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HE-FUS3 Loop: Data Sheets for Code Modelling and Experimental Data for Code Assessment

Abstract

This report contains a detailed description of the HE-FUS 3 helium loop and of the experimental tests performed to assess its performances in steady state and transient conditions. Moreover, all the experimental data acquired during the tests are enclosed to this report.
The report, which is issued within the framework of the SP Safety (WP1) of RAPHAEL for the organization of a benchmark exercise aimed at the validation of the system transient analysis codes for VHTRs, has the purpose to provide the benchmark participants with the needed information for the HE-FUS 3 loop modeling, as well as to offer the data for code-to-experiment comparisons.
In particular this revision 1 of the report would try to collect and answer some questions arisen within the benchmark participants during their earlier attempts to develop the loop model by providing an errata corrige and some integrative information.

Revisions

Rev.	Date	Short description	Author	WP Leader	SP Leader	Coordinator
1	10/04/2008	Data of the HE-FUS3 loop for benchmark exerciseData of the HE-FUS3 loop for benchmark exercise	M.Polidori P. Meloni (ENEA)	**Walter Van Hove** SUEZ-TRACTEBEL	**Carmen Angulo** SUEZ-TRACTEBEL	**Edgar Bogusch** AREVA NP

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HE-FUS3 Loop: Data Sheets for Code Modelling and Experimental Data for Code Assessment

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Sommario

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Errata Corrige

Page 7, §2.2.1, Tab. 2 – The diameter of Line E is 4” instead of 5” and the maximum temperature of Line G is 420°C instead of 530°C.

Page 9, §2.3.1, Tab. 3 – The overall heat transfer surface is 5.09 m^2 instead of 4.52 m^2, the diaphragm pitch is in mm not kW, added the diaphragm diameter and thickness.

Page 9, §2.3.2, Tab. 4 – The vessel inside diameter is 800 mm instead of 880 mm, the vessel total height is 6638.2 mm instead of 7250 mm.

Page 10, §2.3.3, Tab. 5 – The overall heat transfer surface is about 27 m^2 instead of 27.7 m^2, the vessel active length is 4920 mm instead of 5000 mm, added diaphragm diameter and thickness and the tubes support plate thickness. Changed 3/8” tube outside diameter and the thickness of ½”, 3/8” ones.

Page 13, §2.3.7 – Added the valve flow coefficient dimension.

Page 19, §2.6.2, Tab. 13 – The rock wool conductivity is 0.045 instead of 0.04 W/m/K.

Figures – The overall figure numbing is revised.

Added figures:

- Fig. 6 – Electrical Heater Active Rods and Diaphragms Scheme
- Fig. 11 – 7-pin Test Section – Upper Part
- Fig. 14 – Test section Grid
- Fig. 15 – Particular of the Test Section Heating Rod with the position of the thermocouples

Figure 7 (Fig. 6 in Rev0) – Changed the Section A-A and added a particular that show the correct layout and dimension of the economizer diaphragms and tubes support plate.

Figure 11/13 – More Test Section dimensional information.

Figure 14 – Test Section Grid and Rod Bundle.

Figure 15 – Particular of the Test Section Heating Rod with the position of the thermocouples

Appendix A, *Line B* – Insulator thickness 100 mm instead of 160 mm.
Line C+P – Insulator thickness 60 mm instead of 160 mm.
Line D – Insulator thickness 60 mm instead of 160 mm.
Line F – Maximum temperature 530 °C instead of 457/494 °C.
Line G – Maximum temperature 420 °C instead of 530 °C.
Line H – Insulator thickness 100 mm instead of 160 mm.
Line H – Maximum temperature 240 °C instead of 140 °C.
Line I – Insulator thickness 100 mm instead of 160 mm.
Line I – Maximum temperature 140 °C instead of 530/335 °C.
Line L – Maximum temperature 420 °C everywhere.

1. Introduction

HE-FUS 3 is a helium facility that was designed and constructed at ENEA CR Brasimone in mid 90's for the thermal-mechanical testing of prototypical module assemblies of the DEMO reactor. At the end of the nineties a testing program, including steady state, cycling and transient tests was carried out on the facility in order to qualify its capability to perform experimental test campaigns both in normal and off-normal conditions.

Within the frame of the SP Safety (WP1) of the RAPHAEL Integrated Project, ENEA has offered these experimental data for the organization of a benchmark exercise aimed at the validation of the system transient analysis codes for Very High Temperature Reactors (VHTR). Although the loop characteristics are not prototypical of a Very High Temperature Reactor, the HE-FUS3 tests are useful to assess the capability of the codes to deal with a helium loop implementing a wide range of components such as compressor, pressurizer, pipes, diffusers, valves, heaters , heat exchangers and an active test section, and to model both steady-state and transient flows.

The experimental data make available for the benchmark, which are described in detail and completely enclosed to this report, are related to 10 steady state tests for the thermal-hydraulic characterization of the loop, 2 LOFA transients and a test campaign for the characterization of the helium compressor. The report also provides a detailed description of the HE-FUS 3 loop in order to support the participants in the benchmark for the loop modeling in their own codes

2. Facility Description for Code Modeling

2.1 General description

Within the frame of the European Fusion Technology Program, ENEA in 1993 obtained an economic support from EU for the construction of a helium facility, called HE-FUS3 [1]. The facility, which had been planned for the thermal mechanical testing of prototypical module assemblies for the DEMO reactor, was chosen for the selected European Helium Cooled Pebble Bed (HCPB) Blanket design to be tested on ITER reactor. The facility, also defined as the European Helium Cooled Blanket Test Facility, is located at the ENEA Brasimone Laboratories in Italy.

Its eight loop configuration [2], shown in Fig. 1, supplies the helium flowrate to an experimental Test Section, where the mock-up of the HCPB Blanket can be tested. The purpose of the eight-shaped closed loop arrangement is to separate two zones at different temperatures, the cold one including the compressor and the hot one the Test Section. An economizer, placed at the crossover point, recovers the gas enthalpy before recirculating the helium through the compressor. Thereby it has been possible to reduce both the need for external power to get the required temperature at the Test Section inlet and the cooler size to reduce the compressor inlet temperature to the level of its maximum continuative operating temperature. The main performances expected for the facility are reported in Tab. 1.

Parameter		Design Value
Max Pressure	MPa	10.5
Max Temperature	°C	530
Inlet Compressor Max Temperature	°C	100
Compressor Helium Flow Rate	kg/s	0.5-0.35
Max Compressor Speed	rpm	18000
Max Compressor Head	MPa	0.5
Compressor Electrical Power	kVA	136
Heaters Electrical Power	kW	210
Economizer Thermal Power	kW	564
Air-Cooler Thermal Power	kW	280
Helium Tank Capacity	m^3	3
Test Section Electrical Power	kW	350

Tab. 1 – HE-FUS3 Main Performances

The loop components relevant for the code modeling are (Fig. 2):

- Main Piping in AISI 316, 4”-5” (sch. 80);
- regenerative compressor with pneumostatic helium shaft supporting system;
- three modules of a flanged immersion rod bundle electrical heater;
- tube-shell helium-helium economizer;

- air cooler with finned tubes;
- expansion tank ;
- two mixers to make uniform the temperatures of the main and by-pass flowrate in cold and hot zone;
- three global valves for the regulation;
- 7-pin bundle electrically heated Test Section.

Operation and control of the system are guaranteed through several auxiliary systems which are not relevant for the modeling: passive safety system, filling and pressure control system, vacuum preservation system, gas analysis and facility control system. The loop is also provided with on/off valves for the control.

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2.2 Loop Piping

2.2.1 Piping Layout

The piping overall length is about 80 m, with an integral volume of 4m^3 including 3m^3 of the expansion tank and a weight of about 15 ton. The diameters of the main pipes were preliminary fixed at 4” (sch. 80) for the cold zone et 5” (sch.80) for the hot zone in order to limit at 20 m/s the helium velocity in the loop. The piping material is stainless steel AISI 316. Contact temperatures are reduced below 50 °C by means of heat insulator with special asbestos-free material, 60 to160 mm in thickness.

The main characteristics of the different lines constituting the piping are reported in Tab. 2. A 3D sketch of the piping layout reported in Fig. 3 allows visualizing the relative position of the lines.

Line	Description	Diameter (inch)	Wall Thickness	Insulation Thickness (mm)	Max Temp (°C)
A	From TS to Economizer	5”	Sch. 80	160	520
B	From Economizer to Air-cooler	4”	“	100	240
C	From Air-cooler to Compressor	4”	“	60	100
D	From Tank to Cold By-pass T	4”	“	60	140
E	From Economizer to Heater 3	4”	“	160	420
F	From Heater 3 to Heater 1	5”	“	160	530
G	From Heater 1 to TS	5”	“	160	420
H	From Cold By-pass T to Economizer and Cold By-pass	4”	“	100	240
I	By-pass TS	4”	“	100	140
L	By-pass Heater 3-2	4”	“	160	420
P	From Compressor to Tank	1”$^1/_2$	“	60	100

Tab. 2 – HE-FUS3 Lines Main Characteristics

2.2.1 Piping runs and volumes

In order to support the description of the facility in the different T/H codes, in attachment A is reported the noding of the loop used for the thermo-mechanical analysis. The different lines refer to the piping layout in Fig. 3. Both pipes and components are included. For each node the following information are listed:

- The type of hydraulic element used (Straight Element, Curve Element, Bending Center, T-Shape Element)
- 3D Cartesian coordinates
- Node number
- Pipe outside diameter
- Pipe thickness
- Insulator thickness

A schematic representation of the pipe runs is also reported for each line.

2.3 Major Components

Quite detailed information is provided for each of the major component listed in sub. 2.1. This information provided with tables is mainly related to the geometrical data and thermo-hydraulic characteristics because it is addressed to T/H code modeling. Some reproductions of the as-built designs are also reported, where available, in order to provide further geometrical details.

2.3.1 Electrical Heaters E219-1/2/3

The electrical heater is subdivided in three identical modules each of them constituted by a bundle of 30 U-bent active rods immersed in a vertical cylindrical pressure vessel. The rods are made of Ni-Cr spiral wire electrical resistors insulated by MgO compressed powders in AISI 316 cladding to reach the nominal diameter. The pin cold legs are welded to an upper plate, flanged to the vessel, by interposing tubes for the welding accommodation. The rod bundle is provided by diaphragm plates for the heat transfer improvement.

The nominal power supply is 210 kW (70 kW per module). The electrical supply, control and monitoring is independent for each module. The hydraulic configuration of these three modules can be changed by means of manual valves HV 250, HV 251, HV 252 (Fig.1):

- a module serial configuration to supply a Test Section with the whole power
- use of recycling lines to supply a TS with 1/3 (1 module) or 2/3 (the other two modules) of power

The electrical supply is 380 V three-phase at 50 Hz. In the last two modules (E219-1/2) the electrical power is controlled by an SCR controller using as a signal the helium temperature at the outlet of each vessel. Instead the first module is manually actuated with on-off regulation. The main design parameters are reported in Tab. 3. Further geometrical details can find in the as-built drawings from Figs. 4 to 6.

Parameter		Design Value
Nominal Helium Inlet Temperature	°C	420
Nominal Helium Outlet Temperature	°C	525
Design Helium Temperature	°C	530
Design Cladding Temperature	°C	560
Design Helium Pressure	MPa	10.5
Design Helium Flowrate	kg/s	0.35
Electrical Power	kW	70
Overall Heat Transfer Surface	m^2	5.09
Overall Thermal Conductance	W/m^2K	809
Design Pressure Drop	Pa	1011
Rod Diameter	mm	15
Nr U-bent Rods		30
Rod Heated Length	mm	1800
Rod Cold Leg Length	mm	300
Nr of Diaphragm Plates		12
Diaphragm Pitch	mm	145
Vessel Internal Diameter	mm	270
Diaphragm Diameter	mm	268
Diaphragm Thickness	mm	3

Tab. 3 – Heater Single Module Main Design Parameters

2.3.2 Expansion vessel

An expansion vessel is located at the compressor outlet, in order to dump pressure and flow fluctuations during loop operation. The vessel is an 8 m high vertical cylinder with a volumetric capacity of 3 m^3. It is provided with several connections to the loop: two for inlet/outlet main flow, one to the outlet purification circuit, one from the filling and pressurizing line, one for the controlled flow discharge to the environment, the last one for the passive safety rupture disk. The main design parameters are reported in Tab. 4.

Parameter		Design Value
Max Design Pressure	MPa	10.5
Max Design Temperature	°C	160
Maximum Design Flowrate	kg/s	0.35
Vessel Capacity	m^3	3
Vessel Outside Diameter	mm	890
Vessel Inside Diameter	mm	800
Vessel Total Height	mm	6638.2(*)

(*) Because of the uncertainties in the real vessel capacity consider this value as reference for the benchmark.

Tab.4 – Expansion Vessel Main Design Parameters

2.3.3 Economizer E214

This component is a high efficiency (>79%), tube shell geometry, helium/helium heat exchanger with vertical axis. The hot helium coming from the Test Section flows through a bundle of straight tubes that are welded between two tube plates and immersed in a cylindrical pressure vessel. The cold helium counter-flows in the shell zone where a series of diaphragm sheets allow improving the global thermal exchange. The tube bundle is floating respect to the shell by a tube-below compensation system. The pressure vessel is cylindrical and is provided with four welded pipes for the loop connections.
The main design parameters are reported in Tab. 5. Further geometrical details can find in the as-built drawing in Fig. 7.

Parameter		Design Value
Cold Helium Inlet Temperature	°C	130
Cold Helium Outlet Temperature	°C	440
Hot Helium Inlet Temperature	°C	530
Hot Helium Outlet Temperature	°C	220
Maximum Design Pressure	MPa	10,5
Cold Side Pressure Drop	Pa	1660
Hot Side Pressure Drop	Pa	212
Overall Heat Transfer Surface	m^2	27.0
Overall Thermal Conductance	W/m^2K	258
½” Tube Multiplicity		73
½” Tube Outside Diameter	mm	21.3
½” Tube Thickness	mm	1.65
3/8” Tube Multiplicity		12
3/8” Tube Outside Diameter	mm	17.2
3/8” Tube Thickness	mm	1.65
Vessel Active Length	mm	4920
Diaphragm multiplicity		18
Diaphragm Thickness	mm	3
Diaphragm Diameter	mm	266
Tubes Support Plate Thickness	mm	23

Tab. 5 – Economizer Main Design Parameters

2.3.4 Compressor K200

The prototypical compressor developed by RTM company has the electrical motor completely immersed in the helium flow. The regenerative impeller has a shaft bearing system based on pneumostatic helium control of the support clearances, without using any lubricant. In order to control the diametric bearing clearance values in the range of 40 µm, a helium flow is injected through calibrated nozzles in the gaps between the shaft and the bearing at the required pressure. The electrical motor is provided with an inverter driving system capable of controlling the frequency in the range 5-300 Hz, driving the rotor speed at 300-18000 rpm.

A special ancillary circuit provides for helium pressure injection flow in the pneumostatic ring and for the flow necessary to cool the electrical motor internally. Both these helium auxiliary

flows are derived from the compressor outlet at 140 °C (nominal conditions), cooled at room temperature by a two stage water heat exchanger, and then reintroduced at the compressor inlet. More exhaustive information about the characteristic of this derivative flow will be given in chapter 3.
The maximum compressor inlet temperature is fixed at 100 °C in order to control and maintain the nominal bearing clearances at acceptable value.
The main design parameters are reported in Tab. 6. Further geometrical details can find in the as-built drawing in Fig. 8.

Parameter		Design Value
Maximum Design Helium Temperature	°C	160
Maximum Design Helium Pressure	MPa	10.5
Design Flowrate	kg/s	0.05 -0.35
Vessel Inside Diameter	mm	350
Vessel Sheet Thickness	mm	45
Vessel Total High	mm	700
Inlet Design Pressure	MPa	6.0
Outlet Design Pressure	MPa	6.5
Maximum Design Flowrate	kg/s	0,35
Maximum Design Inlet Temperature	°C	100
Mechanical Power	kW	90
Electrical Motor Power	kVA	110
Maximum Inverter Current	A	210
Maximum Inverter Frequency	Hz	400
Impeller Maximum Speed	rpm	18000
Impeller Diameter	mm	230
Motor Shaft Diameter	mm	65
Rotor Diameter	mm	130
Diametrical rotor Clearances	mm	1
Bearing clearances	µm	40

Tab. 6 – Compressor Main Design Parameters

2.3.5 Air Cooler

This component is located at the compressor inlet in order to reduce the corresponding helium temperature below the maximum design value (100°C). It is a counter flow helium-air heat exchanger, where the helium flows inside the tube bundle whilst the air flows outside the external surface of the tubes. A helicoidal stainless steel sheet is welded on the outside surface of the tube to increase the overall thermal conductance. The bundle arrangement is as compact as possible with the finned tubes in a triangular array and welded to two cylindrical distributors.

The air flow is pumped from a fan that is controlled by an SCR using as a signal the helium temperature at the air cooler outlet.

The main design parameters are reported in Tab. 7. Further geometrical details can find in the as-built drawing in Fig. 9.

Parameter		Design Value
Nominal Helium Inlet Temperature	°C	240
Nominal Helium Outlet Temperature	°C	100
Design Helium Temperature	°C	240
Design Helium Pressure	MPa	10.5
Design Helium flow rate	kg/s	0.35
Design Helium Pressure Drop	Pa	4000
Nominal Air Inlet Temperature	°C	30
Nominal Air Outlet Temperature	°C	70
Design Air pressure	MPa	1
Design Air Flowrate	kg/s	6.1
Design Air Pressure Drop	Pa	1200
Nominal Thermal Power	kW	280
Overall Heat Transfer Surface	m^2	165
Overall Thermal Conductance	W/m^2 K	400
Nr of ½” Finned Tubes		22
Finned Tube Outside Diameter	mm	21.3
Fin thickness	mm	0.4
Fin pitch	mm	3.4
Fan Electrical Power	kW	15
Fan Speed	rpm	50-3000

Tab.7 – Air Cooler Main Design Parameters

2.3.6 7-Pin Test Section

The original dummy Test Section, already used for the acceptance test of the facility, was replaced in 1997 this new actively heated test section. This new TS consists of a 7-pin bundle 50 kW of nominal power each, contained in a pipe, which is inserted from the flanged bottom end in the tubular pressure vessel of the dummy mock-up. The bundle is appropriately equipped with thermocouples in order to monitor the transient temperature field during the accident simulations planned in the facility.

The heated pins are made of Ni-Cr spiral wires insulated by MgO powders with a Ni-Fe-Cr alloy cladding. The helium enters in the annular space between the tubular pressure vessel and the TS pipe, flows down to the TS inlet then flow up within the pipe around the pins.

The main design parameters are reported in Tab. 8. Further geometrical details can find in Figs. 10 to 15.

Parameter		Design Value
Nominal Helium Inlet Temperature	°C	420
Nominal Helium Outlet Temperature	°C	525
Design Pressure	MPa	20
Effective Power per Rod	kW	40
Max Cladding Temperature	°C	950
Max Heat Flux	W/cm^2	110.6
Heated Length	mm	2000
Rod Diameter	mm	9.5
Clad thickness	mm	1
TS Pipe		1 ½" (sch.10)
Mock-up Tubular Vessel		3" (sch. 80)

Tab.8 – 7-pin TS Main Design Parameters

2.3.7 Valves

The loop is provided with a series of valves for regulation, flow configuration and safety control (Fig. 1). The regulation valves for the main flow FV 213, FV 234, FV 235 and FV 10 are globe valves with metallic bellows tightness, pneumatically actuated and with a steam opening indicator system. For the flow configuration and safety control there are also 5 on/off valves with a manual or pneumatic actuation and open/close indicator system that are not relevant for the loop simulation. The data sheets of regulation and on/off valves are listed in Tab. 9.

A technical communication related to the regulation valve FV 213, FV 234 and FV 235 reports a value of 27 for the Flow Coefficient (Cv) at 100% opening, moreover it states that 10% opening is the minimal value for their regulation. The characteristic of the regulation valves (Flow Coefficient vs. Stroke) reported in Fig. 16 have been drawn from the same communication.

For a correct use of the information above it is worth to remind that the following correlation is used for valve sizing at sub critical gas flow conditions:

$$W = 355 Cv \sqrt{\frac{G \Delta P (P_1 + P_2)}{T}}$$

W = Weight flow rate [Kg/h]

Cv = Valve flow coefficient [USgpm of water with ΔP=1 psi]

G = Gas specific gravity (air=1)

$$G = \frac{Helium\,Molecular\,Weight}{Air\,Molecular\,Weight} = \frac{4.0026\ [g/mol]}{28.96443[g/mol]} = 0.13819$$

ΔP = Valve pressure drop [bar]

P_1 = Valve upstream pressure [bar abs]

P_2 = Valve downstream pressure [bar abs]

T = Upstream absolute gas temperature [K]

Nr Valve	Builder	LINE	Ø	operation
FV 213	NUOVO PIGNONE	D	1 ½”	Regulated
FV 234	“	I	1 ½”	“
FV 235	“	H	1 ½”	“
FV 10	“	C	1 ½”	“
HV 2	“	P	1 ½”	ON/OFF
HV 250	“	E	3”	“
HV 252	“	F	4”	“
FV 230	ABB	G	4”	“
FV 231	ABB	A	4”	“

Tab.9 –Main Valves Data Sheet

2.3.8 Mixers

Two mixers are used in the loop for the temperature mixing between different main and by-pass flow rates. They are constituted by two annular tubes, with the internal one drilled and provided with sliding pads, assembled in order to avoid the relative temperature stress accumulation on the welding zones. These mixers are welded to the pipelines.

The cold mixer is located between the by-pass line and the economizer outlet to guarantee the thermal mixing between the hotter branch, coming from the economizer outlet, and the colder one, coming from the cold by-pass line.

The hot mixer is located between the TS by-pass line and the last heaters outlet to guarantee the thermal mixing between the hotter branch, coming from the last heater outlet, and the colder one, coming from the hot by-pass line.

The main design parameters for the two mixers are reported in Tab. 10. For geometrical details one can refer to the as-built drawing in Fig. 17.

Parameter		Design Value
Cold Mixer		
Nominal Cold Helium Temperature	°C	130
Nominal Hot Helium Temperature	°C	220
Design Helium Pressure	MPa	10.5
Design Helium Flowrate	kg/s	0.35
Hot Mixer		
Nominal Cold Helium Temperature	°C	130
Nominal Hot Helium Temperature	°C	530
Design Helium Pressure	MPa	10.5
Design Helium Flowrate	kg/s	0.35

Tab.10 – Mixers Main Design Parameters

2.4 Instrumentations and control chains

The instrumentation map of the facility is shown in Fig. 18. In the following paragraphs is given a description of the instrumentation installed in the main loop [2].

2.4.1 Flow measurements

The two flow controllers in the main line, FT 212 and FT 228, are based on the volumetric flow measurements with 2 Vortex flow meters of 2”. In order to compute the mass flowrate, the volumetric flow signal is integrated with measurements of the temperature and pressure upstream of the flow meter location.

The flow transmitters give a correct measurement at a flow rate less than 5% of the measuring range. The measurement elements of the transmitter are located at least 10 diameters upstream and 5 downstream of uninterrupted pipe length for better measurement accuracy. Thus, the accuracy results better than 0.5% of the true value for a flow rate above 10% of its range.

2.4.2 Temperature measurements

The temperature sensors are thermocouples ANSI K (NiCr/NiAl) for temperature values higher than 200 °C and Platinum Thermoresistances ANSI PT 100 for lower temperature values. The accuracy is better than 0.5% on the measuring point.

The thermocouple wire insulator is MgO, and the cladding sheath is ANSI 316. The diameter of the outer thermocouple sheath is 3 mm. All the measurement points are provided with AISI 316 thermo wells welded to the pipes and with interchangeable fitting connections.

Only the thermocouples TT 222, TT 223, TT 232, TT 244 and TT 242, used for the regulation chains, are directly exposed to the fluid in order to monitor as rapidly as possible the real helium temperature. A response time close to 1 second can be considered for the thermocouples not directly exposed to the fluid. The temperature signals are locally compensated and linearized by transmitters.

2.4.3 Pressure measurements

The pressure measurements are based on diaphragm cell transmitters. Only one manometer, mounted on the expansion tank, is a Bourdon type without signal transmission.

All the pressure transmitters are provided with interception manifolds (5-way for differential transmitter). The accuracy of the gauges is better than 0.5% on the measuring point.

2.4.4 Control chains

The operator can manage, in local manual or automatic remote modes, the following six measurements and control:

- TT 232 – Test Section inlet helium temperature with feedback control on the hot by-pass valve FV 235;
- TTT 223 – Heater E 219/1 outlet helium temperature with feedback control on the relative SCR heater supply control;
- TTT 222 – Heater E 219/2 outlet helium temperature with feedback control on the relative SCR heater supply control;
- FT 212 – Compressor helium flowrate with feedback control on the relative inverter driving motor control;
- FT 228 – TS outlet helium flowrate with feedback control on the main control valve FV 213;
- TT 242 – Air cooler E 240 outlet helium temperature with feedback control on the fan inverter driving motor control.

Moreover, it is foreseen a protection system for the emergency shutdown of the facility, which is independent from the control system, based on the following signals:

- TT 236 - Heater E 219/1 outlet helium temperature;
- TT 297 - Heater E 219/2 outlet helium temperature;
- TT 241 - Air cooler E 240 outlet helium temperature.

2.5 Heat Losses and Pressure Drops

2.5.1 Heat Losses

A characterization of the heat losses along the loop based on experimental data is not available. The thickness of insulation material (rock wool) that was calculated to reduce contact temperatures below 50 °C, resulted in 160 mm in the hot zone of the loop and 60 mm in the cold one.

The heat losses distribution resulting by the design calculations [3] at the loop nominal conditions is reported in Tab. 11. According to these calculations the nominal heat losses are well lower than 20 kW that was the design performance. This evaluation seems extremely optimistic for two reasons:

- The conductivity of the rock wool used in the calculation (0.045 W/m°C) is typical for ambient temperature application, whereas its average temperature in the hot zone of the facility should be higher than 300°C. The conductivity increases rapidly with the temperature (e.g. 0.08 W/m°C at 300°C) and this fact should be taken into account in the new calculations (Fig.19).

- The thermal bridges related to mechanical junctions, instrument and electrical connection penetrations are not considered in the calculations.

These considerations suggest that the design calculations considerably under estimated the thermal losses in the design calculation. Further considerations on this subject will be made in next chapter.

Line/Component	Inlet Temperature (°C)	Linear Heat Losses (W/m)	Total Heat Losses (W)
From Compressor to Tank	140	43.69	27,09
Tank	139.98	199.72	882,77
From Tank to Economizer	139.49	43.51	500,39
Economizer	139.21	160,57	791,64
From Economizer to Heater 3	420	142.69	606,45
Heater 219/3	419.66	250.95	552,09
From Heater 3 to Heater 2	457.99	174.54	78,54
Heater 219/2	457.94	275.56	606,25
From Heater 2 to Heater 1	496.24	189.79	465,01
Heater 219/1	496.01	300.16	660,36
From Heater 1 to TS	534.34	204.97	1014,62
From TS to Economizer	533.78	204.75	286,65
From Economizer to Air-cooler	240	59,99	277,26
From Air-cooler to Compressor	100	19,35	34,84
Total			6783,96

Tab. 11 – HE-FUS3 Heat Losses Calculated at Nominal Conditions

2.5.2 Pressure drops

The directed measurements of the pressure drops are available only on two parts of the loop respectively including compressor and Test Section. Although they are the most relevant components for the pressure drops, that is insufficient for a complete characterization of the loop. Moreover, the pressure signals are not sufficiently accurate to be used to this purpose. In Tab. 12 is reported a numerical evaluation of the relevant pressure drops along the loop. It is worth drawing attention on the large pressure drops calculated through the valves FV-213 and FV10.

Component	Helium Velocity (m/s)	k	Pressure Drop (mbar)	Stroke %
Valve FV213 1 ½”	8.37	282.43	650	58.5
Valve HV252 3”	4.25	3.85	1.5	100
Valve FV 230 4”	4.58	3.81	2	100
Test Section Annular Part	15.32	15	71	
Test Section Inner Part	26.25	15	215	
Valve FV 231 4”	5.14	3.65	2	100
Flange FT228	28.35	7	161	
Mixer	5.58	5	4	
Filter Compressor Inlet	15.33	3	25	
Valve FV10 1 ½”	15.34	62.72	501	60.5

Tab. 12 – HE-FUS3 Relevant Pressure Drop Calculated at 0.225 kg/s, 50 bar at nominal temperatures

2.5 Miscellanea

2.6.1 Helium Leakage

According to the design performance of the facility the helium leakage amount to 10^{-5} mbar l/s per component and 2 10^{-3} mbar l/s for the whole facility.

2.6.2 Economizer Global Heat Exchange Coefficient

The thermal-hydraulic behavior of the loop both in steady state and transient conditions is very much depending on the efficiency of the economizer. Its correct evaluation is essential for the accuracy of the loop simulation with a T/H system code. In order to provide further information for the code modeling, the correlations used in the design calculations [4] for the heat transfer coefficients are reported in the following. It is interesting to notice that while the heat transfer coefficient tube side was calculated with the typical Dittus-Boelter correlation, in the shell side, where the presence of diaphragms improves the thermal exchange, a more suitable correlation was used.

$$q = (T_i - T_e) \cdot \pi D_e l \cdot U$$

$$U = \left[\frac{D_e}{D_i h_i} + \frac{D_e \cdot \ln(D_e / D_i)}{2 \cdot K_{steel}} + \frac{1}{h_e} \right]^{-1}$$

$$Nu = \frac{h_i D_i}{K_i} = 0.023 \, \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{1/3}$$

$$h_e = 0.36 \frac{K_e}{D_e} \cdot \mathrm{Re}_{\max}{}^{0.55} \cdot \mathrm{Pr}^{1/3}$$

q = Exchanged Power [W]
T_i = Internal (Tube) Temperature
T_e = External (Shell) Temperature
D_i = Internal Diameter [m]
D_e = External Diameter [m]
l = Length [m]
h_i = Tube Heat Transfer Coefficient [W/m^2·K]
h_e = Shell Heat Transfer Coefficient [W/m^2·K]
U = Global Heat Exchange Coefficient [W/m^2·K]
K_{steel} = Steel Thermal Conductivity [W/m·K]
K_e = External Thermal Conductivity [W/m·K]
K_i = Internal Thermal Conductivity [W/m·K]
Re = Reynolds Number
Re_{max} = Reynolds Number Calculated at Maximum Flow Area
Pr = Prandtl Number
Nu = Nusselt Number

2.6.2 Material Thermal Properties

The thermal property data related to some materials relevant for the T/H modeling of the facility, as used in previous works [5], are reported in Tab. 13.

Material	**Temperature K**	**Conductivity W/m/K**	**Thermal Capacity J/m^{3}K**
AISI 316	273	13.851	4.06E06
	323	14.322	4.09E06
	353	14.793	4.12E06
	373	15.108	4.14E06
	473	16.679	4.20E06
	573	18.249	4.25E06
	673	19.821	4.28E06
	773	21.392	4.30E06
	873	22.963	4.34E06
	973	24.534	4.39E06
Rock Wool	273 - 973	0.045(*)	0.615E06
Magnesium Oxide	273 - 973	2.077	2.681E06

(*) Read page 16 §2.5.1

Tab. 13 – HE-FUS3 Material Thermal Property Data

3. Experimental Data Description

The experimental data available for the assessment of the thermal-hydraulic codes were carried out for the characterization of the facility during the years 1998 and 1999. They include 10 steady state tests (Pressure 25÷50 bar, Helium Mass Flowrate 0.1÷0.227 kg/s, Power 50÷130 kW, Helium Max Temperature 310÷520 °C), 2 Loss of Flow transients and a test campaign for the characterization of the helium compressor (25 and 50 bar).

3.1 Steady State Tests

Most of the steady states were carried out at 50 bar of pressure on 24^{th} and 25^{th} of June 1998. They are identified with one digit number from 1 to 9, followed by ST for steady state and by the indication of the day (e.g. 24-06-98). Data from 8 tests are reported in this document because the recording for test nr 3 is not available.
Other 2 tests were carried out at 25 bar of pressure on 19^{th} of February 1999. They are identified with a two-digit number indicating the power in % supplied by the Test Section, followed by ST for steady state and by the indication of the day (e.g. 19-02-99). In these tests the characteristics of the compressor are enough different from those of the previous tests owing to a new rotor mounted at the beginning of that year.

3.1.1 Facility Configurations

In the following for each test will be described the status of the loop in term of boundary conditions and status of the controls: pressure, mass flowrate, electrical power and way to supply it, active controls description.

<u>1ST24-06-98</u> – This test was carried out at relatively low helium temperature and 50 bar pressure. The compressor operated at 13000 rpm to provide a quite high helium mass flowrate (0,222 kg/s). The electrical power was supplied by heaters E219/2 (26.6 kW) and E219/3 (40 kW) controlled by the corresponding helium outlet temperature. The control of the regulation valves FT 213, FT234, FT235 was not active. The main valve FT213 was completely open, whereas the by-pass valve FT234 and FT235 were closed.

<u>2ST24-06-98</u> – The test was conducted at the same conditions and loop configuration as the previous one, except for some slight differences in the loop pressure (51 bars) and power supplied by heaters (39 and 21 kW).

<u>4ST24-06-98</u> – The test was conducted with the same loop configurations of the previous tests except for the status of the main valve FT213 that was partially closed (70%). The compressor still operating at 13000 rpm supplied a lower mass flowrate (0,173 kg/s) and consequently a lower power was supplied by the heaters (31 and 16 kW).

<u>5ST24-06-98</u> – This test was carried out at higher helium temperature than the previous ones and 51 bar pressure. The compressor operated at 13000 rpm and provided 0,222 kg/s helium mass flowrate. The electrical power was supplied by heater E219/3 (26 kW) and by the 7-pin TS (71 kW). The control of the regulation valves FT 213, FT234, FT235 was not active. The

main valve FT213 was completely open, whereas the by-pass valve FT234 and FT235 were closed.

6ST24-06-98 – This test was carried out at the same configurations and conditions as the previous one. A higher electrical power supplied only by the 7-pin Test Section (118 kW) led the helium in the hot zone of the loop to higher temperatures.

7ST25-06-98 – This test was carried out at 51 bar pressure and at about the same helium temperature of the previous one but with a different loop configuration. The compressor supplied 0.227 kg/s mass flowrate at 13000 rpm. The electrical power was supplied only by the 7-pin test section (130 kW). The hot by-pass valve FT 234 was controlled in order to guarantee 300 °C helium temperature at the inlet of the TS. Owing to this control the valve resulted partially open (37%), while the main valve FT 213 was maintained completely open.

8ST25-06-98 and 9ST25-06-98 – These tests were conducted at the same conditions and loop configuration as the previous one.

40%ST19-02-99 – This test was carried out at relatively low helium pressure (23 bars) and high temperature. The compressor supplied the facility with 0.1 kg/s helium mass flowrate at 14200 rpm to provide a quite high helium mass flowrate (0,222 kg/s). The electrical power was supplied by the 7-pin TS (94 kW). The hot by-pass valve FT 234 was controlled in order to guarantee 350 °C helium temperature at the inlet of the TS. Owing to this control the valve resulted partially open (47.7 %), the main valve FT 213 was partially open (88%) as well.

30%ST19-02-99 – This test was carried out at the same configurations and conditions as the previous one. The electrical power was supplied both by the Test Section (68 kW) and by the two heaters E219/3 (4 kW) and E219/2 (7 kW).

3.1.2 Experimental Data Description

The status of the loop is described through a series of 45 measurements that are provided for each steady state above described. The measurement series reported in Tab. 14 have been drawn from the original material recovered. For 6 steady states (1ST24-06-98, 2ST24-06-98, 7ST25-06-98, 8ST25-06-98, 40%ST19-02-99) they represent the average values on the last 10 minutes of a longer acquisition time; for 3 of them (4ST24-06-98, 5ST24-06-98, 9ST25-06-98) they are the average values on the only 10 minutes available. Finally for the 30%ST19-02-99 steady state only a synoptic with an instantaneous status of the loop is available.

The description of these 45 measurements is given in the following:

TR 218 – Economizer Outlet Temperature (Hot Side) [°C]
TR 215 – Economizer Inlet Temperature (Cold Side) [°C]
TR 217 – Economizer Inlet Temperature (Hot Side) [°C]
TR 216 – Economizer Outlet Temperature (Cold Side) [°C]
FIC 228X – Economizer Outlet Mass Flowrate (Hot Side) [kg/h]
TR 239 – Cold Mixer Outlet Temperature [°C]

TIC 242X – Air Cooler Outlet Temperature (Helium) [°C]
TR 267 - Air Cooler Inlet Temperature (Air) [°C]
TR 266 - Air Cooler Outlet Temperature (Air) [°C]
TR 242W - Air Cooler Outlet Temperature (Helium) for Fan Regulation [°C]
TR 202 - Compressor Inlet Temperature [°C]
TR 204 - Compressor Outlet Temperature [°C]
PDR 201 – In-Out Compressor Differential Pressure [bar]
FIC 212W – Helium Mass Flowrate for Compressor Control [kg/h]
FIC212X - Compressor Outlet Mass Flowrate [kg/h]
FIC228W – Mass Flowrate Set Point for Regulation of Valves V235 [kg/h]
FIC228Y – Signal for Regulation of Valves V235 (%)
ZR 235 – Opening of Valve V235 (%)
ZR 213 – Opening of Valve V213 (%)
ZR 234 – Opening of Valve V234 (%)
TR 220 – Heater E219/3 Inlet Temperature [°C]
TR 221 – Heater E219/3 Outlet Temperature [°C]
TR 226 – Heater E219/3 Rod Temperature [°C]
TIC 222X - Heater E219/2 Outlet Temperature for Power Regulation [°C]
TIC 222W - Heater E219/2 Outlet Temperature Set Point for Power Regulation [°C]
TIC 222Y – Signal for Regulation of E219/2 Electrical Power [%]
TR 225 – Heater E219/2 Rod Temperature [°C]
TIC 223X - Heater E219/1 Outlet Temperature for Power Regulation [°C]
TIC 223W - Heater E219/1 Outlet Temperature Set Point for Power Regulation [°C]
TIC 223Y – Signal for Regulation of E219/1 Electrical Power [%]
TR 224 – Heater E219/1 Rod Temperature [°C]
TIC 232X – Test Section Inlet Temperature for Regulation Valves V234/V213 [°C]
TIC 232W –Set Point for Regulation Valves V234/V213 [°C]
TR 233 - Test Section Outlet Temperature [°C]
TR 241 - Compressor Inlet Temperature for Protection System [°C]
TR 236 - Heater E219/1 Inlet Temperature for Protection System [°C]
TR 297 - Heater E219/2 Inlet Temperature for Protection System [°C]
TIC 242Y – Signal for Regulation Fan [%]
TIC 232Y – Signal for Regulation Valves V234/V213 [%]
ST 270 – Compressor Speed [rpm 10^{-2}]
PR 298 – Compressor Inlet Pressure [bar]
PR 206 – Tank Pressure [bar]
PR 227 – Test Section Inlet Pressure [bar]
PDR 229 – In-Out Test Section Differential Pressure [bar]
FIC 212Y – Signal for Compressor regulation

3.1.3 Experimental Data Evaluation

The acquisition of the measured parameters above described was not followed by a qualification to associate the uncertainty range to the experimental data. The accuracy of the most part of the instrumentation was declared to be within the range of 0.5 % of the instantaneous value. For the temperature measurements that should be equivalent to an uncertainty of ±2-3 °C in the hot side of the loop and ±1 °C in the cold one. Unfortunately no information is available about the real status of the instrumentations during the tests. It is worth to highlight that the few observations in the following have been deduced from an analysis of the experimental data performed about 8 years later.

The distribution of temperature along the loop should be completely characterized through 17 thermocouples properly located. The reliability of the measured values is for a few of them rather questionable. In particular, the temperature TR233 located at the Test Section outlet is completely unreliable, as the recorded values are about 100 °C more than expected with an energy balance on the TS. Moreover, the tests with the TS at 0-power (1/2/4ST24-06-98) show clearly a constant over prediction (8°C) of the temperature at the inlet of the economizer hot side (TR307) that seems to affect all the tests. Some loop positions are provided with two or more instruments that should give very close temperatures. In two cases this is not the reality; in fact, at the economizer cold side outlet TR216 and TR220 differ of about 10 °C as well as at the economizer hot side outlet, where TR218 and TR217 differ of 8-10 °C. According to the notes taken by the operators during the tests, the thermocouple at the compressor outlet (TR204) recorded a value of a few degrees °C (2-3) higher that the value displayed on the compressor console that was considered more reliable.

The compressor speed measurement (ST 270) is not reliable at all. According to the operators the signal to be used for the compressor speed evaluation is FIC 212Y that represents the ratio of the instantaneous speed respect to the maximum speed (18000 rpm). For instance, the value of 0.72 recorded in almost all tests corresponds to 13000 rpm.

Because no information is available about the installation of the thermocouples on the heathers roads (TR224/5/6), a particular caution is recommended in using them. During the steady state tests the signals related to the thermocouples installed in the TS pins were not acquired.

The two mass flowrate measurements at the economizer outlet (FIC 228X) and at the compressor outlet (FIC 212X) generally differ less than 1,5 %, in very good agreement with the accuracy of the instruments (±0.5%), thus partially confirming the low values declared for the helium leakage in the loop.

The pressure drops of the loop are not completely characterized. Only two accurate measurements (±0.5%) are installed through relevant parts of the loop as the compressor (PDR 201) and Test Section (PDR 229). The pressure signals are not sufficiently accurate to be used for it (±1 bar).

There is no signal related to the amount of electrical power supplied in the test section. The information, which has been reported in the test descriptions, has been deduced from the notes taken by the operators during the tests and verified by means of an energy balance on the Test Section.

An energy balance on the whole loop has been calculated for some tests in order to provide an estimate of the thermal losses. The results of these calculations are collected in Tab.14. It has to be observed the large spread of the values that depends by several reasons:

- the different conditions of the tests, the heat losses depends on the helium temperature both in term of temperature drops and for the increase of the rock wool conductivity with the temperature;
- the uncertainty on the helium temperatures used for the balances, which is estimated to account for an uncertainty of ±5 kW on the total heat losses;
- the presence of important thermal bridges in large components like the heaters and the economizer;
- for some tests the limited period of acquisition documented can give rise to some doubts on the effect of the relatively high thermal capacity of the structural material (walls, rods).

Steady State Test	Loop Heat Losses (W)
2ST24-06-98	4800.
4ST24-06-98	5200.
5ST24-06-98	23000.
6ST24-06-98	31000
7ST24-06-98	21900.

Tab.14 – Estimated Thermal Losses in Steady State Tests

3.2 Transient Tests

Two transient tests simulating loss of flow events in the test section were conducted in the HE-FUS3 facility on 9th of July 1998. They are identified with a two digit number (50 and 30) that refers to the power in % supplied by the Test Section, followed by LOFA to indicate the kind of transient and by the indication of the day (e.g. 50LOFA09-07-98).

3.2.1 Facility Configurations

In the following for each test will be described the status of the loop in term of initial and boundary conditions and the status of the controls: pressure, mass flowrate, electrical power and way to supply it, active controls description.

<u>50LOFA09-07-98</u> – The test was carried out at about 50 bar pressure and at quite high temperature (400 °C at test section outlet). The compressor operating at 13000 rpm supplied 0,216 kg/s helium mass flowrate. The electrical power was supplied only by the 7-pin test section (118 kW) manually settled. The hot by-pass valve FT 234 was controlled in order to guarantee 300 °C helium temperature at the inlet of the TS. Owing to this control the valve resulted slightly open (17%), while the main valve FT 213 was maintained completely open. The cold by-pass valve FT235 was closed at the beginning of the test.

After reaching the initial steady state the cold by-pass valve FT 235 was opened in about 10 s to simulate a sudden decrease of the flow rate in the test section (partial LOFA). The helium mass flowrate halved and consequently the TS rods temperatures and the helium TS outlet temperature increased. The modified conditions of cold and hot flows in the economizer affected the temperature at the cold side outlet that increased of about 15 °C. As a consequence the control system actuated a very slight opening of the valve FT 234 to maintain the TS inlet temperature at 300°C. The compressor control was inactive and the compressor speed remained constant (13000 rpm) during the transient. The compressor mass flow rate increased at the opening of the valve FV235 as a consequence of the different hydraulic characteristic of the loop.

The valve FV235 was closed after about 1 minute of transient in 6 s. Due to the high thermal inertial of the structural material and heated pins the helium temperature decreased very slowly.

The trends of the main parameters of the loop are reported in Figs. 20 to 23.

30LOFA09-07-98 – The test was carried out at about 50 bar pressure and at lower temperature than the previous transient (350 °C at test section outlet). The compressor operating at 13000 rpm supplied 0.217 kg/s helium mass flowrate. The electrical power was supplied both by the 7-pin test section (71 kW) manually settled and by the heater E219/1 (**?** kW) controlled by the corresponding helium outlet temperature with a set point of 300 °C. The main valve FT213 was completely open during the test, whereas the hot by-pass valve FT234 was closed. The cold by-pass valve FT235 was closed at the beginning of the test.

After reaching the initial steady state the cold by-pass valve FT 235 was opened in about 10 s to simulate a sudden decrease of the flow rate in the test section (partial LOFA). The helium mass flowrate halved and consequently the TS rods temperatures and the helium TS outlet temperature increased. The modified conditions of cold and hot flows in the economizer affected the temperature at the cold side outlet that increased of about 10 °C. As a consequence the control system switched off the heater E219/1 while no operation was made on valve FT213 and FT234. The compressor control was inactive and the compressor speed remained constant (13000 rpm) during the transient. The compressor mass flow rate increased at the opening of the valve FV235 as a consequence of the different hydraulic characteristic of the loop.

The valve FV235 was closed after about 150 s of transient in 6 s. Due to the high thermal inertial of the structural material and heated pins the helium temperature decreased very slowly.

The trends of the main parameters of the loop are reported in Figs. 24 to 27.

3.2.2 Experimental Data Description

The behavior of the loop during the transients is described through a series of 52 measurements. The 50LOFA09-07-98 series have been reported in Tab. B2 of the Appendix B as originally recovered, likewise the 30LOFA09-07-98 series are reported in Tab. B3. The acquisition frequency of the signals differed according to the type of measurement and its utilization. For instance, the helium temperatures were in general recorded every 16 s, while the signal used for the control system were recorded every 8 s.

The file of the 50LOFA transient contains only 10 s of data recorded at the initial steady state conditions. Owing to the low acquisition frequency, most of the signals have only one value for the steady state characterization. The file of the 30LOFA transient contains 50 s at the initial steady state conditions, which allows defining the initial value of the parameters as an average among some data.

The first 45 signal recorded have been already described in the previous paragraph. The last 7 signals are related to the thermocouples implemented on the hot rods of the 7-pin Test Section (TT400, TT403, TT407, TT411, TT415, TT419, TT427). In Fig. 28 the location of these thermocouples is indicated.

3.2.3 Experimental Data Evaluation

The same remarks advanced for the steady state data in the previous paragraph are still valid for the parameters measured during the transient test. The energy balance at initial steady state conditions estimates a quite different amount of heat losses in the two tests: 25.6 kW in 50LOFA and 9 kW in 30LOFA. It seems very hard that the uncertainty on the temperatures and the different test conditions can completely explain such a large discrepancy. A further reason for it could be that the initial conditions for the 50LOFA transient were not completely stabilized. The registration available for this test starts about 10 minutes after the end of the registration of the previous 30LOFA test. Since in 30LOFA the hot part of the loop was at lower temperature the thermal capacity of the large components like economizer and heaters could have absorbed part of the power. This explanation is only a hypothesis because no experimental evidence is available.

3.3 Compressor Characterization Tests

Several experimental campaigns were carried out in February-March 1998 to characterize the prototypical generative compressor. The tests were conducted at different loop pressures varying the speed of the compressor and the hydraulic characteristic of the loop by means of the main valve F213 (see Fig. 18). The results reported in Tab. B4 and B5 respectively at 50 bar (COMP50-98) and 25 bar (COMP25-98) are related to the characteristics of the compressor as used for the steady states and transients carried out in 1998. As a new rotor was mounted at the beginning of 1999, the campaign was repeated at 25 bar (COMP25-99). These last data, which are the reference for the two steady states carried out in 1999, are reported in Tab. B6.

3.2.1 Tests and data description

The only information available about the configuration of the loop concerns the main valve that was used to change the hydraulic characteristic of the loop, thus obtaining several couples mass flowrate-head at constant speed. Anyway the temperature and pressure of the helium were maintained quasi-constant at the compressor inlet.

The series of data at different speeds (from 10000 rpm to 15000 rpm at 50 bar and from 10000 to 16000 at 25 bar) were obtained at 3-5 different position positions of the valve F213 (the closing degree tested was more limited at high speed). Besides the loop parameter like inlet pressure, compressor differential pressure mass flowrate, inlet and outlet helium, also the parameter related the ancillary system for the electrical motor cooling (see Fig. 29) were recorded. As the auxiliary helium flow is derived at the compressor outlet and reintroduced at the compressor inlet, the mass flowrate and temperature are necessary for the correct mass and energy balances on the compressor.

In the following the description of the 7 measurements of the compressor tests is given:

FV10 - Compressor Speed [rpm]
G 212 - Loop Mass Flowrate [kg/s]
DP 201 - In-Out Compressor Differential Pressure [bar]
Ti 202 - Compressor Inlet Temperature [°C]
Pi 298 - Compressor Inlet Pressure [bar]
Tout 204 - Compressor Outlet Temperature [°C]
Tcusc 286 – Bearings Temperature [°C]
Trit 275 – Auxiliary Loop Helium Return Temperature [°C]
G 256 – Auxiliary Loop Helium Mass Flowrate [kg/s]

The auxiliary loop helium return temperature Trit 275 is available only for the COMP25-99 campaign. However its value is close to the bearings temperature Tcusc 286 that can be used to derive it.

Concerning the uncertainty on the experimental data the remarks advanced in the previous paragraphs are still valid both for the loop and ancillary system parameters.

5. References

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[3] "Progettazione e Calcoli Termofluidodinamici" ANSALDO ENERGIA, DOC. 700RM06128, 1995

[4] P. MELONI and G. Dell'Orco, "Assessment of ATHENA Code Capability to Simulate Helium Cooled Systems for Fusion Reactors," Proc. of Ninth International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-9), San Francisco, California, (1999)

[5] "Relazione di Calcolo Termodinamico Scambiatore Elio-Elio" Ciotec Impianti S.r.l., DOC. 700RM06233, 1995

6. List of Figures

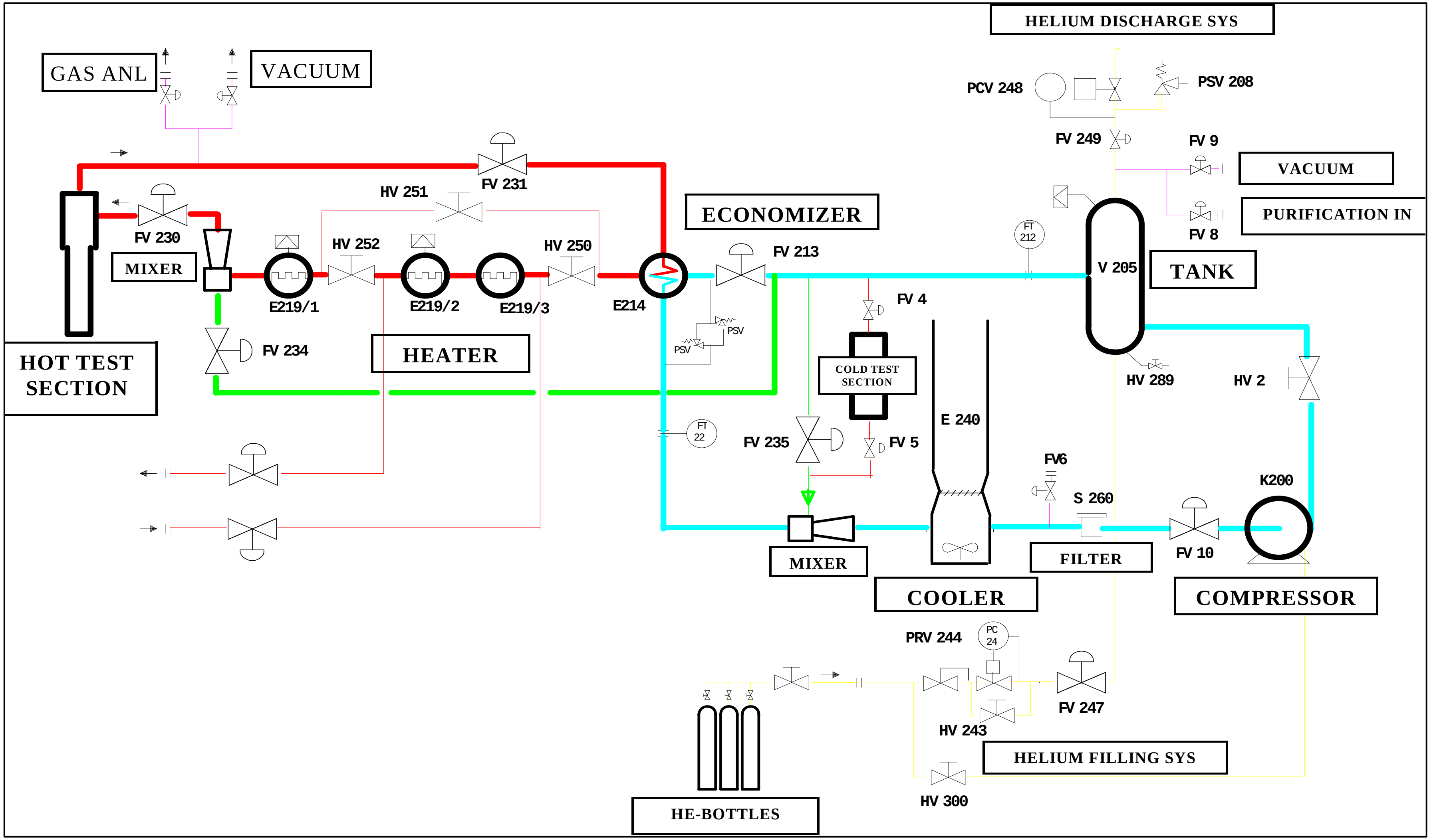


Fig. 1 – HE-FUS3 P&I Scheme

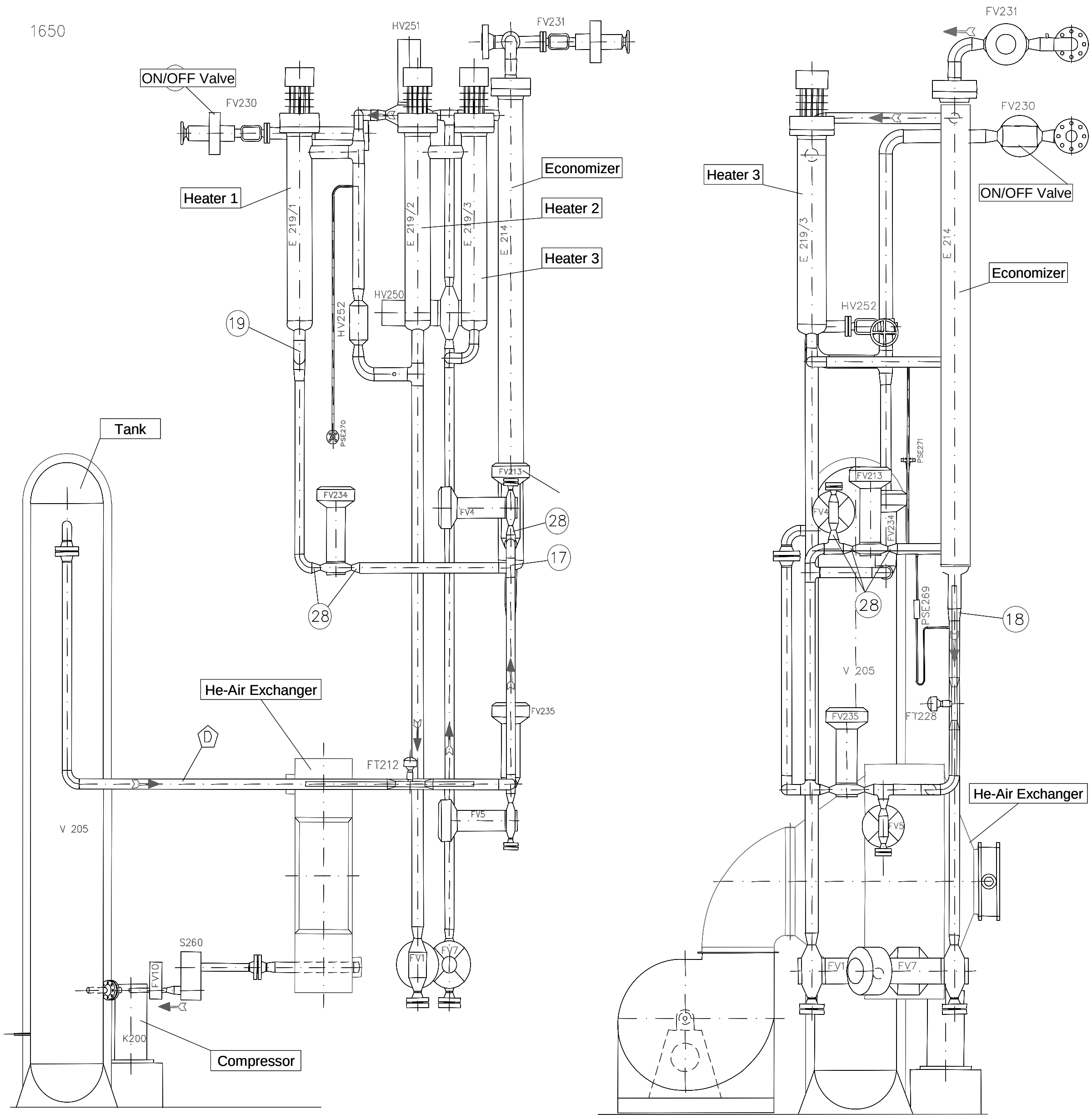


Fig. 2 – HE-FUS3 Vertical View

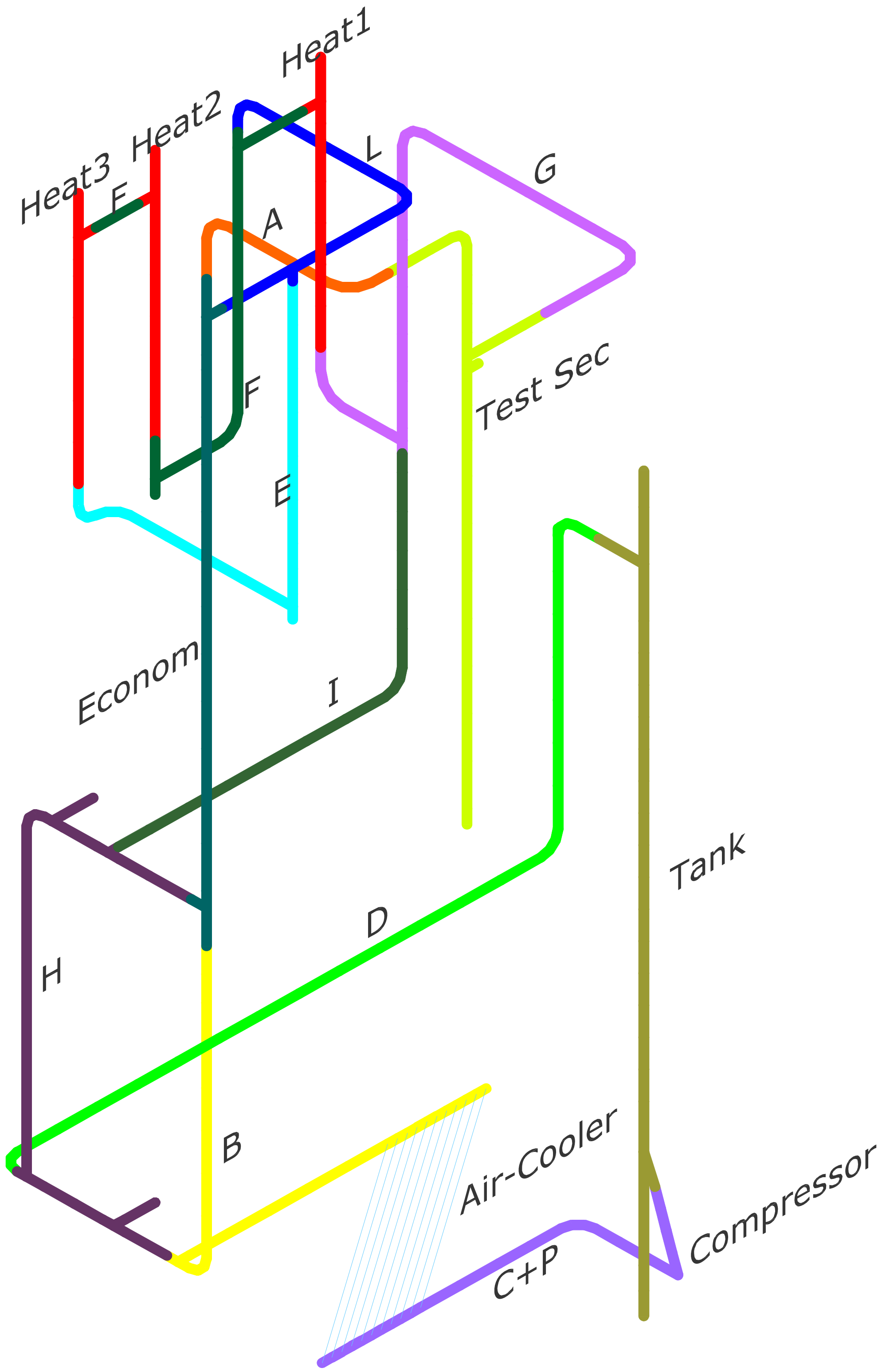


Fig. 3 – Piping Layout 3D Sketch

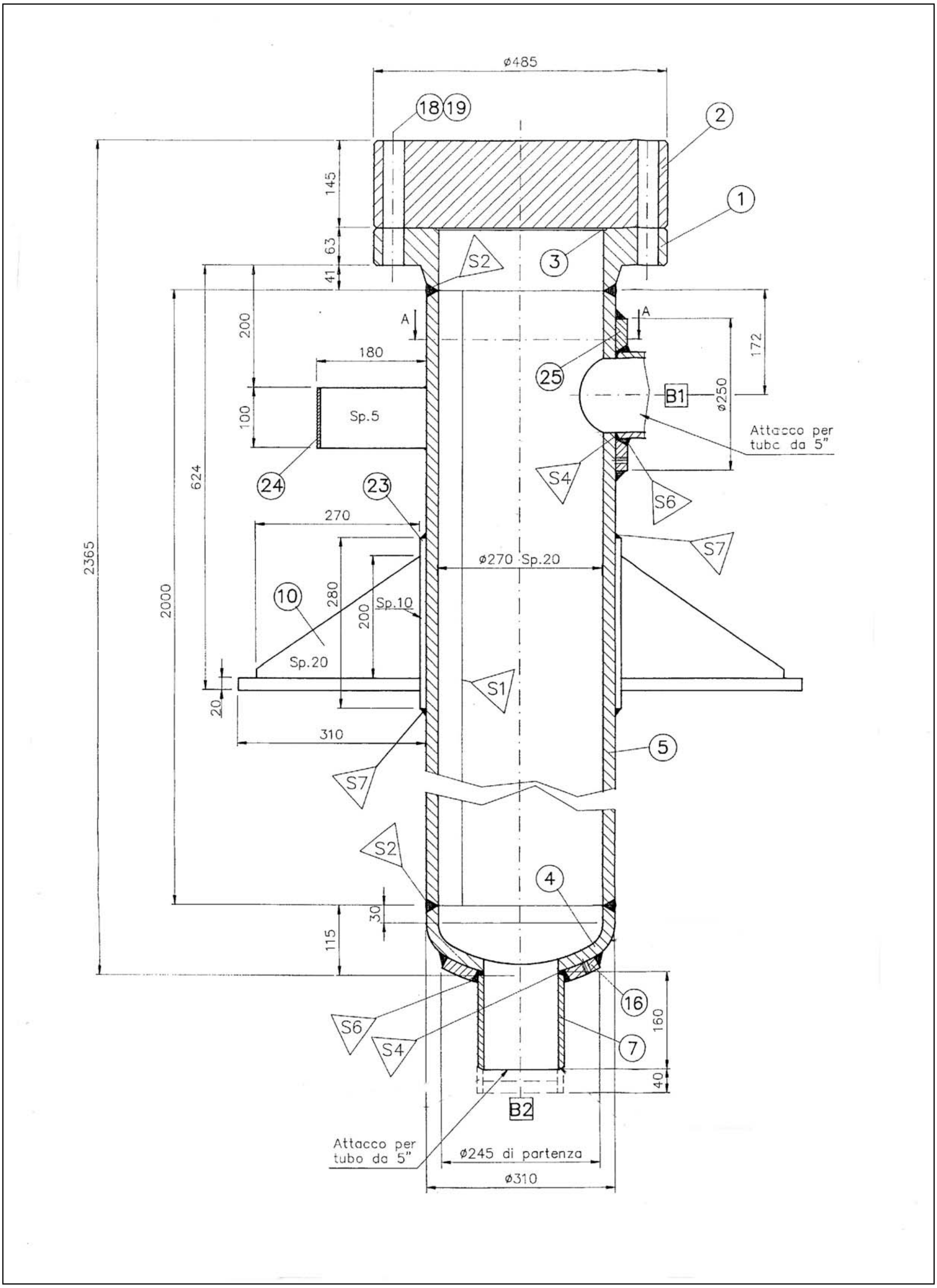


Fig. 4 – Electrical Heater Vessel

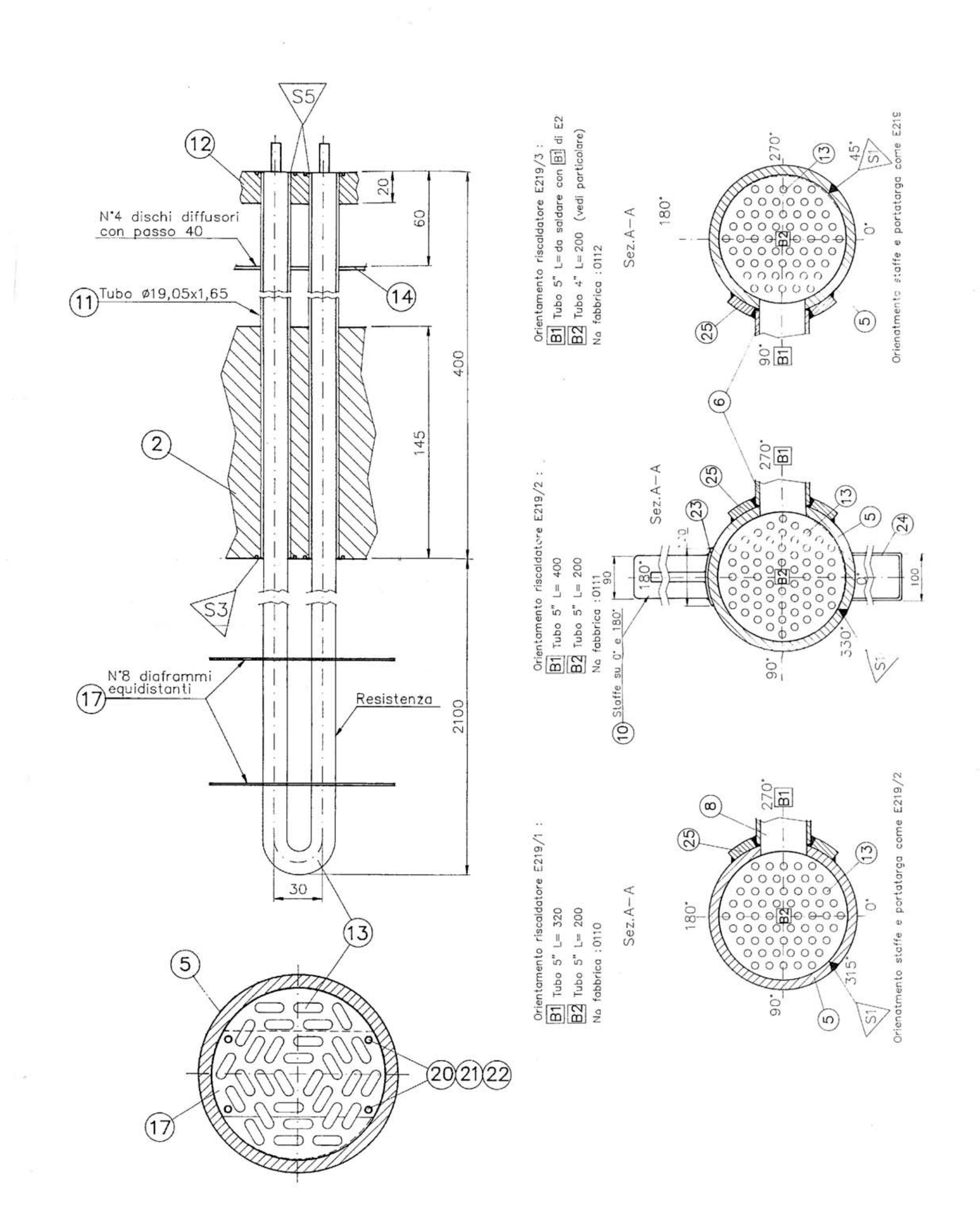


Fig. 5 – Electrical Heater Active Rods and Loop Connections

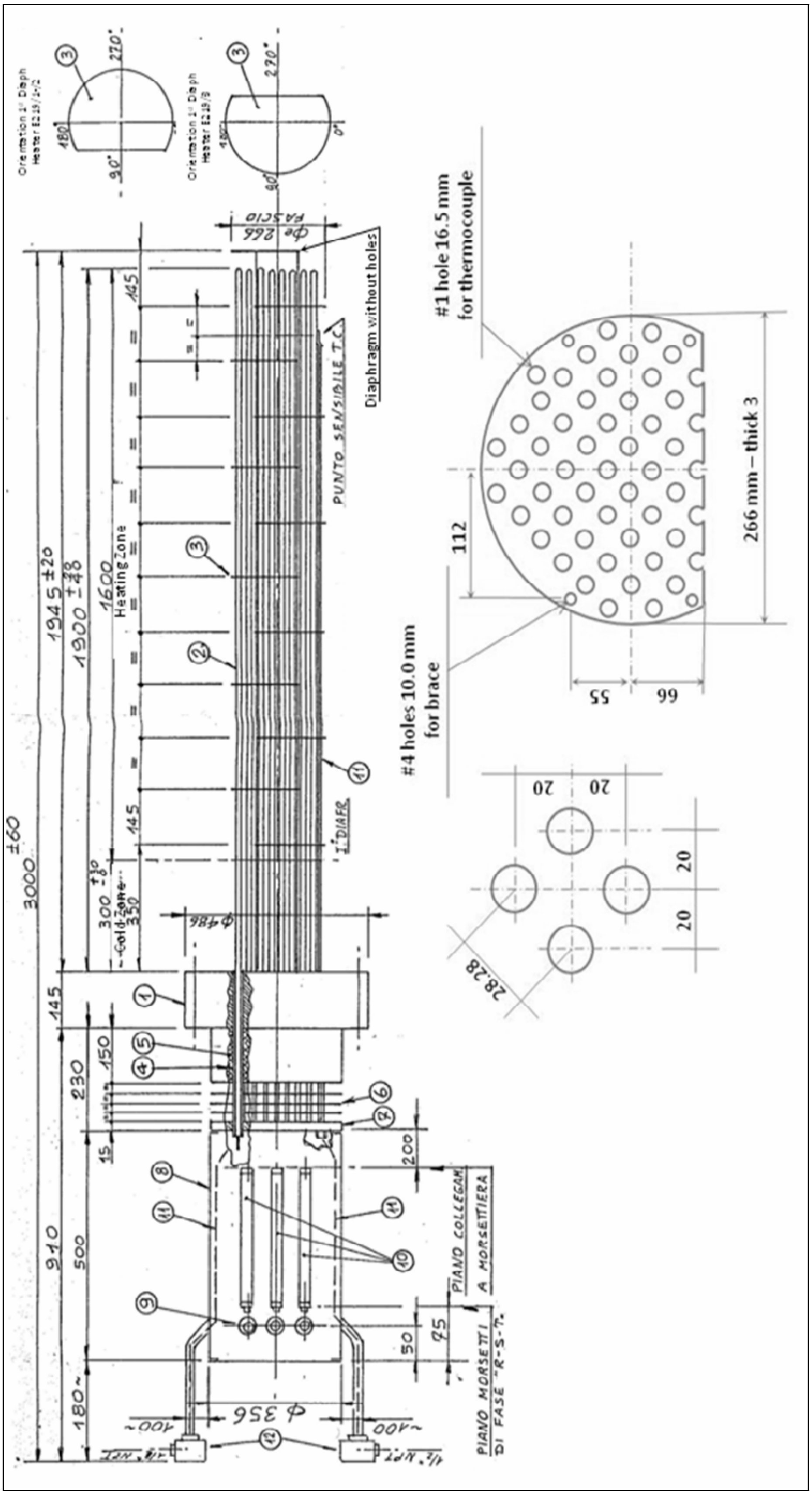


Fig. 6 – Electrical Heater Active Rods and Diaphragms Scheme.

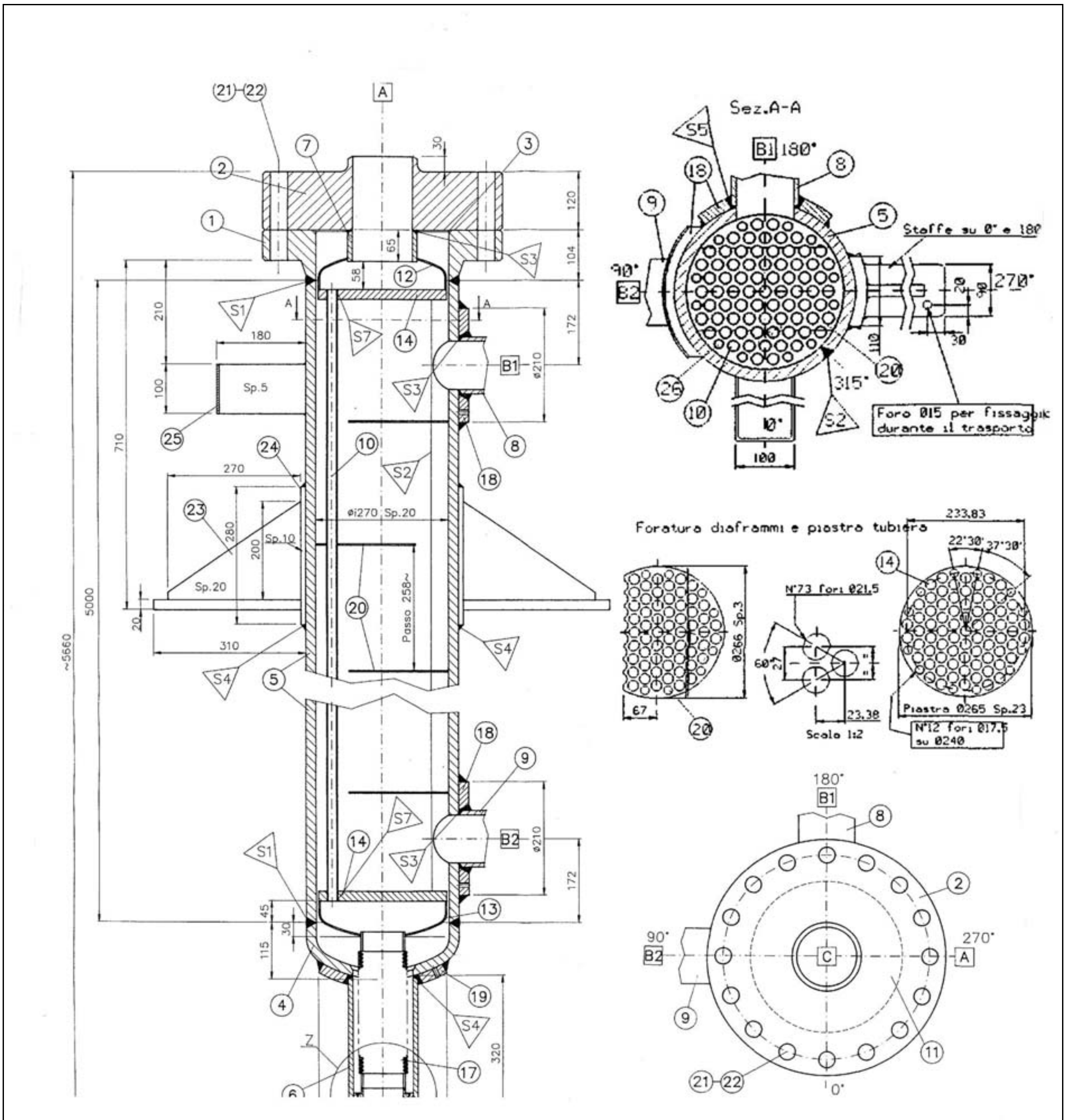


Fig. 7 – Economizer Vessel and Tubes Arrangement

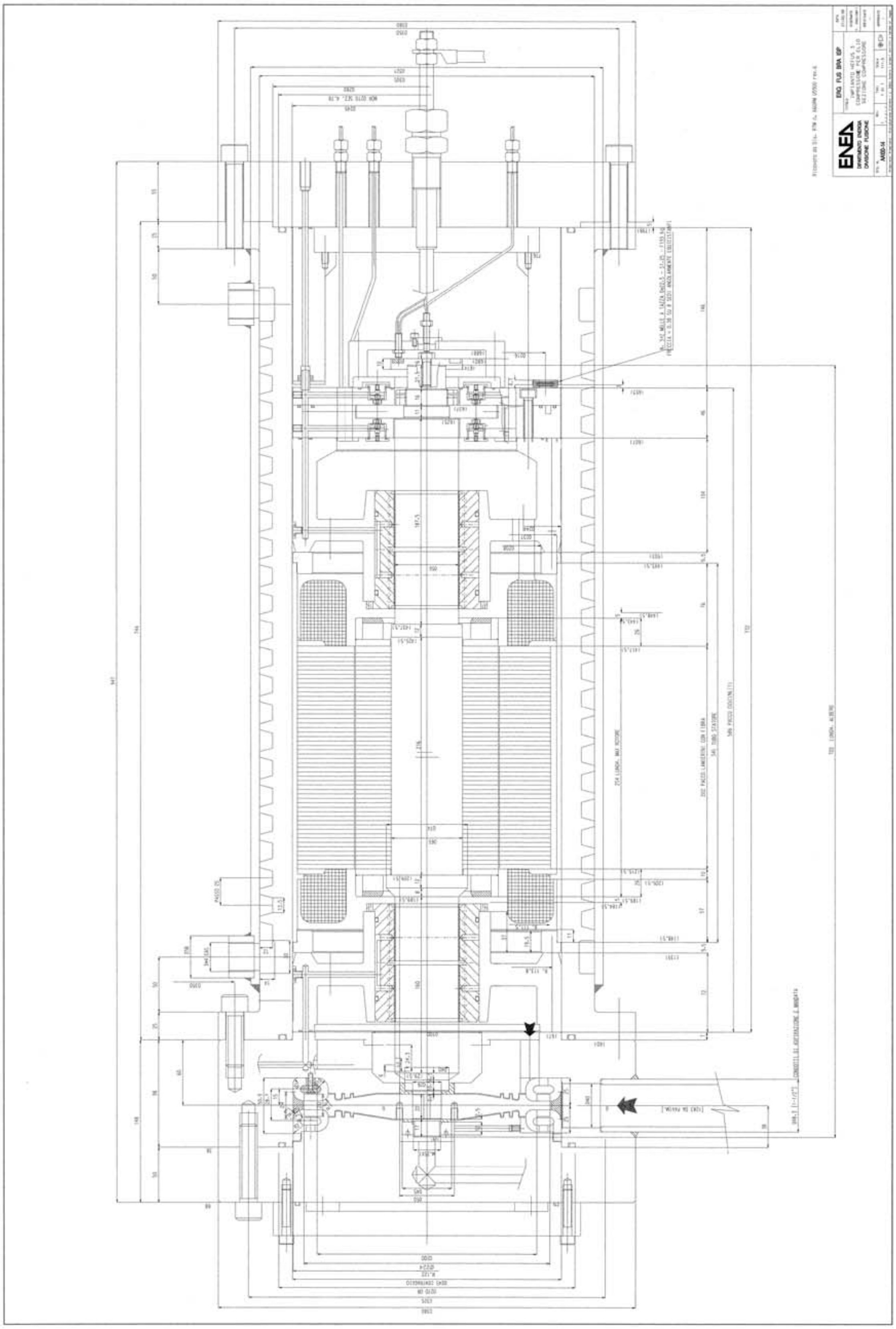


Fig. 8 – Regenerative Compressor

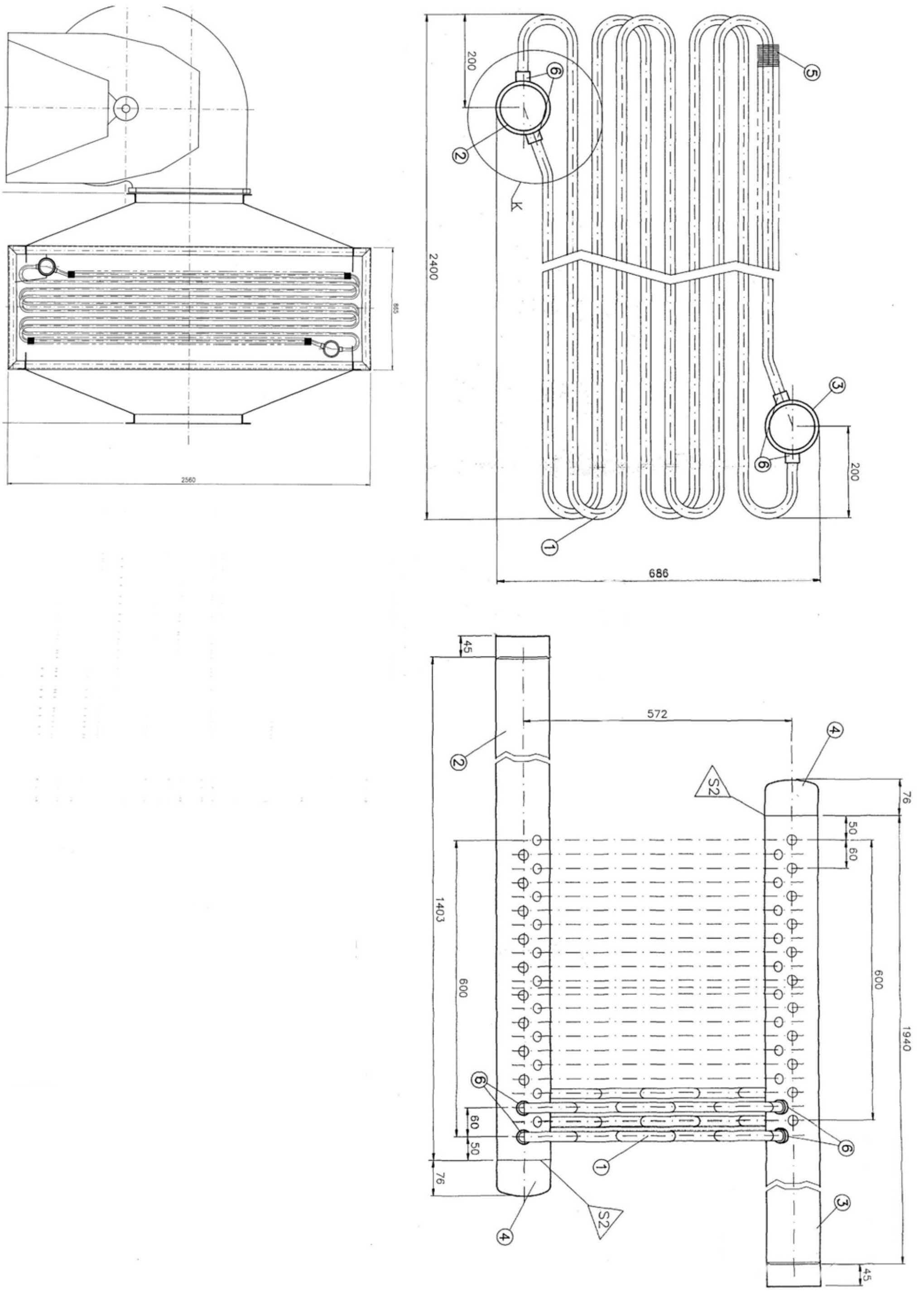


Fig. 9 – Air Cooler Case, Distributors and Finned Tubes

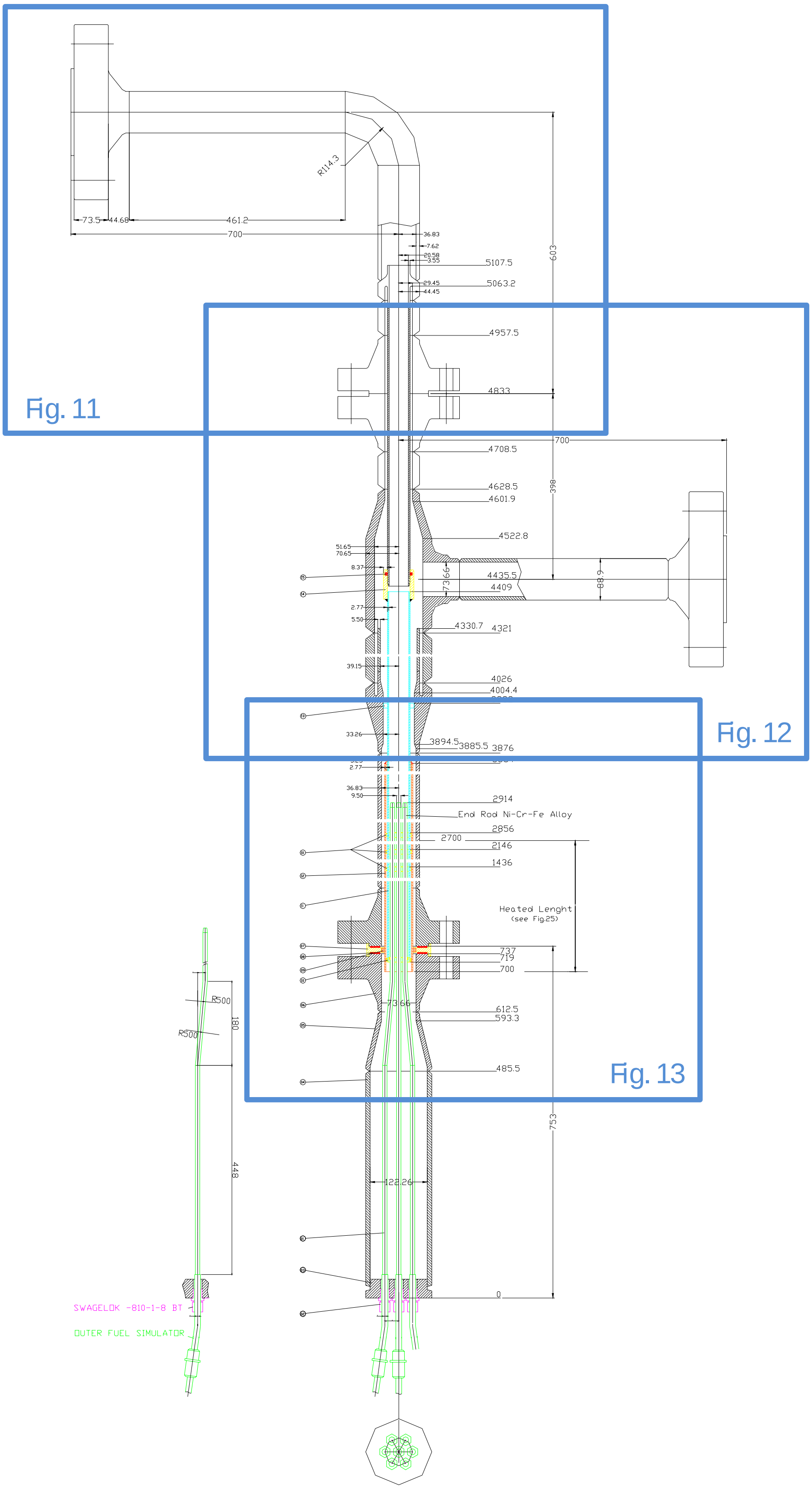


Fig. 10 – 7-pin Test Section Arrangement and Rod Grids

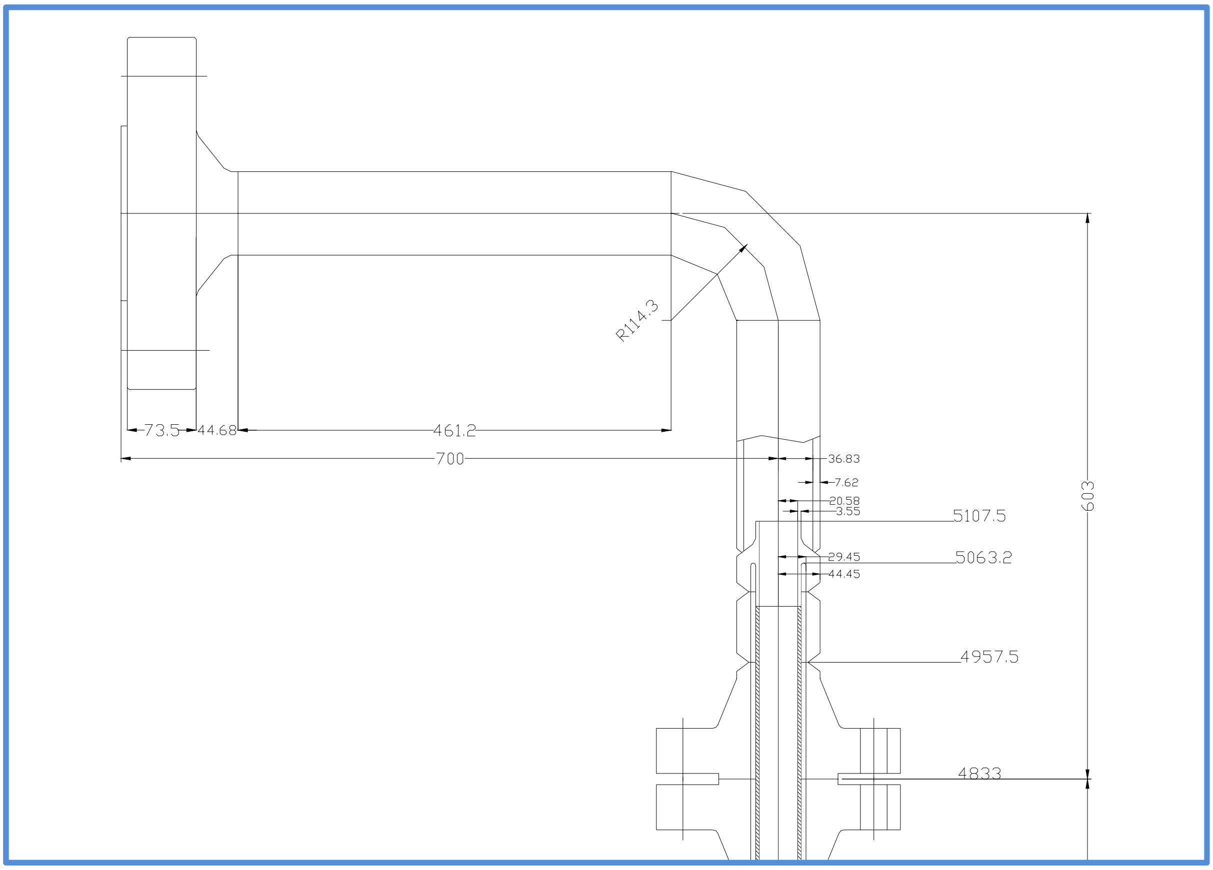


Fig. 11 – 7-pin Test Section – Upper Part

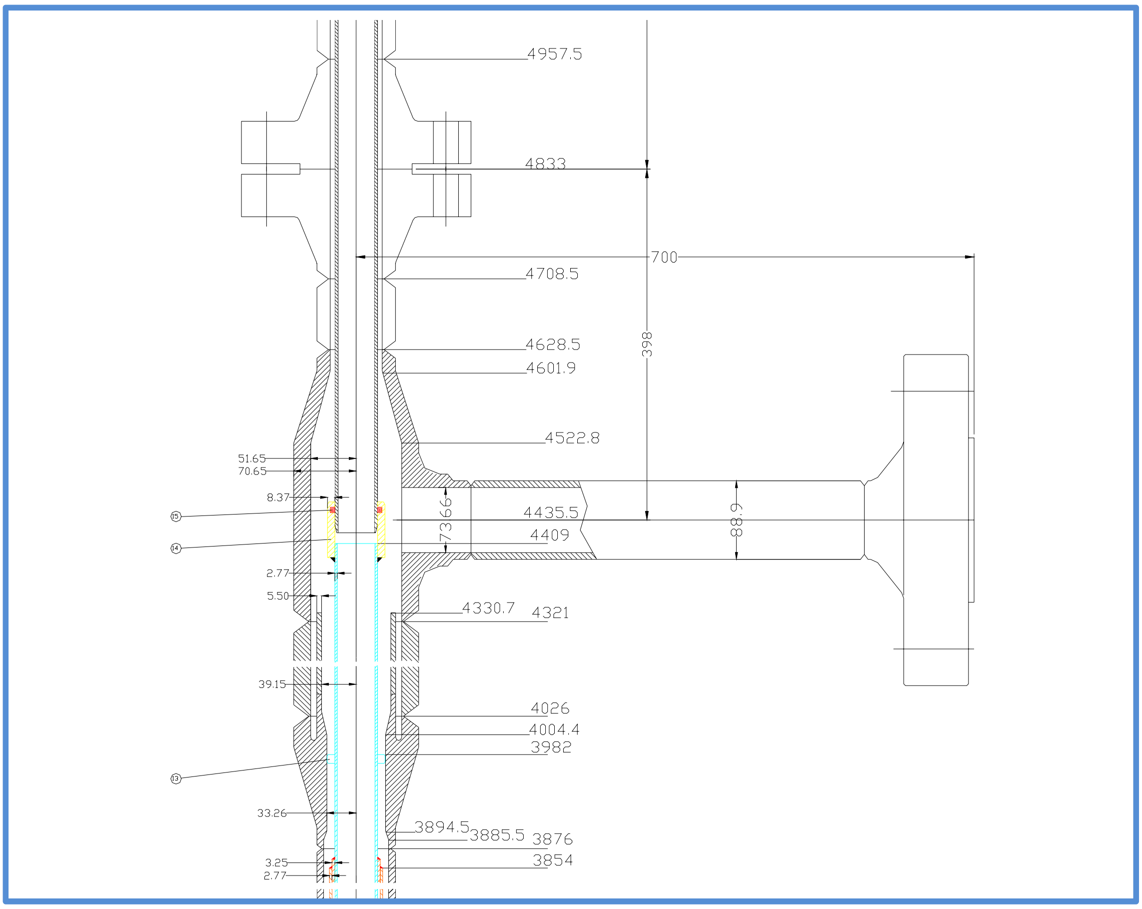


Fig. 12 – 7-pin Test Section – Intermediate Part

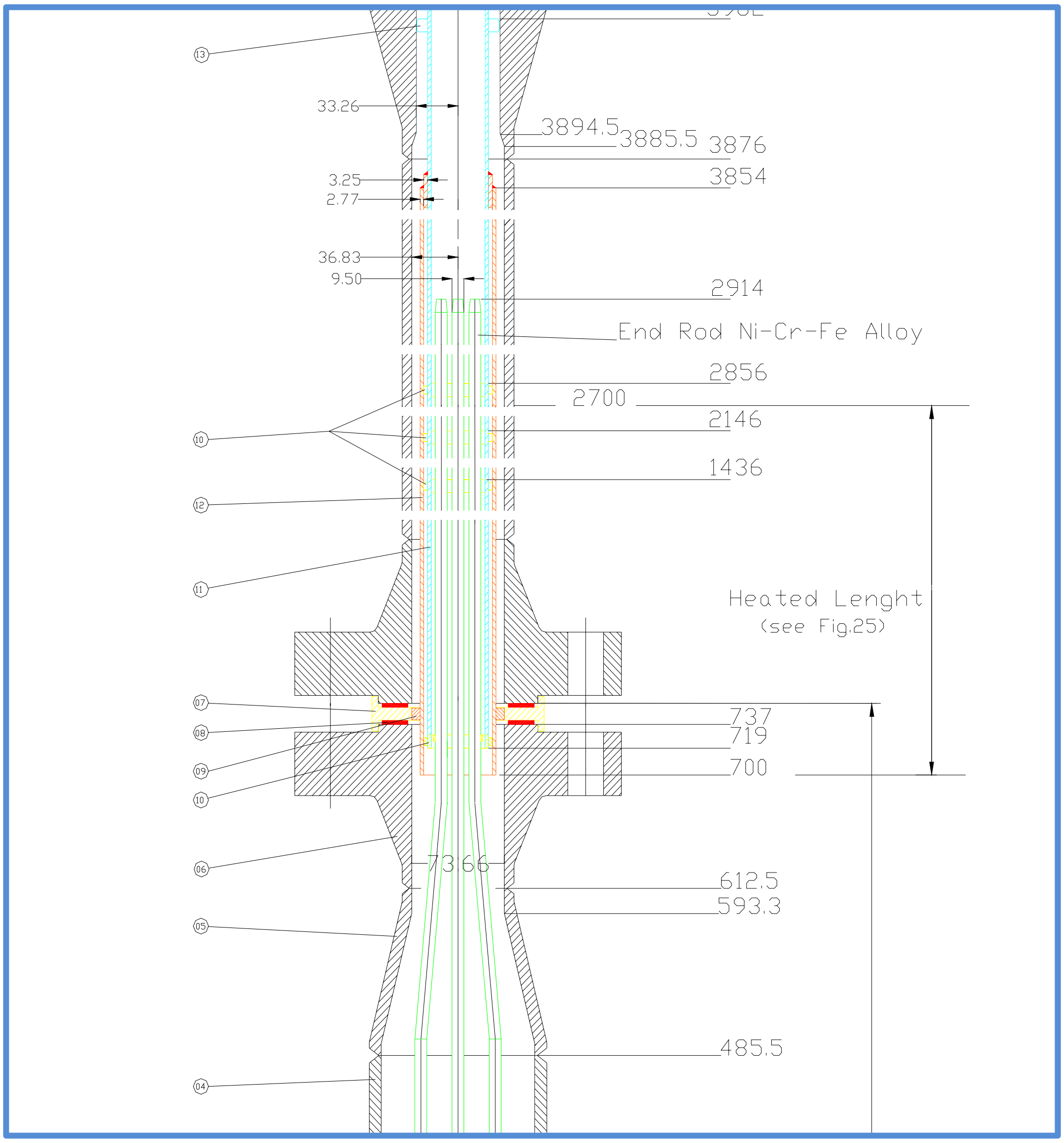


Fig. 13 – 7-pin Test Section – Lower Part

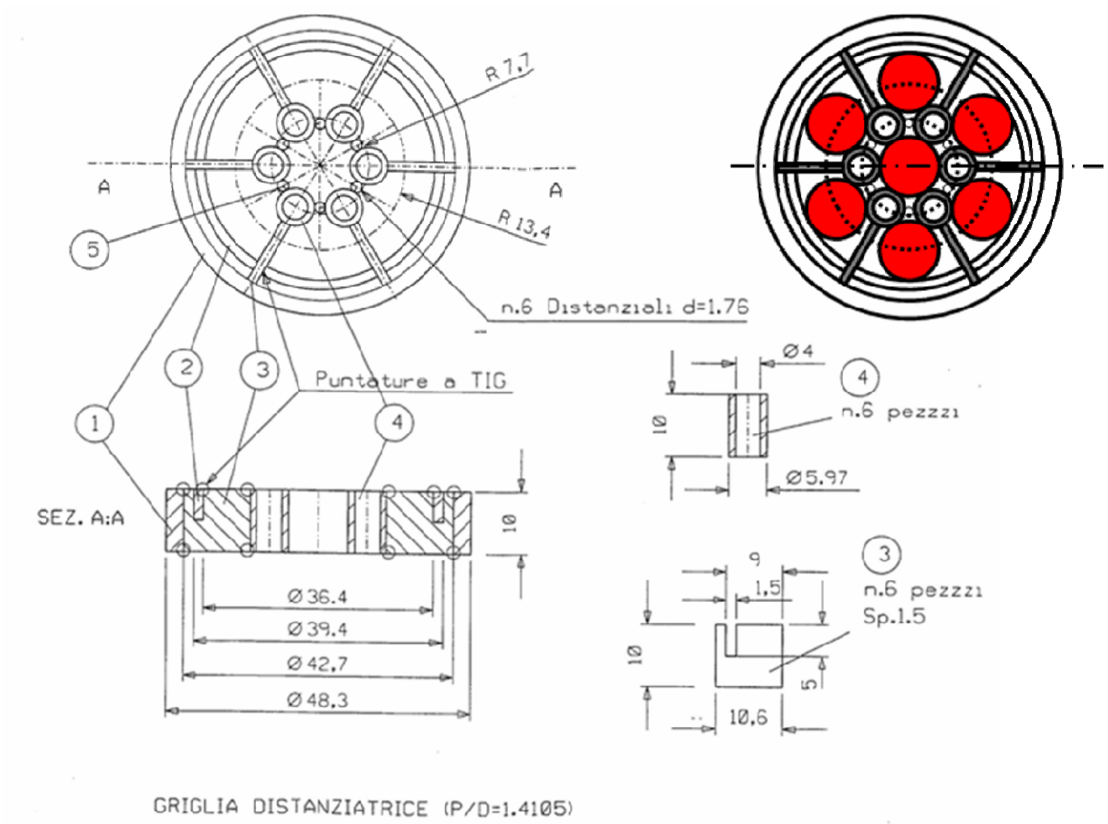


Fig. 14 – Test Section Grid and Rod Bundle (Pitch 29.6mm)

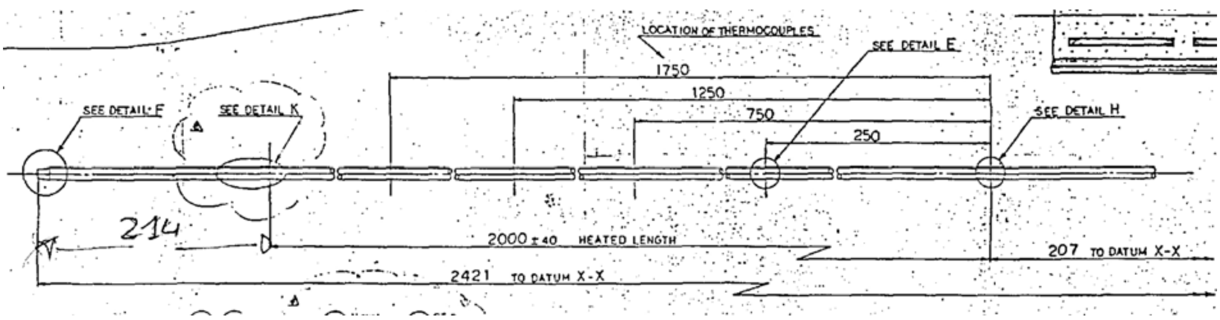


Fig. 15 – Particular of the Test Section Heating Rod with the position of the thermocouples

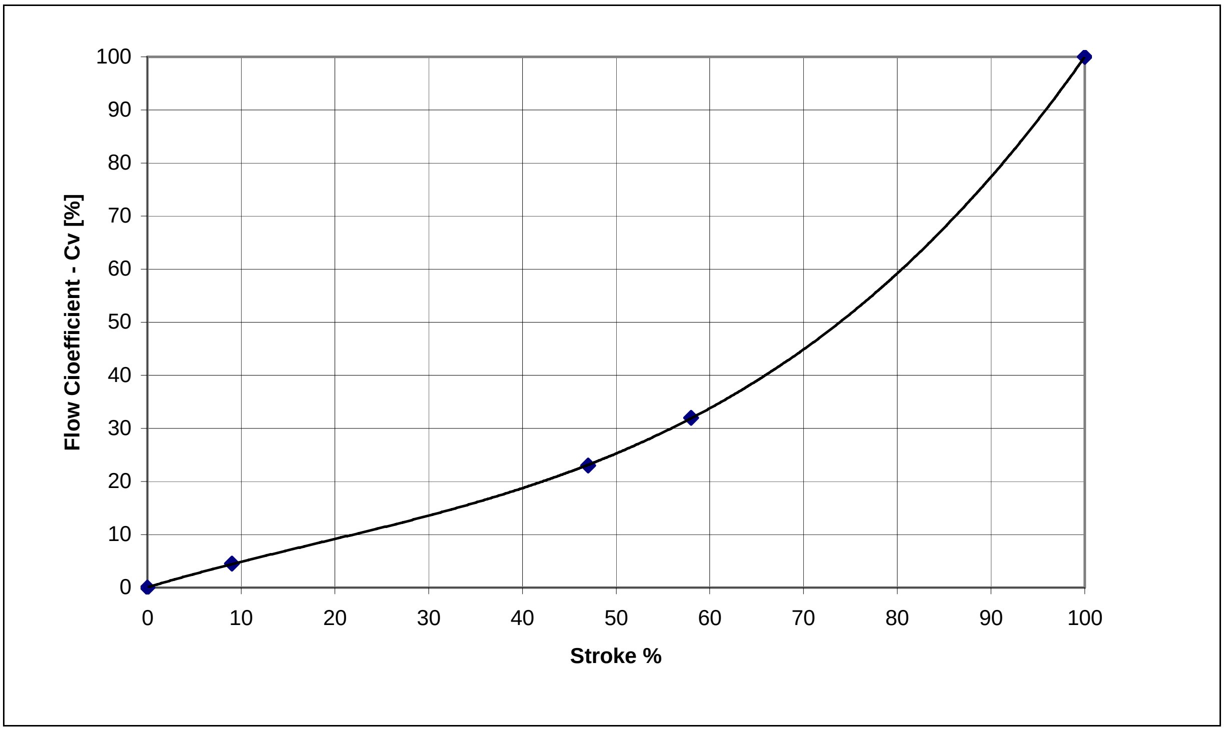


Fig. 16 – Characteristic of the Regulation Valves

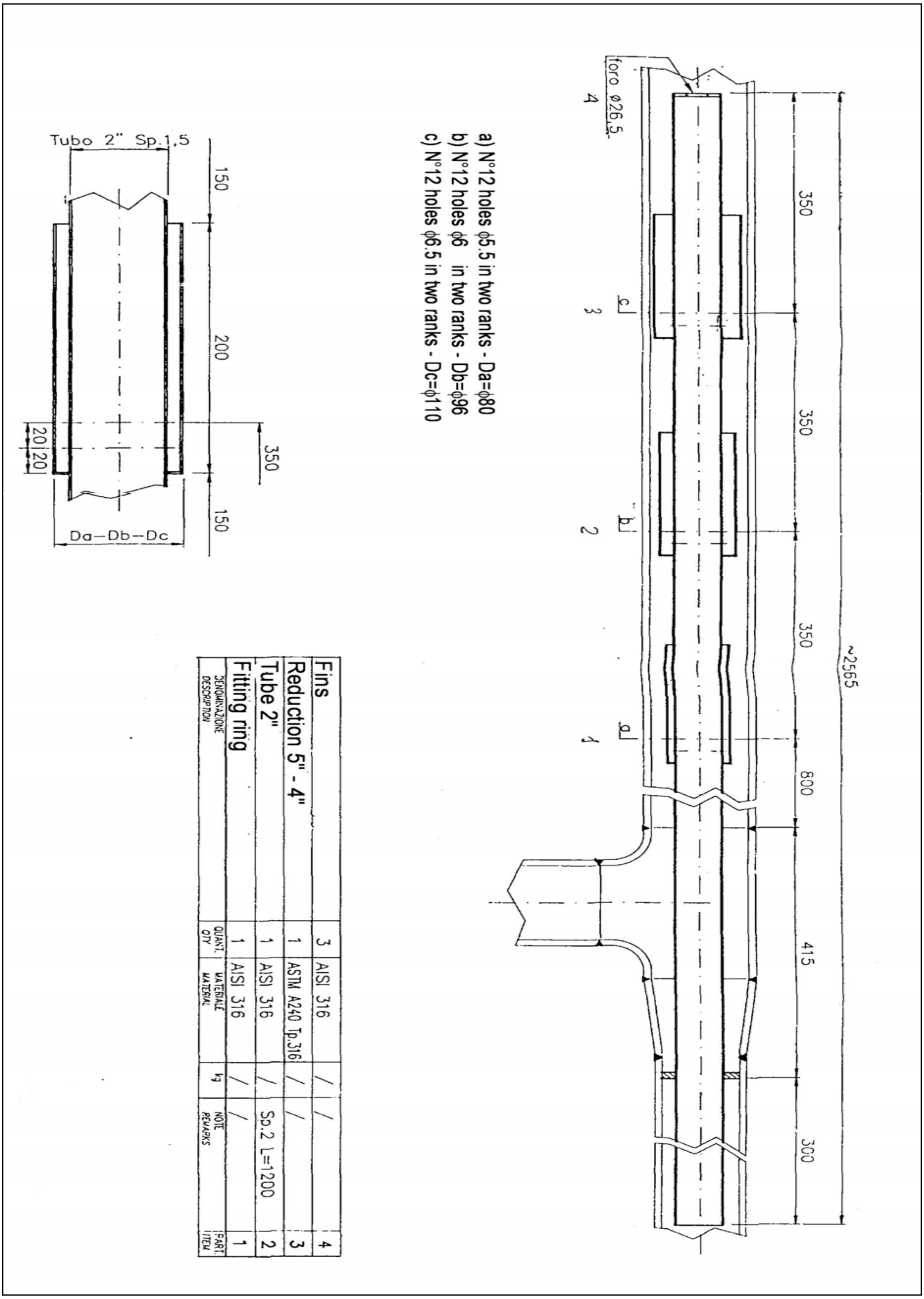


Fig. 17 – Single Module Mixer

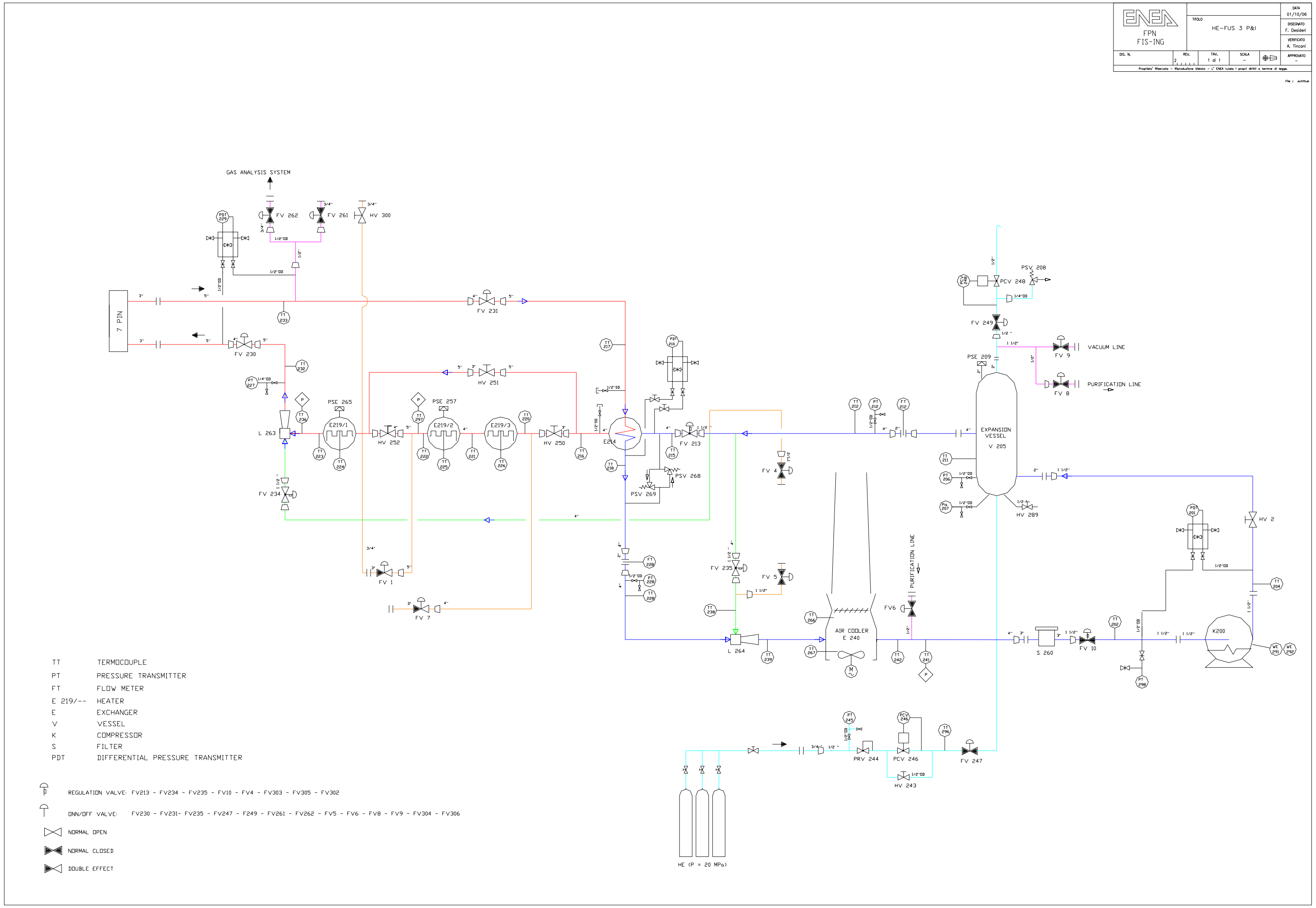


Fig. 18 – Instrumentation Map

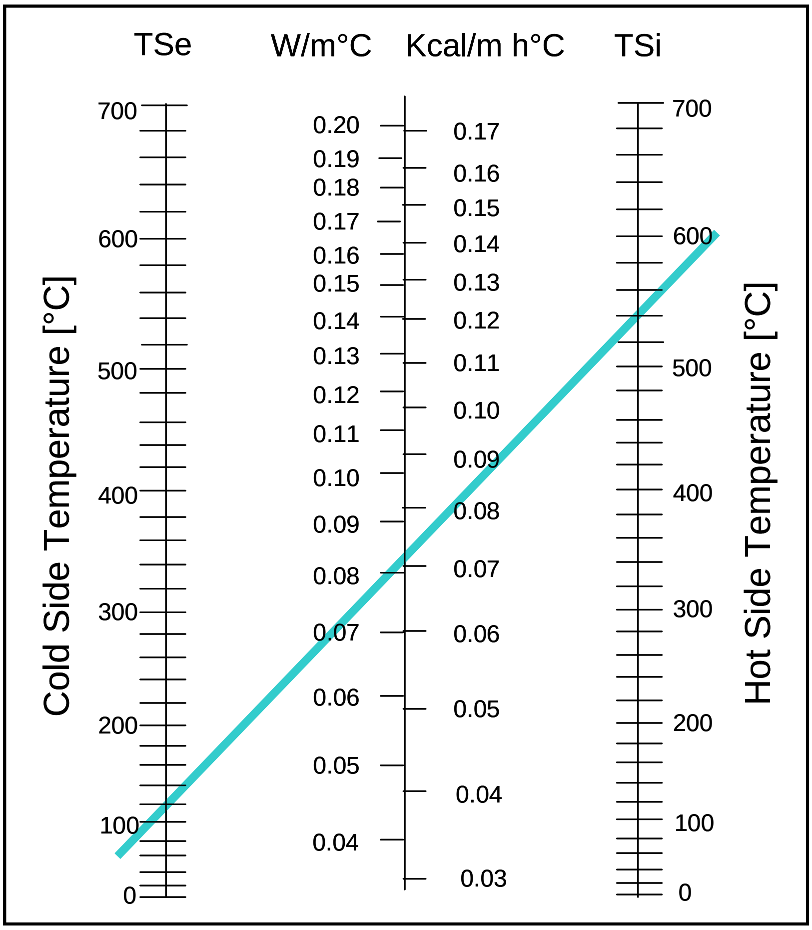


Fig. 19 – Thermal Conductivity of the Rock Wool

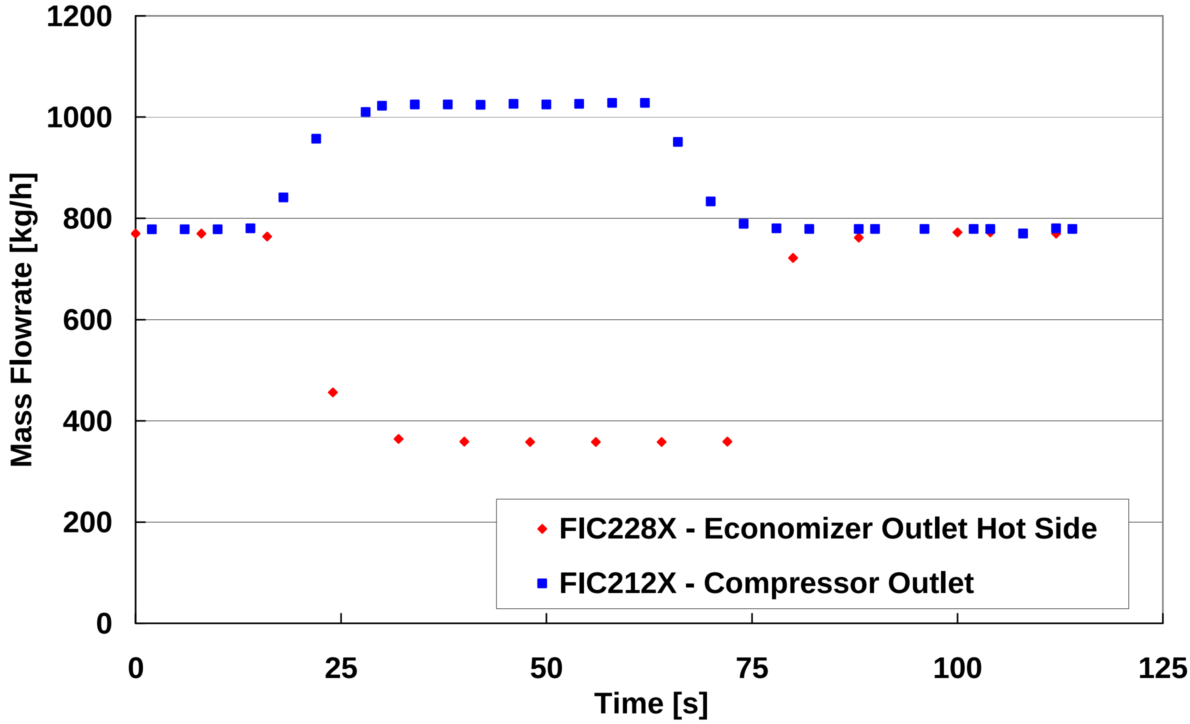


Fig. 20 – Test Section and Compressor Mass Flowrate (50LOFA09-07-98)

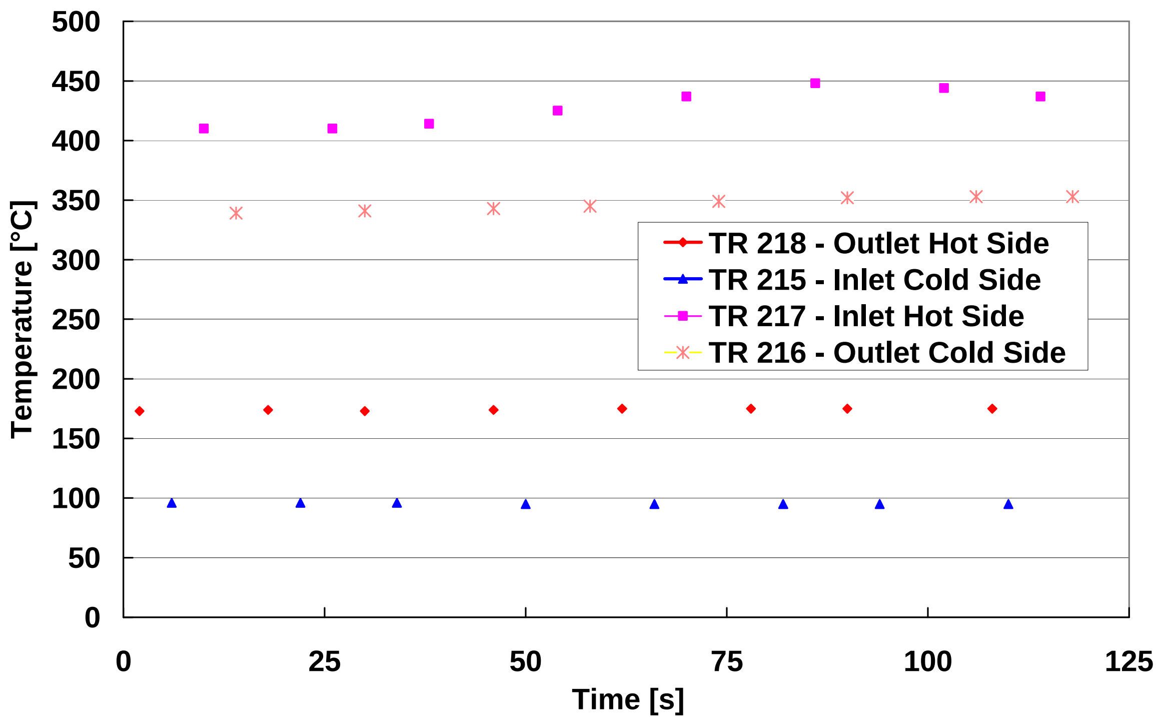


Fig. 21 – Economizer Temperatures (50LOFA09-07-98)

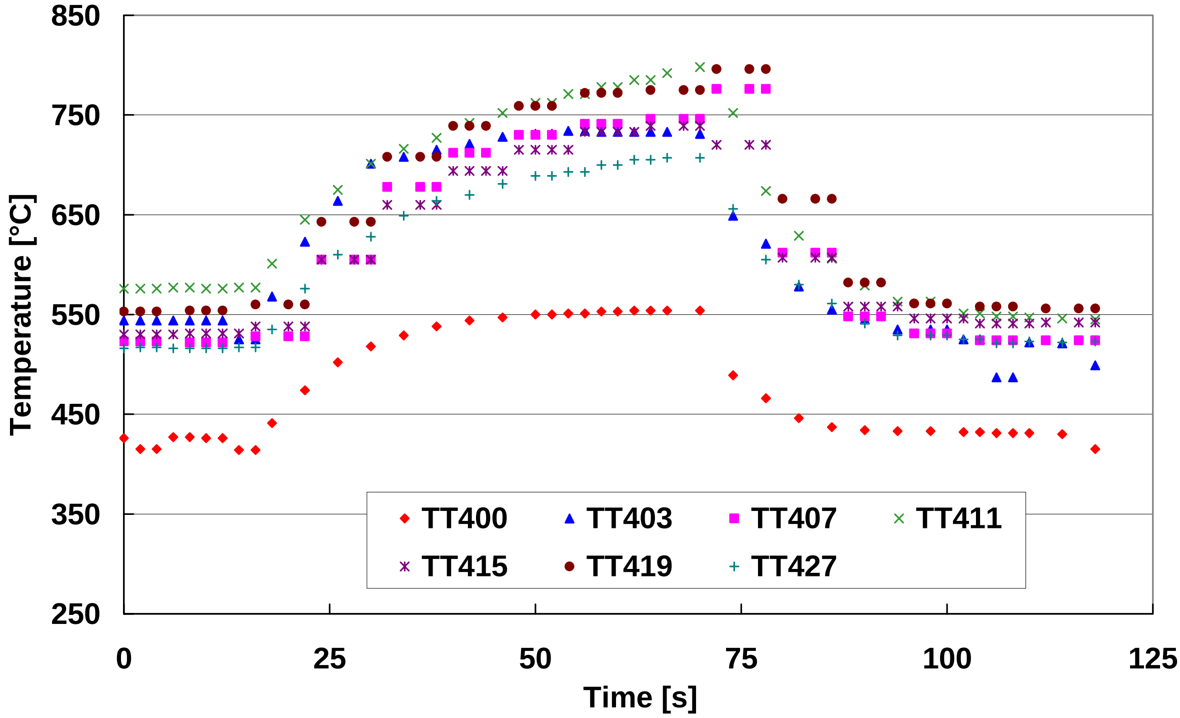


Fig. 22 – Thermocouple Temperatures on 7 TS Positions (50LOFA09-07-98)

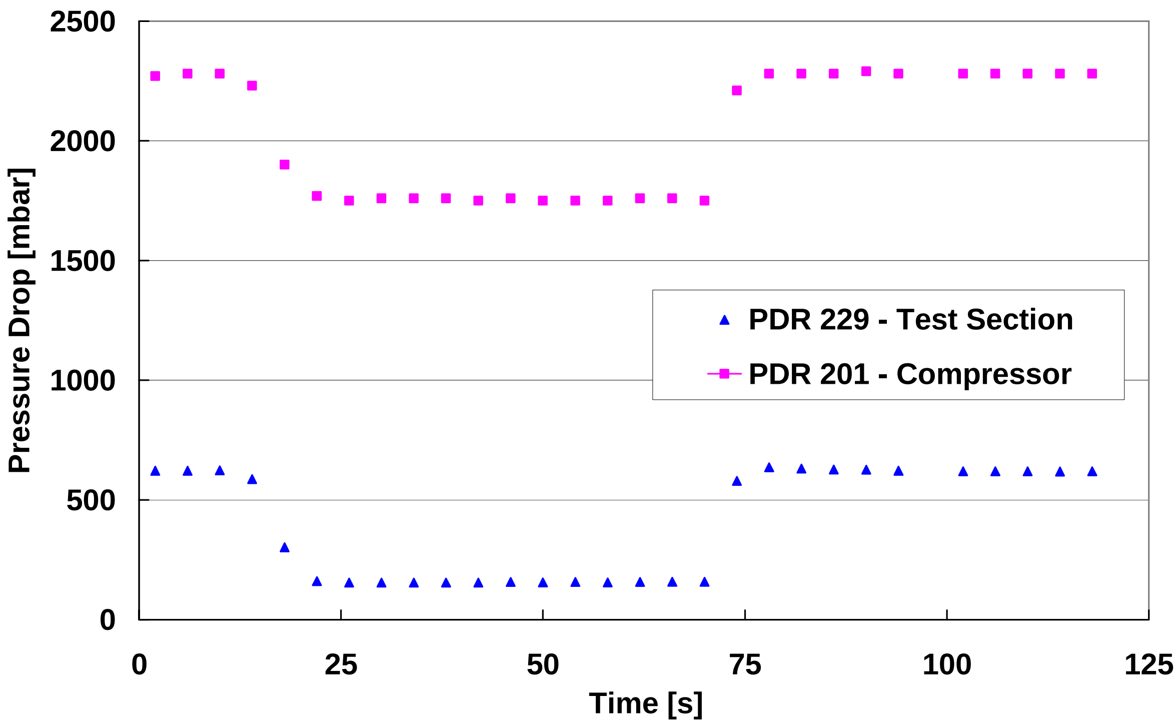


Fig. 23 – TS and Compressor Pressure Drop (50LOFA09-07-98)

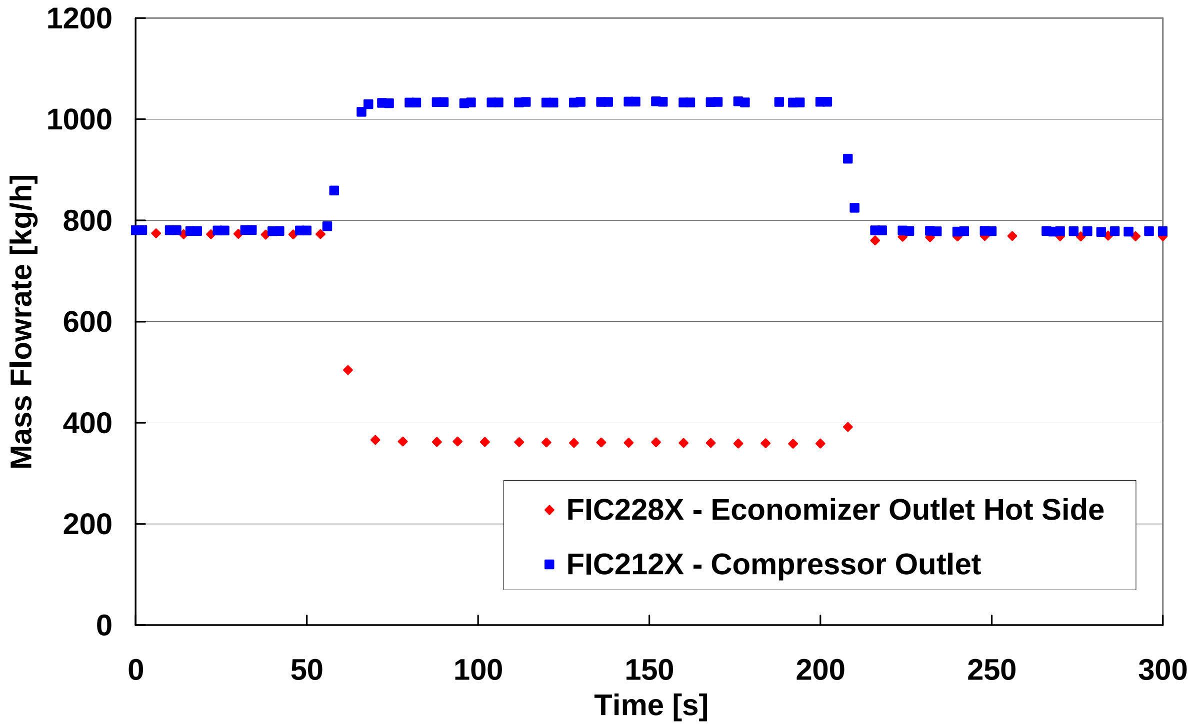


Fig. 24 – Test Section and Compressor Mass Flowrate (30LOFA09-07-98)

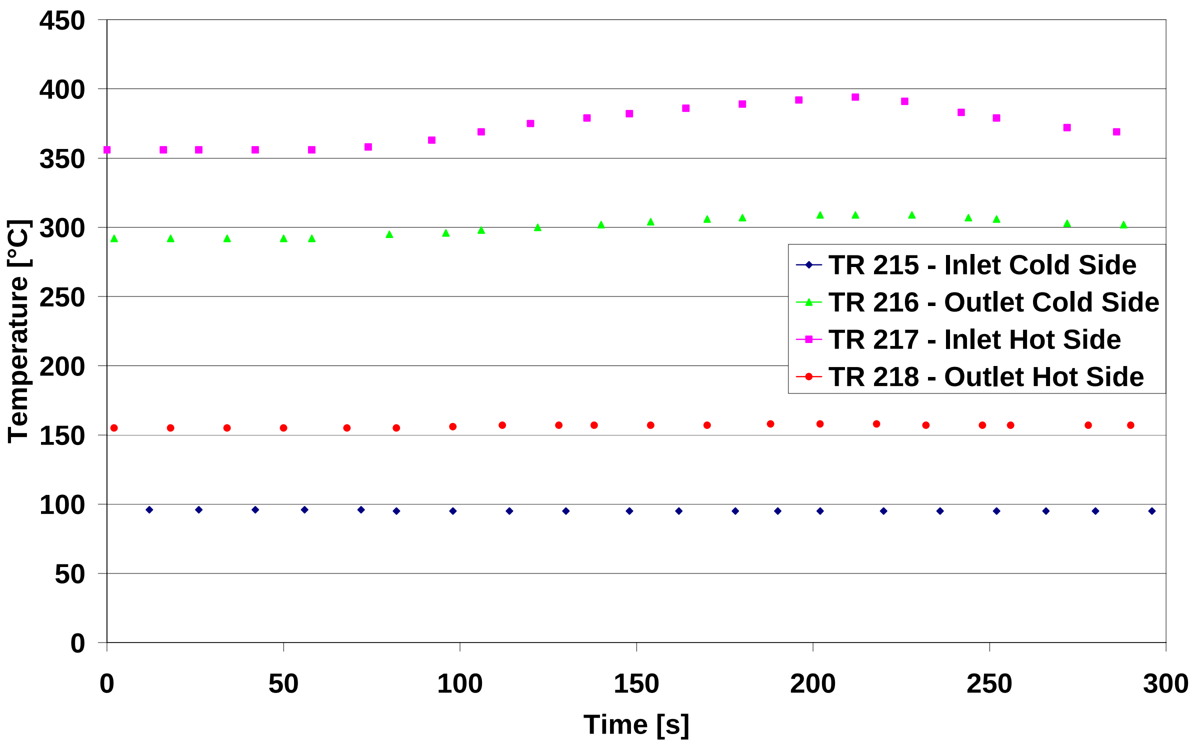


Fig. 25 – Economizer Temperatures (30LOFA09-07-98)

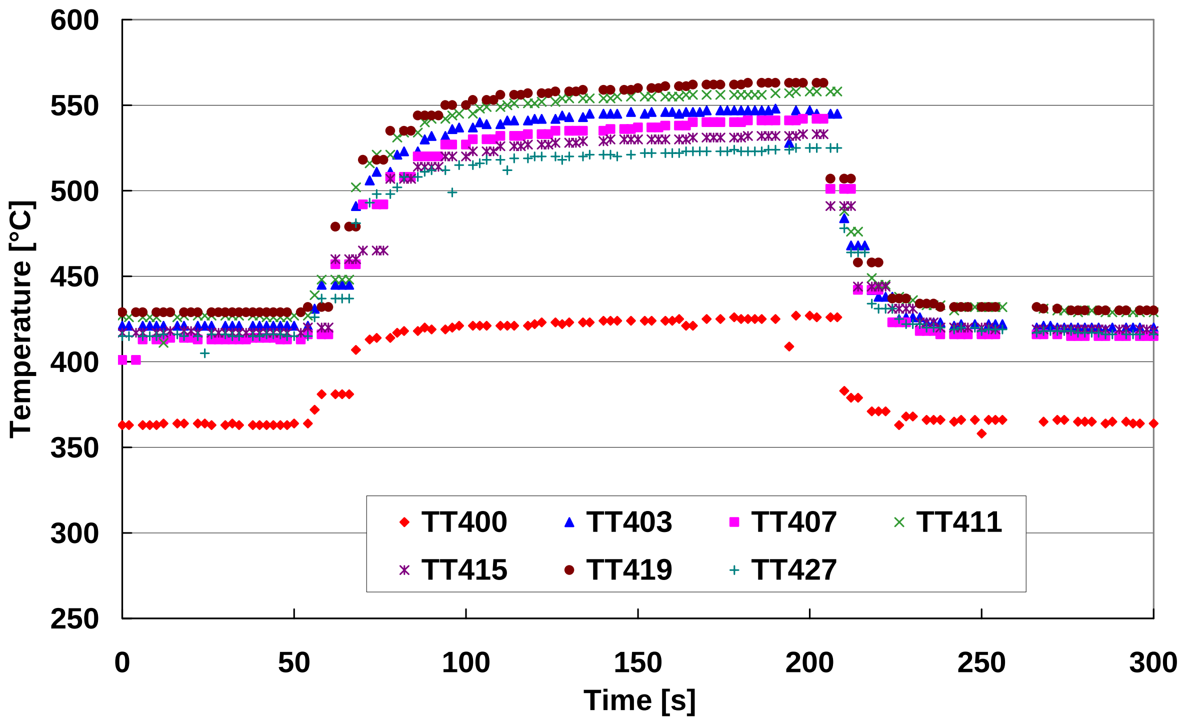


Fig. 26 – Thermocouple Temperatures on 7 TS Positions (30LOFA09-07-98)

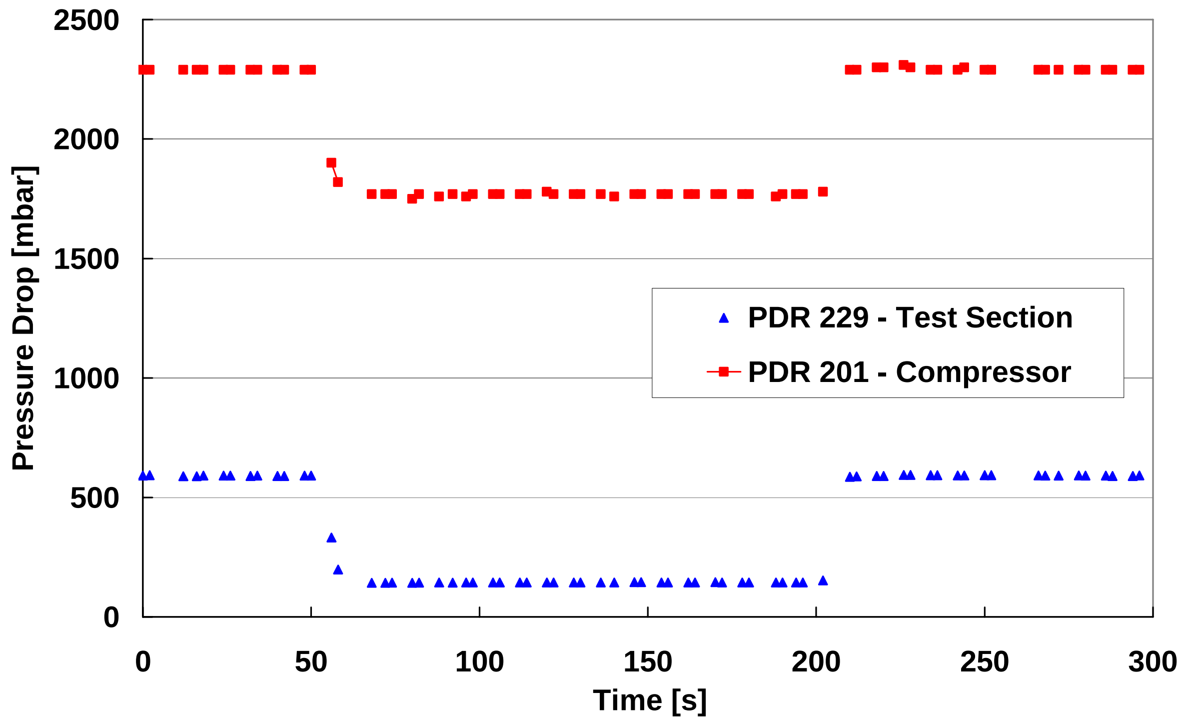


Fig. 27 – TS and Compressor Pressure Drop (30LOFA09-07-98)

SENSOR	RESISTOR	SENSOR HEIGHT
TT400	R1	250
TT401	R1	750
TT402	R1	1250
TT403	R1	1750
TT404	R2	250
TT405	R2	750
TT406	R2	1250
TT407	R2	1750
TT408	R3	250
TT409	R3	750
TT410	R3	1250
TT411	R3	1750
TT412	R4	250
TT413	R4	750
TT414	R4	1250
TT415	R4	1750
TT416	R5	250
TT417	R5	750
TT418	R5	1250
TT419	R5	1750
TT420	R6	250
TT421	R6	750
TT422	R6	1250
TT423	R6	1750
TT424	R7	250
TT425	R7	750
TT426	R7	1250
TT427	R7	1750

Thermocouples location

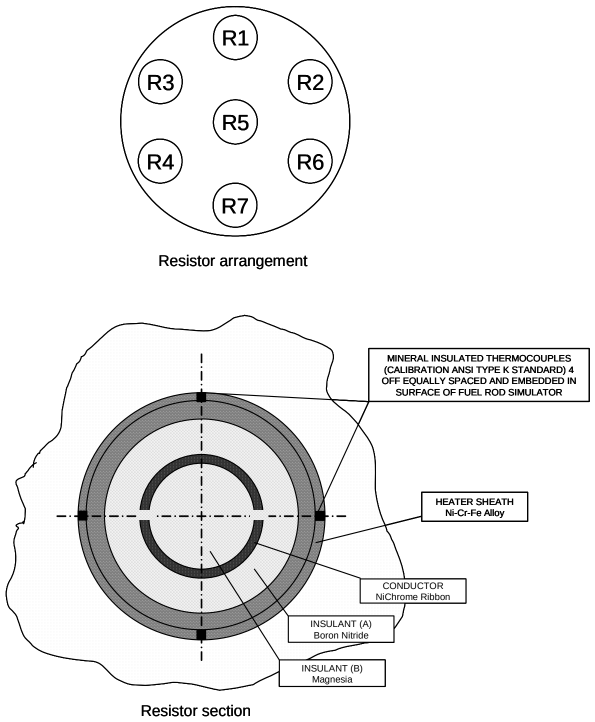


Fig. 28 - Test Section Thermocouples Location

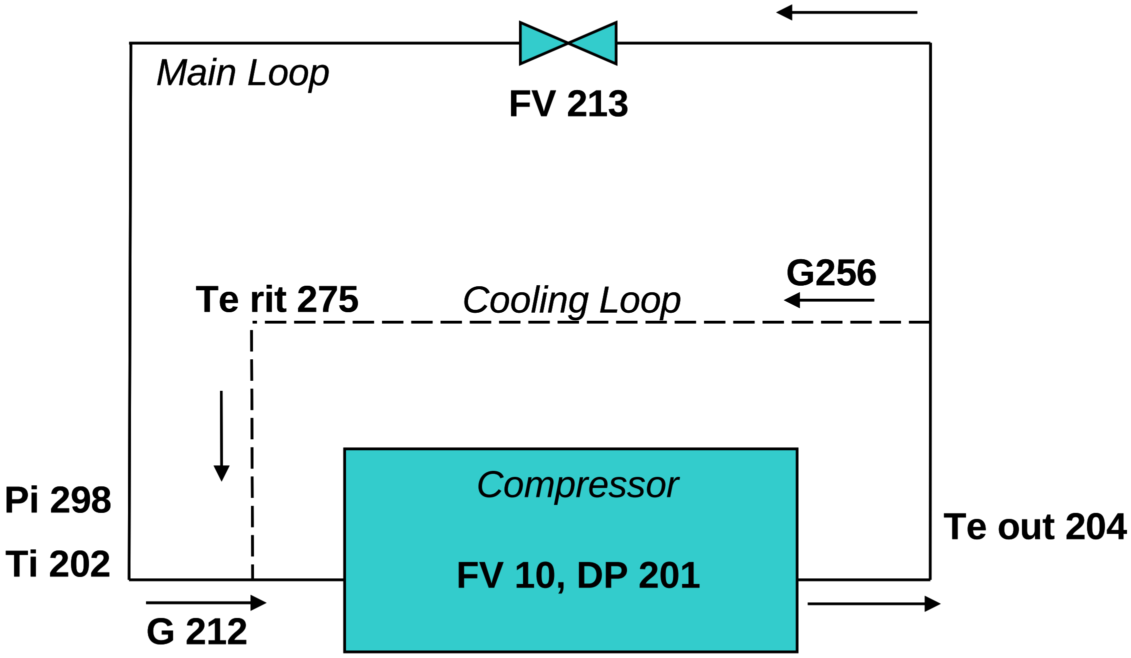
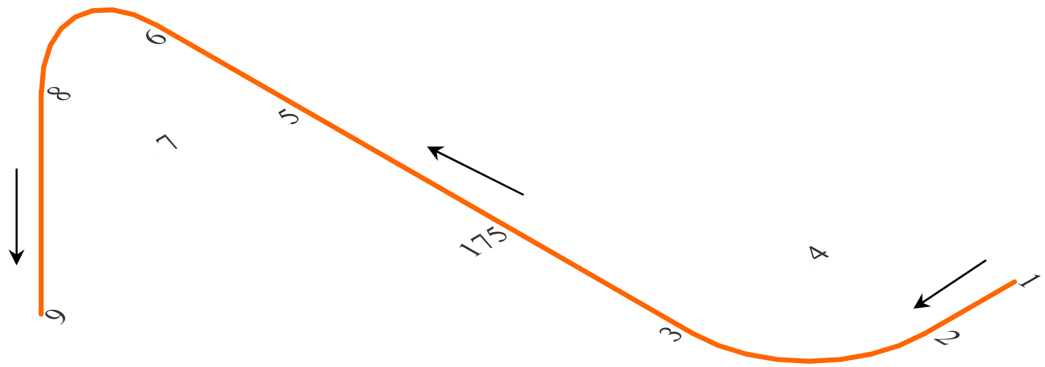


Fig. 29 – Scheme of the Compressor Characterization Test

Appendix A: Loop Noding for Thermo-mechanical Analysis

LINE A

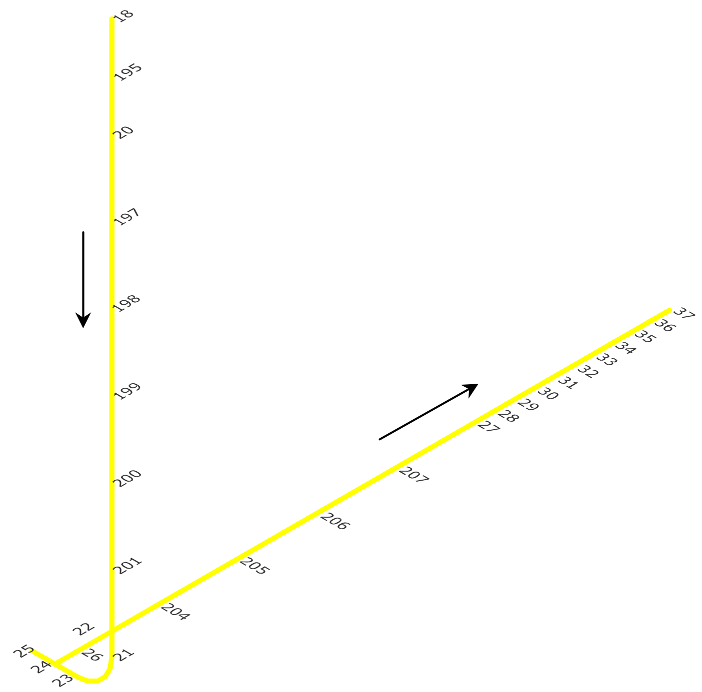


Element	Material	NODE	X	Y	Z	Outside Diameter	Pipe Thickness	Bend Radius	Insulator Thickness	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	1	1	2.3338	-4.5909	11.6520	0.1413	9.52E-03		160	520	10
C	1	2	2.3338	-4.7398	11.6520	0.1413	9.52E-03		160	520	10
C	1	3	2.1433	-4.9303	11.6520	0.1413	9.52E-03		160	520	10
RC	1	4	2.1433	-4.7398	11.6520	0.1413	9.52E-03	0.1905	160	520	10
D	1	175	1.8285	-4.9303	11.6520	0.1413	9.52E-03		160	520	10
D	1	5	1.5138	-4.9303	11.6520	0.1413	9.52E-03		160	520	10
C	1	6	1.2576	-4.9303	11.6520	0.1413	9.52E-03		160	520	10
C	1	8	1.0671	-4.9303	11.4620	0.1413	9.52E-03		160	520	10
RC	1	7	1.2576	-4.9303	11.4620	0.1413	9.52E-03	0.1905	160	520	10
D	1	9	1.0671	-4.9303	11.1420	0.1413	9.52E-03		160	520	10

LEGEND:

- D → Straight Element
- C → Curve Element
- RC → Bending Center
- T → T-Shape Element

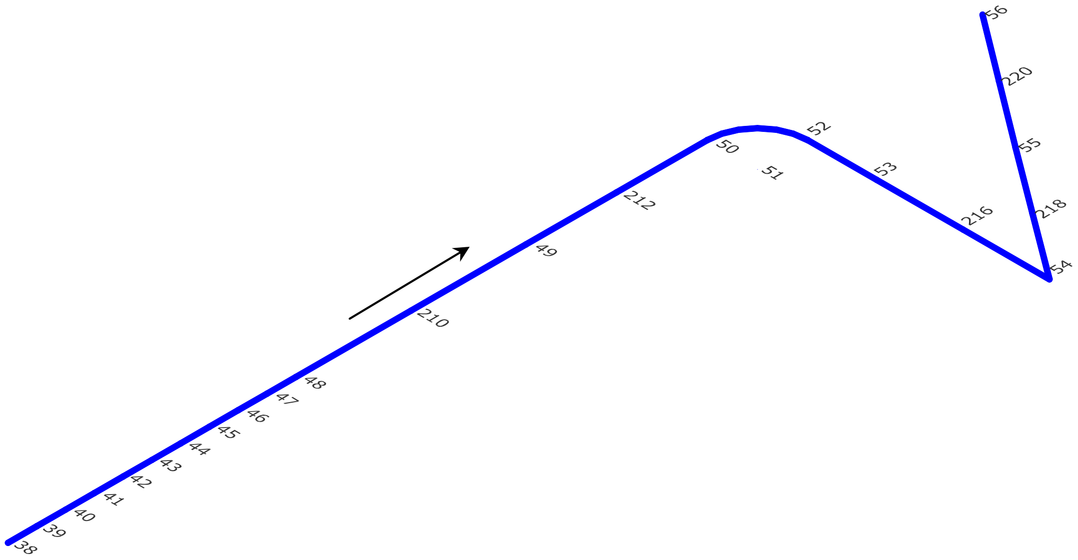
LINE B



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	2	18	1.0671	-4.9303	5.9061	0.1413	9.52E-03		100	240	10
D	2	195	1.0671	-4.9303	5.6828	0.1413	9.52E-03		100	240	10
D	2	20	1.0671	-4.9303	5.4595	0.1140	8.56E-03		100	240	10
D	2	197	1.0671	-4.9303	5.1248	0.1140	8.56E-03		100	240	10
D	2	198	1.0671	-4.9303	4.7900	0.1140	8.56E-03		100	240	10
D	2	199	1.0671	-4.9303	4.4553	0.1140	8.56E-03		100	240	10

D	2	200	1.0671	-4.9303	4.1206	0.1140	8.56E-03		100	240	10
D	2	201	1.0671	-4.9303	3.7859	0.1140	8.56E-03		100	240	10
C	2	21	1.0671	-4.9303	3.4512	0.1140	8.56E-03		100	240	10
RC	2	22	0.91488	-4.9303	3.4512	0.1140	8.56E-03	0.1522	100	240	10
T	2	23	0.91488	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	2	24	0.81561	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	2	26	0.81561	-4.8310	3.2990	0.1140	8.56E-03		100	240	10
T	2	25	0.71635	-4.9303	3.2990	0.1413	8.56E-03		100	240	10
D	2	204	0.81561	-4.4803	3.2990	0.1413	9.52E-03		100	240	10
D	2	205	0.81561	-4.1295	3.2990	0.1413	9.52E-03		100	240	10
D	2	206	0.81561	-3.7787	3.2990	0.1413	9.52E-03		100	240	10
D	2	207	0.81561	-3.4279	3.2990	0.1413	9.52E-03		100	240	10
D	2	27	0.81561	-3.0771	3.2990	0.1413	9.52E-03		100	240	10
D	2	28	0.81561	-2.9903	3.2990	0.1413	9.52E-03		100	240	10
D	2	29	0.81561	-2.9034	3.2990	0.1413	9.52E-03		100	240	10
D	2	30	0.81561	-2.8166	3.2990	0.1413	9.52E-03		100	240	10
D	2	31	0.81561	-2.7297	3.2990	0.1413	9.52E-03		100	240	10
D	2	32	0.81561	-2.6429	3.2990	0.1413	9.52E-03		100	240	10
D	2	33	0.81561	-2.5560	3.2990	0.1413	9.52E-03		100	240	10
D	2	34	0.81561	-2.4692	3.2990	0.1413	9.52E-03		100	240	10
D	2	35	0.81561	-2.3823	3.2990	0.1413	9.52E-03		100	240	10
D	2	36	0.81561	-2.2955	3.2990	0.1413	9.52E-03		100	240	10
D	2	37	0.81561	-2.2086	3.2990	0.1413	9.52E-03		100	240	10

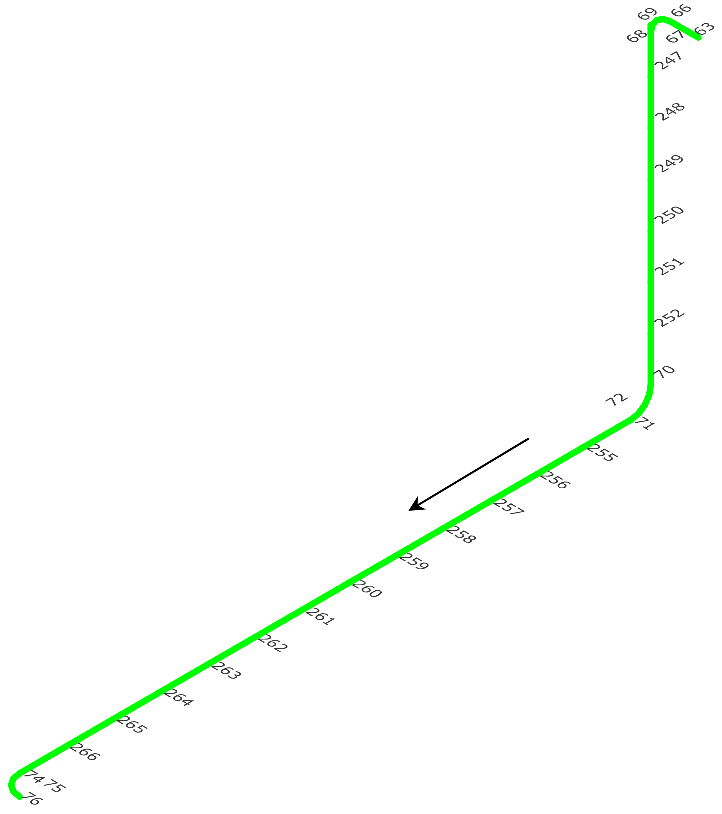
LINE C+P



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	3	38	0.23575	-3.07710	1.2890	0.1140	8.56E-03		60	100	10
D	3	39	0.23575	-2.99030	1.2890	0.1140	8.56E-03		60	100	10
D	3	40	0.23575	-2.90340	1.2890	0.1140	8.56E-03		60	100	10
D	3	41	0.23575	-2.81660	1.2890	0.1140	8.56E-03		60	100	10
D	3	42	0.23575	-2.72970	1.2890	0.1140	8.56E-03		60	100	10
D	3	43	0.23575	-2.64290	1.2890	0.1140	8.56E-03		60	100	10
D	3	44	0.23575	-2.55600	1.2890	0.1140	8.56E-03		60	100	10
D	3	45	0.23575	-2.46920	1.2890	0.1140	8.56E-03		60	100	10
D	3	46	0.23575	-2.38230	1.2890	0.1140	8.56E-03		60	100	10

D	3	47	0.23575	-2.29550	1.2890	0.1140	8.56E-03		60	100	10
D	3	48	0.23575	-2.20860	1.2890	0.1140	8.56E-03		60	100	10
D	3	210	0.23575	-1.86120	1.2890	0.1140	8.56E-03		60	100	10
D	3	49	0.23575	-1.51380	1.2890	0.1140	8.56E-03		60	100	10
D	3	212	0.23575	-1.24080	1.2890	0.1140	8.56E-03		60	100	10
C	3	50	0.23575	-0.96781	1.2890	0.1140	8.56E-03		60	100	10
C	3	52	0.38795	-0.96781	1.2890	0.1140	8.56E-03		60	100	10
RC	3	51	0.38795	-0.81561	1.2890	0.1140	8.56E-03	0.1522	60	100	10
D	3	53	0.59558	-0.81561	1.2890	6.03E-02	2.77E-03		60	100	10
D	3	216	0.85614	-0.81561	1.2890	6.03E-02	2.77E-03		60	100	10
D	3	54	1.11670	-0.81561	1.2890	6.03E-02	2.77E-03		60	100	10
D	3	218	0.91818	-0.66837	1.2890	6.03E-02	2.77E-03		60	100	10
D	3	55	0.71966	-0.52113	1.2890	6.03E-02	2.77E-03		60	100	10
D	3	220	0.52113	-0.37224	1.2890	0.1140	8.56E-03		60	100	10
D	3	56	0.32260	-0.22334	1.2890	0.1140	8.56E-03		60	100	10

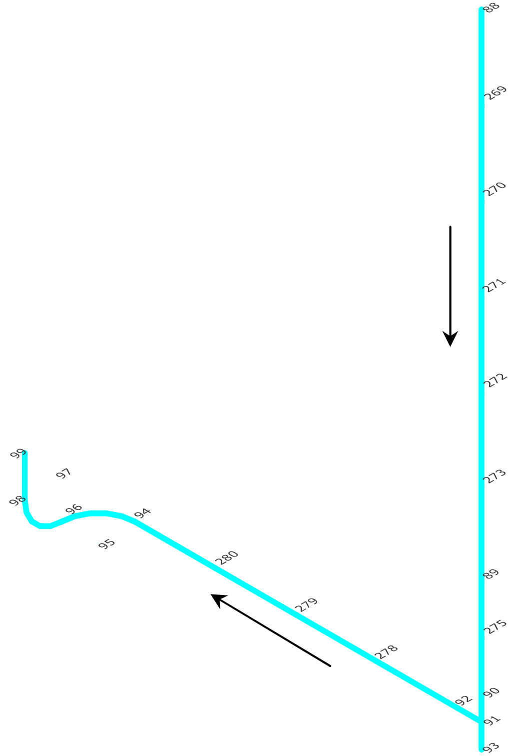
LINE D



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	4	63	-0.39705	0.00E+00	5.9061	0.1140	8.56E-03		60	140	10
C	4	66	-0.60468	0.00E+00	5.9061	0.1140	8.56E-03		60	140	10

C	4	68	-0.60468	0.00E+00	5.7539	0.1140	8.56E-03		60	140	10
RC	4	67	-0.75688	0.00E+00	5.7539	0.1140	8.56E-03	0.1522	60	140	10
D	4	69	-0.75688	0.00E+00	5.8069	0.1140	8.56E-03		60	140	10
D	4	247	-0.75688	0.00E+00	5.4704	0.1140	8.56E-03		60	140	10
D	4	248	-0.75688	0.00E+00	5.1338	0.1140	8.56E-03		60	140	10
D	4	249	-0.75688	0.00E+00	4.7973	0.1140	8.56E-03		60	140	10
D	4	250	-0.75688	0.00E+00	4.4608	0.1140	8.56E-03		60	140	10
D	4	251	-0.75688	0.00E+00	4.1243	0.1140	8.56E-03		60	140	10
D	4	252	-0.75688	0.00E+00	3.7878	0.1140	8.56E-03		60	140	10
C	4	70	-0.75688	0.00E+00	3.4512	0.1140	8.56E-03		60	140	10
C	4	72	-0.75688	-0.1522	3.4512	0.1140	8.56E-03		60	140	10
RC	4	71	-0.75688	-0.1522	3.2990	0.1140	8.56E-03	0.1522	60	140	10
D	4	255	-0.75688	-0.50804	3.2990	0.1140	8.56E-03		60	140	10
D	4	256	-0.75688	-0.86388	3.2990	0.1140	8.56E-03		60	140	10
D	4	257	-0.75688	-1.2197	3.2990	0.1140	8.56E-03		60	140	10
D	4	258	-0.75688	-1.5756	3.2990	0.1140	8.56E-03		60	140	10
D	4	259	-0.75688	-1.9314	3.2990	0.1140	8.56E-03		60	140	10
D	4	260	-0.75688	-2.2872	3.2990	0.1140	8.56E-03		60	140	10
D	4	261	-0.75688	-2.6431	3.2990	0.1140	8.56E-03		60	140	10
D	4	262	-0.75688	-2.9989	3.2990	0.1140	8.56E-03		60	140	10
D	4	263	-0.75688	-3.3547	3.2990	0.1140	8.56E-03		60	140	10
D	4	264	-0.75688	-3.7106	3.2990	0.1140	8.56E-03		60	140	10
D	4	265	-0.75688	-4.0664	3.2990	0.1140	8.56E-03		60	140	10
D	4	266	-0.75688	-4.4223	3.2990	0.1140	8.56E-03		60	140	10
C	4	74	-0.75688	-4.7781	3.2990	0.1140	8.56E-03		60	140	10
RC	4	75	-0.60468	-4.7781	3.2990	0.1140	8.56E-03	0.1522	60	140	10
C	4	76	-0.60468	-4.9303	3.2990	0.1140	8.56E-03		60	140	10

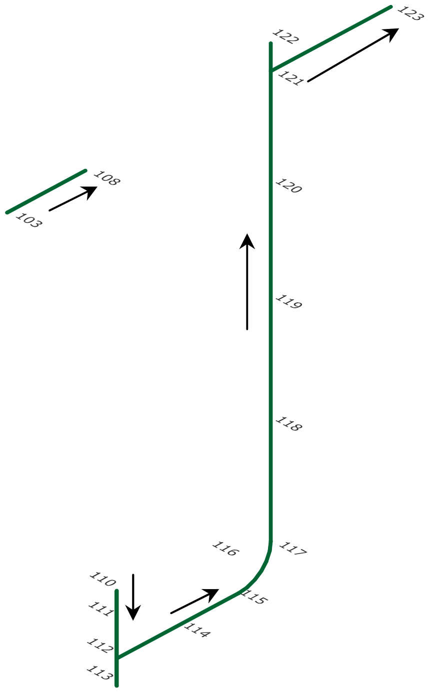
LINE E



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	5	88	1.0671	-4.1690	10.7450	0.1140	8.56E-03		160	420	10
D	5	269	1.0671	-4.1690	10.4020	0.1140	8.56E-03		160	420	10
D	5	270	1.0671	-4.1690	10.0590	0.1140	8.56E-03		160	420	10

D	5	271	1.0671	-4.1690	9.7154	0.1140	8.56E-03		160	420	10
D	5	272	1.0671	-4.1690	9.3721	0.1140	8.56E-03		160	420	10
D	5	273	1.0671	-4.1690	9.0288	0.1140	8.56E-03		160	420	10
D	5	89	1.0671	-4.1690	8.6855	0.1140	8.56E-03		160	420	10
D	5	275	1.0671	-4.1690	8.4870	0.1140	8.56E-03		160	420	10
T	5	90	1.0671	-4.1690	8.2885	0.1140	8.56E-03		160	420	10
T	5	91	1.0671	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
T	5	92	0.96781	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
T	5	93	1.0670	-4.1690	8.0899	0.1140	8.56E-03		160	420	10
D	5	278	0.63363	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
D	5	279	0.29944	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
D	5	280	-0.03470	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
C	5	94	-0.36893	-4.1690	8.1892	0.1140	8.56E-03		160	420	10
RC	5	95	-0.36893	-4.3212	8.1892	0.1140	8.56E-03	0.1522	160	420	10
C	5	96	-0.52113	-4.3212	8.1892	0.1140	8.56E-03		160	420	10
RC	5	97	-0.52113	-4.3212	8.3414	0.1140	8.56E-03	0.1522	160	420	10
C	5	98	-0.52113	-4.4734	8.3414	0.1140	8.56E-03		160	420	10
D	5	99	-0.52113	-4.4734	8.5118	0.1140	8.56E-03		160	420	10

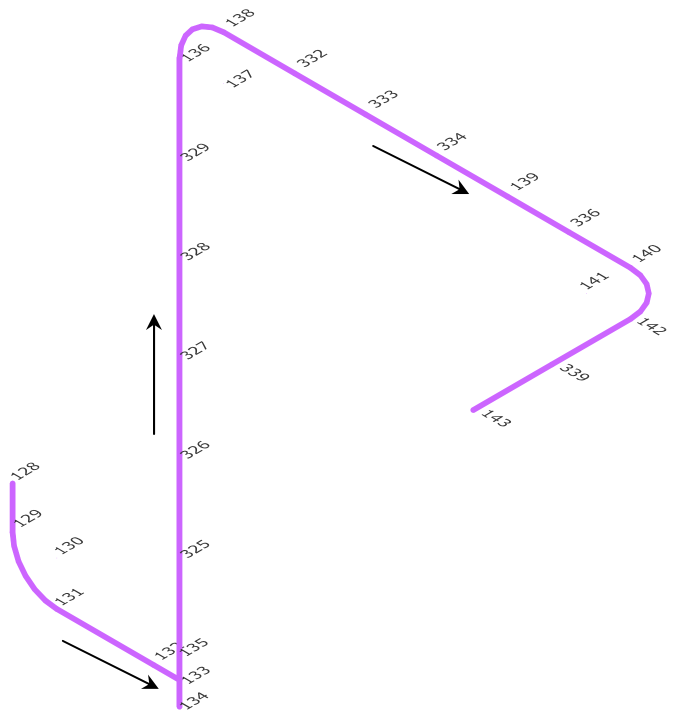
LINE F



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	6	103	-0.52113	-4.3179	10.4470	0.1413	9.52E-03		160	530	10
D	6	108	-0.52113	-3.9457	10.4470	0.1413	9.52E-03		160	530	10
D	6	110	-0.52113	-3.7968	8.5118	0.1413	9.52E-03		160	530	10
T	6	111	-0.52113	-3.7968	8.3615	0.1413	9.52E-03		160	530	10

T	6	112	-0.52113	-3.7968	8.2112	0.1413	9.52E-03		160	530	10
T	6	113	-0.52113	-3.7968	8.0899	0.1413	9.52E-03		160	530	10
T	6	114	-0.52113	-3.6603	8.2112	0.1413	9.52E-03		160	530	10
C	6	115	-0.52113	-3.2169	8.2112	0.1413	9.52E-03		160	530	10
RC	6	116	-0.52113	-3.2169	8.3634	0.1413	9.52E-03		160	530	10
C	6	117	-0.52113	-3.0647	8.3634	0.1413	9.52E-03		160	530	10
D	6	118	-0.52113	-3.0647	8.9153	0.1413	9.52E-03		160	530	10
D	6	119	-0.52113	-3.0647	9.3634	0.1413	9.52E-03		160	530	10
T	6	120	-0.52113	-3.0647	9.9153	0.1413	9.52E-03		160	530	10
T	6	121	-0.52113	-3.0647	10.4470	0.1413	9.52E-03		160	530	10
T	6	122	-0.52113	-3.0647	10.5710	0.1413	9.52E-03		160	530	10
T	6	123	-0.52113	-2.494	10.4470	0.1413	9.52E-03		160	530	10

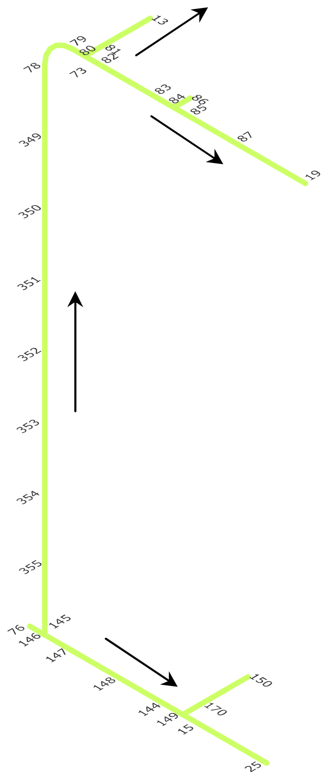
LINE G



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	7	128	-0.52113	-2.3327	8.5118	0.1413	9.52E-03		160	420	10
C	7	129	-0.52113	-2.3327	8.3301	0.1413	9.52E-03		160	420	10
RC	7	130	-0.33063	-2.3327	8.3301	0.1413	9.52E-03	0.1905	160	420	10
C	7	131	-0.33063	-2.3327	8.1396	0.1413	9.52E-03		160	420	10
T	7	132	8.69E-02	-2.3327	8.1396	0.1413	9.52E-03		160	420	10

T	7	133	0.19853	-2.3327	8.1396	0.1413	9.52E-03		160	420	10
T	7	134	0.19853	-2.3327	8.0403	0.1413	9.52E-03		160	420	10
T	7	135	0.19853	-2.3327	8.2388	0.1413	9.52E-03		160	420	10
D	7	325	0.19853	-2.3327	8.6084	0.1413	9.52E-03		160	420	10
D	7	326	0.19853	-2.3327	8.9781	0.1413	9.52E-03		160	420	10
D	7	327	0.19853	-2.3327	9.3477	0.1413	9.52E-03		160	420	10
D	7	328	0.19853	-2.3327	9.7173	0.1413	9.52E-03		160	420	10
D	7	329	0.19853	-2.3327	10.0870	0.1413	9.52E-03		160	420	10
C	7	136	0.19853	-2.3327	10.4570	0.1413	9.52E-03		160	420	10
RC	7	137	0.38903	-2.3327	10.4570	0.1413	9.52E-03	0.1905	160	420	10
C	7	138	0.38903	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
D	7	332	0.69502	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
D	7	333	1.00100	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
D	7	334	1.30700	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
D	7	139	1.61300	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
D	7	336	1.87820	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
C	7	140	2.14330	-2.3327	10.6470	0.1413	9.52E-03		160	420	10
RC	7	141	2.14330	-2.5232	10.6470	0.1413	9.52E-03	0.1905	160	420	10
C	7	142	2.33380	-2.5232	10.6470	0.1413	9.52E-03		160	420	10
D	7	339	2.33380	-2.8622	10.6470	0.1413	9.52E-03		160	420	10
D	7	143	2.33380	-3.2012	10.6470	0.1413	9.52E-03		160	420	10

LINE H

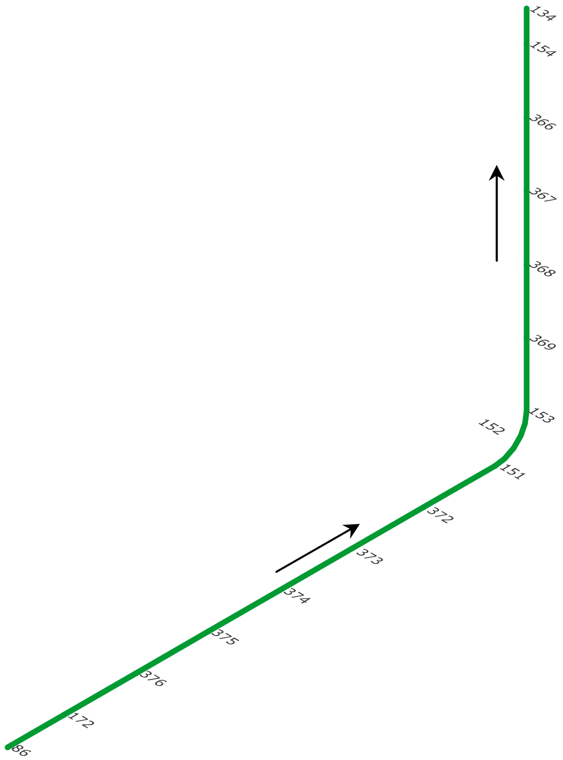


Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
C	8	78	-0.52113	-4.9303	6.0517	0.1140	8.56E-03		100	240	10
C	8	79	-0.36893	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
RC	8	73	-0.36893	-4.9303	6.0517	0.1140	8.56E-03	0.1522	100	240	10

T	8	79	-0.36893	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	80	-0.29779	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	81	-0.29779	-4.8391	6.2039	0.1140	8.56E-03		100	240	10
T	8	82	-0.19853	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	83	9.93E-02	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	84	0.19853	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	85	0.29779	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
T	8	86	0.19853	-4.8391	6.2039	0.1140	8.56E-03		100	240	10
D	8	13	-0.29779	-4.5661	6.2039	0.1140	8.56E-03		100	240	10
D	8	81	-0.29779	-4.8391	6.2039	0.1140	8.56E-03		100	240	10
D	8	82	-0.19853	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
D	8	83	9.93E-02	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
D	8	85	0.29779	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
D	8	87	0.55835	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
D	8	19	0.93208	-4.9303	6.2039	0.1140	8.56E-03		100	240	10
D	8	78	-0.52113	-4.9303	6.0517	0.1140	8.56E-03		100	240	10
D	8	349	-0.52113	-4.9303	5.7080	0.1140	8.56E-03		100	240	10
D	8	350	-0.52113	-4.9303	5.3642	0.1140	8.56E-03		100	240	10
D	8	351	-0.52113	-4.9303	5.0204	0.1140	8.56E-03		100	240	10
D	8	352	-0.52113	-4.9303	4.6766	0.1140	8.56E-03		100	240	10
D	8	353	-0.52113	-4.9303	4.3328	0.1140	8.56E-03		100	240	10
D	8	354	-0.52113	-4.9303	3.9891	0.1140	8.56E-03		100	240	10
D	8	355	-0.52113	-4.9303	3.6453	0.1140	8.56E-03		100	240	10
T	8	145	-0.52113	-4.9303	3.3015	0.1140	8.56E-03		100	240	10
T	8	76	-0.60468	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	146	-0.52113	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	147	-0.36893	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
D	8	148	-9.93E-02	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	144	0.14889	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	149	0.24816	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	15	0.34742	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
T	8	170	0.24816	-4.8310	3.2990	0.1140	8.56E-03		100	240	10

D	8	150	0.24816	-4.5661	3.2990	0.1140	8.56E-03		100	240	10
D	8	15	0.34742	-4.9303	3.2990	0.1140	8.56E-03		100	240	10
D	8	26	0.71635	-4.9303	3.2990	0.1140	8.56E-03		100	240	10

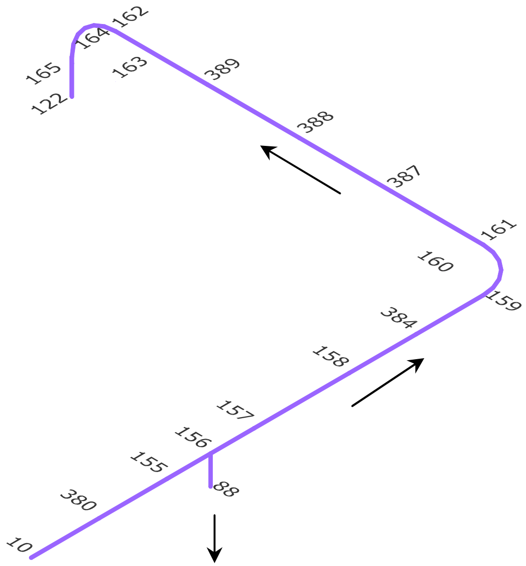
LINE I



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	9	134	0.19853	-2.3327	8.0403	0.1140	8.56E-03		100	140	10
D	9	154	0.19853	-2.3327	7.8914	0.1140	8.56E-03		100	140	10
D	9	366	0.19853	-2.3327	7.5843	0.1140	8.56E-03		100	140	10
D	9	367	0.19853	-2.3327	7.2773	0.1140	8.56E-03		100	140	10

D	9	368	0.19853	-2.3327	6.9702	0.1140	8.56E-03		100	140	10
D	9	369	0.19853	-2.3327	6.6632	0.1140	8.56E-03		100	140	10
C	9	151	0.19853	-2.4849	6.2039	0.1140	8.56E-03		100	140	10
RC	9	152	0.19853	-2.4849	6.3561	0.1140	8.56E-03	0.1522	100	140	10
C	9	153	0.19853	-2.3327	6.3561	0.1140	8.56E-03		100	140	10
D	9	372	0.19853	-2.8317	6.2039	0.1140	8.56E-03		100	140	10
D	9	373	0.19853	-3.1786	6.2039	0.1140	8.56E-03		100	140	10
D	9	374	0.19853	-3.5255	6.2039	0.1140	8.56E-03		100	140	10
D	9	375	0.19853	-3.8724	6.2039	0.1140	8.56E-03		100	140	10
D	9	376	0.19853	-4.2192	6.2039	0.1140	8.56E-03		100	140	10
D	9	172	0.19853	-4.5661	6.2039	0.1140	8.56E-03		100	140	10
D	9	86	0.19853	-4.8391	6.2039	0.1140	8.56E-03		100	140	10

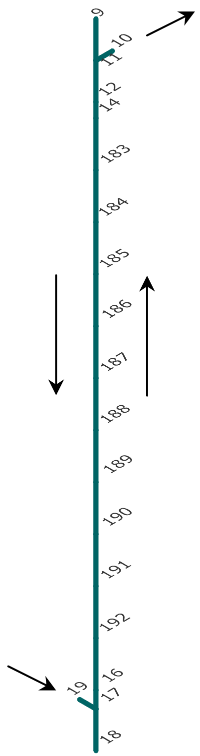
LINE L



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	10	10	1.0671	-4.7953	10.8440	0.1140	8.56E-03		160	420	10
D	10	380	1.0671	-4.5583	10.8440	0.1140	8.56E-03		160	420	10
T	10	155	1.0671	-4.3212	10.8440	0.1140	8.56E-03		160	420	10
T	10	156	1.0671	-4.1690	10.8440	0.1140	8.56E-03		160	420	10
T	10	157	1.0671	-4.0168	10.8440	0.1140	8.56E-03		160	420	10
T	10	88	1.0671	-4.1690	10.7450	0.1140	8.56E-03		160	420	10
D	10	158	1.0671	-3.6851	10.8440	0.1140	8.56E-03		160	420	10
D	10	384	1.0671	-3.4510	10.8440	0.1140	8.56E-03		160	420	10

C	10	159	1.0671	-3.2169	10.8440	0.1140	8.56E-03		160	420	10
RC	10	160	0.91488	-3.2169	10.8440	0.1140	8.56E-03	0.1522	160	420	10
C	10	161	0.91488	-3.0647	10.8440	0.1140	8.56E-03		160	420	10
D	10	387	0.59392	-3.0647	10.8440	0.1140	8.56E-03		160	420	10
D	10	388	0.27297	-3.0647	10.8440	0.1140	8.56E-03		160	420	10
D	10	389	-4.80E-02	-3.0647	10.8440	0.1140	8.56E-03		160	420	10
C	10	162	-0.36893	-3.0647	10.8440	0.1140	8.56E-03		160	420	10
RC	10	163	-0.36893	-3.0647	10.6920	0.1140	8.56E-03		160	420	10
C	10	164	-0.52113	-3.0647	10.6920	0.1140	8.56E-03		160	420	10
D	10	165	-0.52113	-3.0647	10.6710	0.1140	8.56E-03		160	420	10
D	10	122	-0.52113	-3.0647	10.5710	0.1140	8.56E-03		160	420	10

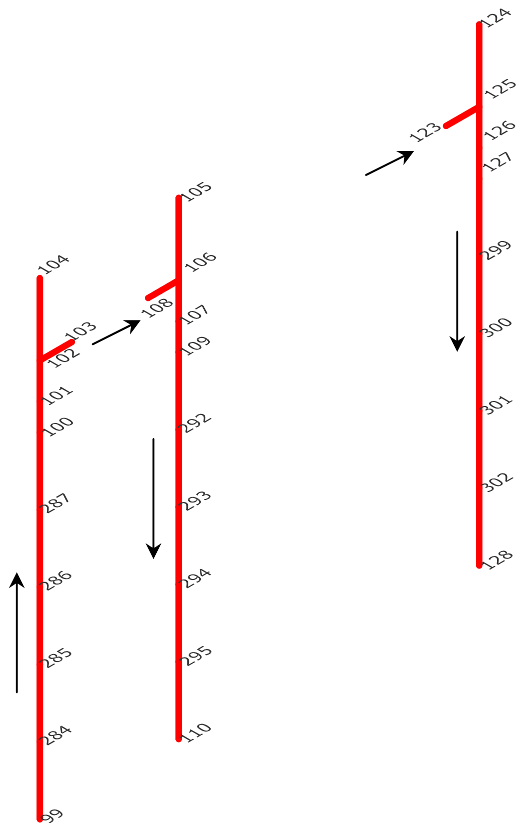
ECONOMIZER



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
T	13	9	1.0671	-4.9303	11.1420	0.31	2.00E-02		160	520	10
T	13	10	1.0671	-4.7953	10.8440	0.31	2.00E-02		160	420	10
T	13	11	1.0671	-4.9303	10.8440	0.31	2.00E-02		160	498	10
T	13	12	1.0671	-4.9303	10.5470	0.31	2.00E-02		160	476	10

D	13	13	-0.29779	-4.5661	6.2039	0.31	2.00E-02		160	140	10
D	13	14	1.0671	-4.9303	10.4310	0.31	2.00E-02		160	454	10
D	13	183	1.0671	-4.9303	10.0590	0.31	2.00E-02		160	410	10
D	13	184	1.0671	-4.9303	9.6871	0.31	2.00E-02		160	366	10
D	13	185	1.0671	-4.9303	9.3151	0.31	2.00E-02		160	322	10
D	13	186	1.0671	-4.9303	8.9431	0.31	2.00E-02		160	278	10
D	13	187	1.0671	-4.9303	8.5710	0.31	2.00E-02		160	234	10
D	13	188	1.0671	-4.9303	8.1990	0.31	2.00E-02		160	190	10
D	13	189	1.0671	-4.9303	7.8270	0.31	2.00E-02		160	146	10
D	13	190	1.0671	-4.9303	7.4550	0.31	2.00E-02		160	102	10
D	13	191	1.0671	-4.9303	7.0830	0.31	2.00E-02		160	58	10
D	13	192	1.0671	-4.9303	6.7110	0.31	2.00E-02		160	14	10
T	13	16	1.0671	-4.9303	6.3389	0.31	2.00E-02		160	212	10
T	13	17	1.0671	-4.9303	6.2039	0.31	2.00E-02		160	190	10
T	13	18	1.0671	-4.9303	5.9061	0.31	2.00E-02		160	240	10
T	13	19	0.93208	-4.9303	6.2039	0.31	2.00E-02		160	140	10

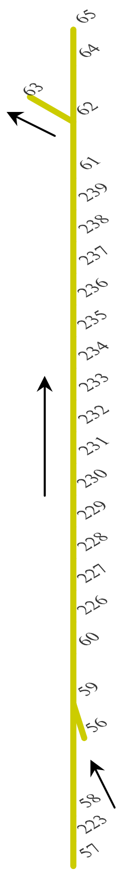
RE-HEATER



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	14	99	-0.52113	-4.4734	8.5118	0.31	2.00E-02		160	420	10
D	14	284	-0.52113	-4.4734	8.8382	0.31	2.00E-02		160	420	10

D	14	285	-0.52113	-4.4734	9.1646	0.31	2.00E-02		160	420	10
D	14	286	-0.52113	-4.4734	9.4910	0.31	2.00E-02		160	420	10
D	14	287	-0.52113	-4.4734	9.8174	0.31	2.00E-02		160	420	10
D	14	100	-0.52113	-4.4734	10.1440	0.31	2.00E-02		160	420	10
T	14	101	-0.52113	-4.4734	10.2740	0.31	2.00E-02		160	420	10
T	14	102	-0.52113	-4.4734	10.4470	0.31	2.00E-02		160	457	10
T	14	103	-0.52113	-4.3179	10.4470	0.31	2.00E-02		160	457	10
T	14	104	-0.52113	-4.4734	10.7950	0.31	2.00E-02		160	457	10
T	14	105	-0.52113	-3.7968	10.7950	0.31	2.00E-02		160	457	10
T	14	106	-0.52113	-3.7968	10.4470	0.31	2.00E-02		160	457	10
T	14	107	-0.52113	-3.7968	10.2740	0.31	2.00E-02		160	457	10
T	14	108	-0.52113	-3.9457	10.4470	0.31	2.00E-02		160	457	10
D	14	109	-0.52113	-3.7968	10.1440	0.31	2.00E-02		160	457	10
D	14	292	-0.52113	-3.7968	9.8174	0.31	2.00E-02		160	457	10
D	14	293	-0.52113	-3.7968	9.4910	0.31	2.00E-02		160	457	10
D	14	294	-0.52113	-3.7968	9.1646	0.31	2.00E-02		160	457	10
D	14	295	-0.52113	-3.7968	8.8382	0.31	2.00E-02		160	457	10
D	14	110	-0.52113	-3.7968	8.5118	0.31	2.00E-02		160	494	10
T	14	123	-0.52113	-2.4940	10.4470	0.31	2.00E-02		160	494	10
T	14	124	-0.52113	-2.3327	10.7950	0.31	2.00E-02		160	494	10
T	14	125	-0.52113	-2.3327	10.4470	0.31	2.00E-02		160	494	10
T	14	126	-0.52113	-2.3327	10.2740	0.31	2.00E-02		160	494	10
D	14	127	-0.52113	-2.3327	10.1440	0.31	2.00E-02		160	494	10
D	14	299	-0.52113	-2.3327	9.8174	0.31	2.00E-02		160	494	10
D	14	300	-0.52113	-2.3327	9.4910	0.31	2.00E-02		160	494	10
D	14	301	-0.52113	-2.3327	9.1646	0.31	2.00E-02		160	494	10
D	14	302	-0.52113	-2.3327	8.8382	0.31	2.00E-02		160	494	10
D	14	128	-0.52113	-2.3327	8.5118	0.31	2.00E-02		160	530	10

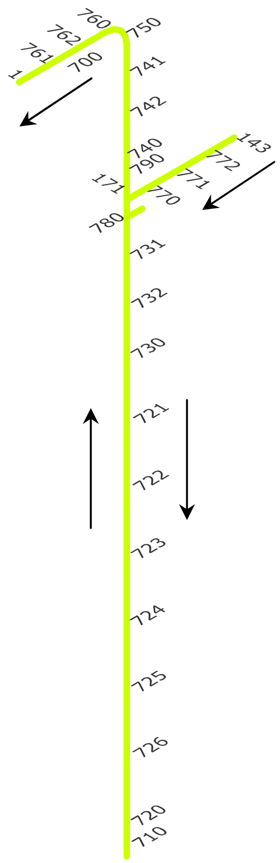
TANK



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	15	57	0.00E+00	0.00E+00	0.00E+00	0.89	4.50E-02		160	100	10

D	15	223	0.00E+00	0.00E+00	0.19853	0.89	4.50E-02		160	100	10
T	15	56	0.3226	-0.22334	1.2890	0.89	4.50E-02		160	100	10
T	15	58	0.00E+00	0.00E+00	0.39705	0.89	4.50E-02		160	100	10
T	15	59	0.00E+00	0.00E+00	1.2890	0.89	4.50E-02		160	100	10
T	15	60	0.00E+00	0.00E+00	1.6860	0.89	4.50E-02		160	100	10
D	15	226	0.00E+00	0.00E+00	1.9376	0.89	4.50E-02		160	100	10
D	15	227	0.00E+00	0.00E+00	2.1891	0.89	4.50E-02		160	100	10
D	15	228	0.00E+00	0.00E+00	2.4407	0.89	4.50E-02		160	100	10
D	15	229	0.00E+00	0.00E+00	2.6923	0.89	4.50E-02		160	100	10
D	15	230	0.00E+00	0.00E+00	2.9438	0.89	4.50E-02		160	100	10
D	15	231	0.00E+00	0.00E+00	3.1954	0.89	4.50E-02		160	100	10
D	15	232	0.00E+00	0.00E+00	3.4470	0.89	4.50E-02		160	100	10
D	15	233	0.00E+00	0.00E+00	3.6985	0.89	4.50E-02		160	100	10
D	15	234	0.00E+00	0.00E+00	3.9501	0.89	4.50E-02		160	100	10
D	15	235	0.00E+00	0.00E+00	4.2016	0.89	4.50E-02		160	100	10
D	15	236	0.00E+00	0.00E+00	4.4532	0.89	4.50E-02		160	100	10
D	15	237	0.00E+00	0.00E+00	4.7048	0.89	4.50E-02		160	100	10
D	15	238	0.00E+00	0.00E+00	4.9563	0.89	4.50E-02		160	100	10
D	15	239	0.00E+00	0.00E+00	5.2079	0.89	4.50E-02		160	100	10
T	15	61	0.00E+00	0.00E+00	5.4595	0.89	4.50E-02		160	100	10
T	15	62	0.00E+00	0.00E+00	5.9061	0.89	4.50E-02		160	140	10
T	15	63	-0.39705	0.00E+00	5.9061	0.89	4.50E-02		160	140	10
T	15	64	0.00E+00	0.00E+00	6.3528	0.89	4.50E-02		160	140	10
D	15	65	0.00E+00	0.00E+00	6.6382	0.89	4.50E-02		160	140	10

TEST SECTION



Element	Material	NODE	X	Y	Z	Outside Diam.	Pipe Thick	Bend Radius	Insulator Thick.	Temp	Press
Type	n°	n°	m	m	m	m	m	m	mm	°C	MPa
D	17	1	2.3338	-4.5909	11.6520	8.89E-02	7.62E-03		160	520	10

D	17	761	2.3338	-4.4037	11.6520	8.89E-02	7.62E-03		160	520	10
D	17	762	2.3338	-4.2166	11.6520	8.89E-02	7.62E-03		160	520	10
C	17	760	2.3338	-4.0294	11.6520	8.89E-02	7.62E-03		160	520	10
C	17	750	2.3338	-3.8961	11.5190	8.89E-02	7.62E-03		160	520	10
RC	17	700	2.3338	-4.0294	11.5190	8.89E-02	7.62E-03	0.1333	160	520	10
D	17	741	2.3338	-3.8961	11.2920	8.89E-02	7.62E-03		160	520	10
D	17	742	2.3338	-3.8961	11.0660	8.89E-02	7.62E-03		160	520	10
D	17	740	2.3338	-3.8961	10.8400	0.1413	1.91E-02		160	520	10
T	17	790	2.3338	-3.8961	10.7470	0.1413	1.91E-02		160	520	10
T	17	171	2.3338	-3.8961	10.6470	0.1413	1.91E-02		160	520	10
T	17	770	2.3338	-3.7961	10.6470	0.1413	1.91E-02		160	520	10
T	17	780	2.3338	-3.7961	10.5470	0.1413	1.91E-02		160	520	10
D	17	771	2.3338	-3.5978	10.6470	8.89E-02	7.62E-03		160	520	10
D	17	772	2.3338	-3.3995	10.6470	8.89E-02	7.62E-03		160	520	10
D	17	143	2.3338	-3.2012	10.6470	8.89E-02	7.62E-03		160	520	10
D	17	780	2.3338	-3.8961	10.5470	0.1413	1.91E-02		160	520	10
D	17	731	2.3338	-3.8961	10.2690	0.1413	1.91E-02		160	520	10
D	17	732	2.3338	-3.8961	9.9917	0.1413	1.91E-02		160	520	10
D	17	730	2.3338	-3.8961	9.7140	0.1413	1.91E-02		160	520	10
D	17	721	2.3338	-3.8961	9.3407	8.89E-02	7.62E-03		160	520	10
D	17	722	2.3338	-3.8961	8.9674	8.89E-02	7.62E-03		160	520	10
D	17	723	2.3338	-3.8961	8.5941	8.89E-02	7.62E-03		160	520	10
D	17	724	2.3338	-3.8961	8.2209	8.89E-02	7.62E-03		160	520	10
D	17	725	2.3338	-3.8961	7.8476	8.89E-02	7.62E-03		160	520	10
D	17	726	2.3338	-3.8961	7.4743	8.89E-02	7.62E-03		160	520	10
D	17	720	2.3338	-3.8961	7.1010	8.89E-02	7.62E-03		160	520	10
D	17	710	2.3338	-3.8961	6.9770	8.89E-02	7.62E-03		160	520	10

Appendix B: HE-FUS3 Experimental Data

HE-FUS3 Steady State Tests	TR 218	TR 215	TR 217	TR 216	FIC 228X	TR 239	TIC 242X	TR 267	TR 266	TIC 242W	TR 202	TR 204	PDR 201	FIC 212W	FIC 212X	FIC 228W	FIC 228Y	ZR 235	ZR 213	ZR 234	TR 220
1ST24-06-98	134.00	88.00	306.00	251.00	795.04	140.00	75.00	14.00	102.00	75.00	78.00	99.00	233.00	449.83	802.61	699.71	1.10	-3.00	101.00	-4.00	242.00
2ST24-06-98	140.00	94.00	307.00	254.00	802.21	146.00	75.03	14.00	102.00	75.00	78.60	99.90	235.20	449.83	809.63	699.71	1.10	-3.00	101.00	-4.00	244.80
4ST24-06-98	138.00	96.00	307.00	256.00	623.17	145.00	75.04	15.00	108.00	75.00	78.00	104.00	270.00	449.83	627.93	699.71	0.50	-3.00	70.00	-4.00	246.00
5ST24-06-98	152.40	96.00	366.40	296.20	791.90	159.40	74.99	15.00	104.00	75.00	78.00	99.00	234.00	449.83	799.32	699.71	1.10	-3.00	101.00	-4.00	284.00
6ST24-06-98	165.00	95.00	424.00	340.00	787.84	173.00	75.01	15.00	106.00	75.00	78.00	99.00	237.20	449.83	795.81	699.71	1.10	-3.00	101.00	-4.00	327.85
7ST-06-98	185.00	94.00	415.00	360.00	806.04	193.00	75.00	11.00	109.00	75.00	78.00	99.00	232.00	449.83	818.36	699.71	1.10	-3.00	102.00	38.00	349.00
8ST-06-98	185.00	94.00	415.00	360.00	807.01	193.00	74.98	12.00	109.00	75.00	78.00	99.00	232.50	449.83	818.26	699.71	1.10	-3.00	101.50	37.30	349.00
9ST-06-98	186.00	95.00	416.00	361.50	807.07	194.00	75.00	16.00	107.00	75.00	77.50	99.00	231.00	449.83	817.51	699.71	1.10	-3.00	101.00	38.00	350.00
40%ST19-02-99	230.00	90.00	521.00	460.00	352.07	234.00	75.00	5.00	137.00	75.00	74.00	99.00	112.40	359.86	359.36	699.71	1.10	-4.00	88.00	47.70	455.00
30%ST19-02-99	204.00	89.00	467.00	408.00	352.00	208.00	75.00	8.00	131.00	75.00	74.00	98.00	112.40	360.00	360.00	700.00	1.10	-4.00	88.00	42.00	404.00

Tab. B1 – Steady State Tests (cont’d)

HE-FUS3 Steady State Tests	TR 221	TR 226	TIC 222X	TIC 222W	TIC 222Y	TR 225	TIC 223X	TIC 223W	TIC 223Y	TR 224	TIC 232X	TIC 232W	TR 233	TR 241	TR 236	TR 297	TIC 242Y	TIC 232Y	ST 270	PR 298	PR 206	PR 227	PDR 229	FIC 212Y
1ST24-06-98	250.00	243.95	269.88	269.97	0.38	269.00	300.04	300.00	0.57	291.00	301.07	499.99	392.00	76.00	303.00	268.00	0.17	-0.05	127.00	47.00	50.00	50.00	568.00	0.72
2ST24-06-98	253.00	246.30	270.00	269.97	0.30	270.00	299.96	300.00	0.56	291.00	301.23	499.99	398.00	76.00	303.10	268.80	0.20	-0.05	128.60	48.00	51.00	50.00	573.10	0.72
4ST24-06-98	255.00	248.00	269.93	269.97	0.23	270.00	299.89	300.00	0.44	291.00	301.14	499.99	402.00	76.00	303.00	269.00	0.13	-0.05	143.00	48.00	51.00	50.00	360.00	0.72
5ST24-06-98	286.60	284.80	274.15	269.97	-0.05	282.20	300.16	300.00	0.37	291.80	301.55	499.99	466.80	75.60	303.60	272.80	0.24	-0.05	143.00	48.00	51.00	51.00	597.60	0.72
6ST24-06-98	331.85	328.85	320.07	269.97	-0.05	328.71	310.28	300.00	-0.05	311.86	310.75	300.00	531.29	75.14	313.57	318.86	0.28	-0.05	143.00	48.00	51.00	51.00	632.29	0.72
7ST-06-98	358.00	351.00	348.41	269.97	-0.05	357.00	342.74	300.00	-0.05	344.00	300.00	300.00	503.00	75.00	346.00	346.00	0.31	0.04	111.00	48.00	51.00	51.00	655.00	0.72
8ST-06-98	358.00	351.00	348.36	269.97	-0.05	357.00	342.71	300.00	-0.05	344.00	299.89	300.00	507.80	75.00	346.00	346.80	0.31	0.63	115.80	48.00	51.00	51.00	655.70	0.72
9ST-06-98	359.00	351.00	348.85	269.97	-0.05	358.00	343.91	300.00	-0.05	345.00	299.96	300.00	526.00	75.00	348.00	348.00	0.35	0.64	143.00	48.00	51.00	51.00	659.00	0.72
40%ST19-02-99	448.00	455.00	445.65	419.97	-0.05	456.00	432.86	419.97	-0.05	433.00	350.06	349.99	392.00	72.00	433.60	442.60	0.39	0.51	181.40	22.00	23.00	24.00	466.60	0.55
30%ST19-02-99	399.00	403.00	420.00	420.00	0.10	423.00	420.00	420.00	0.05	417.00	350.00	350.00	280.00	72.00	421.00	417.00	0.51	0.68	141.82	22.00	24.00	24.00	441.00	0.79

Tab. B1 – Steady State Tests

50LOFA09-07-98 day/hour	TR 218	TR 215	TR 217	TR 216	FIC 228X	TR 239	TIC 242X	TR 267	TR 266	TIC 242W	TR 202	TR 204	PDR 201	FIC 212W	FIC 212X	FIC 228W	FIC 228Y	ZR 235	ZR 213	ZR 234	TR 220	TR 221	TR 226	TIC 222X	TIC 222W	TIC 222Y	TR 225	TIC 223X	TIC 223W	TIC 223Y	TR 224	TIC 232X	TIC 232W	TR 233	TR 241	TR 236	TR 297	TIC 242Y	TIC 232Y	ST 270	PR 298	PR 206	PR 227	PDR 229	FIC 212Y	TT 400	TT 403	TT 407	TT 411	TT 415	TT 419	TT 427
09/07/98 13.41.00					770		74			75						699	1																	420				0	0							426	544	523	576	530	553	516
09/07/98 13.41.02	173					176		13				100	227	449	778			-2	101	17		332		328	270	0		317	300	0		300	300	420	74					127	46	49	49	622	72	415	544	523	576	530	553	517
09/07/98 13.41.04																																		420												415	544	523	576	530	553	517
09/07/98 13.41.06		96				176			108				228	449	778			-2	101	17			336	328	270	0		318	300	0		300	300	420		321				127	46	49	49	622	72	427	544		577	530		516
09/07/98 13.41.08					770		75			75						699	1																	420				0	0							427	544	522	577	531	554	516
09/07/98 13.41.10			410			176							228	449	778			-2	101	17				328	270	0	337	318	300	0	320	300	300	420			327			127	46	49	49	624	72	426	544	522	576	531	554	516
09/07/98 13.41.12																																		420												426	544	522	576	531	554	516
09/07/98 13.41.14				339		176					75		223	449	780			19	101	17	335			328	270	0		318	300	0		300	300	420						127	46	49	49	587	72	414	525		577	531		517
09/07/98 13.41.16					764		75			75						699	1																	420				0	0							414	525	528	577	538	560	517
09/07/98 13.41.18	174					160		13				99	190	449	841			78	101	17		332		328	270	0		318	300	0		300	300	421	74					127	47	49	49	302	72	441	568		601			535
09/07/98 13.41.20																																																528		538	560	
09/07/98 13.41.22		96				138			108				177	449	957			96	101	18			336	328	270	0	337	318	300	0		300	300	425		321				127	47	49	49	161	72	474	623	528	645	538	560	576
09/07/98 13.41.24					456		76			75						699	1																					0	0									605		605	643	
09/07/98 13.41.26			410			131							175						101		335										320			433			326			127	47	49	49	155		502	664		675			610
09/07/98 13.41.28														449	1010			101		20				328	270	0		318	300	0		302	300												72			605		605	643	
09/07/98 13.41.30	173			341		129		13			75		176	449	1022			101	101	20		332		328	270	0		317	300	0		303	300	440	74					127	47	49	49	155	72	518	701	605	701	605	643	628
09/07/98 13.41.32					364		77			75						699	1																					0	0									678		660	708	
09/07/98 13.41.34		96				128			107			96	176	449	1025			102	101	21				328	270	0		318	300	0		302	300	449						127	47	49	49	155	72	529	708		716			649
09/07/98 13.41.36																																																678		660	708	
09/07/98 13.41.38			414			126							176	449	1025			102	101	21			336	328	270	0	337	317	300	0		303	300	457		320				127	47	49	49	155	72	538	715	678	727	660	708	664
09/07/98 13.41.40					359		77			75						699	1																					0	0									712		694	739	
09/07/98 13.41.42						126							175	449	1024			102	101	22	336			328	270	0		318	300	0	320	302	300	465			327			127	47	49	49	155	72	544	721	712	742	694	739	670
09/07/98 13.41.44																																																712		694	739	
09/07/98 13.41.46	174			343		125		13			76		176	449	1026			102	101	23		332		328	270	0		318	300	0		302	300	470	76					127	47	49	49	157	72	547	728		752	694		681
09/07/98 13.41.48					358		76			75						699	1																					0	0									730		715	759	
09/07/98 13.41.50		95				125			105			96	175	449	1025			102	101	23			337	328	270	0		317	300	0		302	300	475		321				127	47	49	49	156	72	550	731	730	762	715	759	689
09/07/98 13.41.52																																		475												550	731	730	762	715	759	689
09/07/98 13.41.54			425			124							175	449	1026			102	101	23				328	270	0	337	318	300	0	320	301	300	481			327			127	47	49	49	157	72	551	734		771	715		693
09/07/98 13.41.56					358		75			75						699	1																	481				0	0							551	734	741	771	733	772	693
09/07/98 13.41.58				345		124					76		175	449	1028			102	101	24	337			328	270	0		317	300	0		301	300	485						127	47	49	49	156	72	553	733	741	778	733	772	700
09/07/98 13.42.00																																		485												553	733	741	778	733	772	700
09/07/98 13.42.02	175					124		13				95	176	449	1028			102	101	24		332		328	270	0		317	300	0		301	300	488	75					127	47	49	49	157	72	554	733		785	733		705
09/07/98 13.42.04					358		74			75						699	1																	488				0	0							554	733	746	785	739	775	705
09/07/98 13.42.06		95				123			102				176	449	951			102	101	24			337	328	270	0		318	300	0		301	300	493		321				127	47	49	49	158	72	554	733		792			707
09/07/98 13.42.08																																																746		739	775	
09/07/98 13.42.10			437			123							175	449	833			102	101	24				328	270	0	337	318	300	0	320	301	300	496			327			127	47	49	49	158	72	554	731	746	798	739	775	707
09/07/98 13.42.12					359		74			75						699	1																					0	0									776		720	796	
09/07/98 13.42.14				349		140					74		221	449	789			15	101	22	338			328	270	0		318	300	0		300	300	498						127	46	49	49	580	72	489	649		752			656
09/07/98 13.42.16																																																776		720	796	
09/07/98 13.42.18	175					163		13				96	228	449	780			-1	101	20		332		328	270	0		318	300	0		296	300	491	74					127	46	49	49	636	72	466	621	776	674	720	796	605
09/07/98 13.42.20					722		72			75						699	1																					0	0									612		607	666	
09/07/98 13.42.22		95				169			100				228	449	779			-2	101	20			338	328	270	0	337	318	300	0		297	300	477		321				127	46	49	49	631	72	446	578		629			580
09/07/98 13.42.24																																																612		607	666	
09/07/98 13.42.26			448			170							228																					465			327						49	627		437	555	612	606	607	666	561
09/07/98 13.42.28					762		72			75				449	779	699	1	-2	101	20	340			328	270	0		318	300	0	320	297	300					0	0	127	46	49			72			548		558	582	
09/07/98 13.42.30	175			352		172		13			73		229	449	779			-2	102	20		332		329	270	0		318	300	0		297	300	459	73					127	46	49	49	626	72	434	545	548	579	558	582	541
09/07/98 13.42.32																																																548		558	582	
09/07/98 13.42.34		95				173			99			98	228														337							450									49	622		433	535		563	558		529
09/07/98 13.42.36														449	779			-2	101	19			340	329	270	0		318	300	0		298	300			321				127	46	49			72			531		546	561	
09/07/98 13.42.38																																		450												433	535	531	563	546	561	529
09/07/98 13.42.40					772		71			75						699	1																	450				0	0								535	531		546	561	529
10/07/98 13.42.42			444			174							228	449	779			-2	101	18	342			329	270	0		318	300	0	321	298	300	441			327			127	46	49	49	620	72	432	525		551	546		525
11/07/98 13.42.44					772		71			75				449	779	699	1											318	300	0		298	300	441				0	0						72	432	525	524	551	541	558	525
12/07/98 13.42.46				353		175					73		228									332												437									49	620		431	487	524	548	541	558	521
13/07/98 13.42.48	175							14						449	770			-2	101	18				329	270	0		318	300	0		298	300	437	71					127	46	49			72	431	487	524	548	541	558	521
14/07/98 13.42.50		95				175			99			98	228																					435									49	620		431	522		547	541		523
15/07/98 13.42.52					770		71			75				449	780	699	1	-2	101	18			341	329	270	0		318	300	0		298	300			321		0	0	127	46	49			72			524		542	556	
16/07/98 13.42.54			437			176							228	449	779			-2	102	18				329	270	0	337	318	300	0	320	299	300	433			327			127	46	49	49	619	72	430	521		546			522
17/07/98 13.42.56																																																524		542	556	
18/07/98 13.42.58				353		176					72		228																					432									49	620		415	499	524	545	542	556	523

Tab. B2 – Transient Test 50LOFA09-07-98

Starting Time of Data Acquisition 08/07/1998 13.27.00

Time (s)	TR 218	TR 215	TR 217	TR 216	FIC 228X	TR 239	TIC 242X	TR 267	TR 266	TIC 242W	TR 202	TR 204	PDR 201	FIC 212W	FIC 212X	FIC 228W	FIC 228Y	ZR 235	ZR 213	ZR 234	TR 220	TR 221	TR 226	TIC 222X	TIC 222W	TIC 222Y	TR 225	TIC 223X	TIC 223W	TIC 223Y	TR 224	TIC 232X	TIC 232W	TR 233	TR 241	TR 236	TR 297	TIC 242Y	TIC 232Y	ST 270	PR 298	PR 206	PR 227	PDR 229	FIC 212Y	TT 400	TT 403	TT 407	TT 411	TT 415	TT 419	TT 427
0			356			157							229	449.8	780.4			-2	101	-3				291	270	0	298	299.9	300	0.1		300.2	300	362						127	47	50	50	591	0.7	363	421	401	427	417	429	415
2	155			292		157		14			74	100	229	449.8	780.9			-2	101	-4	290	291		290.9	270	0		300	300	0.1	297	300.1	300	362	74		289			127	47	50	50	593	0.7	363	421		426			415
4																																															401		417	429	
6					774.5		75			75						699.7	1																	362				0.2	0.2							363	421	413	426	417	429	415
8																																		362												363	421		426			415
10														449.8	780.6			-2	101	-3						0		299.9	300				300	362								50			0.7	363	421	413	426	417	429	415
12		96				157			105				229	449.8	780.3			-2	101	-4			292	290.9	270	0	298	299.8	300	0.2		299.7	300	361		303				127	47	50	50	589	0.7	364	421	413	411	417	429	416
14					772.6		75			75						699.7	1																					0.2	0.3									414		418	429	
16			356			157							229	449.8	778.9			-2	101	-3				290.9	270	0		299.9	300	0.1	297	300	300	361			289			127	47	50	50	589	0.7	364	421		426			416
18	155			292		157		14			75		229	449.8	778.8			-2	101	-4	290	291		290.7	270	0		300.1	300	0.1		300	300	361	74					127	47	50	50	591	0.7	364	421	414	427	418	429	415
20																																																414		418	429	
22					772.6		74.9			75						699.7	1																	361				0.2	0.3							364	421	413	427	417	429	415
24						157						100	229	449.8	779.5			-2	101	-4				291	270	0		300	300	0.2		300.3	300	362						143	47	50	50	591	0.7	364	421		427			405
26		96	356			157			105				229	449.8	779.5			-2	101	-3			292	291.1	270	0	298	300.1	300	0.1		300.3	300	362		303				127	47	50	49	591	0.7	363	421	413	427	417	429	416
28																																																413		417	429	
30					773.3		75			75						699.7	1																	362				0.2	0.2							363	421	413	427	417	429	416
32						157							229	449.8	781			-2	101	-3				290.9	270	0		300.1	300	0.1	297	299.9	300	362			289			127	47	50	50	590	0.7	364	421	413	427	417	429	415
34	155			292		157		14			74		229	449.8	781			-2	101	-3	290	291		290.9	270	0		300.1	300	0.1		299.9	300	362	74					127	47	50	50	591	0.7	363	421	413	427	417	429	415
36																																																413		417	429	
38					771.9		75			75						699.7	1																	362				0.2	0.3							363	421	414	427	417	429	415
40						157						100	229	449.8	778.6			-2	101	-3				290.9	270	0		300	300	0.1		300	300	362						127	47	50	50	590	0.7	363	421	414	427	417	429	415
42		96	356			157			105				229	449.8	778.8			-2	101	-4			292	290.8	270	0	298	300	300	0.1		300.1	300	362		303	289			127	47	50	50	590	0.7	363	421	414	426	417	429	416
44																																		362												363	421	414	426	417	429	416
46					772.2		75.2			75						699.7	1																	362				0.2	0.2							363	421	413	426	417	429	416
48						157							229	449.8	779.7			-2	101	-3	290			290.9	270	0		300.1	300	0.1	297	300.1	300	362						127	47	50	50	591	0.7	363	421	413	426	417	429	415
50	155			292		157		14			74	100	229	449.8	779.7			-2	101	-4		291		290.8	270	0		300.1	300	0.1		300.1	300	362	74					127	47	50	50	591	0.7	364	421		427			415
52																																																413		417	429	
54					773.1		74.9			75						699.7	1																	362				0.2	0.2							364	421	416	427	420	432	415
56		96				144			105				190	449.8	788.3			64	101	-3				291	270	0		300.2	300	0.1		300	300	362						143	47	50	50	332	0.7	372	431		439			426
58			356	292		135					75		182	449.8	858.9			81	101	-3	290		292	290.8	270	0	298	300.4	300	0.1	296	300	300	363		303	289			127	47	50	50	198	0.7	381	445	416	448	420	432	437
60																																																416		420	432	
62					504		75.9			75						699.7	1																	363				0.3	0.2							381	445	457	448	460	479	437
64																																		363												381	445		448			437
66														449.8	1014.4			101	101	-3						0		300.8	300				300	363								50			0.7	381	445	457	448	460	479	437
68	155					122		14				97	177	449.8	1029.4			101	101	-4		291		290.9	270	0		300.8	300	0		300.1	300	372	74					127	47	50	50	142	0.7	407	491	457	502	460	479	481
70					366.2		77.1			75						699.7	1																					0.4	0.2									492		465	518	
72		96				120			105				177	449.8	1032.1			101	101	-4			292	290.8	270	0		301.1	300	0		300.2	300	377		303				127	47	50	50	142	0.7	413	506		516			493
74			358			120							177	449.8	1031.7			102	101	-3	290			290.8	270	0	298	301.4	300	0	298	300.2	300	379			289			127	47	50	50	143	0.7	414	511	492	521	465	518	498
76																																																492		465	518	
78					362.8		77			75						699.7	1																	379				0.4	0.3							414	511	508	521	507	535	498
80				295		119					76		175	449.8	1032.6			102	101	-4				290.8	270	0		301.4	300	0		300.5	300	385						127	47	50	50	142	0.7	417	521		531			502
82	155	95				119		14	104			96	177	449.8	1032.6			102	101	-4		291		290.8	270	0		301.5	300	0		300.3	300	387	75					127	47	50	50	143	0.7	418	523	508	534	507	535	508
84																																																508		507	535	
86																																		387												418	523	520	534	514	544	508
88					362.1	118	76.4			75			176	449.8	1033.6	699.7	1	102	101	-3			292	290.9	270	0		300.8	300	0		300.2	300	391		303		0.4	0.3	127	47	49	50	144	0.7	420	530	520	540	514	544	511
90														449.8	1033.6			102	101	-4	291			291	270	0	298	300.7	300	0	298	300	300				289			127	47	49			0.7	419	532	520	542	514	544	512
92			363			118							177																					393									50	143				520		514	544	
94					362.7		75.8			75						699.7	1																	393				0.4	0.3							419	532	527	542	520	550	512
96				296		117					75		176	449.8	1031.5			102	101	-3				290.8	270	0		300.5	300	0		299.7	300	396						127	47	49	50	144	0.7	420	536	527	544	520	550	499
98	156	95				117		14	101			95	177	449.8	1033.1			102	101	-3		291	292	290.8	270	0		300.4	300	0		299.9	300	397	76	303				127	47	49	50	144	0.7	421	537		545			515
100																																																527		520	550	
102					362.2											699.7																		397					0.3							421	537	530	545	523	553	515
104						117	74.9			75			177	449.8	1033.3		1	102	101	-4				291	270	0	298	300.3	300	0.1		299.9	300	400				0.3		127	47	49	50	144	0.7	421	540		548			516
106			369	298		117					75		177	449.8	1033.3			102	101	-3	292			291	270	0		300.1	300	0.1	297	299.8	300	401			289			127	47	49	50	144	0.7	421	539	530	549	523	553	518
108																																																530		523	553	
110																																		401												421	539	532	549	526	556	518
112	157				361.6	116	74.5	14		75			177	449.8	1033.2	699.7	1	102	101	-3		291		290.9	270	0		300	300	0.1		299.7	300	402	75			0.3	0.2	127	47	49	50	144	0.7	421	541		550			512
114		95				116			99			94	177	449.8	1033.8			102	101	-3			293	290.9	270	0		300.1	300	0.1		299.7	300	403		303				127	47	49	50	144	0.7	421	541	532	551	526	556	519

Tab. B3 – Transient Test 30LOFA09-07-98 (cont’d)

Time (s)	TR 218	TR 215	TR 217	TR 216	FIC 228X	TR 239	TIC 242X	TR 267	TR 266	TIC 242W	TR 202	TR 204	PDR 201	FIC 212W	FIC 212X	FIC 228W	FIC 228Y	ZR 235	ZR 213	ZR 234	TR 220	TR 221	TR 226	TIC 222X	TIC 222W	TIC 222Y
116																										
118																										
120			375		361.1	116	74			75			178	449.8	1032.7	699.7	1	102	101	-3				290.8	270	0
122				300		116					74		177	449.8	1032.7			102	101	-3	292			290.8	270	0
124																										
126																										
128	157				360.2	116	74	14		75			177	449.8	1032.8	699.7	1	102	101	-3		291		290.8	270	0
130		95				115			97			94	177	449.8	1034.1			102	101	-4			293	290.6	270	0
132																										
134																										
136			379		361.1	115	74			75			177	449.8	1034.1	699.7	1	102	101	-3				290.8	270	0
138	157							14						449.8	1034.1			102	101	-3	294			290.8	270	0
140				302		115					74		176									291				
142																										
144					360.5	115	73.9			75				449.8	1034.8	699.7	1	102	101	-3				290.6	270	0
146												94	177	449.8	1034.8			102	101	-3			294	290.6	270	0
148		95	382			115			96				177													
150																										
152					361.2	114	74			75				449.8	1035	699.7	1	102	101	-4				290.8	270	0
154	157			304				14					177	449.8	1034.4			102	101	-3	295	291		290.8	270	0
156						115					74	94	177													
158																										
160					360		74.3			75				449.8	1033	699.7	1	102	101	-3				290.9	270	0
162		95				114			96				177	449.8	1033			102	101	-3			294	290.6	270	0
164			386			114							177													
166																										
168					360.1		74.3			75				449.8	1033.4	699.7	1	102	101	-4	296			290.7	270	0
170	157			306		114		14					177	449.8	1033.8			102	101	-3		291		290.6	270	0
172						114					74	94	177													
174																										
176					359.1		74.4			75				449.8	1034.9	699.7	1	102	101	-3				290.7	270	0
178		95				114			95				177	449.8	1033.1			102	101	-3	297		295	290.7	270	0
180			389	307		114					74		177													
182																										
184					359.4		74.4			75						699.7	1									
186																										
188	158							14					176	449.8	1034.1			102	101	-3		291		290.9	270	0
190		95				114			95			94	177													
192					358.6		74.6			75				449.8	1032.8	699.7	1	102	101	-3			296	290.5	270	0
194						114							177	449.8	1033.2			102	101	-4	298			290.5	270	0
196			392			114							177													
198																										
200					359.1		74.6			75				449.8	1034.2	699.7	1	102	101	-3				290.6	270	0
202	158	95		309		114		14	94		74	94	178	449.8	1034.2			100	101	-3		291		290.5	270	0
204																										
206																										
208					391.8		74.4			75				449.8	921.6	699.7	1	1	101	-3			297	290.6	270	0
210						145							229	449.8	824.5			-1	101	-3	299			290.5	270	0
212			394	309		147					74		229													
214																										
216					760.3		73.4			75				449.8	779.9	699.7	1	-2	101	-3				291	270	0
218	158					151		14					230	449.8	779.9			-2	101	-3		291	298	291	270	0
220		95				152			94			98	230													
222																										
224					767.3		72.9			75				449.8	779.5	699.7	1	-2	101	-3				290.9	270	0
226			391			153							231	449.8	778.9			-2	101	-4	300			290.7	270	0
228				309		153					74		230													
230																										
232	157				766.7		73.3	14		75				449.8	779.3	699.7	1	-2	101	-4				291	270	0
234						154							229	449.8	778.1			-2	101	-4		292	299	291	270	0

Time (s)	TR 225	TIC 223X	TIC 223W	TIC 223Y	TR 224	TIC 232X	TIC 232W	TR 233	TR 241	TR 236	TR 297	TIC 242Y	TIC 232Y	ST 270	PR 298	PR 206	PR 227	PDR 229	FIC 212Y	TT 400	TT 403	TT 407	TT 411	TT 415	TT 419	TT 427
116																						532		526	556	
118								403												421	541	533	551	527	557	519
120	298	300.1	300	0.1		300	300	405				0.2	0.3	127	47	49	50	144	0.7	422	542		551			520
122		300.1	300	0.1	297	300	300	406			289			127	47	49	50	144	0.7	423	542	533	552	527	557	520
124																						533		527	557	
126								406												423	542	535	552	528	558	520
128		300.2	300	0.1		300	300	407	74			0.2	0.2	127	47	49	50	144	0.7	422	544		554			518
130	298	300.2	300	0.1		300	300	407		303				127	47	49	50	144	0.7	423	543	535	554	528	558	520
132																						535		528	558	
134								407												423	543	535	554	529	559	520
136		300.3	300	0.1	297	300.1	300	408			289	0.2	0.3	127	47	49	50	144	0.7	423	545		554			521
138		300.3	300	0.1		300.1	300		74					127	47	49			0.7							
140								409									50	144		424	545	535	554	529	559	521
142								409												424	545	536	554	530	559	521
144		300.4	300	0		300.1	300	410				0.2	0.2	127	47	49			0.7	424	545		555			520
146		300.6	300	0		300.1	300			303				127	47	49	50	145	0.7			536		530	559	
148	298							410									50	145		424	546	536	555	530	559	521
150																						537		530	560	
152		300.5	300	0	297	299.9	300	411			288	0.2	0.2	127	47	49			0.7	424	545		555			522
154		300.3	300	0		299.9	300	411	73					127	47	49	50	144	0.7	424	546	537	555	530	560	522
156																	50	144				537		530	560	
158								411												424	546	538	555	530	561	522
160		300.4	300	0		300	300	411				0.2	0.3	127	47	49			0.7	424	546		555			522
162		300.3	300	0	297	300	300	412		303				127	47	49	50	144	0.7	425	545	538	555	530	561	522
164	298							413			288						50	144		421	546	538	556	530	561	523
166								413												421	546	540	556	531	562	523
168		300.1	300	0		300.1	300	413				0.2	0.2	127	47	49			0.7		546					523
170		300	300	0.1		300.1	300	413	73					127	47	49	50	145	0.7	425	547	540	556	531	562	523
172																	50	144				540		531	562	
174								413												425	547	540	556	531	562	523
176		300.1	300	0.1		300	300	413				0.2	0.3	127	47	49			0.7		547					523
178		300.1	300	0.1	297	300	300	414		303				127	47	49	50	144	0.7	426	547	540	556	531	562	524
180	298							415			288						50	144		425	547	540	556	531	562	523
182								415												425	547	541	556	532	563	523
184								415				0.2	0.2							425	547		556			523
186								415												425	547	541	556	532	563	523
188		300	300	0.1		299.9	300	416	74					127	47	49	49	144	0.7		547	541		532	563	524
190								416									50	144		425	548	541	557	532	563	524
192		299.9	300	0.1		299.9	300			303		0.2	0.2	127	47	49			0.7							
194		300.1	300	0	297	300	300	416						127	47	49	50	144	0.7	409	528	541	557	532	563	524
196	298							416			288						50	144		427	547	541	558	532	563	525
198																						542		533	563	
200		300	300	0.1		300.1	300	416				0.2	0.3	127	47	49			0.7	427	547		558			525
202		299.9	300	0.1		300	300	417	74					127	47	49	50	152	0.7	426	545	542	558	533	563	525
204																						542		533	563	
206								417												426	545	501	558	491	507	525
208		299.7	300	0.1		299.8	300	417		303		0.2	0.2	127	46	50			0.7	426	545		558			525
210	298	299.4	300	0.1	297	299.8	300	411						127	46	50	49	586	0.7	383	484	501	488	491	507	478
212								407			288						49	588		379	468	501	476	491	507	464
214								407												379	468	442	476	444	458	464
216		298.8	300	0.2		299.6	300	407				0.1	0.2	127	46	50			0.7		468					464
218		298.8	300	0.2		299.6	300	393	74	302				127	46	50	49	590	0.7	371	442	442	449	444	458	434
220								391									49	590		371	438	442	445	444	458	431
222								391												371	438		445	444		431
224		298.6	300	0.2		299.5	300	391				0	0.2	127	46	50			0.7		438	423		431	437	431
226	298	298.6	300	0.2	296	299.5	300	384						127	46	50	49	594	0.7	363	425	423	438	431	437	425
228								382			288						50	594		368	426	423	436	431	437	422
230								382												368	426		436	431		422
232		298.7	300	0.2		299.6	300	382	73			0	0.2	127	46	50			0.7		426	418		423	434	422
234		298.9	300	0.2		299.5	300	377		302				127	46	50	49	593	0.7	366	423	418	433	423	434	420

Tab. B3 – Transient Test 30LOFA09-07-98 (cont’d)

Time (s)	TR 218	TR 215	TR 217	TR 216	FIC 228X	TR 239	TIC 242X	TR 267	TR 266	TIC 242W	TR 202	TR 204	PDR 201	FIC 212W
236		95				154			95			98	229	
238														
240					768.2		73.4			75				449.8
242			383			155							229	449.8
244				307		155					73		230	
246														
248	157				768.9		74	14		75				449.8
250						156						99	229	449.8
252		95	379	306		156			96		74	99	229	
254														
256	157				768.9		74.8	14		75				
258														
260														
262														
264														
266		95				156			97				229	449.8
268						157							229	449.8
270					768.7		75.9			75				449.8
272			372	303		157					75		229	
274														449.8
276					768.2		76			75				
278	157					157		14					229	449.8
280		95				157			98			100	229	
282														449.8
284					769.7		76			75				
286			369			157							229	449.8
288				302		157					75		229	
290	157							14						449.8
292					768.8		75.9			75				
294						157							229	
296		95				157			100			100	229	449.8
298														
300					768.7		75.6			75				449.8

Time (s)	FIC 212X	FIC 228W	FIC 228Y	ZR 235	ZR 213	ZR 234	TR 220	TR 221	TR 226	TIC 222X	TIC 222W	TIC 222Y	TR 225
236													298
238													
240	777.6	699.7	1	-2	101	-4				291.1	270	0	
242	778.3			-2	101	-4	300			291.1	270	0	
244								292					
246													
248	779.3	699.7	1	-2	101	-4				291.1	270	0	
250	778.4			-2	101	-3			299	291.1	270	0	
252								292					298
254													
256		699.7	1		101		300						
258													
260				-2									
262													
264						-3							
266	778.7									291.1	270	0	
268	777.8			-2	101	-3			299	291.4	270	0	299
270	778.4	699.7	1	-2	101	-3				291.4	270	0	
272													
274	778.4			-2	101	-4	299			291.6	270	0	
276		699.7	1										
278	778.3			-2	101	-4		294		291.5	270	0	
280													
282	776.9			-2	101	-3			299	291.5	270	0	
284		699.7	1										
286	778.4			-2	101	-3	299			291.7	270	0	299
288													
290	777.7			-2	101	-4				291.8	270	0	
292		699.7	1										
294								294					
296	778.4			-2	101	-3			299	291.8	270	0	300
298													
300	778.3	699.7	1	-2	101	-3				291.9	270	0	

Time (s)	TIC 223X	TIC 223W	TIC 223Y	TR 224	TIC 232X	TIC 232W	TR 233	TR 241	TR 236	TR 297	TIC 242Y	TIC 232Y	ST 270
236							377						
238							377						
240	299.2	300	0.2		299.6	300					0	0.2	127
242	299.3	300	0.2	296	299.8	300	374			288			127
244							374						
246													
248	299.6	300	0.1		300	300	374	73			0.1	0.2	127
250	299.6	300	0.1		299.9	300	372		302				127
252							371			288			
254							371						
256				296			371	73			0.1	0.2	127
258													
260													
262													
264													
266	299.7	300	0.1		299.9	300	369						
268	299.7	300	0.1		300.1	300	368		302				127
270	299.7	300	0.1	296	300.2	300	368				0.2	0.2	127
272							368			289			
274	299.8	300	0.1		300.2	300	368						127
276							368				0.2	0.2	
278	299.7	300	0.1		300.1	300	367	75					127
280							367						
282	299.7	300	0.1		300.2	300	367		302				127
284							367				0.2	0.2	
286	299.7	300	0.1	297	300.2	300	367						127
288							366			289			
290	299.7	300	0.1		300.1	300		75					127
292							366				0.2	0.2	
294							366						
296	299.6	300	0.1		300	300	366		302				127
298													
300	299.6	300	0.2	297	300.2	300	366				0.2	0.2	127

Time (s)	PR 298	PR 206	PR 227	PDR 229	FIC 212Y	TT 400	TT 403	TT 407	TT 411	TT 415	TT 419	TT 427
236			50	593		366	423	418	433	423	434	420
238						366	423	416	433	420	432	420
240	46	50			0.7							
242	46	50	50	592	0.7	365	421	416	430	420	432	419
244			49	592		366	422	416	432	420	432	420
246								416		420	432	
248	46	50			0.7	366	422		432			420
250	47	50	49	593	0.7	358	418	416	432	420	432	418
252			50	593		366	422	416	432	420	432	419
254						366	422	416	432	419	432	419
256	47	50				366	422		432			419
258												
260												
262												
264												
266			49	592	0.7		420	416		419	432	417
268	47	50	50	591	0.7	365	421	416	431	419	431	418
270	47	50			0.7		421					418
272			50	591		366	420	416	430	419	431	418
274	47	50			0.7	366	420		430	419		418
276							420	415		419	430	418
278	47	50	50	592	0.7	365	420	415	429	419	430	417
280			50	591		365	420	415	430	419	430	417
282	47	50			0.7	365	420		430	419		417
284							420	415		419	430	417
286	47	50	50	591	0.7	364	419	415	429	419	430	416
288			49	590		365	420		429			416
290	47	50			0.7			415		419	430	
292						365	420	415	429	419	430	416
294			49	590		364	420		429			416
296	47	50	50	592	0.7	364	420	415	429	419	430	416
298	47	50						415		419	430	
300					0.7	364	420	415	429	418	430	416

Tab. B3 – Transient Test 30LOFA09-07-98

Compressor Characterization Tests 14/03/98									
FV10	**FV 213**	**G 212**	**DP 201**	**Ti 202**	**Pi 298**	**Te out 204**	**Tcusc 276**	**Te rit 275**	**G 256**
rpm	%	kg/s	bar	°C	bar ass	°C	°C	°C	kg/s
10000 rpm (55.5%)									
	100	0,162	1,46	79,7	49,6	85,3	46,4		0,052
	80	0,157	1,49	79,3	49,7	85,4	46,9		0,053
	70	0,147	1,55	79,3	49,6	85,9	47,1		0,054
	60	0,132	1,66	79,3	49,4	86,6	47,4		0,056
	50	0,112	1,81	78,1	49,2	87,2	47,8		0,058
	40	0,087	1,98	74,9	48,9	87,9	48,2		0,061
12000 (66.6%)									
	100	0,193	2,07	80,3	49,6	93,6	52		0,063
	80	0,188	2,12	79,7	49,6	94,7	53,3		0,064
	70	0,176	2,2	79,3	49,6	95,5	53,8		0,065
	60	0,158	2,36	79	49,3	97,3	54,6		0,067
	50	0,131	2,56	79,1	49	100,5	55,5		0,070
	40	0,102	2,76	77,1	48,8	104	56,6		0,073
13000 (72.2%)									
	100	0,211	2,42	79,7	49,7	99,3	56,9		0,068
	80	0,204	2,47	79,6	49,6	100,1	57,6		0,069
	70	0,192	2,58	79,3	49,6	101,5	58,4		0,070
	60	0,171	2,74	79,1	49,4	104,3	59,3		0,072
	50	0,143	3	79,1	49,1	108,1	60,3		0,076
14000 (77.7 %)									
	100	0,228	2,8	79,9	49,8	105,3	61,6		0,073
	80	0,22	2,86	79,6	49,8	106,2	62,1		0,074
	70	0,206	3	79,4	49,7	108	62,8		0,076
	60	0,187	3,17	79,6	49,4	110,6	63,5		0,078
15000 (83.3%)	83,30%								
	100	0,245	3,23	75,5	49,7	107,4	64,1		0,078
	80	0,238	3,29	74,7	49,7	108,6	65		0,079
	70	0,222	3,42	74,6	49,6	110,8	65,9		0,081

Tab. B4 – Compressor Characterization Test – COMP50-1998

Compressor Characterization Tests 14/03/98									
FV10	**FV 213**	**G 212**	**DP 201**	**Ti 202**	**Pi 298**	**Te out 204**	**Tcusc 276**	**Te rit 275**	**G 256**
rpm	%	kg/s	bar	°C	bar ass	°C	°C	°C	kg/s
10000 rpm (55.5%)									
	100	0,086	0,76	69,6	25,4	75	38,6	38,8	0,027
	80	0,083	0,78	69,5	25,4	75,8	39,8	39,3	0,028
	70	0,078	0,83	69,6	25,4	76,3	40,3	39,8	0,028
	60	0,07	0,89	69,3	25,3	77,1	40,8	40,1	0,029
	50	0,058	0,96	69,2	25,2	78,4	41,4	40,2	0,030
12000 (66.6%)									
	100	0,104	1,1	69,5	25,4	82,3	45	44,1	0,033
	80	0,1	1,13	69,5	25,4	84,4	46	44,9	0,033
	70	0,094	1,18	69,5	25,4	85,7	46,7	45,5	0,034
	60	0,083	1,26	69,2	25,3	87,6	47,5	46	0,035
13000 (72.2%)									
	100	0,113	1,27	69,3	25,5	88,6	50,2	48,8	0,035
	80	0,109	1,31	69,2	25,7	90,7	53,2	51,5	0,036
	70	0,103	1,38	69,2	25,7	91,9	53,8	51,9	0,037
14000 (77.7 %)									
	100	0,122	1,49	69,2	25,8	95,8	55,8	54,1	0,039
	80	0,118	1,52	69,2	25,8	97,6	57,2	55,2	0,039
	70	0,11	1,58	69	25,6	99	57,8	55,6	0,040
15000 (83.3%)									
	100	0,131	1,7	69	25,8	101,2	59,2	57,5	0,041
	80	0,126	1,74	69,2	25,8	102,4	60,6	58,2	0,042
	70	0,118	1,81	69,2	25,8	104,2	61,4	58,9	0,043
16000 (88.8%)									
	100	0,14	1,9	69,2	25,9	106,5	62,6	60,3	0,044
	80	0,135	1,95	69	25,8	108,3	63,7	61,2	0,045
	70	0,126	2,05	68,7	25,8	111,2	64,7	62,1	0,046

Tab. B5 – Compressor Characterization Tests – COMP25-1998

Compressor Characterization Tests 14/03/98									
FV10	**FV 213**	**G 212**	**DP 201**	**Ti 202**	**Pi 298**	**Te out 204**	**Tcusc 276**	**Te rit 275**	**G 256**
rpm	%	kg/s	bar	°C	bar ass	°C	°C	°C	kg/s
10000 (55.5%)									
	100	0,068	0,57	71,8	23,1	81,8	43,2		0,018
	80	0,066	0,59	71,8	23,1	82,1	43		0,019
	70	0,062	0,61	71,8	23	82,3	42,9		0,019
	60	0,055	0,65	71,6	23	82,6	42,9		0,020
	50	0,046	0,7	71,6	22,9	83,5	42,9		0,020
	40	0,036	0,75	71,4	22,9	84,8	43		0,021
	30	0,024	0,83	71,2	22,8	86,4	43,4		0,022
12000 (66.6%)									
	100	0,081	0,79	71,8	22,9	88,9	46,9		0,023
	80	0,078	0,81	71,6	22,9	89,4	47,1		0,023
	70	0,073	0,85	71,8	22,8	90,1	47,2		0,023
	60	0,065	0,9	71,5	22,8	91,3	47,3		0,024
	50	0,055	0,95	71,5	22,7	93,5	47,7		0,025
	40	0,043	1,04	71,4	22,6	97	48,4		0,026
	30	0,029	1,11	71,2	22,5	101,2	49,1		0,027
13000 (72.2%)									
	100	0,087	0,92	72,1	22,8	93,3	49,8		0,024
	80	0,084	0,94	71,8	22,8	93,6	49,8		0,025
	70	0,079	0,97	71,8	22,8	95,1	50,3		0,025
	60	0,071	1,03	71,5	22,7	96,5	50,6		0,026
	50	0,059	1,1	71,5	22,7	99,6	51,2		0,027
	40	0,046	1,18	71,5	22,6	103,7	52		0,028
	30	0,031	1,3	71,1	22,5	110	53,2		0,029
14000 (77.7 %)									
	100	0,094	1,05	71,9	22,8	98	52,9		0,026
	80	0,091	1,07	71,6	22,8	98,6	53,3		0,026
	70	0,085	1,11	72,2	22,9	102,7	55,4		0,027
	60	0,076	1,18	72,1	22,8	112,5	56		0,028
	50	0,063	1,26	73,1	22,7	109,2	56,8		0,029
	40	0,05	1,37	70,5	22,6	113	56,9		0,030
15000 (83.3%)									
	100	0,101	1,2	71,8	22,9	103,6	56,8		0,028
	80	0,098	1,22	71,8	22,9	104,5	56,9		0,028
	70	0,091	1,27	71,6	22,8	105,9	57,3		0,029
	60	0,081	1,35	71,5	22,7	108,6	57,8		0,030
	50	0,067	1,45	71,2	22,6	113,5	58,8		0,031
16000 (88.8%)									
	100	0,107	1,34	72,8	22,9	108,9	58,8		0,030
	80	0,104	1,38	71,5	22,8	109,2	59,1		0,031
	70	0,101	1,43	71,4	22,8	111	59,5		0,031
	60	0,087	1,51	71,5	22,7	114	60,2		0,032

Tab. B6 – Compressor Characterization Tests – COMP25-1999