



UNIVERSITÀ DI PISA

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GRUPPO DI RICERCA NUCLEARE – SAN PIERO A GRADO (GRNSPG)



Innovations in Nuclear Technology 2012

Brazil: Challenges and Opportunities

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Auditorio Mario Covas – Escola Politécnica da USP

The Current Status in Building the CHF-TF at University of Pisa

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CONTENT



- ❑ OVERVIEW OF THE PROJECT;
- ❑ CRITICAL HEAT FLUX –TEST FACILITY (CHF-TF) CONFIGURATION;
- ❑ INFRASTRUCTURES;
- ❑ KEY COMPONENT OF THE CHF-TF;
 - INSTRUMENTED ROD;
- ❑ STATUS OF THE ACTIVITIES:

OVERVIEW OF THE PROJECT



❑ Objective*

*“To supply the design and construction of **two Testing Sections**, including **instrumentation**, and perform the **experimental tests** regarding the **Critical Heat Flux (CHF) experiments** for the validation of the Nucleo Electric Generation Laboratory – LABGENE.*

The goal is to produce experimental thermal hydraulic campaigns to investigate typical phenomena occurring during operational and abnormal transients, regarding the LABGENE reactor thermal hydraulic fuel design.”

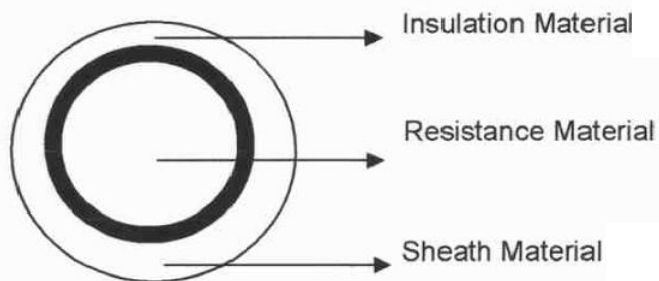
❑ Duration: 12 Months from the signature of the contract (30 January 2012)

** Reference: **CONTRACT N°. 42.000/2011-065/00, NAVY TECHNOLOGICAL CENTER IN SÃO PAULO – CTMSP, and the UNIVERSITÀ DI PISA –***

OVERVIEW OF THE PROJECT

□ Characteristics of the two TS*:

Heating	indirect
Heated length	1000 mm (TS1) and 300 mm (TS2)
External tube diameter	
Pitch	
Channel dimensions	
Channel thickness	
Resistance material	Monel K 500
Insulation material	Boron Nitride
Sheath material	Stainless Steel (AISI-348 or AISI-347 or AISI-304L)



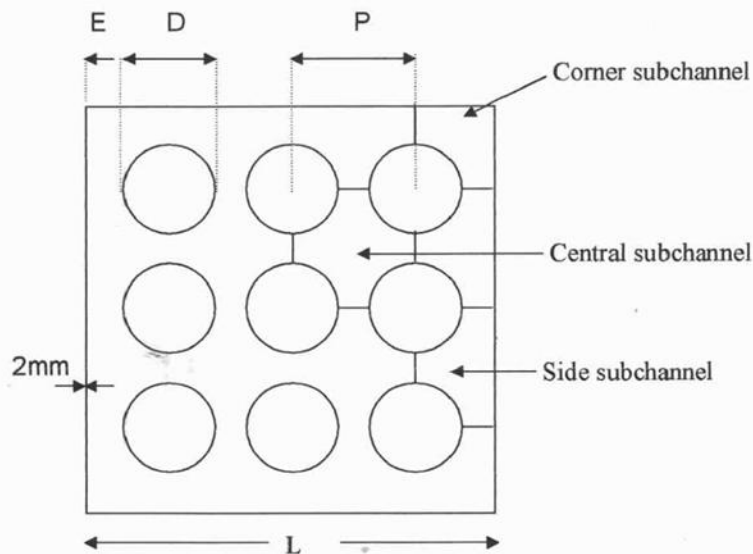
***Annex d of the contract: Technical Specification n° R11.99-8221-AC-0001**

OVERVIEW OF THE PROJECT



□ Characteristics of the two TS*:

	TS1		TS2	
Rod Place	side	central	side	central
Heating length	1000 mm	1000 mm	300 mm	300 mm
Resistance	0,108 Ω	0,098 Ω	0,271 Ω	0,246 Ω
Maximum Voltage	100 V	100 V	100 V	100 V
Maximum Power	92,3 KW	101,6 KW	36,9 KW	40,5 KW
Maximum linear Power	0,923 KW/cm	1,016 KW/cm	1,231 KW/cm	1,354 KW/cm
Heat Flux	300 W/cm ²	330 W/cm ²	400 W/cm ²	440 W/cm ²



***Annex d of the contract: Technical Specification n° R11.99-8221-AC-0001**

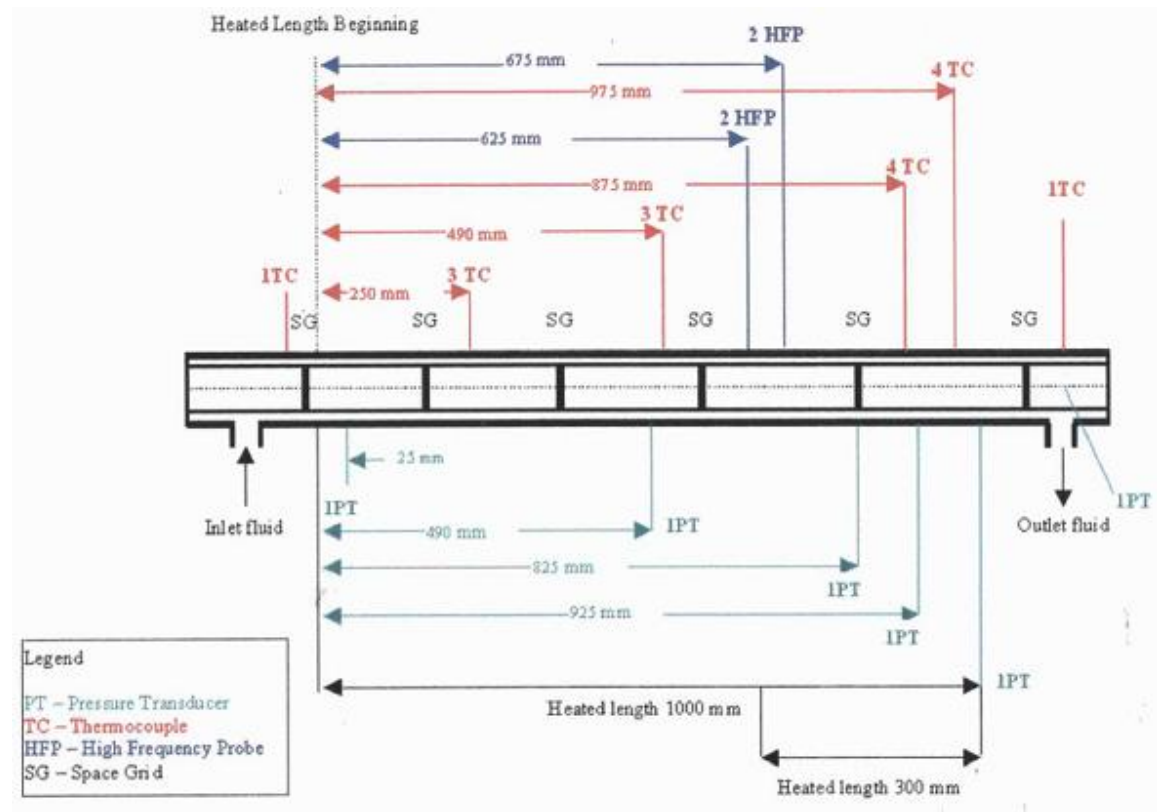
OVERVIEW OF THE PROJECT

□ Design and construction of the facility to house the TS:

The Design conditions for the loop are*:

- $P = 16.5 \text{ MPa}$
- $T = 350 \text{ }^{\circ}\text{C}$

□ TS instrumentation sketch*:



*Annex d of the contract: Technical Specification n° R11.99-8221-AC-0001

OVERVIEW OF THE PROJECT



□ Thermocouples*

Each central rod will have 4 thermocouples at the place where should occur the CHF (height = 975 mm for TS1 and height = 275 mm for TS2) and each one of the side rods will have 2 thermocouples (height = 975 mm for TS1 and height = 275 mm for TS2).

Fifteen thermocouples will be used to measure the radial and axial fluid temperature inside the subchannels. In particular, with reference to the beginning of the heated length of TS1 (1000 mm), the thermocouples are located along the pressure tube at elevations:

- one TC to measure TS fluid inlet temperature;
- 250, 490 mm, three TC's for each elevation;
- 875, 975 mm, four TC's for each elevation.

□ Pressure Transducers*

Six coolant pressures will be measured at the pressure tube coolant outlet and at elevations: 25, 490, 825, 925, 1000 mm along the pressure tube. These pressure transducers should also be used for Pressure Noise Analysis.

***Annex d of the contract: Technical Specification n° R11.99-8221-AC-0001**

TEST MATRIX

Experimental matrix for
heated
pin of **1000 mm**.

Ps (bar)	Me (kg/s)	Ge (kg/s.m ²)	Te (° C)	Aflux (MW/ m ²)	Qel (kW)	DNBR -	Xe (%)	Xs (%)
120	0,452	381	215	2,69	744	1,00	-47	-40
120	0,452	381	240	2,52	698	1,00	-38	-31
120	0,452	381	265	2,32	643	1,00	-28	-21
120	0,452	381	290	2,11	584	1,00	-17	-10
120	0,452	381	315	1,88	521	1,00	-5	-2
131	0,452	381	215	2,71	751	1,00	-53	-46
131	0,452	381	240	2,54	704	1,00	-44	-37
131	0,452	381	265	2,34	650	1,00	-34	-26
131	0,452	381	290	2,13	591	1,00	-22	-15
131	0,452	381	315	190	527	1,00	-9	-2
155	0,452	381	215	2,72	754	1,00	-72	-63
155	0,452	381	240	2,55	708	1,00	-61	-53
155	0,452	381	265	2,36	653	1,00	-49	-40
155	0,452	381	290	2,14	594	1,00	-35	-27
155	0,452	381	315	1,91	530	1,00	-21	-12
120	0,907	764	215	4,37	1210	1,00	-47	-43
120	0,907	764	240	4,03	1120	1,00	-38	-35
120	0,907	764	265	3,64	1010	1,00	-28	-25
120	0,907	764	290	3,21	890	1,00	-17	-14
120	0,907	764	315	2,75	762	1,00	-5	-2
131	0,907	764	215	4,41	1220	1,00	-53	-50
131	0,907	764	240	4,08	1130	1,00	-44	-41
131	0,907	764	265	3,69	1020	1,00	-34	-30
131	0,907	764	290	3,26	903	1,00	-22	-18
131	0,907	764	315	2,80	775	1,00	-9	-6
155	0,907	764	215	4,47	1240	1,00	-72	-68
155	0,907	764	240	4,13	1150	1,00	-61	-57
155	0,907	764	265	3,74	1050	1,00	-49	-45
155	0,907	764	290	3,31	918	1,00	-35	-31
155	0,907	764	315	2,85	790	1,00	-21	-17

Ps – Coolant pressure at the outlet of the test section ;
Me – Coolant mass flow at the inlet of the test section;
Ge – Coolant flux at the inlet of the test section;
Te – Coolant temperature at the inlet of the test section;
Aflux – Heat flux within the heated length of the pin;
Qel – Electrical Power of the pin setup;
DNBR – Departure from Nucleate Boiling Ratio;
Xe – liquid quality at the inlet of the test section;
Xs – coolant quality at the outlet of the test section.

TEST MATRIX

Ps (bar)	Me (kg/s)	Ge (kg/s.m ²)	Te (°C)	Aflux (MW/ m ²)	Qel (kW)	DNBR -	Xe (%)	Xs (%)
120	0,452	381	215	8,95	744	1,00	-47	-40
120	0,452	381	240	8,40	698	1,00	-38	-31
120	0,452	381	265	7,74	643	1,00	-28	-21
120	0,452	381	290	7,03	584	1,00	-17	-10
120	0,452	381	315	6,26	521	1,00	-5	-2
131	0,452	381	215	9,03	751	1,00	-53	-46
131	0,452	381	240	8,47	704	1,00	-44	-37
131	0,452	381	265	7,82	650	1,00	-34	-26
131	0,452	381	290	7,11	591	1,00	-22	-15
131	0,452	381	315	6,34	527	1,00	-9	-2
155	0,452	381	215	9,07	754	1,00	-72	-63
155	0,452	381	240	8,51	708	1,00	-61	-53
155	0,452	381	265	7,86	653	1,00	-49	-40
155	0,452	381	290	7,15	594	1,00	-35	-27
155	0,452	381	315	6,38	530	1,00	-21	-12
120	0,907	764	215	14,6	1210	1,00	-47	-43
120	0,907	764	240	13,4	1120	1,00	-38	-35
120	0,907	764	265	12,1	1010	1,00	-28	-25
120	0,907	764	290	10,7	890	1,00	-17	-14
120	0,907	764	315	9,17	762	1,00	-5	-2
131	0,907	764	215	14,7	1220	1,00	-53	-50
131	0,907	764	240	13,6	1130	1,00	-44	-41
131	0,907	764	265	12,3	1020	1,00	-34	-30
131	0,907	764	290	10,9	903	1,00	-22	-18
131	0,907	764	315	9,32	775	1,00	-9	-6
155	0,907	764	215	14,9	1240	1,00	-72	-68
155	0,907	764	240	13,8	1150	1,00	-61	-57
155	0,907	764	265	12,5	1050	1,00	-49	-45
155	0,907	764	290	11,0	918	1,00	-35	-31
155	0,907	764	315	9,50	790	1,00	-21	-17

Experimental matrix for heated
pin of **300 mm**.

Ps – Coolant pressure at the outlet of
the test section ;

Me – Coolant mass flow at the inlet of
the test section;

Ge – Coolant flux at the inlet of the test
section;

Te – Coolant temperature at the inlet of
the test section;

Aflux – Heat flux within the heated
length of the pin;

Qel – Electrical Power of the pin setup;

DNBR – Departure from Nucleate
Boiling Ratio;

Xe – liquid quality at the inlet of the test
section;

Xs – coolant quality at the outlet of the
test section.

TEST MATRIX

□ Results of the simulations with COBRA performed at GRNSPG.

				1000 mm Test section		300 mm Test section	
	Ps	Ge	Te	POWER	Linear Power	POWER	Linear Power
CASE	(bar)	(kg/s.m ²)	(° C)	W	KW/m	W	KW/m
1	120	381	215	3.34E+05	40.4	1.61E+05	64.8
2	120	381	240	3.10E+05	37.4	1.47E+05	59.4
3	120	381	265	2.84E+05	34.4	1.35E+05	54.4
4	120	381	290	2.54E+05	30.8	1.21E+05	48.7
5	120	381	315	2.23E+05	27.0	1.05E+05	42.4
6	131	381	215	3.15E+05	38.1	1.43E+05	57.6
7	131	381	240	2.90E+05	35.1	1.32E+05	53.3
8	131	381	265	2.65E+05	32.0	1.21E+05	48.6
9	131	381	290	2.38E+05	28.7	1.08E+05	43.7
10	131	381	315	2.08E+05	25.2	9.44E+04	38.1
11	155	381	215	2.73E+05	33.0	1.08E+05	43.5
12	155	381	240	2.52E+05	30.4	1.00E+05	40.5
13	155	381	265	2.30E+05	27.8	9.31E+04	37.5
14	155	381	290	2.05E+05	24.8	8.42E+04	33.9
15	155	381	315	1.79E+05	21.7	7.48E+04	30.1
16	120	764	215	4.80E+05	58.0	2.07E+05	83.5
17	120	764	240	4.24E+05	51.3	1.88E+05	75.9
18	120	764	265	3.83E+05	46.3	1.68E+05	67.9
19	120	764	290	3.35E+05	40.5	1.46E+05	58.7
20	120	764	315	3.05E+05	36.9	1.27E+05	51.2
21	131	764	215	4.44E+05	53.7	1.91E+05	76.9
22	131	764	240	4.07E+05	49.1	1.74E+05	70.1
23	131	764	265	3.65E+05	44.2	1.56E+05	62.9
24	131	764	290	3.22E+05	38.9	1.36E+05	54.9
25	131	764	315	2.74E+05	33.1	1.17E+05	47.2
26	155	764	215	4.10E+05	49.6	1.64E+05	66.3
27	155	764	240	3.73E+05	45.1	1.50E+05	60.6
28	155	764	265	3.34E+05	40.4	1.35E+05	54.5
29	155	764	290	2.96E+05	35.7	1.19E+05	48.1
30	155	764	315	2.53E+05	30.5	1.04E+05	41.9

Very high q'
(roughly 45 kW/m
max q' in
commercial PWR)
**To be considered
in experimental
procedure**

Max q'

INFRASTRUCTURE



❑ The CHF-TF requires some infrastructures:

- Warehouse;
- High power electrical system;
- Demineralization water system;
- DAS and Control system.

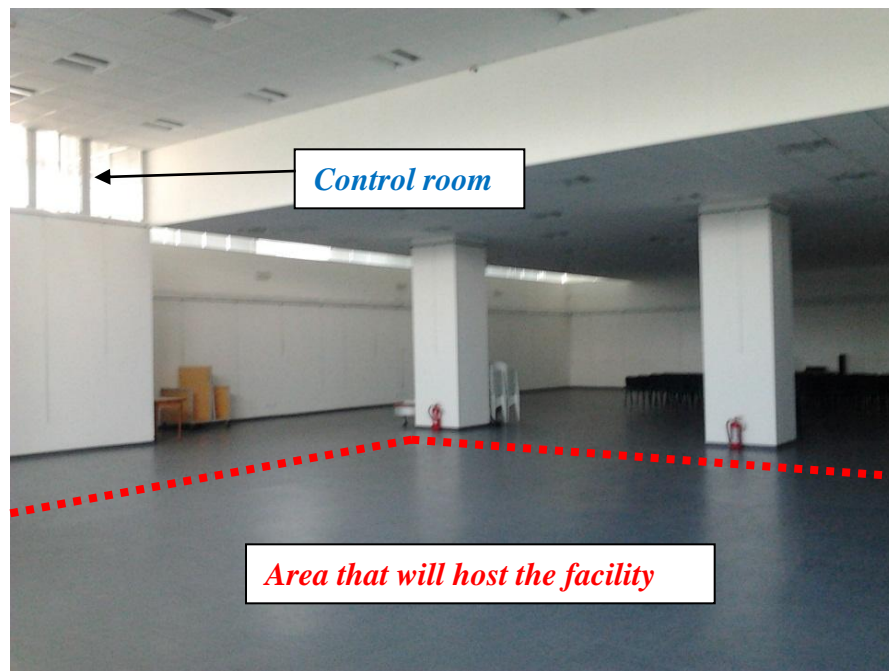
INFRASTRUCTURE

□ *The warehouse has been selected taking into account:*

➤ *Technological aspects:*

- *Dimensions: $H > 5 \text{ m}$, $\text{Area} \geq 200 \text{ m}^2$;*
- *External space for the Diesel generator, cooling tower;*

➤ *Security (for the facility and for the data)*



HIGH POWER ELECTRICAL SYSTEM



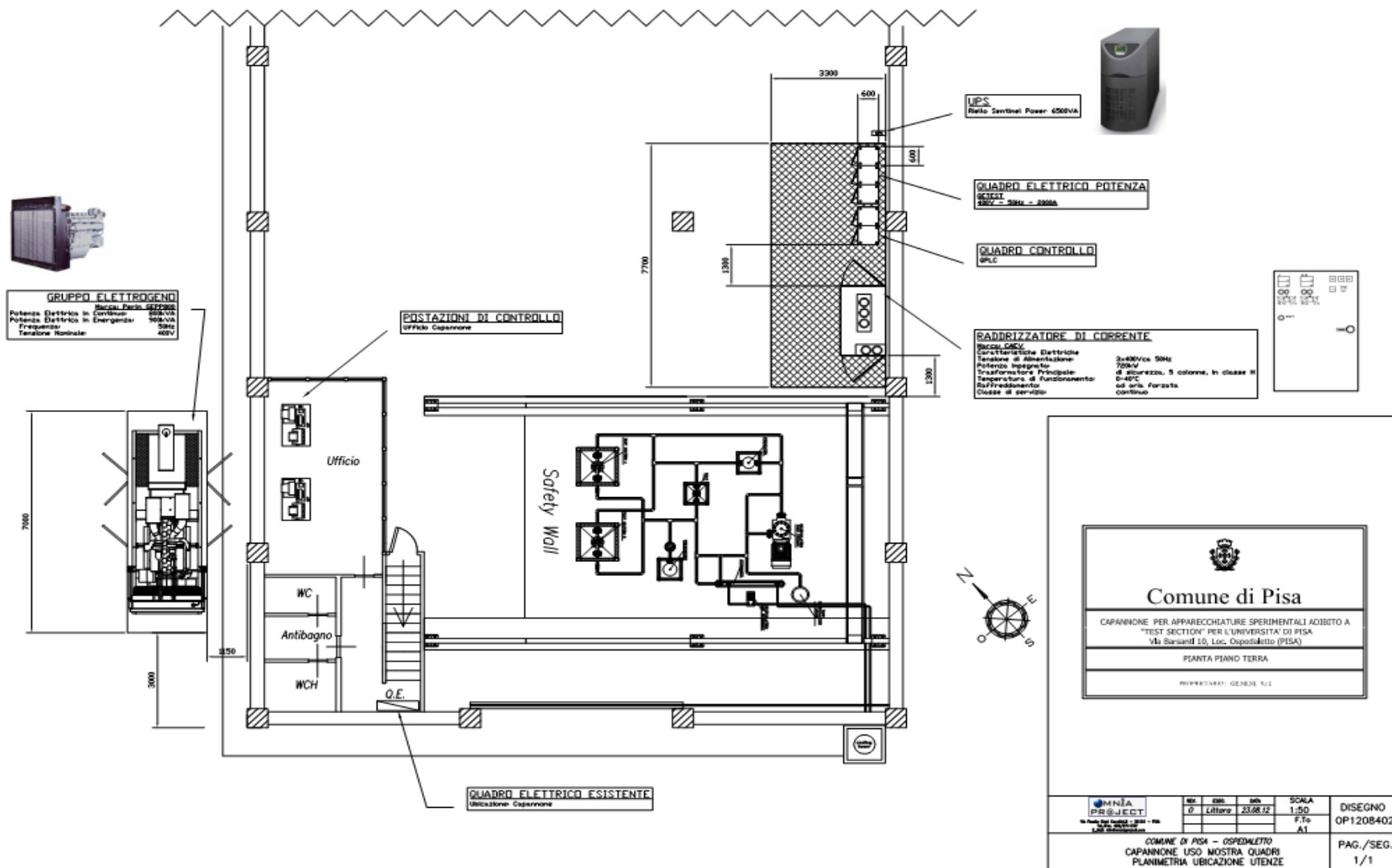
□ High power electrical system

The electrical system has been designed for supplying the instrumented rods with DC current and the other component of the circuit (pump, PRZ heaters, etc.) with AC current.

- The power supplier is a diesel generator (PERIN GEPP800 SUPER SILENT) which provides AC current at 400 V and 50 Hz. The total power supplied is 800 kVA with a power peak of 900 kVA for 1 hour.
- The transformer-inverter (CAEV) is equipped with the interface to be connected to the control system for automatic control of the power during the experiments execution.
- The transformer-inverter has two output lines, in order to independently feed the central rod and the ensemble of remaining 8 rods (the former with a 10% higher power than the latter).

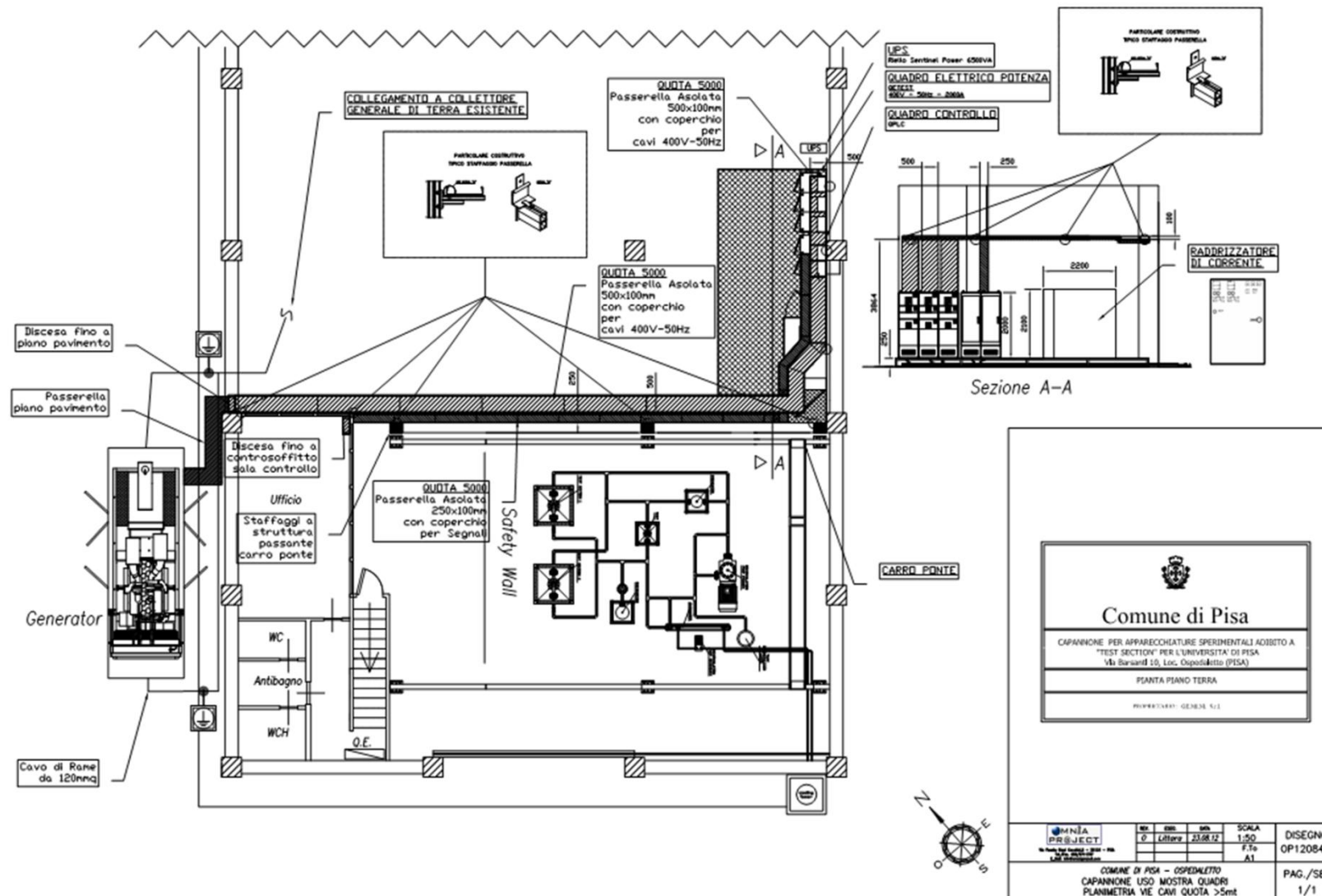
HIGH POWER ELECTRICAL SYSTEM

Position of the main components



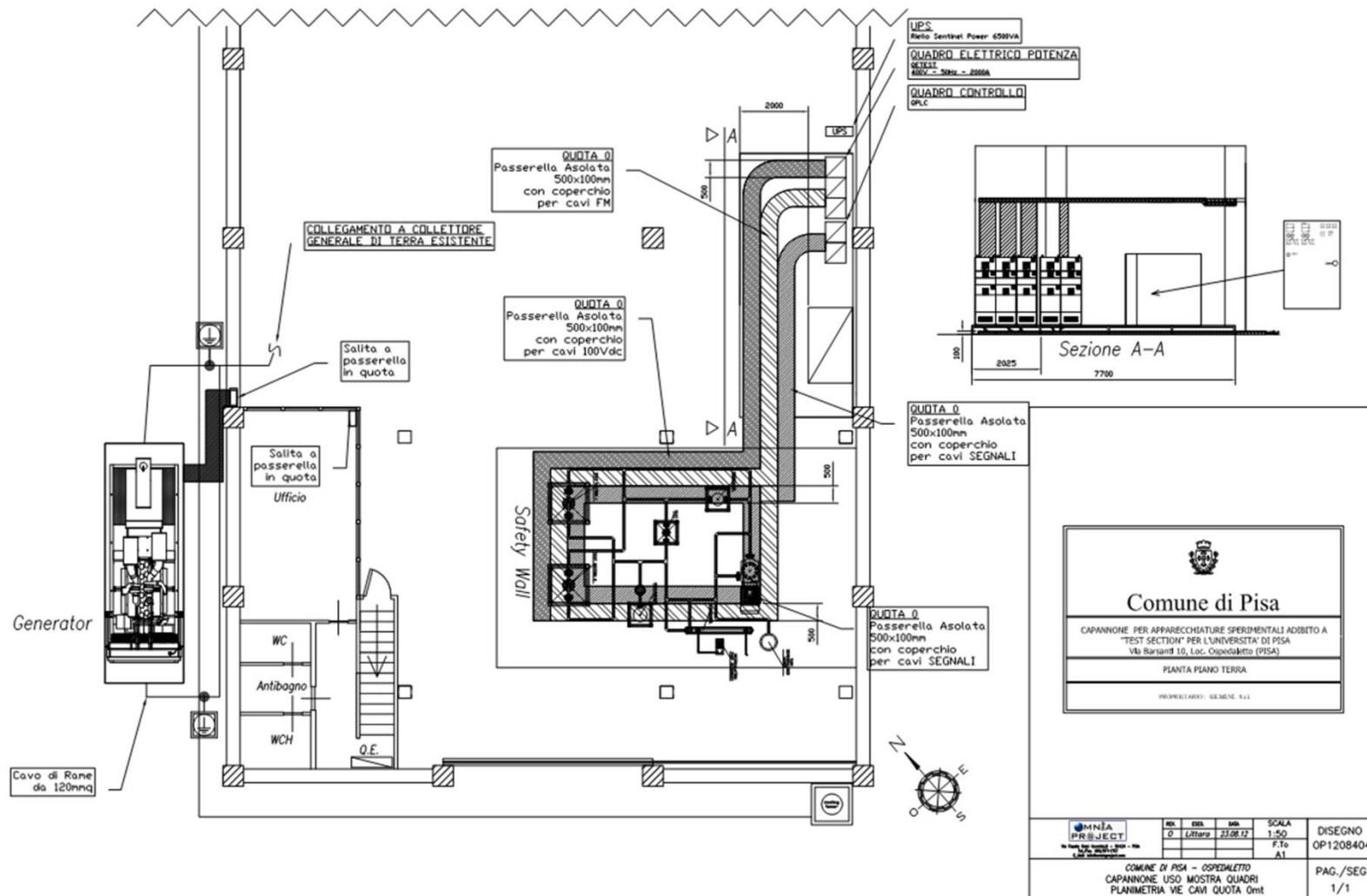
HIGH POWER ELECTRICAL SYSTEM

Cable ways from Diesel Generator to Transformer Inverter



HIGH POWER ELECTRICAL SYSTEM

- ☐ Cable ways from Transformer Inverter to TS (high current)



DEMINERALIZED SYSTEM



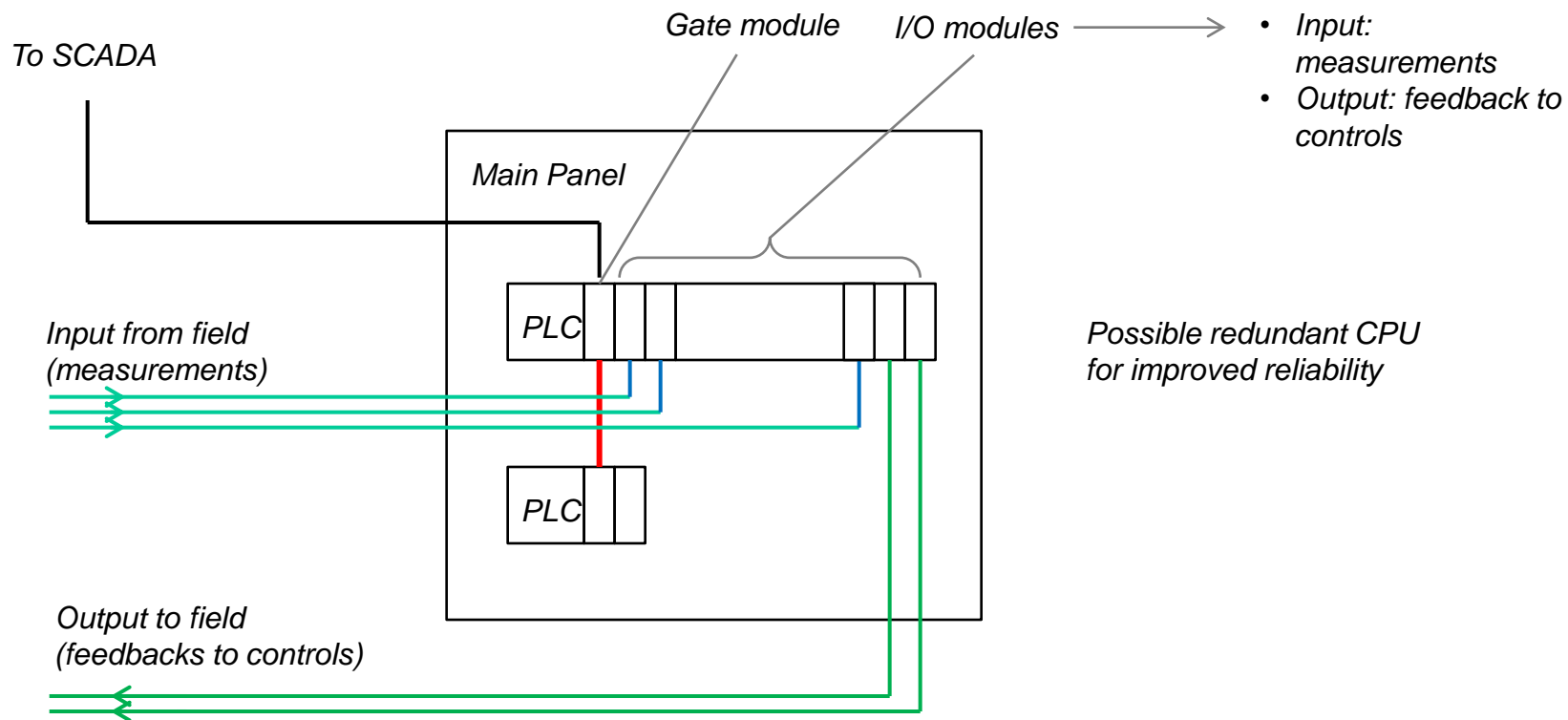
- ❑ Demineralization water system has been designed to fulfill the requirements:
 - Conductivity: $< 1 \mu\text{S}/\text{cm}$;
 - $\text{Ph} \approx 7$ (neutral);
 - Total Dissolved Salinity (TDS) $< 0.5 \text{ mg/l}$ (CaCO_3)

I&C SYSTEM



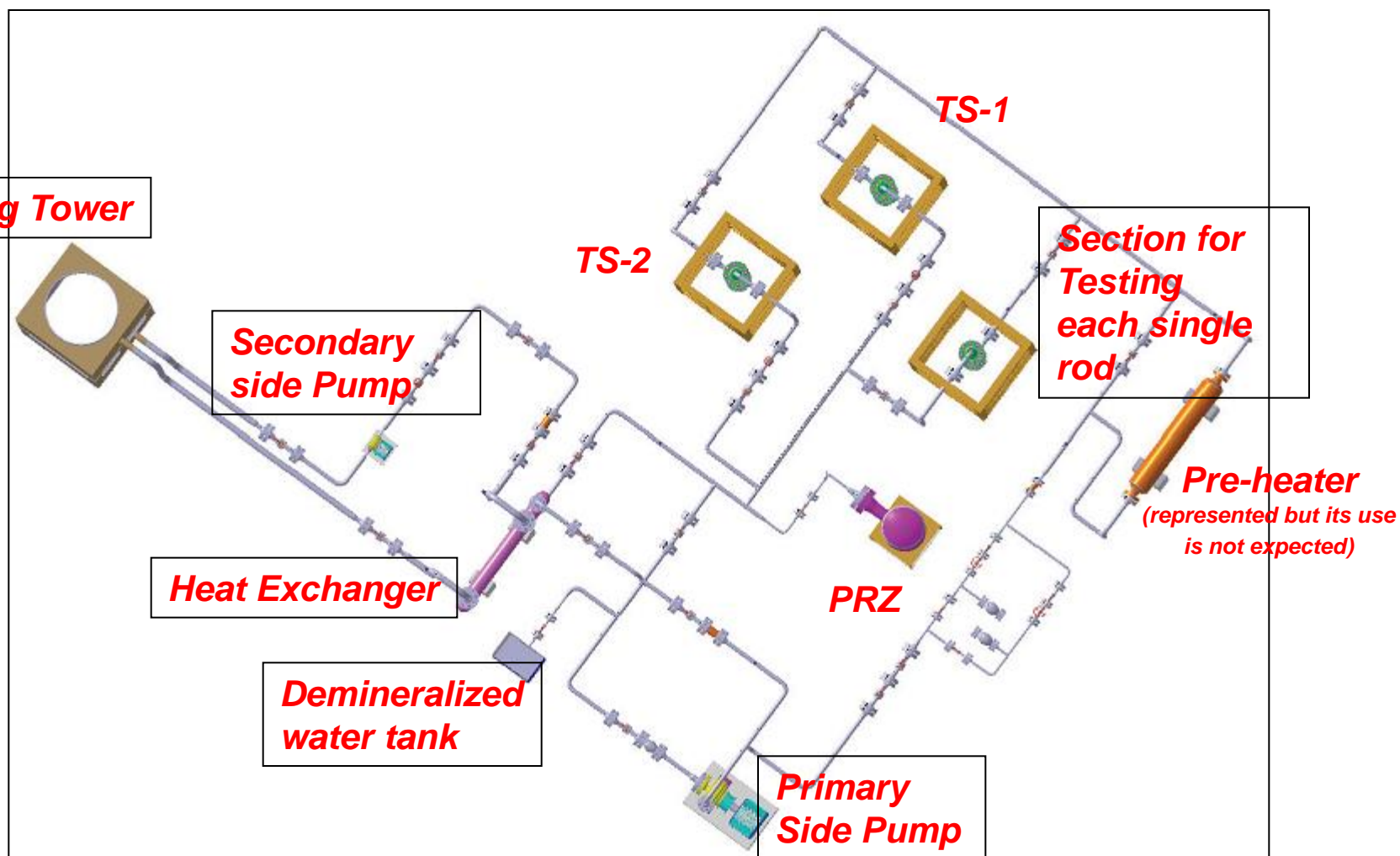
- ❑ DEWESOFT systems were envisaged in the preliminary design, for data acquisition, supervision and automated control purposes
 - Expected benefit from resorting to a technology more «familiar» to GRNSPG
- ❑ Later technical and economic assessment indicated that more robust, reliable and performant hardware would be needed
 - especially for «Heated Rod Protection System», which requires very fast and reliable data acquisition and elaboration and subsequent possible action
- ❑ Therefore, the following options have been evaluated:
 - Industrial-type system, based on a Programmable Logic Controller (PLC) plus SCADA (Supervisory Control and Data Acquisition)
 - System based on National Instruments' hardware and software

□ Scheme of the Control and data acquisition systems:



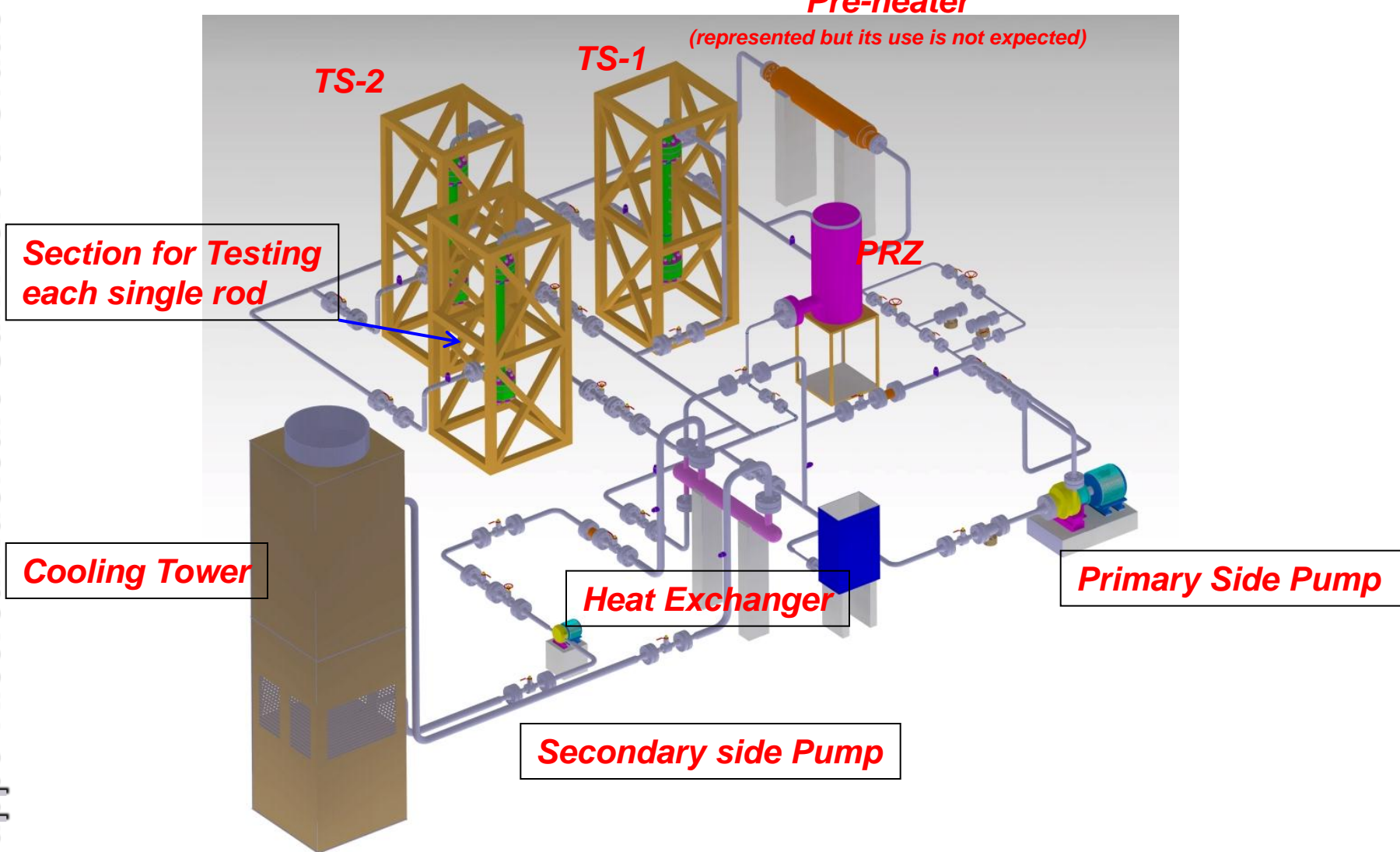
CHF-TF CONFIGURATION

View of the CHF-TF



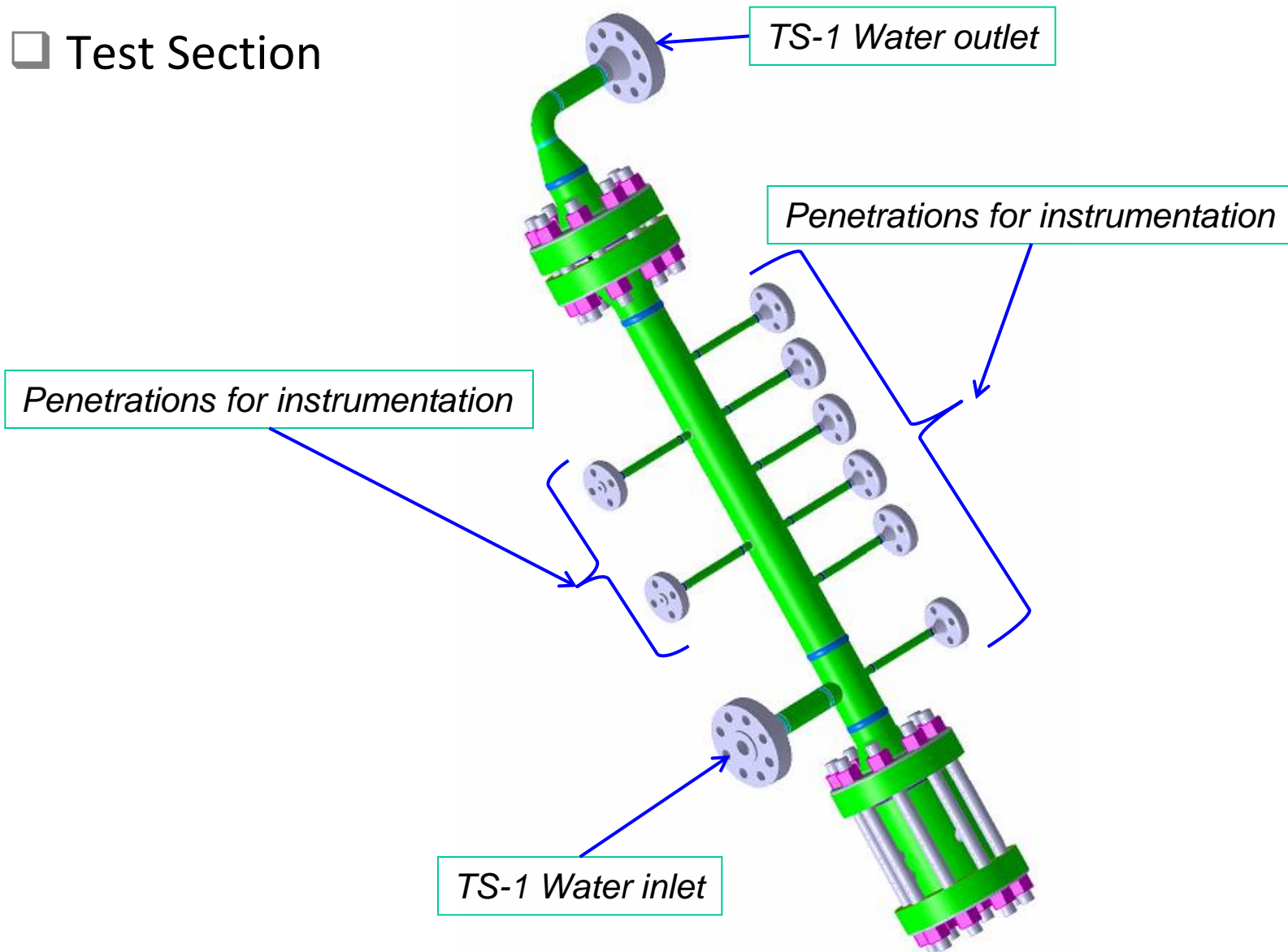
CHF-TF CONFIGURATION

3D drawings of CHF-TF

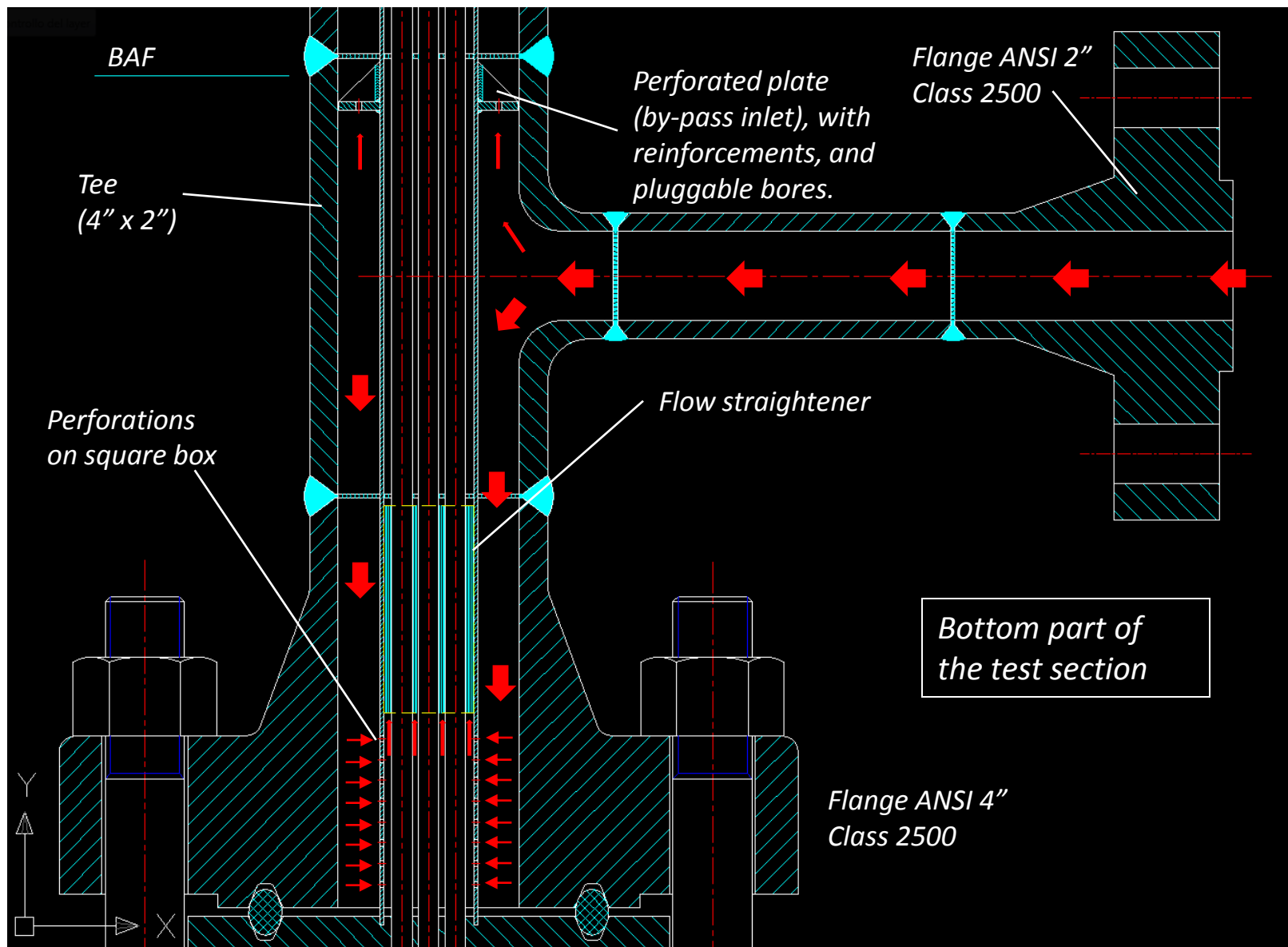


CHF-TF CONFIGURATION

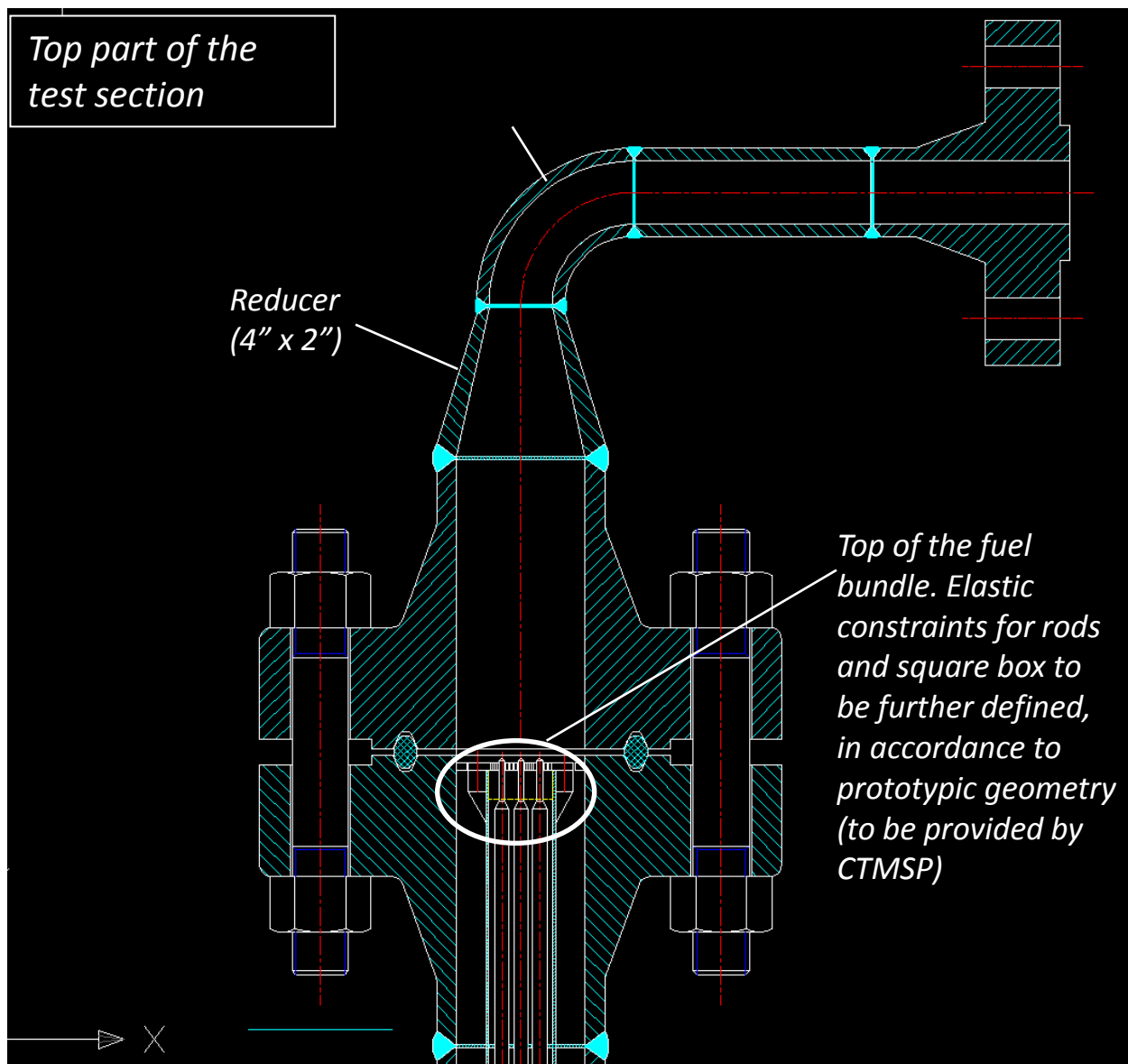
Test Section



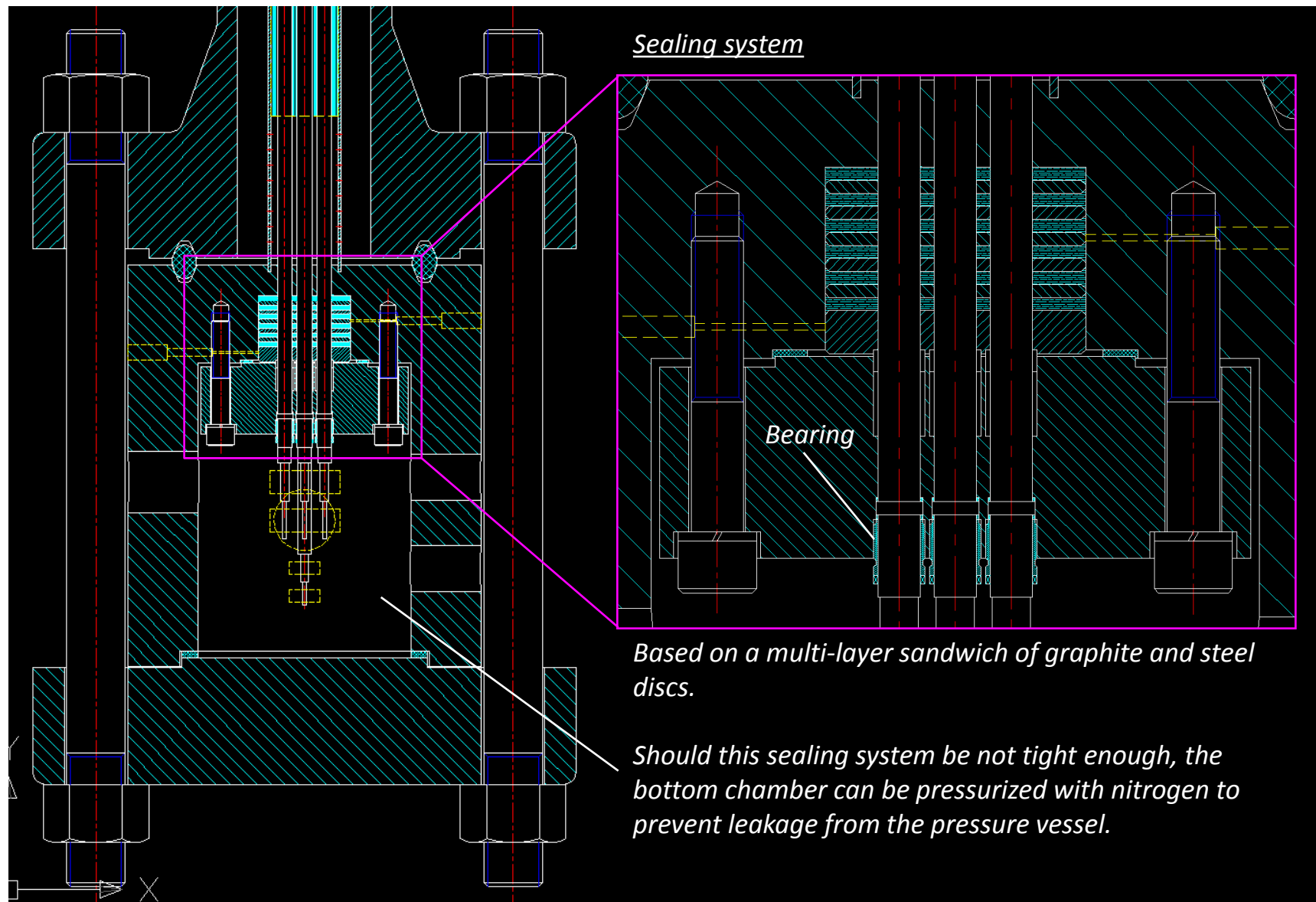
CHF-TF CONFIGURATION



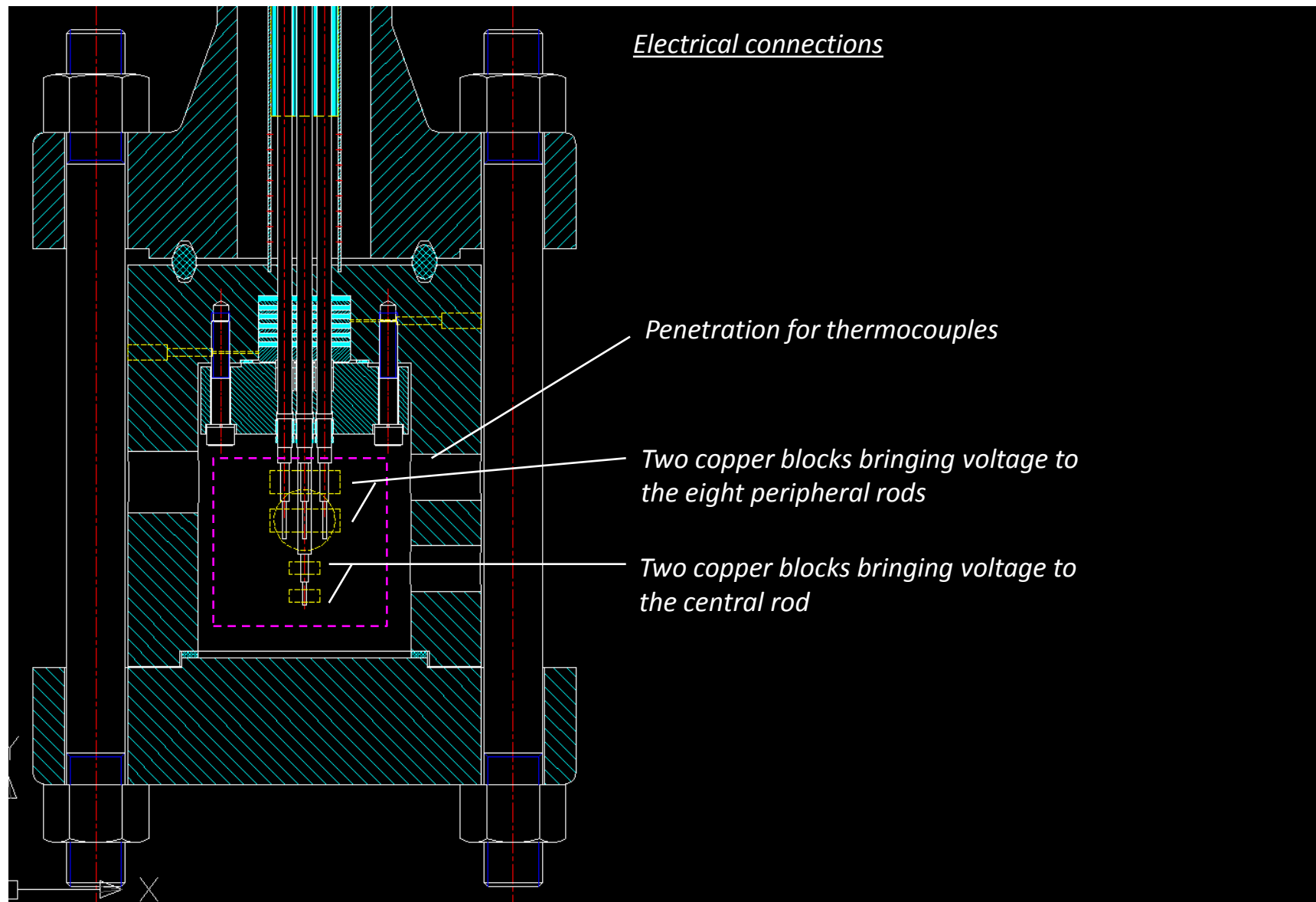
CHF-TF CONFIGURATION



CHF-TF CONFIGURATION



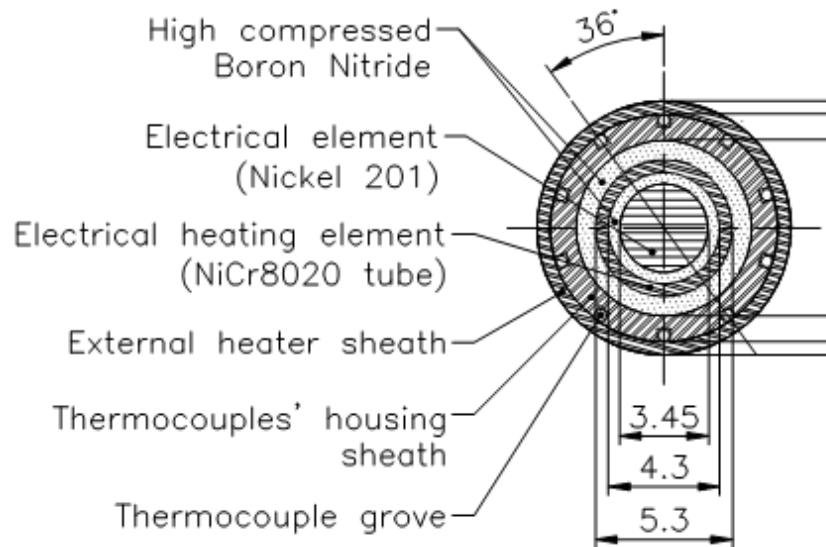
CHF-TF CONFIGURATION



KEY COMPONENT OF THE CHF-TF

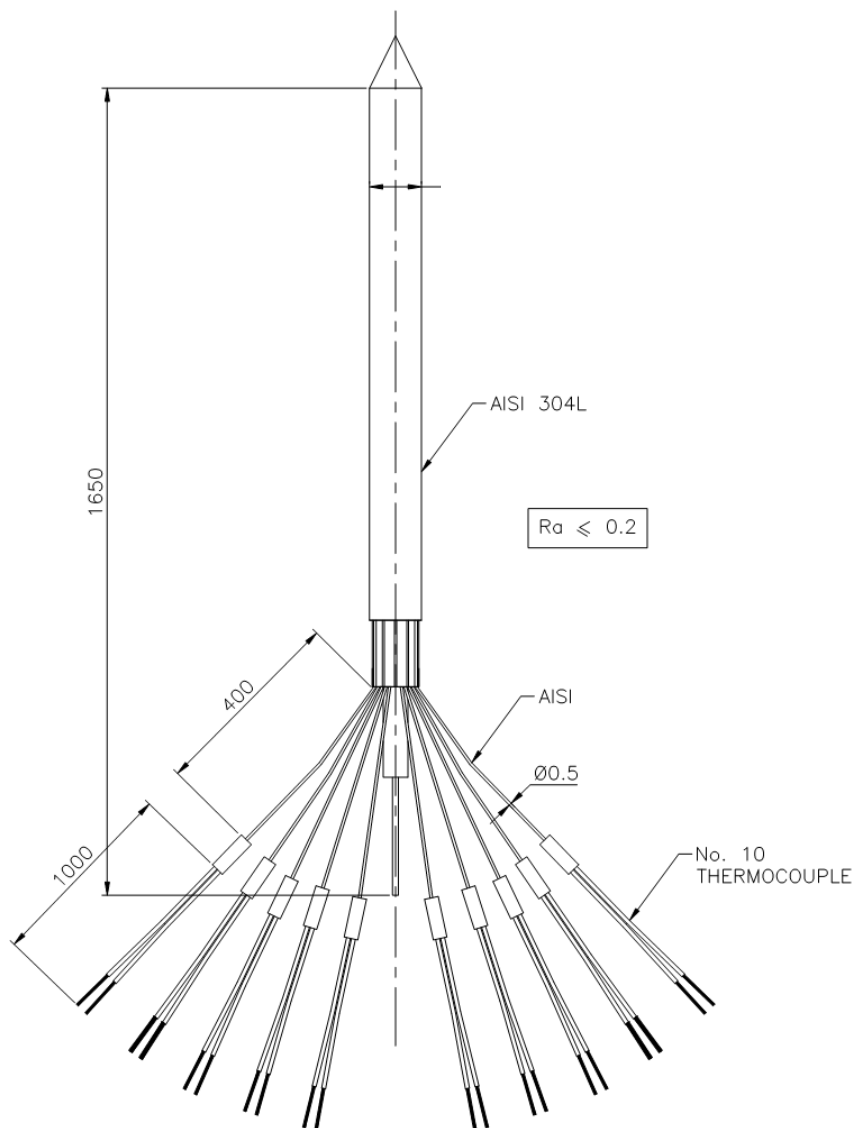


- ❑ A key component of CHF-TF is the instrumented rod:
 - High linear power (up to 50 kW/m);
 - This configuration has the two poles (+ and -) at the same side;
 - The 1000 mm active length rod has 10 thermocouples placed under the external tube;
 - The electrical insulator is compressed Boron Nitride;
 - Maximum Voltage 100 V;



KEY COMPONENT OF THE CHF-TF

□ Rods configuration



STATUS OF THE ACTIVITIES



❑ COSTRUCTION OF THE CHF-TF

- The procedure for renting the warehouse has been longer than the usual due to special authorizations needed because of high pressure loop, high electrical power;
- The main components of the loop are designed. The start of the construction activity was subject to the check of the warehouse (previous item);
- The high power electrical system is designed and the administrative procedure for the construction is started;
- The final configuration of the rods is achieved even if the manufacturer requested to perform some tests on the rods in the same conditions listed in the test matrix;
- The DAS and Control system with adequate intervention speed and reliability have been identified based on the feedback of the rod manufacturer.