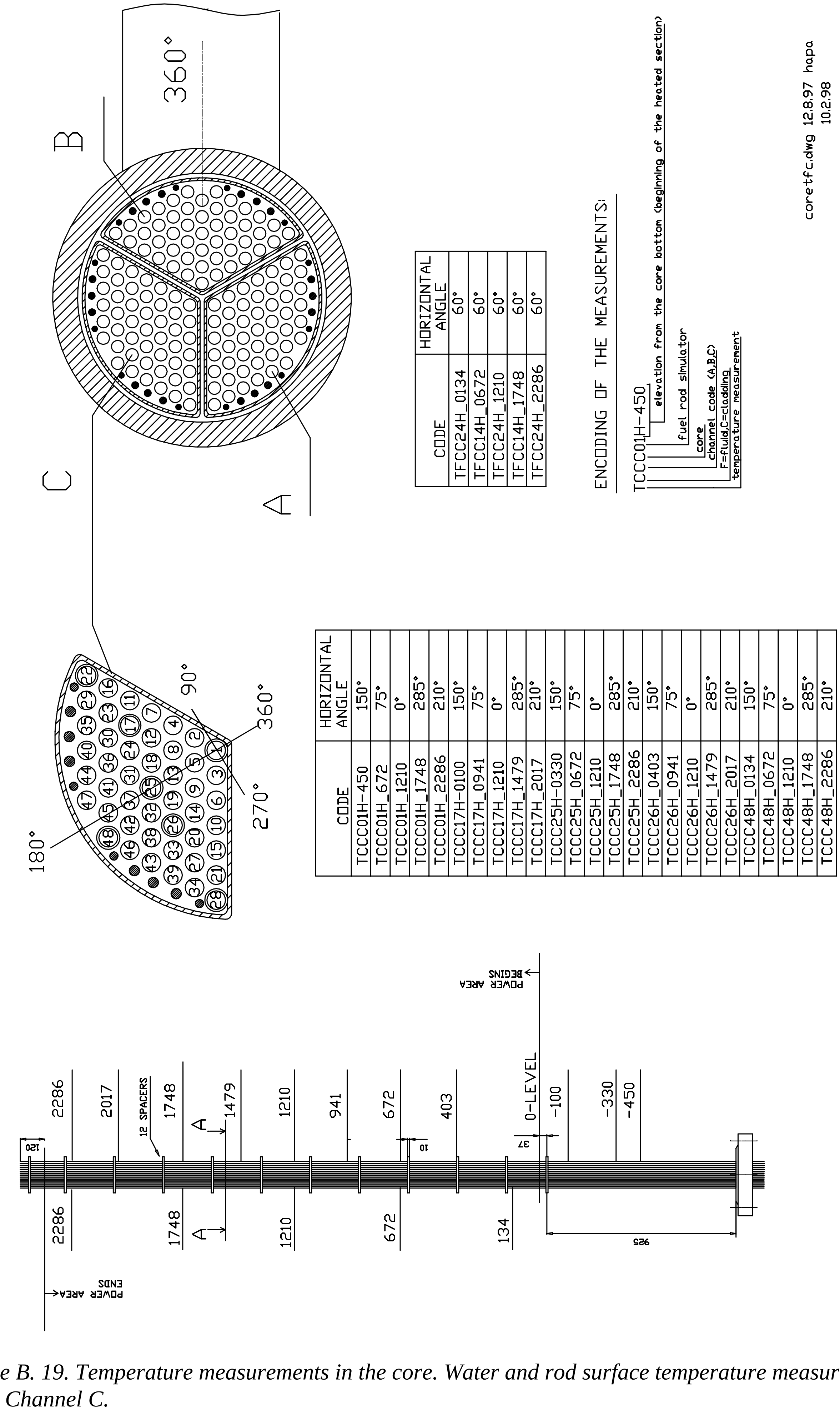
CODE	HORIZONTAL ANGLE
TFBC24H_0134	60°
TFBC14H_0672	60°
TFBC24H_1210	60°
TFBC14H_1748	60°
TFBC24H_2286	60°

ENCODING OF THE MEASUREMENTS:

TCBC01H-450
- elevation from the core bottom (beginning of the heated section)
- fuel rod simulator number
- core
- channel code (A,B,C)
- F=fluid,C=cladding
- temperature measurement

coretfb.dwg 12.8.97 hapa
10.02.1998

Figure B. 18. Temperature measurements in the core. Water and rod surface temperature measurements in the Channel B



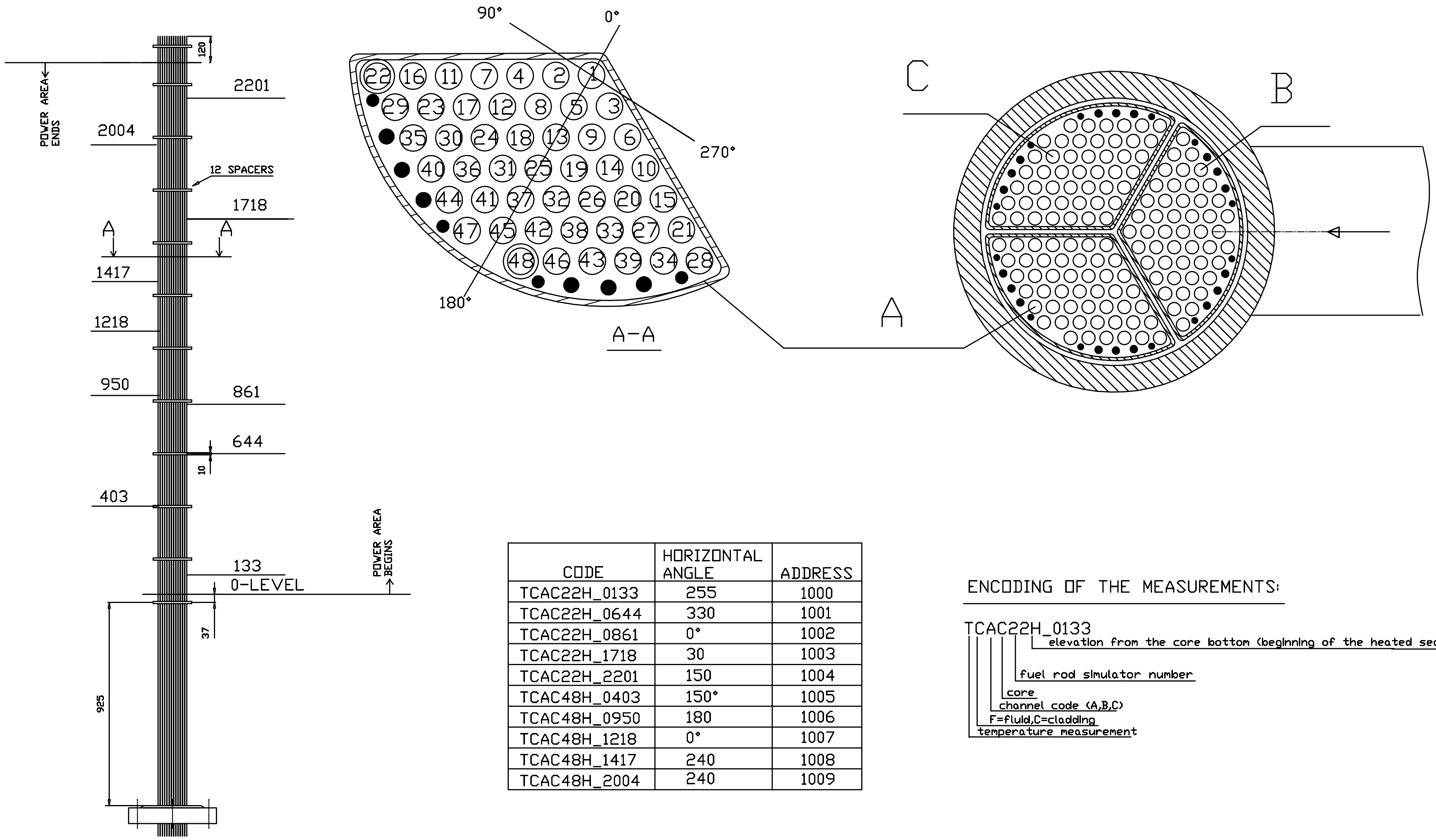
CODE	HORIZONTAL ANGLE
TFCC24H_0134	60°
TFCC14H_0672	60°
TFCC24H_1210	60°
TFCC14H_1748	60°
TFCC24H_2286	60°

CODE	HORIZONTAL ANGLE
TCCC01H-450	150°
TCCC01H_672	75°
TCCC01H_1210	0°
TCCC01H_1748	285°
TCCC01H_2286	210°
TCCC17H-0100	150°
TCCC17H_0941	75°
TCCC17H_1210	0°
TCCC17H_1479	285°
TCCC17H_2017	210°
TCCC25H-0330	150°
TCCC25H_0672	75°
TCCC25H_1210	0°
TCCC25H_1748	285°
TCCC25H_2286	210°
TCCC26H_0403	150°
TCCC26H_0941	75°
TCCC26H_1210	0°
TCCC26H_1479	285°
TCCC26H_2017	210°
TCCC48H_0134	150°
TCCC48H_0672	75°
TCCC48H_1210	0°
TCCC48H_1748	285°
TCCC48H_2286	210°

ENCODING OF THE MEASUREMENTS:

TCCC01H-450
elevation from the core bottom (beginning of the heated section)
fuel rod simulator
core
channel code (A,B,C)
F=fluid,C=cladding
temperature measurement

Figure B. 19. Temperature measurements in the core. Water and rod surface temperature measurements in the Channel C.



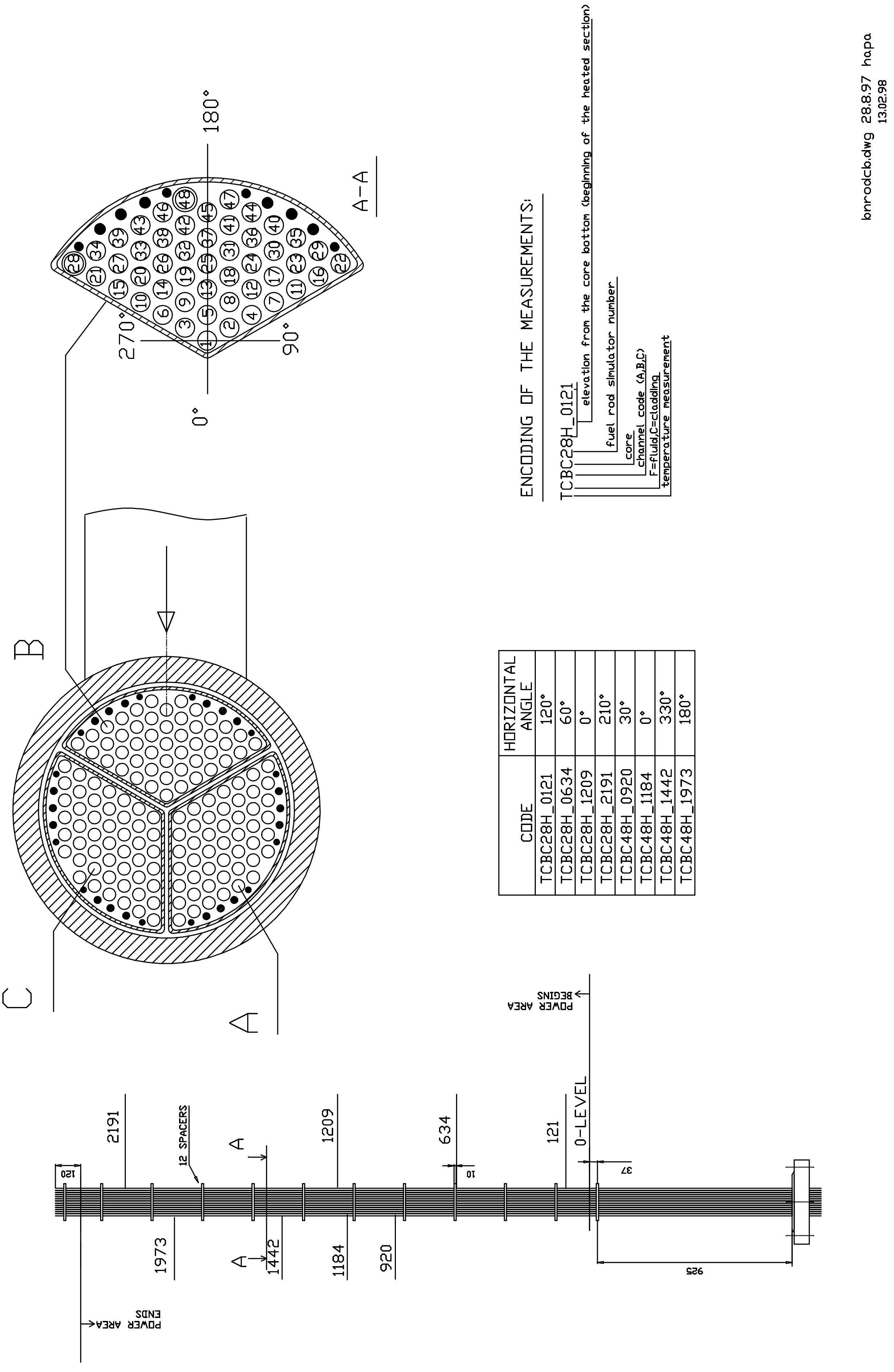
CODE	HORIZONTAL ANGLE	ADDRESS
TCAC22H_0133	255	1000
TCAC22H_0644	330	1001
TCAC22H_0861	0°	1002
TCAC22H_1718	30	1003
TCAC22H_2201	150	1004
TCAC48H_0403	150°	1005
TCAC48H_0950	180	1006
TCAC48H_1218	0°	1007
TCAC48H_1417	240	1008
TCAC48H_2004	240	1009

ENCODING OF THE MEASUREMENTS:

TCAC22H_0133
elevation from the core bottom (beginning of the heated section)
fuel rod simulator number
core
channel code (A,B,C)
F=fluid,C=cladding
temperature measurement

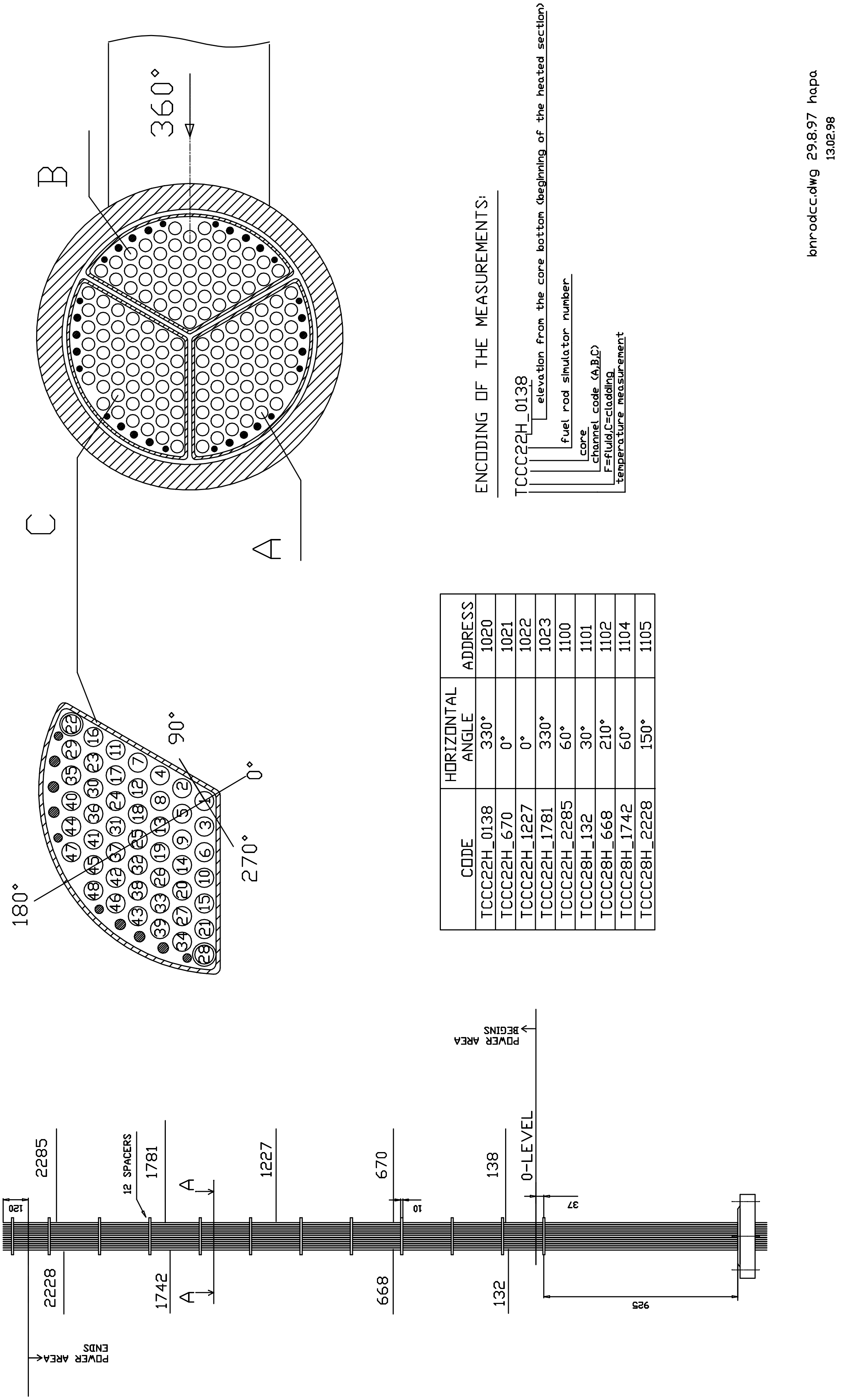
bnrodca.dwg 28.8.97 hapa
10.2.98

Figure B. 20. Temperature measurements inside the cladding in the Channel A.



CODE	HORIZONTAL ANGLE
TCBC28H_0121	120°
TCBC28H_0634	60°
TCBC28H_1209	0°
TCBC28H_2191	210°
TCBC48H_0920	30°
TCBC48H_1184	0°
TCBC48H_1442	330°
TCBC48H_1973	180°

Figure B. 21. Temperature measurements inside the cladding in the Channel B.



ENCODING OF THE MEASUREMENTS:

TCCC22H_0138
- elevation from the core bottom (beginning of the heated section)
- fuel rod simulator number
- core
- channel code (A,B,C)
- F=fluid,C=cladding
- temperature measurement

CODE	HORIZONTAL ANGLE	ADDRESS
TCCC22H_0138	330°	1020
TCCC22H_670	0°	1021
TCCC22H_1227	0°	1022
TCCC22H_1781	330°	1023
TCCC22H_2285	60°	1100
TCCC28H_132	30°	1101
TCCC28H_668	210°	1102
TCCC28H_1742	60°	1104
TCCC28H_2228	150°	1105

Figure B. 22. Temperature measurements inside the cladding in the Channel C.

Table B.1. Flow measurement locations.

Measurement	**Figure**
Downcomer flow	B.8
Loop 1 flow	B.8
Loop 2 flow	B.8
Loop 3 flow	B.8
High pressure injection	A.30
Accumulator injection to downcomer	A.29
Accumulator injection to upper plenum	A.28
Low pressure injection	A.28 and A.29
Steam generator 1 steam flow	A.36
Steam generator 2 steam flow	A.37
Steam generator 3 steam flow	A.38
Steam generator 1 feed water flow	A.39
Steam generator 2 feed water flow	A.40
Steam generator 3 feed water flow	A.41
Drainage flow	B.10
Break flow	A.34 and B.9
Pressurizer spray flow	A.44