Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

MINISTERO DELLO SVILUPPO ECONOMICO

Ricerca di Sistema elettrico

Feasibility Study on the Experimentation of a Decay Heat Removal System (DHRS) for Lead Fast Reactors (LFR)

O. De Pace, A. Achilli, S. Botti, G. Cattadori

SIET
sperimentiamo le tue idee

Report RdS/PAR2013/092

Feasibility Study on the Experimentation of a Decay Heat Removal System (DHRS) for Lead Fast Reactors (LFR)

O. De Pace, A. Achilli, S. Botti, G. Cattadori - SIET

Settembre 2014

Report Ricerca di Sistema Elettrico

Accordo di Programma Ministero dello Sviluppo Economico - ENEA
Piano Annuale di Realizzazione 2013
Area: Produzione di energia elettrica e protezione dell'ambiente
Progetto: Sviluppo competenze scientifiche nel campo della sicurezza nucleare e collaborazione ai programmi internazionali per il nucleare di IV Generazione
Obiettivo: Sviluppo competenze scientifiche nel campo della sicurezza nucleare
Responsabile del Progetto: Felice De Rosa, ENEA

ENEA **Ricerca Sistema Elettrico**	**Sigla di identificazione** ADPFISS-LP1-035	**Distrib.** L	**Pag.** 1 **di** 76

Titolo

Feasibility study on the experimentation of a Decay Heat Removal System (DHRS) for Lead Fast Reactors (LFR)

Ente emittente SIET

PAGINA DI GUARDIA

Descrittori

Tipologia del documento: Rapporto Tecnico
Collocazione contrattuale: Accordo di programma ENEA-MSE su sicurezza nucleare e reattori di IV generazione
Argomenti trattati: Reattori e sistemi innovativi
Sicurezza Nucleare

Sommario

A feasibility study for the construction and operation of an experimental facility devoted to the simulation of the Decay Heat Removal System (DHRS) of the Advanced Lead Fast Reactor European Demonstrator (ALFRED) is developed with reference to the DHRS concept proposed by Ansaldo Nucleare, including a steam generator, an in-pool condenser (Isolation Condenser), a non-condensable gas tank, a steam and a feed water line each equipped with isolation valves.

A preliminary design of the experimental plant is developed with the aim to use existing SIET facilities/infrastructures as much as possible. The main considered facilities/infrastructures are as follows: technological hall with the existing SPES-3 support frame 30 m high equipped with a suitable crane and elevator; an existing pool already installed at the requested elevation; the IETI facility with power supply and control room; auxiliary systems; an on-site calibration laboratory for the instrumentation; an on-site workshop for all the needed mechanical works.

Taking into account both technical feasibility and budget constraints two different options are considered for the scaling factor of the facility. A scaling factor 16:6 is assumed for the basic design while a scaling factor 16:2 is considered for possible cost reduction.

The technical feasibility of the test facility has to be checked for both the above mentioned options. The outcomes of the study are: design criteria, detailed description and drawings of the facility main components, information about the foreseen instrumentation as well as the operation basics.

Time schedule and budget estimate, including the facility design, realization and operation are provided for both the facility scaling options.

Note

Copia n. **In carico a:**

2			NOME			
			FIRMA			
1			NOME			
			FIRMA			
0	EMISSIONE	17/09/2014	NOME	P. Meloni		F. De Rosa
			FIRMA			
REV.	DESCRIZIONE	DATA		CONVALIDA	VISTO	APPROVAZIONE

sperimentiamo le tue idee	**EMITTENTE** *issued by* **UNITA' INGEGNERIA** *Engineering Unit*

CLIENTE: *client*	**ENEA**	**COMMESSA:** *job*	**1IISFVJU40077**	**PAGINA:** *page*	**1**	**DI:** *of*	**75**
IDENTIFICATIVO: *document*		**02321RT14**		**Classe Ris.:** *confidentiality*	**L**	**Allegati:** *enclosures*	**11**

TITOLO:
title

Feasibility study on the experimentation of a Decay Heat Removal System (DHRS) for Lead Fast Reactors (LFR)

REDATTORI:
prepared by

O. De Pace, A. Achilli, S. Botti, G. Cattadori

LISTA DI DISTRIBUZIONE
distribution list

ENEA
Paride Meloni

SIET
Andrea Achilli
Stefano Botti
Gustavo Cattadori
Orlando De Pace
Alfredo Luce

0	09-09-2014		Emissione / *issue*	Orlando De Pace O. De Pace	Gustavo Cattadori G. Cattadori
REV *rev*	DATA EMISSIONE *issue date*	DATA AUTORIZZAZIONE (*) *authorization date*	DESCRIZIONE *description*	REDAZIONE *prepared by*	APPROVAZIONE *approved by*

(*) Autorizzazione esterna: *External authorization* ☐ Necessaria / *Required* ☒ Non necessaria /*Not required* Organismo esterno: *External organization* --

CONTENT

I. LIST OF TABLES

II. LIST OF FIGURES

III. NOMENCLATURE

ALFRED	Advanced Lead Fast Reactor European Demonstrator
DHRS	Decay Heat Removal System
DAS	Data Acquisition System
ESNII	European Sustainable Nuclear Industrial Initiative
GFR	Gas-cooled Fast Reactor
IC	Isolation Condenser
LFR	Lead Fast Reactor
PLC	Programmable Logic Controller
SET-Plan	Strategic Energy Technology Plan
SFR	Sodium Fast Reactor
SG	Steam Generator

1. SCOPE

This document describes the feasibility study for the construction of an experimental facility devoted to the simulation of the Decay Heat Removal System (DHRS) of the ALFRED Lead Fast Reactor.

It provides the adopted design criteria, a detailed description of the geometric characteristics of the facility, information about the foreseen instrumentation as well as the operation basics.

Finally, time schedule and budget estimates for the overall Project (ie: test facility design, procurement, realization and operation) are included for two test facilities, having different scaling factor with respect to the prototypical system.

2. INTRODUCTION

Since 2000 a new vision for the nuclear energy is being put forward by the Generation IV International Forum, aiming at Nuclear Energy Systems addressing the main acceptance issues for a nuclear renaissance.

In the definition of the European energy strategy, declared in the Strategic Energy Technology Plan (SET-Plan), and aiming at strengthening the sustainability of energy production, the European Union shared the long-term vision for a more safe and sustainable generation of Nuclear Energy Systems, and launched the European Sustainable Nuclear Industrial Initiative (ESNII) to support the R&D which is necessary to target the deployment of the three most promising options: the Sodium-, Lead- and Gas-cooled Fast Reactors (SFR, LFR and GFR, respectively).

Although the SFR is presently considered as the option with the most advanced technology readiness level, the relevance of the LFR option is increasing thanks to the significant benefits allowed by the use of lead as coolant.

The excellent neutronic properties, the good heat capacity and the inertness with air and water make lead a very “ductile” coolant, allowing the design of extremely safe, simple and robust systems.

The small capture cross section and the low slowing power allow for an extreme flexibility in the design of the core, opening to the possibility of conceiving battery-like systems, or cores able to burn their own-produced plutonium and minor actinides, so as to easily implement the closure of the fuel cycle. The latter option can be achieved through the homogeneous reprocessing of the spent fuel, strongly enhancing the fuel cycle proliferation resistance.

Core configurations very prone to natural circulation can be considered, so as to achieve extreme safety levels even in the most severe accidental conditions without impairing the overall neutronic performances of the system.

The inertness with air and water allow for both the elimination of the intermediate cooling circuit and the installation, directly within the primary circuit, of decay heat removal systems based on air and water as ultimate heat sink, increasing the safety performances and robustness of the system.

Finally the optimal gamma shielding and fission product retention capabilities of lead make the coolant itself an effective physical barrier for the protection of the environment, in addition to the engineering ones.

Among the international R&D activities on the LFR the ELSY and LEADER EU Projects played a very important role for the deployment of this technology. Thanks to these Projects the Advanced Lead Fast Reactor European Demonstrator (ALFRED) is being developed under an EU initiative. A consortium has been formally set up for the construction of the ALFRED reactor in Romania.

The demonstration ALFRED unit should be built at ICN's facility in Mioveni, near Pitesti in southern Romania. Construction could begin in 2017 and the unit could start operating in 2025.

The conceptual design of the ALFRED reactor and the integrated project were led by Ansaldo Nucleare under the seventh Euratom framework program. ENEA performed the core design, the technological development and the safety analysis through numerical and experimental approaches.

3. THE DECAY HEAT REMOVAL SYSTEM

The Decay Heat Removal System (DHRS) is a fundamental passive safety system allowing the decay heat removal from the reactor core during accident conditions by means of heat transfer to an atmospheric water pool in natural circulation mode. One of the challenges of the system design consists of avoiding the lead freezing in the steam generator due to a excess of cooling. Accordingly Ansaldo Nucleare has proposed a DHRS design which allow the control of heat transfer rate by injecting uncondensable gas in the system.

3.1. General description

The DHRS proposed by Ansaldo Nucleare is a passive heat removal system operating on the basis of physical phenomena such as steam condensation and natural circulation. It has been designed to avoid the lead freezing in the LFR.

A simplified scheme of DHRS is reported in Figure 1. The system mainly consists of:

- a steam generator (SG);
- an in-pool condenser (Isolation Condenser);
- a non-condensable gas tank;
- a steam and a feed water line each equipped with isolation valves.

The condenser consists of two headers and sixteen tubes installed in an atmospheric pool full of water; the upper (steam) header is connected to the SG outlet through the steam line while the lower (condensate) header is connected to the steam generator inlet through the feed water line. The noncondensable gas tank is connected to the lower header of the IC.

In normal operation condition of LFR the IC system (condenser and gas tank) is filled with non-condensable gas at 110 bar and it is isolated upstream and downstream, respectively, from the SG steam line and feedwater line through the isolation valves, V_1 and V_3 respectively, kept closed.

As a consequence of a reactor accidental event (e.g. station blackout) both the plant feed water and the steam line valves, V_2 and V_4 respectively, are automatically closed. The SG pressure increases up to the pressure set point (190 bar,a) for the opening of the steam isolation valve (V_1). The steam enters the IC, "pushes" the non-condensable in the gas tank and condenses along the IC tubes. When the pressure inside the IC is equal to the pressure in the SG the condensate isolation valve (V_3) opens and a natural circulation occurs providing heat transfer from the SG to the water of the IC pool. In the long period, when the power removal capacity of the IC exceeds the LFR decay power, the pressure of the system (SG+IC) decreases; at this time the non-condensable gases flow back from the tank into the IC tubes so decreasing its condensing capacity. As consequence the pressure remains almost constant and the system is able to control the temperature of the lead at the SG output.

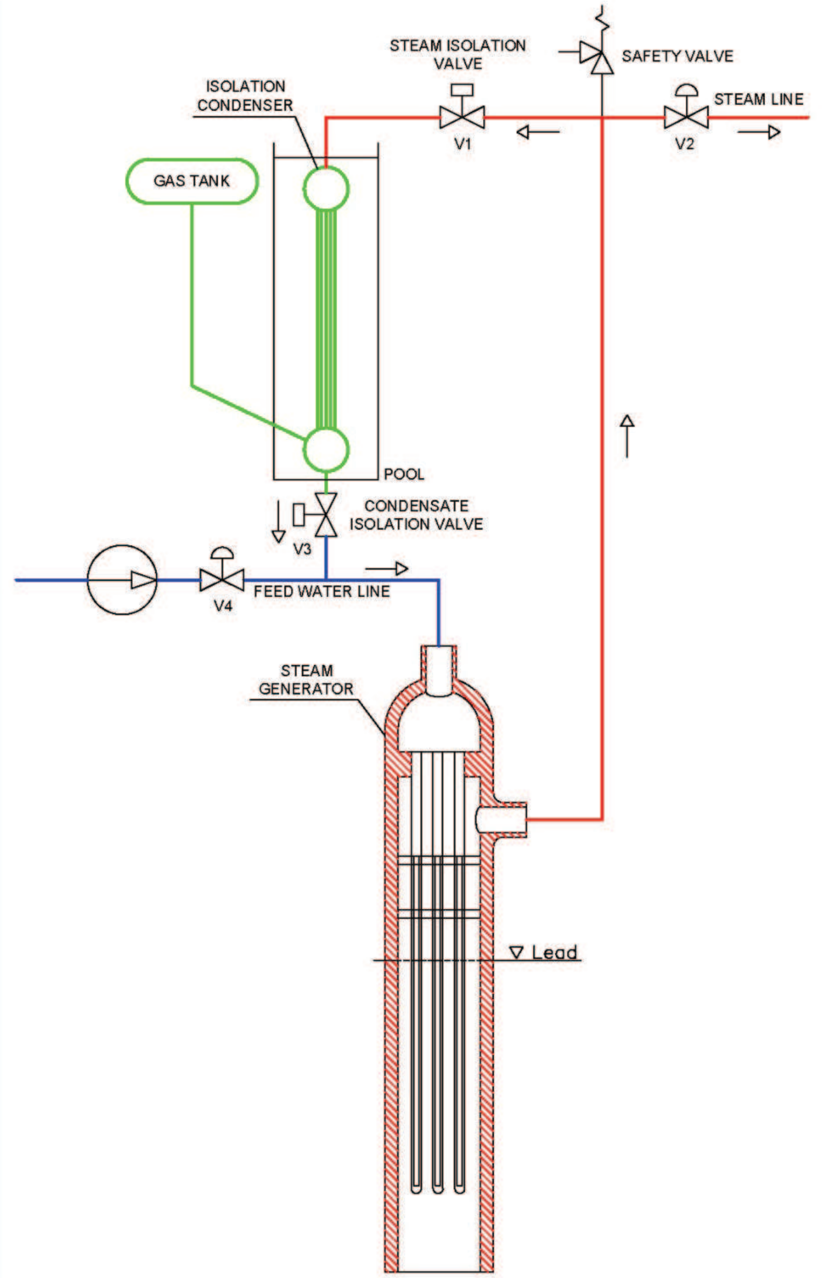


Figure 1 – Simplified scheme of Decay Heat Removal System

3.2. Isolation Condenser & Gas Tank

The characteristics of the main components of the DHRS are summarized in the following:

Steam and condensate headers

Geometry:	spherical	
External diameter:	560	mm
Thickness:	60	mm
Volume:	0.045	m^3
Material:	Inconel 600	

Isolation Condenser Tubes

Number:	16	
Length:	2000	mm
External diameter:	38.1	mm
Thickness:	3.0	mm
P/D (triangular array):	1.36	

Inlet steam line

External diameter:	114.3	mm
Thickness:	11.13	mm
Elevation from the SG outlet:	≈ 14000	mm
Length:	≈ 20000	mm

Outlet condensate line

External diameter:	114.3	mm
Thickness:	11.13	mm
Elevation from the SG inlet:	≈ 11000	mm
Length:	≈ 11000	mm

Isolation Condenser pool

Capacity:	140	m^3

Gas tank

Volume:	6	m^3

IC header / gas tank connection line

External diameter:	38.1	mm
Thickness:	3	mm

3.3. Steam generator

The ALFRED steam generator is composed by 542 bayonet tubes. Figure 2 shows the conceptual design and the geometrical characteristcs of one of these tubes as extracted from the Ansaldo Nucleare technical specification [1].

Each bayonet tube is composed by four coaxial tubes: slave, inner, outer and outermost tube, respectively. The molten lead wets the outermost tube (diameter 31.73 mm) for about 6000 mm from the bottom. The space between the outermost tube and the outer tube (diameter 25.4 mm) is filled with helium and high conductivity particles. The feed water flows through the slave tube (diameter 9.52 mm), moves downwards through the inner tube (diameter 19.05 mm) and goes back upwards into the gap between the inner and outer tubes where boiloff occurs due to heat transfer from lead side.

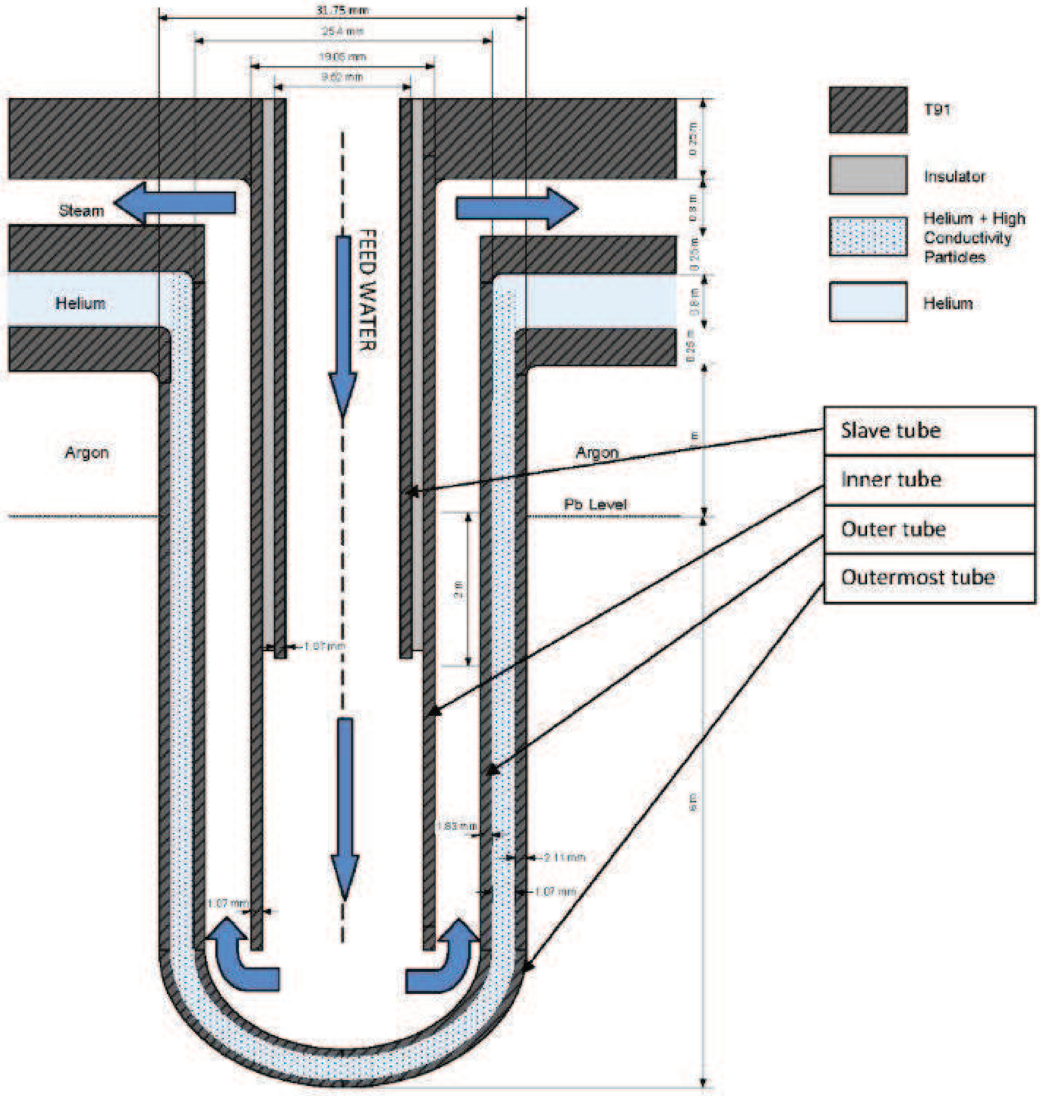


Figure 2 – Bayonet tube of ALFRED Steam Generator

Bayonet tube characteristics

Number of tubes:	542	
Number of coaxial tubes per bayonet:	4	
Length:	9.35	m
P/D (triangular array):	1.42	

Slave tube

Outside diameter:	9.52	mm
Thickness:	1.07	mm
Length:	5.35	m

Inner tube

Outside diameter:	19.05	mm
Thickness:	1.07	mm
Length:	9.35	m

Outer tube

Outside diameter:	25.4	mm
Thickness:	1.83	mm
Length:	8.05	m

Outermost tube

Outside diameter:	31.75	mm
Thickness:	2.11	mm
Length:	7.0	m
Lenght of exchange:	6.0	m

Steam Generator Plena

Argon plenum height:	1.0	m
Helium plenum height:	0.8	m
Steam plenum height:	0.8	m

4. SIET PROPOSED FACILITY FOR ALFRED REACTOR DHRS TESTING

In this section an experimental facility is proposed to simulate the reference DHRS system of ALFRED LFR, with an appropriate scaling factor.

The general criteria of the scaling factors and their impact on the geometrical characteristics of the main components of the facility are described.

4.1. Facility components

The facility includes the following components/systems:

- steam generator
- condenser
- condenser pool
- gas tank and relevant feeding system
- gas tank/IC connection lines
- feed water circuit
- automatically operated isolation valves
- safety valves
- IC/SG connecting piping
- instrumentation and data acquisition system
- auxiliary systems

The test facility P&I is reported in the Annex 1/a and Annex 1/b.

4.2. Scaling factor and design criteria

The range for the scaling factor is within a lower value which depends both on budget constrains and SIET capabilities (ie: space for facility installation and power), and an upper value able to ensure a good significance of the experimental tests and, consequently, the ability to characterize the behavior of the reference DHRS system.

The number of isolation condenser tubes represents the starting point to define the scaling factor. The design of the ALFRED IC provides a number of 16 tubes. SIET proposes to realize a condenser with a smaller number of tubes (6 or 2) while maintaining the same geometry of the reference system.

The scaling factor is defined as:

$$f_i = N_{FS} / N_i$$

where:

N_{FS} is the condenser tube number of the reference plant

N_i is the tube number of SIET proposed experimental condenser

Two scaling factors are considered for the purpose of the present work:

$$f_1 = 16/6 = 2.67$$

$$f_2 = 16/2 = 8$$

In the present feasibility study all the calculations and the relevant drawings refer to the application of the greater scaling factor f_1, while technical considerations, cost evaluation and time schedule are supplied for both the scale factor f_1 and f_2 application.

The test facility is full-scale in elevation (ie: facility component elevations equal to the reference plant component elevations) in order to guarantee a correct reproduction of the natural circulation phenomena. As far as the component volumes and cross sections are concerned the following three scaling criteria are considered:

a) reducing the volume on the basis of the adopted f_i scaling factor:

$$V_i = V_{FS} / f_i$$

where:

V_i	is the facility component volume
V_{FS}	is the reference plant component volume

and by a cross section reduction of a factor f_i:

$$D_i^2 = D_{FS}^2 / f_i$$

where:

D_i	is the facility component diameter
D_{FS}	is the reference plant component diameter

b) reducing the volume of the Isolation Condenser and Steam Generator bayonet tubes by a reduction of the corresponding tube number while maintaining their dimensions (diameter, thickness, lenght) as the reference plant;

c) reducing the pipe diameter (e.g. steam line, condensate line, feed water line) maintaining the prototypical value of the friction pressure drops. In this case the diameter is calculated by the following criteria.

In natural circulation condition the following relationship applies:

$$g * \Delta z * (\rho_f - \rho_c) = \frac{8 * \lambda * L}{\pi^2 \rho} \frac{\dot{m}_{FS}^2}{D_{FS}^5} = \frac{8 * \lambda * L}{\pi^2 \rho} \frac{\dot{m}_i^2}{D_i^5}$$

where :

g	gravity acceleration
Δz	height difference
ρ_f	average density of the condensate
ρ_c	average density of the the steam
ρ	average value between ρ_f and ρ_c
λ	friction factor

L	sum of steam and condensate line lengths
$\dot{m}_{FS}$	mass flow rate in the ALFRED circuit
$\dot{m}_i$	mass flow rate in the SIET facility
D_{FS}	pipe internal diameter in the ALFRED circuit
D_i	pipe internal diameter in the SIET facility

placing

$$\dot{m}_i = \frac{\dot{m}_{FS}}{\mathrm{fi}}$$

we obtain:

$$D_i = \frac{D_{FS}}{\sqrt[5]{\mathrm{fi}^2}}$$

By appling criteria a) and c) the theoretical diameter of the components is often different from commercial pipe diameter; in this case the closest diameter pipe is choosen.

4.3. Isolation condenser and gas tank

The volume of each upper and lower header of the ALFRED Isolation Condenser is 0.045 m^3.

According to the adopted scaling factor (f_1 = 2.67) the unit volume of these two heardes in the SIET test facility should be 0.0169 m^3. The two headers are simulated by an ANSI B36.10 standard pipe , size DN10" schedule 160, internal diameter 215.94 mm, thickness 28.58 mm, height 440 mm (same height as the spherical headers of the reference plant), equipped with an upper and a lower semi-elliptic head. In this configuration, the volume of each header is about 0.0167 m^3.

The reference elevation (14000 mm) between the SG steam line outlet and the IC header inlet section has been maintained.

The tubes of the facility IC maintain the same geometry of the ALFRED plant: external diameter 38.1 mm, thickness 3 mm, length 2000 mm. The total volume of the tube bundle amounts to 0.00971 m^3.

Similarly, according to the adopted scaling factor (f_1 = 2.67), the volume of the gas tank shall be scaled from 6 m^3 to 2.25 m^3.

For the simulation of this component, three possible solutions have been considered, as follows:

- use of a forged tank in stainless steel 304 type;
- use of three pipes ANSI B 36.10, size DN20" schedule 160, connected togheter;
- use of a set of 42 bottles such as those used for gas storage.

More details are given in Chapter 5.1.

Unlike the reference ALFRED plant, in the SIET proposed facility the gas tank is connected to both the upper and lower condenser headers; each line can be isolated by means of a blind disc. This plant arrangement increase the test facility flexibility allowing injection of the gas in different IC parts and the possible use of both heavier (air, nitrogen) and lighter (helium) than steam gases.

The theoretical inner diameter of these connection lines are calculated according to the scaling criteria defined in paragraph 4.2 c) is 21.67 mm. Taking care to choose a pipe schedule 160 at least with an internal diameter as close as possible to that calculated, the adopted piping for these lines in the SIET facility is a DN32 (1" ¼) schedule XXS pipe with an internal diameter of 22.8 mm.

4.4. Steam and condensate lines

The RELAP input file for the ALFRED steam generator and isolation condenser provides:

- a condensate line 11000 mm long with an elevation of 11000 mm on respect to SG inlet;
- a steam line 20000 mm long with an elevation of 14000 mm on respect to SG oulet.

In a first approximated calculation, since the elevations and lengths of the lines in the ALFRED plant and SIET proposed facility are comparable, we can apply the scaling criteria defined in 4.2 c).

By assuming:

D_{ALFRED} = 92.04 mm

f_1 = 16/6 = 2.67

We obtain:

$D_{FACILITY}$ = 62.14 mm

The standard pipe with an internal diameter closest to that calculated is a 3" schedule 160 pipe, external diameter 88.9 mm, thickness 11.13 mm, internal diameter 66.64 mm, which is considered for using in the facility.

4.5. Steam Generator

The steam generator designed for the ALFRED reactor consists of 542 bayonet tubes.

In accordance with a scale factor of 2.67 the tube number of the facility steam generator should be 203.25 (542 / 2.67).

The SG designed for the facility consists of 12 water/steam collectors each with 17 bayonet tubes for a total of 204 tubes. As the dimensions of the SIET SG tubes are prototypical, also the volume is scaled of the same factor (2.67).

Compared with the ALFRED SG as described in paragraph 3.2, the bayonet tube proposed by SIET includes only three tubes: the slave, the inner and the outer. The outermost tube and the cavity filled with helium and high conductive particles are not simulated, being the thermal power from the lead pool (SG primary side) supplied by electrical heating .

Two different technical solutions can be adopted to provide the steam generator with electrical power.

The first solution involves the direct heating of SG outer tubes (outside diameter 26.67 mm) by Joule effect applying a proper electrical voltage and maintaining these tubes isolated from the inner tubes by means of ceramic insulators whose details are reported in the drawings of Annex 2/a and Annex 2/b.

The second solution involves the indirect heating of SG outer tubes consisting on heating the outer tubes by wrapping them with "heating cables" tightened with bolted metal straps. The thermal insulation of the whole steam generator is obtained by entering the tubes assembly into an aluminum case fully filled in with rockwool. The top and the bottom of this case is maintened open to allow the power and instrumentation connections. The assembly and preliminary detailed drawings of the steam generator are reported in Annex 2/c.

4.6. Isolation Condenser Pool

The ALFRED pool volume for each IC unit is 140 m^3; by applying the scaling factor of 2.67 the theoretical pool volume of the proposed SIET facility should be 52.43 m^3.

Indeed we have thought of use an existing pool 16,35 m^3 in volume; being the external volume of SIET IC 0.077m^3, the net capacity of the proposed pool is 16,273 m^3 (16,35 m^3 - 0,077 m^3).

Established that this significant volume difference does not impaict on the in-pool heat transfer phenomenology, an auxiliary circuit to cool or replace the pool water during the tests is necessary, in particular in case of long duration transient tests.

The sizing of the lines to discharge and refill the pool water is obtained by the following calculation.

In the ALFRED reactor the thermal power dissipated by the condenser is about 1,75 MW. Therefore, the power dissipated by the facility condenser is 655,43 kW (1.75 MW / 2.67).

Assuming an initial water temperature of 293.15 K the pool water starts to boil after:

$$\Delta t = \frac{\rho * V * (hsat(1bar\ (a)) - \ h(293K; 1bar(a)))}{P} = 2.3\ hours$$

with:

ρ, water density = 1000 kg/m^3
V, water volume = 16,27 m^3
h_{sat} (1 bar,a), saturated water specific enthalpy = 417,4 kJ/kg
h (293 K /1 bar,a), subcooled water specific enthalpy = 84,0 J/kg
P, thermal power = 655 kW

This time is certainly much less than the expected duration of the tests and this obviously makes necessary to insert lines for the continuous replacement of the pool water.

Assuming to remove all the thermal power exchanged by the condenser with an inlet water temperature of 20 °C and an outlet temperature of 60 °C, by applying the following pool power balance equation:

$$P = \ \rho * v * \frac{\pi}{4} * D^2 * \ c_p * (T_{out}\ - T_{in})$$

with :

P, thermal power = 655 kW
ρ, water density = 1000 kg/m^3
v, water average velocity in the pipes = 1,5 m/s
$c_{p,}$ water specific heat = 4186 J/kg/K

T_{out}, water temperature at the pool oulet = 60 °C
T_{in}, water temperature at the pool inlet = 20 °C

We obtain a piping internal diameter of 57.64 mm.

A 2" ½ pipe, schedule 80 ANSI B36.10, internal diameter 58.98 mm, is chosen for this application.

5. TEST FACILITY PRELIMINARY DESIGN

The scope of the preliminary design is to verify if the proposed solutions are feasible both from structural and functional point of view.

More accurate verification in agreement with the design standards have to be executed during the final design of the test facility which is out of the scope of the present document.

5.1. Isolation Condenser

As previously mentioned the condenser tube number is chosen as reference. Assuming a IC tube number of the proposed facility equal to 6, a 2.67 scale factor applies.

The design of the condenser headers consists in defining their external diameter and thickness to obtain a scaled volume according to the above mentioned factor. On the contrary, thickness and diameter of the condenser tubes are exactly the same of the ALFRED reference plant .

The design pressure is assumed at 220 bar. Preliminary structural verications are carried out on the IC headers, IC tubes and SG bayonet tubes by assuming as reference temperatures those resulting from a simplified heat transfer calculations as presented in the following.

Isolation condenser headers

The temperature profile in the condenser header thickness is detected taking as reference the convective heat transfer coefficients available in literature and assuming a pool water temperature of 100 °C.

The input data are:

Pressure	22	MPa
T_{steam}	450	°C
Temperature of pool water	100	°C
Thickness	0,02858	m
Thermal conductivity (AISI 304)	14,1	$Wm^{-1}K^{-1}$
Heat transfer coefficient (steam side)	10000	$Wm^{-2}K^{-1}$
Heat transfer coefficient (water side)	5000	$Wm^{-2}K^{-1}$
Overall Heat Transfer Coefficient	429	$Wm^{-2}K^{-1}$

Table 1 shows the results of an approximate thermal calculation for the IC headers:

Heat flux	150086	W/m^2
Header inner surface temperature	435,0	°C
Header outer surface header temperature	130,0	°C
Mean temperature	282,5	°C

Table 1 – Temperature profile for IC headers

Based on this temperature profile the results of an approximate verification of the proposed IC headers are presented below.

Steam header design (f = 2,67)			
Internal pressure	P_i	22	MPa
External diameter	D_e	273,1	mm
Thickness	s	28,58	mm
Internal diameter	D_i	215,94	mm
Cross section area	A	36623	mm^2
Lenght	L	440	mm
β	D_i / D_e	0,791	
Radial stress	σ_{rad}	-22	MPa
Peripheral stress	σ_{circ}	95,4	MPa
Axial stress	σ_{ass}	36,7	MPa
Equivalent stress	σ_{equ} (Von Mises)	101,7	MPa
Material		AISI 304	
Design Temperature		282,5	°C
Allowable stress	σ_{adm}	134,8	MPa
Check	$\sigma_{adm} \geq \sigma_{equ}$	OK	

Table 2 – IC header thickness verification

Isolation condenser tubes

The same assumptions and methodology adopted for the headers of the isolation condenser are extended to the IC tubes. In this case the input data are:

Pressure	22	MPa
T_{sat} (at 22 MPa)	373,7	°C
Temperature of pool water	100	°C
Tube thickness	0,003	m
Thermal conductivity (AISI 304)	14,1	$Wm^{-1}K^{-1}$
Heat transfer coefficient (steam side)	10000	$Wm^{-2}K^{-1}$
Heat transfer coefficient (water side)	5000	$Wm^{-2}K^{-1}$
Overall Heat Transfer Coefficient	1948	$Wm^{-2}K^{-1}$

Table 3 shows the results of an approximate thermal calculation for the IC tubes:

Heat flux	533240	W/m^2
inner surface temperature	320,4	°C
Outer surface tube temperature	206,6	°C
Mean temperature	263,5	°C

Table 3 – Temperature profile for IC tubes

The results of a preliminary structural verification for the IC tube is presented in Table 4.

Internal pressure	P_i	22	MPa
External diameter	D_e	38,1	mm
Thickness	s	3	mm
Internal diameter	D_i	32,1	mm
Area	A	809,3	mm^2
β	D_i / D_e	0,84	
Radial stress	σ_{rad}	-22	MPa
Peripheral stress	σ_{circ}	129,6	MPa
Axial stress	σ_{ass}	53,8	MPa
Equivalent stress	σ_{equ} (Von Mises)	131,3	MPa
Material		AISI 316	
Temperature		263,5	°C
Allowable stress	σ_{adm}	137,5	MPa
Check	$\sigma_{adm} \geq \sigma_{equ}$	OK	

Table 4 – Condenser tube thickness verification

The IC drawing is reported in Annex 4.

5.2. Steam Generator

The steam generator consists of 12 identical modules each including an upper feed water header, 17 bayonet tubes and a lower steam header. The elevation difference between the upper and lower header is 650 mm. The water feeds the 12 modules through a single collector.

As mentioned in paragraf 4.1 each bayonet tube of the SIET proposed steam generator is composed of three coaxial tubes: the slave, the inner and the outer tube respectively.

The outer tube is plugged at the bottom while the inner and the slave tubes are open to allow the feed water flow.

The slave tube - external diameter 9.52 mm - is connected to the upper feed water header and it develops downward for a total length of 5.35 m. The upper and lower ends of the slave tube are welded to the inner tube - external diameter 19.05 mm. The space (2.89 mm) between the slave and inner tube operates as insulation for the feed water flowing downwards.

The SG feed water goes down at first along the slave tube - internal diameter 7.38 mm - then through the inner tube - internal diameter 15.29 mm - reaching the bayonet tube bottom. At this point the feed water goes back through the interspace (1.31 mm) between the inner and outer tube where the boiloff occurs due to heat transfer reaching the steam header.

The outer tube is heated by Joule effect or by means of electrical resistors wrapped on the external surface in order to simulate the heat accumulated in the molten lead plus the decay heat to be removed from the molten lead.

The 17 outer tubes - external diameter 26.67 mm, thickness 2.50 mm - are connected to a steam header - internal diameter 65 mm. The 12 steam headers address the steam to a single collector which is connected to the isolation condenser through a 3" schedule 160 pipe.

The water and steam headers, the three pipes forming the bayonet tube and the steam and condensate lines are manufactured in AISI 304 stainless steel.

The results of a preliminary structural verification of the steam generator are reported in the following paragraphs 5.2.1 and 5.2.2, in particular as regards:
1) the bayonet tubes;
2) the steam header.

5.2.1. Bayonet tube structural analysis

The dimensional characteristics of the three tubes constituting the bayonet tube proposed by SIET are summarized below:

slave pipe

- external diameter: 9.52 mm
- thickness: 1.07 mm

inner pipe

- external diameter: 19.05 mm
- thickness: 1.88 mm

outer pipe

- external diameter: 26.67 mm
- thickness: 2.5 mm

The design pressure and temperature are respectively:

P_{design} = 220 bar
T_{design} = 373.7 °C for the slave pipe and for the bottom part of inner pipe
T_{design} = 450 °C for the upper part of inner pipe and for the outer pipe

Due to the internal pressure of the SG the most critical bayonet tube is the outer tube. The results of a mechanical resistance verification are summarized in Table 5.

BAYONET OUTER TUBE			
Internal pressure	P_i	22	MPa (a)
External diameter	D_e	26,67	mm
Thickness	s	2,5	mm
Internal diameter	D_i	21,67	mm
Cross section area	A	368,8	mm^2
β	D_i / D_e	0,81	
Radial stress	σ_{rad}	-22	MPa
Periferical stress	σ_{circ}	107,5	MPa
Axial stress	σ_{ass}	42,7	MPa
Equivalent stress	σ_{equ} (Von Mises)	112,1	MPa
Material		AISI 304	
Temperature		450	°C
Allowable stress	σ_{adm}	114,4	MPa
Check	$\sigma_{adm} >= \sigma_{equ}$	OK	

Table 5 – Outer tube thickness verification

Due to the presence of the insulation gap between the slave and the upper part of inner tube, the slave pipe is subjected to a load due to an internal pressure only.

Table 6 summarizes the results of the mechanical verification performed on the slave tube.

The part of the inner pipe isolated from the slave pipe by a gap is subjected to a state of stress due to the pressure acting on its outer surface. The worst operating conditions for this tube consists of an external pressure of 22 MPa, an internal pressure of 0.1 MPa and a surface temperature of about 450 °C. In this conditions the inner tube should have a minimum thickness of about 2.01 mm.

The results of the mechanical verification performed on the inner tube are summarized in Table 7.

To prevent stress conditions too different in the SIET configuration compared to the ALFRED reference plant and to eliminate the strong pressure gradient on this tube the gap could be filled with mineral oxide.

More accurate verification in agreement with the applicable standards has to be executed during the final design of the steam generator.

BAYONET SLAVE TUBE			
Internal pressure	P_i	22	MPa (a)
External diameter	D_e	9,52	mm
Thickness	s	1,07	mm
Internal diameter	D_i	7,38	mm
Area	A	42,8	mm^2
β	D_i / D_e	0,78	
Radial stress	σ_{rad}	-22	MPa
Periferical stress	σ_{circ}	88,3	MPa
Axial stress	σ_{ass}	0,0	MPa
Equivalent stress	σ_{equ} (Von Mises)	101,1	MPa
Material		AISI 304	
Temperature		373,71	°C
Allowable stress	σ_{adm}	121,7	MPa
Check	$\sigma_{adm} >= \sigma_{equ}$	OK	

Table 6 – Slave tube thickness verification

BAYONET INNER TUBE			
External pressure	P_e	22	MPa (a)
External diameter	D_e	19,05	mm
Material		AISI 304	
Temperature design		450	°C
Allowable stress	σ_{adm}	114,4	MPa
Thickness	s	2,01	mm
(thickness calculated according the VSR 1.M.3)			

Table 7 – Inner tube thickness verification

5.2.2. SG steam header structural analysis

A preliminary structural analysis of the SG steam header based on Von Mises criterion is reported in the following.

The minimum cross section of the steam header material, as determined from SIET drawing 100.02.00, is equal to 10018 mm^2. The axial force acting on the steam header is:

$$F = p * \frac{\pi}{4} \mathrm{d}^2 = 73003 \ \mathrm{N}$$

where:

p = 22 MPa

d = 65 mm

The maximum axial stress is therefore:

$$\sigma_{ass} = F/A = 7.29 \ \mathrm{MPa}$$

The internal pressure causes a normal stress equal to:

$$\sigma_{norm} = -22 \text{ MPa}$$

For the calculation of the peripheral stress, σ_{perp}, in the plane of the minimum cross section of the steam header is useful to refer to the following figure.

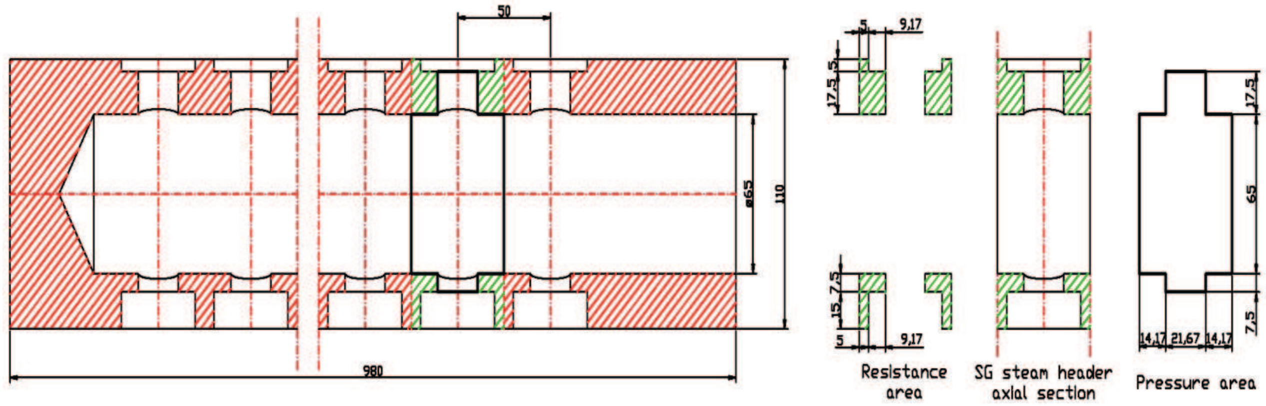


Figure 3 – SG steam header resistance area

As a first approximation the area of material (A_1) resistant to the stress due to the pressure acting along the central (diameter 65 mm) and the vertical tube (diameter 21.67 mm) holes, with the exclusion of the area filled with the o-rings, is that outlined with green lines in the figure.

It is equal to 908 mm^2.

The section A_2 on which the internal pressure acts is 3792 mm^2.

Therefore the peripheral stress due to the internal pressure is:

$$\sigma_{perp} = p \times A_2 / A_1 = 91.84 \text{ MPa}$$

According to Von Mises criterion the equivalent stress is equal to:

$$\sigma_{eq} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_{ass} - \sigma_{nor})^2 + ({\sigma_{ass}}^2 - {\sigma_{perp}}^2) + ({\sigma_{nor}}^2 - {\sigma_{perp}}^2)} = 104\, MPa$$

At the temperature of 450 °C the yielding stress of AISI 304 is about Rp0.2 = 114.4 MPa.

A proper finite element analysis has to be carried out to confirm the strength of the steam header.

5.3. Gas Tank

According to the ALFRED design, the isolation condenser and the gas tank come into operation around 190 bar. The safety valves are set at 220 bar.

Therefore the design conditions for the gas tank are:

P_{design} = 220 bar

T_{design} = 373.71 °C

where the design temperature is the water saturation temperature corresponding to the design pressure. The results of the mechanical verification of the gas tank are presented here below.

ITEM	VARIABLE	INPUT/OUTPUT	V.N.	U.M
Internal design pressure	p_i	INPUT	220	bar
Internal design temperature	T_i	INPUT	373,7	°C
External design pressure	p_e	INPUT	1	bar
Material	AISI 304	INPUT		
Admissible stress	σ_{adm}	INPUT	121,7	N/mm^2
External diameter	d_e	INPUT	1200	mm
Thickness	s	INPUT	110	mm
Steel density		INPUT	7850	kg/m^3
Water density		INPUT	1000	kg/m^3
Shell length	L	INPUT	2864	mm
Internal diameter	d_i	OUTPUT	980	mm
Tank volume	V	OUTPUT	2160303054	mm^3
		OUTPUT	2,16	m^3
Tank weight (empty)	P_{empty}	OUTPUT	8468	kg
Tank weight (full of water)	P_{full}	OUTPUT	10629	kg
β	d_i / d_e	OUTPUT	0,82	
Longitudinal stress	σ_{long}	OUTPUT	43,75	N/mm^2
Radial stress	σ_{rad}	OUTPUT	-22	N/mm^2
Peripheral stress	σ_θ	OUTPUT	110,11	N/mm^2
Equivalent stress	σ_e	OUTPUT	114,41	N/mm^2
Check	$\sigma_{adm} \geq \sigma_e$	OUTPUT	OK	

Table 8 – Mechanical verification of forged gas tank

The assembly drawing of the forged gas tank is reported in Annex 7; the installation of this tank on the existing steel structure is shown in the plant view reported in Annex 8.

Since the above described tank is very expensive as consequence of its high thickness (110 mm), which implies a complex forging operation and sophisticated non-destructive inspections, other options are evaluated with the primary aim of reducing the fabricating costs.

As a first alternative a gas tank composed by three tubes of standard size DN 20" schedule 160 or tubes fabricated with calendered sheets can be realized. This option requires lower costs and allows the splitting of the gas volume that could be very useful for the testing scope.
The following Table 9 shows the results of the verification performed on the thickness of the cylindrical shell of the gas tank.

Internal pressure	P_i	22	MPa (a)
External diameter	D_e	504	mm
Thickness	s	50,1	mm
Internal diameter	D_i	403,8	mm
Area	A	128062,5	mm^2
β	D_i / D_e	0,80	
Radial stress	σ_{rad}	-22	MPa
Periferical stress	σ_{circ}	100,9	MPa
Axial stress	σ_{ass}	39,4	MPa
Equivalent stress	σ_{equ} (Von Mises)	106,4	MPa
Material		AISI 304	
Temperature		373,71	°C
Allowable stress	σ_{adm}	121,7	MPa
Check	$\sigma_{adm} >= \sigma_{equ}$	OK	

Table 9 – Mechanical calculation of gas tank manufactured by calendered sheets

The drawing of the gas tank manufactured with tubes is reported in Annex 9 while the plant view of these three tanks is shown in Annex 10.

The second alternative taken into account foresees to realize the gas tank using inert gas storage tanks. All the contacted suppliers proposed us cylinders in carbon steel free of surface treatments to prevent the formation of iron oxides. Because of the small gap of the bayonet tubes in which the steam flows, this solution was rejected as the iron oxide may potentially obstruct the steam flow.

For the installation of both the forged tank and the three tanks a more detailed structural analysis has to be conducted in the final design of the test facility. A preliminary calculation for the forged tank (the most conservative option) has been reported in the Annex 11 in order to evaluate the feasibility.

Anyway for the scope of the present work the cost estimate is referred to the three tank option, which is the less expensive one.

5.4. Isolation valves

The isolation valves installed on steam and condensate lines are pneumatically actuated ball valve type, flanged end connections, stainless steel AISI 316 material. Each valve is equipped with a compressed air tank, the limit switches, a potentiometer to measure the opening position, a pneumatic control circuit to adjust the opening and closing speed and a two-way solenoid valve.
The steam isolation valve is dimensioned to withstand a pressure of 220 bar (3190 psi) and a temperature of 450 °C (842 °F). Based on the table extracted from ASME B16.34 - 1998 Code, as reported in the following, a rating of # 2500 can be choosen.

A same valve can be adopted for the condensate line, being the design condition lower (220 bar, 373.7 °C).

5.5. Steam and condensate lines

A stress analysis of both the steam and condensate lines is performed taking into account the piping thermal expansion. For this purpose a simplified method based on the ANSI B31.1 "Power Piping - ASME Code for Pressure Piping" is used. According to this criterion, we have to verify that:

$$\frac{D\ x\ Y}{(L-U)^2} \leq 208$$

where:

D (mm)	external diameter of the pipe
L (m)	total length of the pipe line
U (m)	length of straight line between the pipe anchors
Y (mm)	resultant displacement between the anchors to be absorbed by the piping system

(a)

TABLE 2-2.2
RATINGS FOR GROUP 2.2 MATERIALS

A 182 Gr. F316 (1)
A 182 Gr. F316H
A 240 Gr. 316 (1)
A 240 Gr. 316H
A 240 Gr. 317 (1)
A 312 Gr. TP316 (1)
A 312 Gr. TP316H
A 312 Gr. TP317 (1)
A 351 Gr. CF3A (2)
A 351 Gr. CF3M (3)
A 351 Gr. CF8A (2)
A 351 Gr. CF8M (1)
A 358 Gr. 316 (1)
A 376 Gr. TP316 (1)
A 376 Gr. TP316H
A 430 Gr. FP316 (1)
A 430 Gr. FP316H
A 479 Gr. 316 (1)
A 479 Gr. 316H
A 351 Gr. CG8M (4)

NOTES:
(1) At temperatures over 1000°F, use only when the carbon content is 0.04% or higher.
(2) Not to be used over 650°F.
(3) Not to be used over 850°F.
(4) Not to be used over 1000°F.

TABLE 2-2.2A STANDARD CLASS

	Working Pressures by Classes, psig							
Temperature, °F	150	300	400	600	900	1500	2500	4500
-20 to 100	275	720	960	1,440	2,160	3,600	6,000	10,800
200	235	620	825	1,240	1,860	3,095	5,160	9,290
300	215	560	745	1,120	1,680	2,795	4,660	8,390
400	195	515	685	1,025	1,540	2,570	4,280	7,705
500	170	480	635	955	1,435	2,390	3,980	7,165
600	140	450	600	900	1,355	2,255	3,760	6,770
650	125	445	590	890	1,330	2,220	3,700	6,660
700	110	430	580	870	1,305	2,170	3,620	6,515
750	95	425	570	855	1,280	2,135	3,560	6,410
800	80	420	565	845	1,265	2,110	3,520	6,335
850	65	420	555	835	1,255	2,090	3,480	6,265
900	50	415	555	830	1,245	2,075	3,460	6,230
950	35	385	515	775	1,160	1,930	3,220	5,795
1000	20	350	465	700	1,050	1,750	2,915	5,245
1050	20(1)	345	460	685	1,030	1,720	2,865	5,155
1100	20(1)	305	405	610	915	1,525	2,545	4,575
1150	20(1)	235	315	475	710	1,185	1,970	3,550
1200	20(1)	185	245	370	555	925	1,545	2,775
1250	20(1)	145	195	295	440	735	1,230	2,210
1300	20(1)	115	155	235	350	585	970	1,750
1350	20(1)	95	130	190	290	480	800	1,440
1400	20(1)	75	100	150	225	380	630	1,130
1450	20(1)	60	80	115	175	290	485	875
1500	20(1)	40	55	85	125	205	345	620

NOTE:
(1) For welding end valves only. Flanged end ratings terminate at 1000°F.

For the condensate line:

L = 17959 mm

U = 11113 mm

D = 88.9 mm

Mounting temperature T_{mn}: 20 °C

Operating temperature T_{op}: 373.7 °C

Mean thermal expansion coefficient of AISI 304 L (20°C ÷ 400°C): $\alpha = 17{,}5 \times 10^{-6}\ K^{-1}$

$Y = \alpha * U * (T_{op} - T_{mn}) = 68.8$ mm

$$\frac{D\ x\ Y}{(L-U)^2} = 130.5 \leq 208$$

For the steam line:

L = 22283 mm

U = 15394 mm

D = 88.9 mm

Mounting temperature [T_{mn}]: 20 °C

Operating temperature [T_{op}]: 450 °C

Mean thermal expansion coefficient of AISI 304 L (20°C ÷ 450°C): $\alpha = 17{,}5 \times 10^{-6}\ K^{-1}$

$Y = \alpha * U * (T_{op} - T_{mn}) = 115.8$ mm

$$\frac{D\ x\ Y}{(L-U)^2} = 217 > 208$$

The lenght of the steam line has to be sligtly increased at 22.5 m.

In this preliminary analysis only the flexibility of the lines has been verified. A more accurate calculation will be needed to identify the most suitable position of the line supports and their effect on the piping.

The drawings of the steam and condensate lines are reported in Annex 3.

5.6. SG feed water and steam plena

The steam generator of the ALFRED reactor is equipped with a feed water and a steam plena. In the SIET facility these plena are scaled according to the criterion a) of paragraph 4.2.

The following Table 10 shows the volume of the piping and plena in the reference plant and the volume in the proposed facility compared with that obtained by applying the scale factor f_1 = 16:6.

	ALFRED volume [m^3]	SIET facility volume [m^3]	Scaled volume [m^3] (f_1=16:6)
Condensate line	0,073	0,063	0,027
Steam line	0,133	0,078	0,050
Feed water plenum	0,330	0,044	0,124
Steam plenum	0,600	0,050	0,225
Total	1,136	0,235	0,426

Table 10 – Volumes of pipes and plena

In the final test facility design, the upstream and downstream volumes of the steam generator have to be increased to simulate the feed water plenum and the steam plenum, respectively.

5.7. Instrumentation

Table 10 shows a preliminary list of instruments to be installed on the experimental facility. For each instrument the table gives:

- a rough indication of location,
- the type,
- the facility code,
- the reference drawing (100.01.00rev0fg1of2 and 100.01.00rev0fg2of2) where more detailed information on their position are available.

The proposed instruments should be used to obtain information regarding the following main thermofluidodynamic quantities necessary to understand the behaviuor of the DHRS:

- SG thermal power
- IC thermal power
- IC inlet pressure
- IC outlet pressure
- IC inlet temperature
- IC outlet temperature
- IC internal / external tube wall temperature
- IC header condensate level
- gas tank pressure
- gas tank temperature
- IC pool temperature
- SG inlet pressure
- SG inlet temperature
- bottom bayonet tube pressure
- bottom bayonet tube temperature
- SG outlet temperature
- SG outlet pressure
- SG tube wall temperature
- IC + SG total flow rate
- Circuit pressure drops

The relevant P&I is reported in Annex1/a and Annex1/b.

N.	Location	Instrument type	Plant code	Drawing
1	IC condensate header	Relative pressure transmitter	P001	100.01.00rev0.dwg fg 1 of 2
2	SG feed water header	Relative pressure transmitter	P002	100.01.00rev0.dwg fg 1 of 2
3	SG steam header	Relative pressure transmitter	P003	100.01.00rev0.dwg fg 1 of 2
4	IC steam header inlet	Relative pressure transmitter	P004	100.01.00rev0.dwg fg 1 of 2
5	Gas tank	Relative pressure transmitter	P005	100.01.00rev0.dwg fg 1 of 2
6	Bayonet tube no. 7, position 1	Relative pressure transmitter	P006	100.01.00rev0.dwg fg 2 of 2
7	Bayonet tube no. 7, position 17	Relative pressure transmitter	P007	100.01.00rev0.dwg fg 2 of 2
8	Condensate line	Differential pressure trasmitter	DP001	100.01.00rev0.dwg fg 1 of 2
9	Condensate line - isolation valve	Differential pressure trasmitter	DP002	100.01.00rev0.dwg fg 1 of 2
10	Condensate line - measurement orifice	Differential pressure trasmitter	DP003	100.01.00rev0.dwg fg 1 of 2
11	Condensate line	Differential pressure trasmitter	DP004	100.01.00rev0.dwg fg 1 of 2
12	Steam line	Differential pressure trasmitter	DP005	100.01.00rev0.dwg fg 1 of 2
13	Steam line - measurement orifice	Differential pressure trasmitter	DP006	100.01.00rev0.dwg fg 1 of 2
14	Steam line - isolation valve	Differential pressure trasmitter	DP007	100.01.00rev0.dwg fg 1 of 2
15	Steam line	Differential pressure trasmitter	DP008	100.01.00rev0.dwg fg 1 of 2
16	IC instrumented tube	Differential pressure trasmitter	DP009	100.01.00rev0.dwg fg 1 of 2
17	IC instrumented tube	Differential pressure trasmitter	DP010	100.01.00rev0.dwg fg 1 of 2
18	IC instrumented tube	Differential pressure trasmitter	DP011	100.01.00rev0.dwg fg 1 of 2
19	IC instrumented tube	Differential pressure trasmitter	DP012	100.01.00rev0.dwg fg 1 of 2
20	Condensate line	Differential pressure trasmitter	DP013	100.01.00rev0.dwg fg 1 of 2
21	IC steam / condensate header	Differential pressure trasmitter	DP014	100.01.00rev0.dwg fg 1 of 2
22	Gas tank / IC condensate header	Differential pressure trasmitter	DP015	100.01.00rev0.dwg fg 1 of 2
23	Steam line - manual valve	Differential pressure trasmitter	DP016	100.01.00rev0.dwg fg 1 of 2
24	SG feed water header - instrumented bayonet tube	Differential pressure trasmitter	DP017	100.01.00rev0.dwg fg 2 of 2
25	SG feed water header - instrumented bayonet tube	Differential pressure trasmitter	DP018	100.01.00rev0.dwg fg 2 of 2
26	Instrumented bayonet tube	Differential pressure trasmitter	DP019	100.01.00rev0.dwg fg 2 of 2
27	Instrumented bayonet tube	Differential pressure trasmitter	DP020	100.01.00rev0.dwg fg 2 of 2
28	Instrumented bayonet tube	Differential pressure trasmitter	DP021	100.01.00rev0.dwg fg 2 of 2
29	Instrumented bayonet tube	Differential pressure trasmitter	DP022	100.01.00rev0.dwg fg 2 of 2
30	Instrumented bayonet tube	Differential pressure trasmitter	DP023	100.01.00rev0.dwg fg 2 of 2
31	Instrumented bayonet tube	Differential pressure trasmitter	DP024	100.01.00rev0.dwg fg 2 of 2
32	Condensate / steam header DP	Differential pressure trasmitter	DP025	100.01.00rev0.dwg fg 1 of 2
33	IC pool level	Differential pressure trasmitter	L001	100.01.00rev0.dwg fg 1 of 2

N.	Location	Instrument type	Plant code	Drawing
34	IC condensate header level	Differential pressure trasmitter	L002	100.01.00rev0.dwg fg 1 of 2
35	Gas separator level	Differential pressure trasmitter	L003	100.01.00rev0.dwg fg 1 of 2
36	Gas tank level	Differential pressure trasmitter	L004	100.01.00rev0.dwg fg 1 of 2
37	IC pool temperature	Termocouple K diam. 2 mm	TF005	100.01.00rev0.dwg fg 1 of 2
38	IC pool temperature	Termocouple K diam. 2 mm	TF006	100.01.00rev0.dwg fg 1 of 2
39	IC pool temperature	Termocouple K diam. 2 mm	TF007	100.01.00rev0.dwg fg 1 of 2
40	IC pool temperature	Termocouple K diam. 2 mm	TF008	100.01.00rev0.dwg fg 1 of 2
41	IC pool temperature	Termocouple K diam. 2 mm	TF009	100.01.00rev0.dwg fg 1 of 2
42	IC pool temperature	Termocouple K diam. 2 mm	TF010	100.01.00rev0.dwg fg 1 of 2
43	IC pool temperature	Termocouple K diam. 2 mm	TF011	100.01.00rev0.dwg fg 1 of 2
44	IC pool temperature	Termocouple K diam. 2 mm	TF012	100.01.00rev0.dwg fg 1 of 2
45	IC pool temperature	Termocouple K diam. 2 mm	TF013	100.01.00rev0.dwg fg 1 of 2
46	IC pool temperature	Termocouple K diam. 2 mm	TF014	100.01.00rev0.dwg fg 1 of 2
47	IC pool temperature	Termocouple K diam. 2 mm	TF015	100.01.00rev0.dwg fg 1 of 2
48	IC pool temperature	Termocouple K diam. 2 mm	TF016	100.01.00rev0.dwg fg 1 of 2
49	Condensate line fluid temperature	Termocouple K diam. 1,5 mm	TF001	100.01.00rev0.dwg fg 1 of 2
50	SG feed water header temperature	Termocouple K diam. 1,5 mm	TF002	100.01.00rev0.dwg fg 1 of 2
51	SG steam header fluid temperature	Termocouple K diam. 1,5 mm	TF003	100.01.00rev0.dwg fg 1 of 2
52	Steam line	Termocouple K diam. 1,5 mm	TF004	100.01.00rev0.dwg fg 1 of 2
53	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF017	100.01.00rev0.dwg fg 1 of 2
54	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF018	100.01.00rev0.dwg fg 1 of 2
55	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF019	100.01.00rev0.dwg fg 1 of 2
56	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF020	100.01.00rev0.dwg fg 1 of 2
57	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF021	100.01.00rev0.dwg fg 1 of 2
58	Gas Tank fluid temperature	Termocouple K diam. 1,5 mm	TF022	100.01.00rev0.dwg fg 1 of 2
59	IC steam header temperature	Termocouple K diam. 1,5 mm	TF023	100.01.00rev0.dwg fg 1 of 2
60	IC steam header temperature	Termocouple K diam. 1,5 mm	TF024	100.01.00rev0.dwg fg 1 of 2
61	IC condensate header temperature	Termocouple K diam. 1,5 mm	TF025	100.01.00rev0.dwg fg 1 of 2
62	IC condensate header temperature	Termocouple K diam. 1,5 mm	TF026	100.01.00rev0.dwg fg 1 of 2
63	IC instrumented tube	Termocouple K diam. 1,5 mm	TF027	100.01.00rev0.dwg fg 1 of 2
64	IC instrumented tube	Termocouple K diam. 1,5 mm	TF028	100.01.00rev0.dwg fg 1 of 2
65	IC instrumented tube	Termocouple K diam. 1,5 mm	TF029	100.01.00rev0.dwg fg 1 of 2
66	IC instrumented tube	Termocouple K diam. 1,5 mm	TF030	100.01.00rev0.dwg fg 1 of 2

N.	Location	Instrument type	Plant code	Drawing
67	IC instrumented tube	Termocouple K diam. 1,5 mm	TF031	100.01.00rev0.dwg fg 1 of 2
68	IC instrumented tube	Termocouple K diam. 1,5 mm	TF032	100.01.00rev0.dwg fg 1 of 2
69	IC instrumented tube	Termocouple K diam. 1,5 mm	TF033	100.01.00rev0.dwg fg 1 of 2
70	IC instrumented tube	Termocouple K diam. 1,5 mm	TF034	100.01.00rev0.dwg fg 1 of 2
71	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF035	100.01.00rev0.dwg fg 1 of 2
72	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF036	100.01.00rev0.dwg fg 1 of 2
73	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF037	100.01.00rev0.dwg fg 1 of 2
74	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF038	100.01.00rev0.dwg fg 1 of 2
75	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF039	100.01.00rev0.dwg fg 1 of 2
76	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF040	100.01.00rev0.dwg fg 1 of 2
77	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF041	100.01.00rev0.dwg fg 1 of 2
78	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF042	100.01.00rev0.dwg fg 1 of 2
79	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF043	100.01.00rev0.dwg fg 1 of 2
80	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF044	100.01.00rev0.dwg fg 1 of 2
81	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF045	100.01.00rev0.dwg fg 1 of 2
82	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF046	100.01.00rev0.dwg fg 1 of 2
83	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF047	100.01.00rev0.dwg fg 1 of 2
84	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF048	100.01.00rev0.dwg fg 1 of 2
85	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF049	100.01.00rev0.dwg fg 1 of 2
86	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF050	100.01.00rev0.dwg fg 1 of 2
87	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF051	100.01.00rev0.dwg fg 1 of 2
88	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF052	100.01.00rev0.dwg fg 1 of 2
89	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF053	100.01.00rev0.dwg fg 1 of 2
90	Bayonet tube safety TC	Termocouple K diam. 1,5 mm	TF054	100.01.00rev0.dwg fg 1 of 2
91	IC instrumented tube	Termocouple K diam. 1,5 mm	TW001	100.01.00rev0.dwg fg 1 of 2
92	IC instrumented tube	Termocouple K diam. 1,5 mm	TW002	100.01.00rev0.dwg fg 1 of 2
93	IC instrumented tube	Termocouple K diam. 1,5 mm	TW003	100.01.00rev0.dwg fg 1 of 2
94	IC instrumented tube	Termocouple K diam. 1,5 mm	TW004	100.01.00rev0.dwg fg 1 of 2
95	IC instrumented tube	Termocouple K diam. 1,5 mm	TW005	100.01.00rev0.dwg fg 1 of 2
96	IC instrumented tube	Termocouple K diam. 1,5 mm	TW006	100.01.00rev0.dwg fg 1 of 2
97	IC instrumented tube	Termocouple K diam. 1,5 mm	TW012	100.01.00rev0.dwg fg 1 of 2
98	IC instrumented tube	Termocouple K diam. 1,5 mm	TW011	100.01.00rev0.dwg fg 1 of 2
99	IC instrumented tube	Termocouple K diam. 1,5 mm	TW009	100.01.00rev0.dwg fg 1 of 2

N.	Location	Instrument type	Plant code	Drawing
100	IC instrumented tube	Termocouple K diam. 1,5 mm	TW010	100.01.00rev0.dwg fg 1 of 2
101	IC instrumented tube	Termocouple K diam. 1,5 mm	TW007	100.01.00rev0.dwg fg 1 of 2
102	IC instrumented tube	Termocouple K diam. 1,5 mm	TW008	100.01.00rev0.dwg fg 1 of 2
103	Gas tank wall temperature	Termocouple K diam. 1,5 mm	TW013	100.01.00rev0.dwg fg 1 of 2
104	Gas tank wall temperature	Termocouple K diam. 1,5 mm	TW014	100.01.00rev0.dwg fg 1 of 2
105	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW015	100.01.00rev0.dwg fg 2 of 2
106	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW016	100.01.00rev0.dwg fg 2 of 2
107	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW017	100.01.00rev0.dwg fg 2 of 2
108	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW018	100.01.00rev0.dwg fg 2 of 2
109	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW019	100.01.00rev0.dwg fg 2 of 2
110	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW020	100.01.00rev0.dwg fg 2 of 2
111	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW021	100.01.00rev0.dwg fg 2 of 2
112	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW022	100.01.00rev0.dwg fg 2 of 2
113	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW023	100.01.00rev0.dwg fg 2 of 2
114	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW024	100.01.00rev0.dwg fg 2 of 2
115	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW025	100.01.00rev0.dwg fg 2 of 2
116	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW026	100.01.00rev0.dwg fg 2 of 2
117	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW027	100.01.00rev0.dwg fg 2 of 2
118	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW028	100.01.00rev0.dwg fg 2 of 2
119	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW029	100.01.00rev0.dwg fg 2 of 2
120	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW030	100.01.00rev0.dwg fg 2 of 2
121	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW031	100.01.00rev0.dwg fg 2 of 2
122	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW032	100.01.00rev0.dwg fg 2 of 2
123	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW033	100.01.00rev0.dwg fg 2 of 2
124	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW034	100.01.00rev0.dwg fg 2 of 2
125	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW035	100.01.00rev0.dwg fg 2 of 2
126	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW036	100.01.00rev0.dwg fg 2 of 2
127	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW037	100.01.00rev0.dwg fg 2 of 2
128	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW038	100.01.00rev0.dwg fg 2 of 2
129	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW039	100.01.00rev0.dwg fg 2 of 2
130	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW040	100.01.00rev0.dwg fg 2 of 2
131	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW041	100.01.00rev0.dwg fg 2 of 2
132	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW042	100.01.00rev0.dwg fg 2 of 2

N.	Location	Instrument type	Plant code	Drawing
133	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW043	100.01.00rev0.dwg fg 2 of 2
134	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW044	100.01.00rev0.dwg fg 2 of 2
135	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW045	100.01.00rev0.dwg fg 2 of 2
136	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW046	100.01.00rev0.dwg fg 2 of 2
137	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW047	100.01.00rev0.dwg fg 2 of 2
138	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW048	100.01.00rev0.dwg fg 2 of 2
139	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW049	100.01.00rev0.dwg fg 2 of 2
140	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW050	100.01.00rev0.dwg fg 2 of 2
141	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW051	100.01.00rev0.dwg fg 2 of 2
142	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW052	100.01.00rev0.dwg fg 2 of 2
143	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW053	100.01.00rev0.dwg fg 2 of 2
144	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW054	100.01.00rev0.dwg fg 2 of 2
145	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW055	100.01.00rev0.dwg fg 2 of 2
146	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW056	100.01.00rev0.dwg fg 2 of 2
147	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW057	100.01.00rev0.dwg fg 2 of 2
148	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW058	100.01.00rev0.dwg fg 2 of 2
149	Bayonet tube external wall termperature	Termocouple K diam. 1,5 mm	TW059	100.01.00rev0.dwg fg 2 of 2
150	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF055	100.01.00rev0.dwg fg 2 of 2
151	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF056	100.01.00rev0.dwg fg 2 of 2
152	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF057	100.01.00rev0.dwg fg 2 of 2
153	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF058	100.01.00rev0.dwg fg 2 of 2
154	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF059	100.01.00rev0.dwg fg 2 of 2
155	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF060	100.01.00rev0.dwg fg 2 of 2
156	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF061	100.01.00rev0.dwg fg 2 of 2
157	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF062	100.01.00rev0.dwg fg 2 of 2
158	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF063	100.01.00rev0.dwg fg 2 of 2
159	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF064	100.01.00rev0.dwg fg 2 of 2
160	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF065	100.01.00rev0.dwg fg 2 of 2
161	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF066	100.01.00rev0.dwg fg 2 of 2
162	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF067	100.01.00rev0.dwg fg 2 of 2
163	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF068	100.01.00rev0.dwg fg 2 of 2
164	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF069	100.01.00rev0.dwg fg 2 of 2
165	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF070	100.01.00rev0.dwg fg 2 of 2

N.	Location	Instrument type	Plant code	Drawing
166	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF071	100.01.00rev0.dwg fg 2 of 2
167	Bayonet fluid temperature	Termocouple K diam. 1,5 mm	TF072	100.01.00rev0.dwg fg 2 of 2
168	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF073	100.01.00rev0.dwg fg 2 of 2
169	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF074	100.01.00rev0.dwg fg 2 of 2
170	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF075	100.01.00rev0.dwg fg 2 of 2
171	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF076	100.01.00rev0.dwg fg 2 of 2
172	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF077	100.01.00rev0.dwg fg 2 of 2
173	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF078	100.01.00rev0.dwg fg 2 of 2
174	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF079	100.01.00rev0.dwg fg 2 of 2
175	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF080	100.01.00rev0.dwg fg 2 of 2
176	Bayonet fluid temperature (bottom tube)	Termocouple K diam. 1,5 mm	TF081	100.01.00rev0.dwg fg 2 of 2

Table 11 – Instrumentation

5.8. Electrical scheme

The thermal power is supplied to the steam generator from an existing power unit capable to delivery a maximum power of 4 MW.

The group consists of three units, each inculding a transformer (3000V/136V 1550kWA) and a controlled diode system rectifier; the transformer of each unit is connected to simple triangle on the primary side and to double triangle on the secondary side. This last supplies the three-phase thyristor bridge which is the rectifier system of each unit. The power is drivable in a continuous manner on the whole load by means of a control circuit of the starting time of the diodes. The three units can be connected in series or in parallel according to the needs of the load.

Some characteristics of the group are listed below:

Parallel connection		
Parameter	Continuos service	Overload (15 sec)
Voltage	155 V	160 V
Electricity	24 kA	25 kA
Electrical power	3.72 MW	4.00 MW
Optimal load	6.46 mΩ	6.40 mΩ
Series connection		
Voltage	310 V	320 V
Electricity	8.00 kA	8.33 kA
Electrical power	2.48 MW	2.66 MW
Optimal load	38.75 mΩ	38.42 mΩ

A specific linear thermal power of 2000 W/m for each bayonet tube has imposed as design parameter.

There are two possible solutions to provide the thermal power to SG.

In the first solution (steam generator “directly heated”) the thermal power is generated within the outer tube of the three pipes forming the bayonet by Joule effect. In this configuration the tubes are powered electrically by means of clamp arranged longitudinally along the tube at a distance of 6000 mm.

Groups of 34 bayonet tubes are connected in parallel and the various groups in series. The electrical diagram of pipe connection is shown in Annex 5.

The second solution (SG “indirectly heated”) involves the use of heating cables wrapped along the outer surface of the bayonet outer tube. The thermal power is generated by Joule effect in the heating cables and transmitted by conduction to the outer tube of the bayonet group.

The electrical circuit describing this solution is shown in Annex 6.

The main calculated electrical parameters relevant to the SG directly heated configuration are collected in Table 12. These values are obtained assuming that the design thermal power to simulate the decay heat plus the thermal power coming from the thermal energy stored in the molten lead is equal to 2 MW.

Overall steam generator power	2,448	MW
Linear power for each bayonet tube	2000	W/m
Total power for a bayonet tube	12000	W
Bayonet heated lenght	6000	mm
Outside diameter	26,67	mm
Thickness	2,5	mm
Inside diameter	21,67	mm
Section	190	mm^2
Electrical resistivity at 450°C	1,0038E-06	Ωm
Elettrical resistance for a tube	3,1727E-02	Ω
Steam generator elettrical resistance	5,5989E-03	Ω
Steam generator design power	2448000	W
Steam generator total electrical current	20910	A
Power group voltage	117,1	V

Table 12 – Steam generator directly heated – Electrical calculation

From Table 12 it can be noticed that the SG has a resistance of 5.6 mΩ and that the electric power must be supplied with a voltage of 117.07 V which implies a current of 20.9 kA.

The power unit already available at the SIET Laboratories is therefore able to provide the necessary power.

A summary of the electrical data relevant to the SG heated by electrical cables is shown in the following Table 13.

Heating cables		
Overall steam generator power	2,448	MW
Linear power for each bayonet tube	2000	W/m
Total power for a bayonet tube	12000	W
Bayonet heated lenght	6000	mm
Heating cable electrical resistance	14,4	Ω
Equivalent heating cable elettrical resistance (4 resistances of 500 mm each connected in parallel)	3,6	Ω
Electrical current (for 2000 mm bayonet lenght)	33,33	A
Voltage for each power group	120	V
Steam generator total electrical current	20400	A

Table 13 – Steam generator indirectly heated – Electrical calculation

Even in this case, the voltage and current supplied by the SIET power groups are suitable to the scope.

In both cases, directly and indirectly SG heating, the thermal losses are considered negligible as the steam generator is insulated.

5.9. Auxiliary systems and infrastructures

The SIET Laboratory is equipped with several suitable devices, structures and components that can be immediately used to arrange the proposed test facility, such as:

- a building able to accommodate the whole test facility
- test facility control room equipped with the facility process control devices
- electrical power groups for SG heating up and part of the power cables
- air compressors for valves actuation and other services
- pumps to feed the idraulic circuits
- cooling systems for machinery and heat sink for thermal power
- 30 m high steel structure (equipped with an elevator and a 25 t crane) allowing a full scale simulation of ALFRED DHRS; it is the structure built-up in 2012 year for the SPES-3 facility
- water pool for installation of the Isolation Condenser; it is the pool installed in 2012 year for the SPES-3 facility
- PLC for the facility safety management.

Figures 4 through 8 show some examples of significant equipments currently available at SIET Laboratories.

5.10. Infrastructures, mechanical and electrical activities

Various activities on existing SIET plants are necessary to carry out the facility construction. The main are described here below

5.10.1. Isolation condenser pool

The existing condenser pool is currently in the state depicted in Figures 2 and 3. It therefore requires some activities to restore it, such as:

1) removing of the the condenser installed inside the pool;
2) fabrication of the feed water and discharging pipes; this implies some modifications of existing lines and the installation of new supports and grafts.

5.10.2. Gas tank

The non-condensable gas tank requires the installation of additional beams.

Moreover, a special area must be set up for the storage of helium and/or nitrogen cylinders and a gas charging system need to be carried out for gas replacement.

5.10.3. Steam generator

Two IPE400 beams have to be relocated for the steam generator mounting. Even any provisional scaffolding will be installed for the assembly of the various headers, tube welding insulation assembly and heating system.

Figure 4 – SPES 3 condenser pool: side view

Figure 5 – SPES 3 condenser pool with condenser: inside view

Figure 6 – Test Facility control room

Figure 7 – SPES 3 steel structure

Figure 8 – SPES 3 crane

5.10.4. Electric power lines

Electrical cables have to be installed to provide thermal power to the steam generator. These lines start from the 4MW power group and they arrive to an electrical panel disposed below the steam generator.

5.10.5. Compressor, pump and valve maintenance

Compressors, pumps, valves and auxiliary systems will be maintained to ensure a proper test facility operation during the whole experimental campaign.

5.11. List of materials

A list of the material (piping & fittings, valves, instruments) needed for the construction of the SIET facility for the configuration 16:6 is shown in Tables 14 through 22.

Table 14 – Piping (scaling factor 16:6)

DN	Sch	Material	Lenght (m)
1/2"	160	AISI 304	20
1"	160	CARBON STEEL	15
1 1/4"	160	AISI 304	13
2 1/2"	80	CARBON STEEL	50
3"	160	AISI 304	42
		TOTAL	140

Table 15 – Bends (scaling factor 16:6)

DN	Sch	Material	Type	Number
3"	160	AISI 304	90° LR	7
TOTAL				7

Table 16 – Concentric reducers (scaling factor 16:6)

DN	Sch	Material	Number
3" x 4"	160	AISI 304	2
3" x 6"	160	AISI 304	2
		TOTAL	4

Table 17 – Spectable blinds (scaling factor 16:6)

DN	Rating	Material	Number
1" 1/4	2500	AISI 304	2
		TOTAL	2

Table 18 – Flanges (scaling factor 16:6)

DN	Material	Type	Sch	Facing	Rating	Number
1" 1/4	AISI 304	Welding neck	160	RF	2500	4
3"	AISI 304	Orifice flanges	160	RF	2500	2
3"	AISI 304	Welding neck	160	RF	2500	12
					TOTAL	18

Table 19 – Pneumatic valves (scaling factor 16:6)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Connection	Material
2	22	373,7	Steam / water	3" - 2500	Flanged	AISI 304

Table 20 – Manual valve (scaling factor 16:6)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Connection	Type	Material
2	22	373,7	Steam / water	1/2" - 2500	Flanged	Ball	AISI 304
1	22	373,7	Steam / water	3/4" - 2500	Flanged	Globe	AISI 304
1	22	373,7	Steam / water	3" - 2500	Flanged	Globe	AISI 304

Table 21 – Safety valve (scaling factor 16:6)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Material
3	22	373,71	Saturated steam	3" x 1" - 2500	AISI 304

Table 22 – Instrumentation (scaling factor 16:6)

Parameter	Number	Type	Note
Pressure	36	Relative and differential pressure transmitters with variable span	no.7 relative pressure no. 29 differential pressure
Temperature	140	Termocouple type K	no. 128 - ϕ=1,5 mm no. 12 - ϕ =2,0 mm
Electrical	8	Voltmeters and amperometers	no. 3 voltmeters no. 5 amperometers
Total	184		

This table includes the electrical instrument not reported in Table 11.

6. FACILITY PARAMETERS WITH THE SCALING FACTOR 16:2

Two scaling factors are considered for the proposed SIET facility as already explained in the paragraph 4.2 (“Scaling factor and design criteria”).

The smallest isolation condenser must be composed of two tubes at least. Maintaining the same dimensions of the condensing tubes as for the ALFRED reference plant, this means a scale factor of:

$$f_2 = 16:2 = 8$$

By applying this factor, the facility steam generator has 68 tubes, which represents the best approximation of the theoretical value:

$$542 * 2/16 = 67.75$$

According to the formula specified in 4.2, the steam and condensate line inside diameters result equal to 40.06 mm, being 92.04 mm the steam and condensate line of the reference plant. The commercial pipe that best approximates this value is the DN 2” schedule 160 pipe with an internal diameter of 42.82 mm.

For the gas tank, being the ratio $f_1/f_2 \cong 0.33$, we can reasonably assume to use a single commercial 20” schedule 160 standard pipe instead of the three planned in the previous configuration, for an equivalent volume of about 0.75 m^3.

According to a scalig factor 16:2 the proposed SIET facility has the following configuration:

- Condenser tube number: 2
- Steam generator tube number: 68
- Steam generator condensate/steam header: 4
- Bayonet tubes for each condensate/steam header: 17
- Steam/condensate line diameter: 42.82 mm (2” schedule 160)
- Gas tank volume: 0.75 m^3
- Condenser pool volume: 16.35 m^3 (by using the existing pool)
- Steam generator electrical power: 218.75 kW

The instrument configuration of the smaller facility is considered equal to that of the larger one.
All the quantities required by the ANSALDO technical specification [1] are measurable and the same information on the behavouir on DHRS as for the larger facility can be obtained.
The most significant benefit of this largest scaling concerns the reduction of the construction costs, as reported in detail in paragraph 8.

A list of the material (piping & fittings, valves, instruments) needed for the construction of the SIET facility for the configuration 16:2 is shown in Tables 23 through 31.

Table 23 – Piping (scaling factor 16:2)

DN	Sch	Material	Lenght (m)
1/2"	160	AISI 304	20,0
3/4"	160	AISI 304	12,6
1"	160	CARBON STEEL	15,0
2"	160	AISI 304	42,0
2" 1/2	80	CARBON STEEL	50,0
TOTAL			139,6

Table 24 – Bend (scaling factor 16:2)

DN	Sch	Material	Type	Number
2"	160	AISI 304	90° LR	7
			TOTAL	7

Table 25 – Concentric reducer (scaling factor 16:2)

DN	Sch	Material	Number
2" x 4"	160	AISI 304	2
2" x 6"	160	AISI 304	2
		TOTAL	4

Table 26 – Spectable blind (scaling factor 16:2)

DN	Rating	Material	Number
3/4	2500	AISI 304	2
		TOTAL	2

Table 27 – Flange (scaling factor 16:2)

DN	Material	Type	Sch	Facing	Rating	Number
3/4"	AISI 304	Welding neck	160	RF	2500	4
2"	AISI 304	Orifice flanges	160	RF	2500	2
2"	AISI 304	Welding neck	160	RF	2500	12
					TOTAL	18

Table 28 – Pneumatic valve (scaling factor 16:2)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Connection	Material
2	22	373,71	Steam / water	2" - 2500	Flanged	AISI 304

Table 29 – Manual valve (scaling factor 16:2)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Connection	Type	Material
2	22	373,71	Steam / water	1/2" - 2500	Flanged	Ball	AISI 304
1	22	373,71	Steam / water	3/4" - 2500	Flanged	Globe	AISI 304
1	22	373,71	Steam / water	2" - 2500	Flanged	Globe	AISI 304

Table 30 – Safety valve (scaling factor 16:2)

No.	Design pressure [MPa]	Design temperature [°C]	Fluid	DN - Rating	Material
3	22	373,71	Saturated steam	2" x 1" - 2500	AISI 304

Table 31 – Instrumentation (scaling factor 16:2)

Parameter	Number	Type	Note
Pressure	36	Relative and differential pressure transmitters with variable span	no.7 relative pressure no. 29 differential pressure
Temperature	140	Termocouple type K	no. 128 - ϕ=1,5 mm no. 12 - ϕ =2,0 mm
Electrical	8	Voltmeters and amperometers	no. 3 voltmeters no. 5 amperometers
Total	184		

This table includes the electrical instrument not reported in Table 11.

7. EXPERIMENTAL PLANT OPERATION

The primary testing purpose is to simulate the sequence of events expected in the reference plant after an accident condition.

Compared with the reference plant, the difference in the SIET facility to be taken into consideration during the plant operation is the absence of the feed and steam lines able to simulate the normal reactor operation with nominal power.

For this reason the circuit including SG, the steam and condensate lines have to be initially filled with a defined quantity of water - depending on the experimental matrix - to simulate the mass entrapped in the loop after the main isolation valve closure.

The Isolation condenser will be filled with nitrogen or air at 190 bar.

A pre-testing phase will be performed supplying a very low heating power up to reach a stable pressure of 160 bars; during this slow heating the gas in the closed loop will be vented.

Starting from a SG stable condition of 160 bar, the power has to be increased up to the maximum value corresponding to the power transferred from the molten lead.

By opening the steam isolation valve when the pressure is 190 bar and opening the condensate isolation valve when the IC inside pressure is equal to the SG pressure, the facility simulates the reference plant transient.

After a defined time the power has to be reduced in order to simulate the power reduction due to the lead cooling; after this reduction only the power corresponding to the decay heat is supplied.

During the complete transient also the IC pool water temperature has to be controlled to reply the real pool temperature increasing.

The test can be closed when the long term decay power is reached in stable condition avoiding temperatures lower than the lead freezing point in any part of the SG.

8. COST ESTIMATE

A commercial budget estimate for both the facilities as defined in the chapters 5 and 6, corresponding to scaling factors of f1=16:6 and f2=16:2 respectively, is presented.

Among the various technical solutions described in the previous chapters, the economic analysis is based on these two main assumptions:

a) use of an indirectly heated SG (by means of heating cables)
b) gas tank fabricated by 20" schedule 160 standard pipe

The main items that have been taken into account in drafting the cost estimate are as follows:

- Project Management
- Quality Assurance
- Safety Assessment & Safety Management
- Mechanical Design
- Instrumentation & DAS Design
- Test Plan & Procedure issue

- Procurement of main components (SG,Gas Tank, IC)
- Procurement of instrumentation & Data Acquisition System (DAS)
- Procurement of other materials (valves, piping, support materials, etc.)
- Test facility realization
- Main components installation work
- Piping, valves & auxiliary services connection (including sketch fabrication work)
- Instrumentation & DAS calibration and installation
- As-built characterization work
- Test facility commissioning
- Matrix test (including characterization test)
- Data validation & reporting

8.1. Cost estimate for scaling factor 16:6 test facility

The total price for the overall program amounts to 2.496.000,00 €.

The relevant price breakdown is reported as follows:

Item	TASK	LABOUR (€)	MATERIALS & SERVICES (€)	TOTAL PRICE (€)
1	**Project Management & Quality Assurance**	**107 000**	**5 000**	**112 000**
2	**Safety Assessment & Safety Management**	**33 000**	**20 000**	**53 000**
3	**Design & Specification**	**140 000**	**20 000**	**160 000**
4	**Test Facility Realization & Set-Up**	**441 000**	**1 254 000**	**1 695 000**
5	**Commissioning & Test Matrix**	**211 000**	**193 000**	**404 000**
6	**Data Validation & Reporting**	**72 000**	**-**	**72 000**
	TOTAL	**1 004 000**	**1 492 000**	**2 496 000**

The above costs do not consider the expenses that may arise from the possible application of the requirements provided by the italian law on public procurement (Legislative Decree No. 163 April 12, 2006 and subsequent amendments and additions).

These costs have also to be considered subjected to a significant uncertainty (≅ 20%) because they are based on non-binding offers.

8.2. Cost estimate for scaling factor 16:2 test facility

The total price for the overall program amounts to 1.790.000,00 €.

The relevant price breakdown is reported as follows:

Item	TASK	LABOUR (€)	MATERIALS & SERVICES (€)	TOTAL PRICE (€)
1	**Project Management & Quality Assurance**	**94 000**	**5 000**	**99 000**
2	**Safety Assessment & Safety Management**	**28 000**	**20 000**	**48 000**
3	**Design & Specification**	**140 000**	**15 000**	**155 000**
4	**Test Facility Realization & Set-Up**	**372 000**	**725 000**	**1 097 000**
5	**Commissioning & Test Matrix**	**211 000**	**108 000**	**319 000**
6	**Data Validation & Reporting**	**72 000**	**-**	**72 000**
	TOTAL	**917 000**	**873 000**	**1 790 000**

Similarly to that specified for the configuration with scaling factor 16:6 also the above costs do not consider the expenses that may arise from the possible application of the requirements provided by the italian law on public procurement (Legislative Decree No. 163 April 12, 2006 and subsequent amendments and additions).

These costs have also to be considered subjected to a significant uncertainty (≅ 20%) because they are based on non-binding offers.

9. TIME SCHEDULE

9.1. Time schedule for scaling factor 16:6 test facility

The time requested for the overall Project is estimated in 30 months assuming 40 days for the testing period. A detailed Schedule is reported in the following Figure 9.

9.2. Time schedule for scaling factor 16:2 test facility

The overall time requested for the Testing Program is estimated in 26 months assuming 40 days for the testing period. A detailed Schedule is reported in the following Figure 10.

10. CONCLUSIONS

A feasibility study for the construction of an experimental facility devoted to the simulation of the Decay Heat Removal System (DHRS) of the ALFRED Lead Fast Reactor has been done with reference to the DHRS concept proposed by Ansaldo Nucleare, which includes the following main components:

- a steam generator (SG);
- an in-pool condenser (Isolation Condenser);
- a non-condensable gas tank;
- a steam and a feed water line each equipped with isolation valves.

A preliminary design of the experimental plant has been done with the aim to use existing SIET facilities/infrastructures as much as possible. The main considered facilities/infrastructures are as follows: technological hall with the existing SPES-3 support frame 30 m high equipped with a suitable crane and elevator; an existing pool already installed at the requested elevation; the IETI facility with power supply and control room; auxiliary systems; an on-site calibration laboratory for the instrumentation; an on-site workshop for all the needed mechanical works, etc.

Taking into account both technical feasibility and budget constraints two different options have been considered for the scaling factor of the facility. A scaling factor 16:6 has been assumed for the basic design while a scaling factor 16:2 has been considered for possible cost reduction.

The technical feasibility of the test facility has been confirmed for both the above mentioned options. The outcomes of the study are: design criteria, detailed description and drawings of the facility main components, information about the foreseen instrumentation as well as the operation basics.

Concerning the time schedule and budget estimates the main results are:

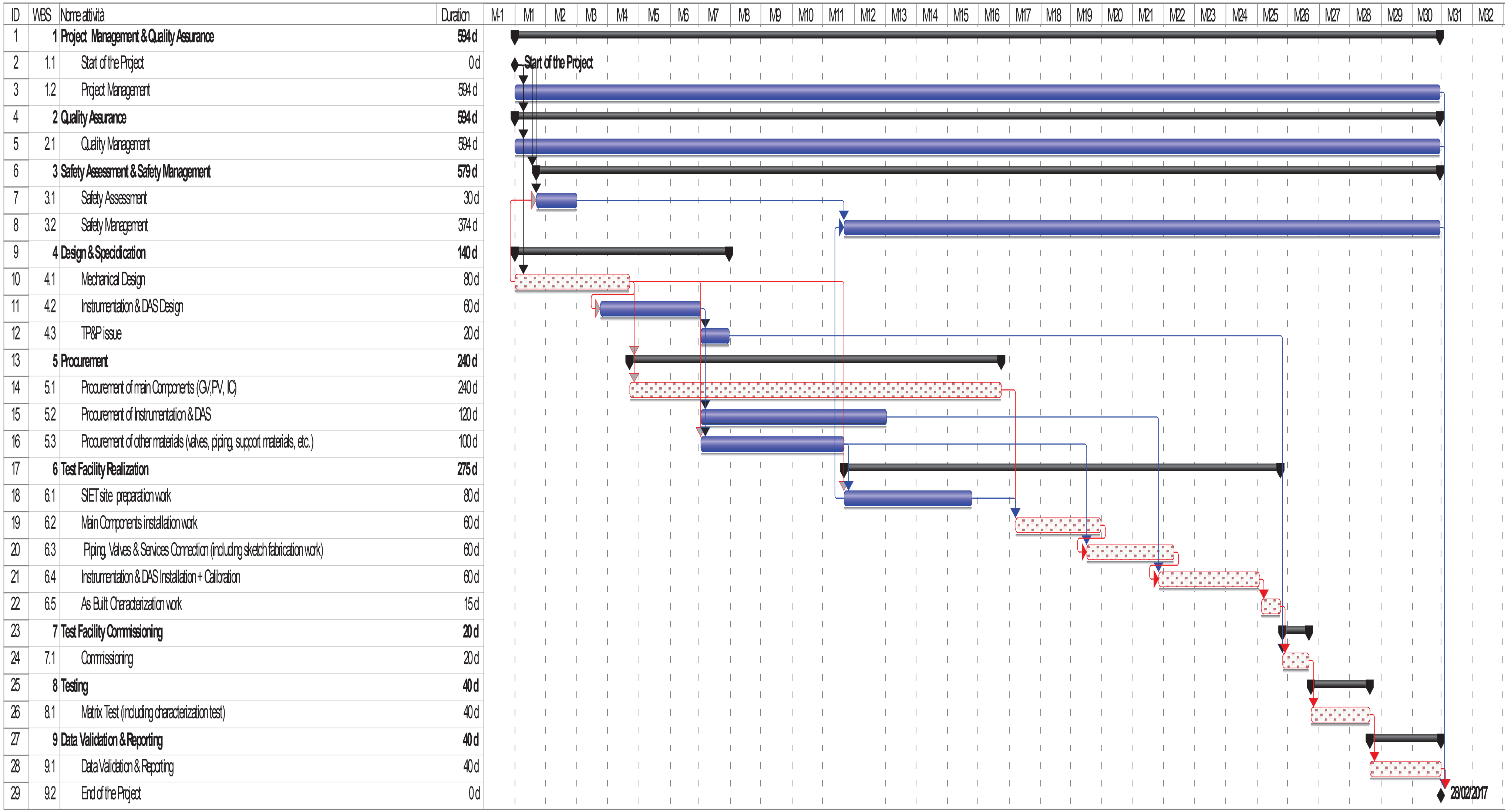
- the duration of the whole Project is 30 months with an overall cost of about 2.5 M€ for the larger test facility (scaling factor 16:6);

- the duration of the whole Project is 26 months with an overall cost of about 1.8 M€ for the smaller test facility (scaling factor 16:2).

11. REFERENCES

[1] Ansaldo Nucleare: "Specifica per la realizzazione di un impianto di prova del sistema Isolation Condenser con incondensabili"

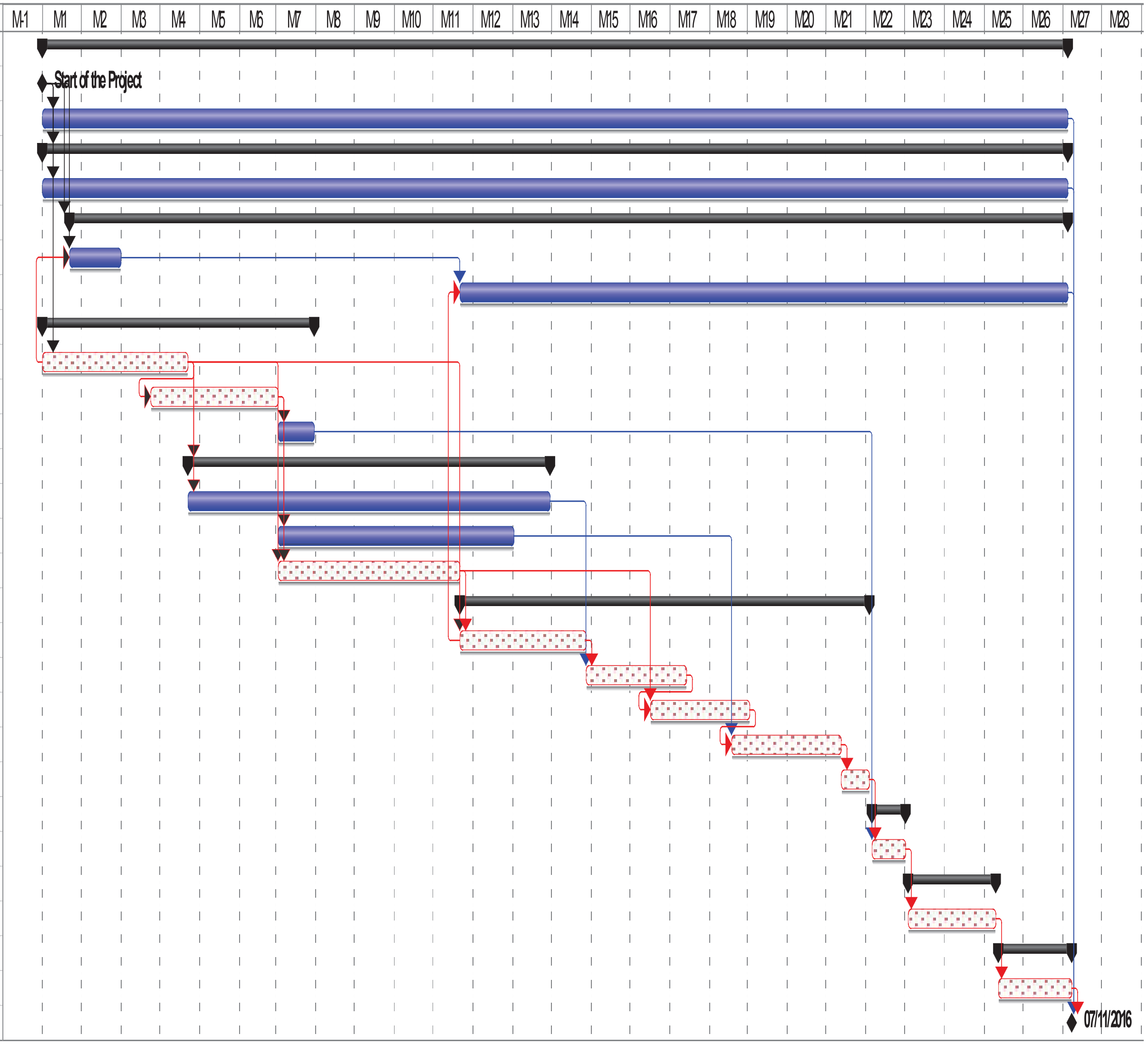
Figure 9 – Project Time Schedule for Scaling Factor 16 : 6



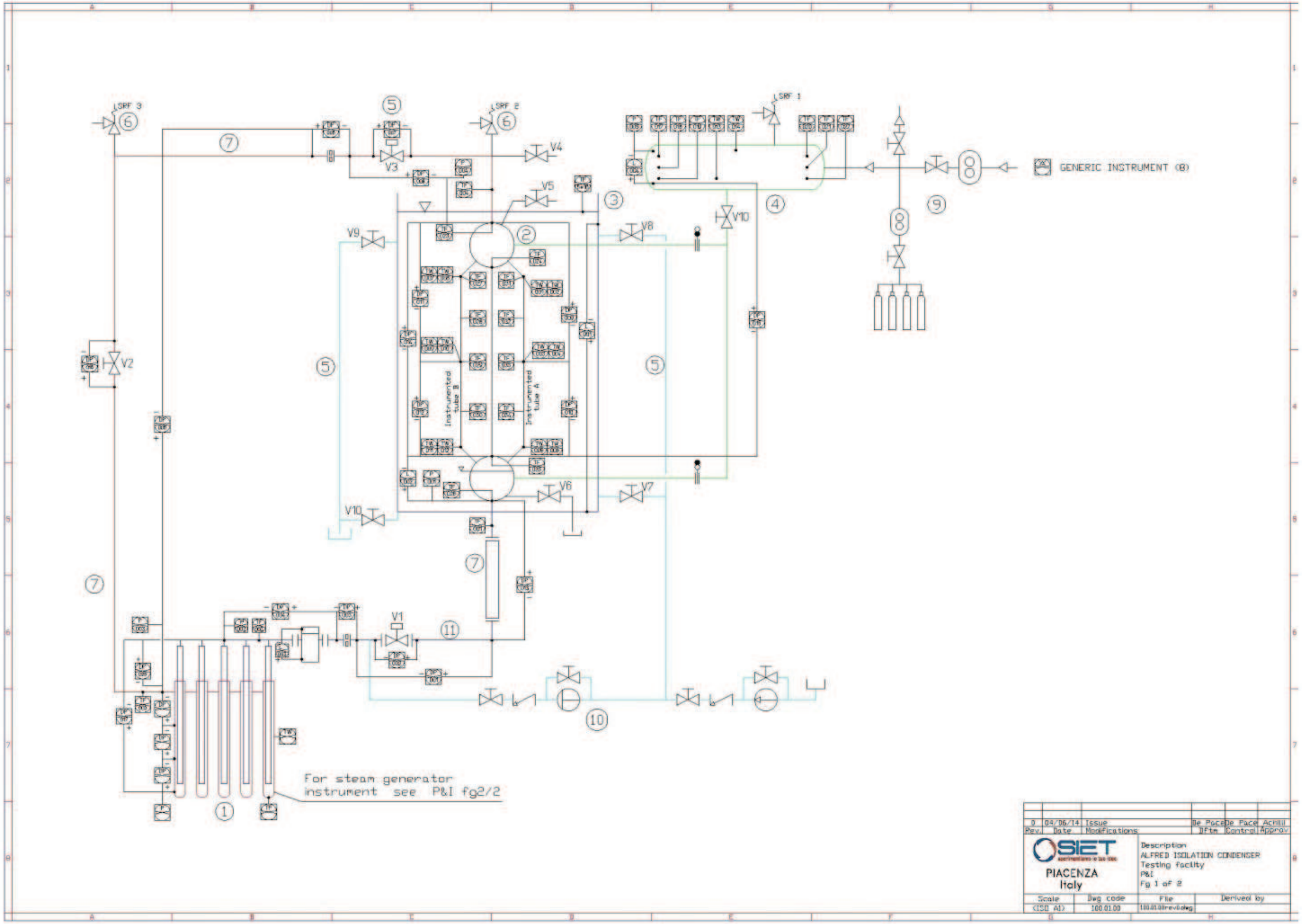
ID	WBS	Nome attività	Duration
1	**1**	**Project Management & Quality Assurance**	**594 d**
2	1.1	Start of the Project	0 d
3	1.2	Project Management	594 d
4	**2**	**Quality Assurance**	**594 d**
5	2.1	Quality Management	594 d
6	**3**	**Safety Assessment & Safety Management**	**579 d**
7	3.1	Safety Assessment	30 d
8	3.2	Safety Management	374 d
9	**4**	**Design & Specidication**	**140 d**
10	4.1	Mechanical Design	80 d
11	4.2	Instrumentation & DAS Design	60 d
12	4.3	TP&P issue	20 d
13	**5**	**Procurement**	**240 d**
14	5.1	Procurement of main Components (GV,PV, IC)	240 d
15	5.2	Procurement of Instrumentation & DAS	120 d
16	5.3	Procurement of other materials (valves, piping, support materials, etc.)	100 d
17	**6**	**Test Facility Realization**	**275 d**
18	6.1	SIET site preparation work	80 d
19	6.2	Main Components installation work	60 d
20	6.3	Piping, Valves & Services Connection (including sketch fabrication work)	60 d
21	6.4	Instrumentation & DAS Installation + Calibration	60 d
22	6.5	As Built Characterization work	15 d
23	**7**	**Test Facility Commissioning**	**20 d**
24	7.1	Commissioning	20 d
25	**8**	**Testing**	**40 d**
26	8.1	Matrix Test (including characterization test)	40 d
27	**9**	**Data Validation & Reporting**	**40 d**
28	9.1	Data Validation & Reporting	40 d
29	9.2	End of the Project	0 d

Figure 10 – Project Time Schedule for Scaling Factor 16 : 2

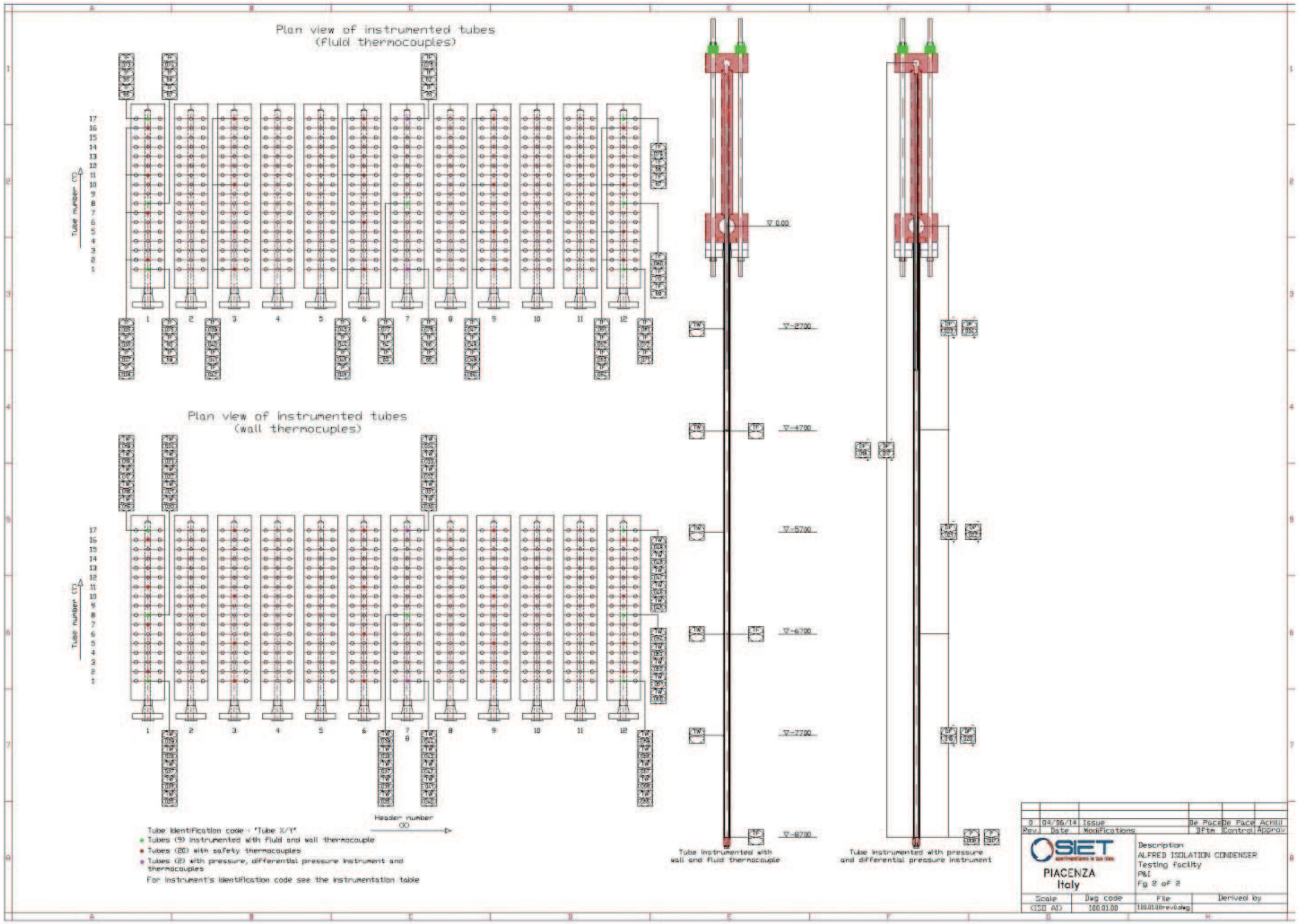
ID	WBS	Nome attività	Duration	Start	Finish
1	1	**Project Management & Quality Assurance**	**524 d**	**Mon 01/09/14**	**Fri 04/11/16**
2	1.1	Start of the Project	0 d	Mon 01/09/14	Mon 01/09/14
3	1.2	Project Management	524 d	Mon 01/09/14	Fri 04/11/16
4	2	**Quality Assurance**	**524 d**	**Mon 01/09/14**	**Fri 04/11/16**
5	2.1	Quality Management	524 d	Mon 01/09/14	Fri 04/11/16
6	3	**Safety Assessment & Safety Management**	**509 d**	**Mon 22/09/14**	**Fri 04/11/16**
7	3.1	Safety Assessment	30 d	Mon 22/09/14	Fri 31/10/14
8	3.2	Safety Management	304 d	Wed 22/07/15	Fri 04/11/16
9	4	**Design & Specification**	**140 d**	**Mon 01/09/14**	**Mon 30/03/15**
10	4.1	Mechanical Design	80 d	Mon 01/09/14	Mon 22/12/14
11	4.2	Instrumentation & DAS Design	60 d	Mon 24/11/14	Mon 02/03/15
12	4.3	TP&P issue	20 d	Tue 03/03/15	Mon 30/03/15
13	5	**Procurement**	**180 d**	**Tue 23/12/14**	**Tue 29/09/15**
14	5.1	Procurement of main Components (GV, PV, IC)	180 d	Tue 23/12/14	Tue 29/09/15
15	5.2	Procurement of Instrumentation & DAS	120 d	Tue 03/03/15	Tue 01/09/15
16	5.3	Procurement of other materials (valves, piping, support materials, etc.)	100 d	Tue 03/03/15	Tue 21/07/15
17	6	**Test Facility Realization**	**205 d**	**Wed 22/07/15**	**Fri 03/06/16**
18	6.1	SIET site preparation work	60 d	Wed 22/07/15	Tue 27/10/15
19	6.2	Main Components installation work	45 d	Wed 28/10/15	Wed 13/01/16
20	6.3	Piping, Valves & Services Connection (including sketch fabrication work)	45 d	Thu 17/12/15	Wed 02/03/16
21	6.4	Instrumentation & DAS Installation + Calibration	60 d	Thu 18/02/16	Thu 12/05/16
22	6.5	As Built Characterization work	15 d	Fri 13/05/16	Fri 03/06/16
23	7	**Test Facility Commissioning**	**20 d**	**Mon 06/06/16**	**Fri 01/07/16**
24	7.1	Commissioning	20 d	Mon 06/06/16	Fri 01/07/16
25	8	**Testing**	**40 d**	**Mon 04/07/16**	**Fri 09/09/16**
26	8.1	Matrix Test (including characterization test)	40 d	Mon 04/07/16	Fri 09/09/16
27	9	**Data Validation & Reporting**	**40 d**	**Mon 12/09/16**	**Mon 07/11/16**
28	9.1	Data Validation & Reporting	40 d	Mon 12/09/16	Mon 07/11/16
29	9.2	End of the Project	0 d	Mon 07/11/16	Mon 07/11/16



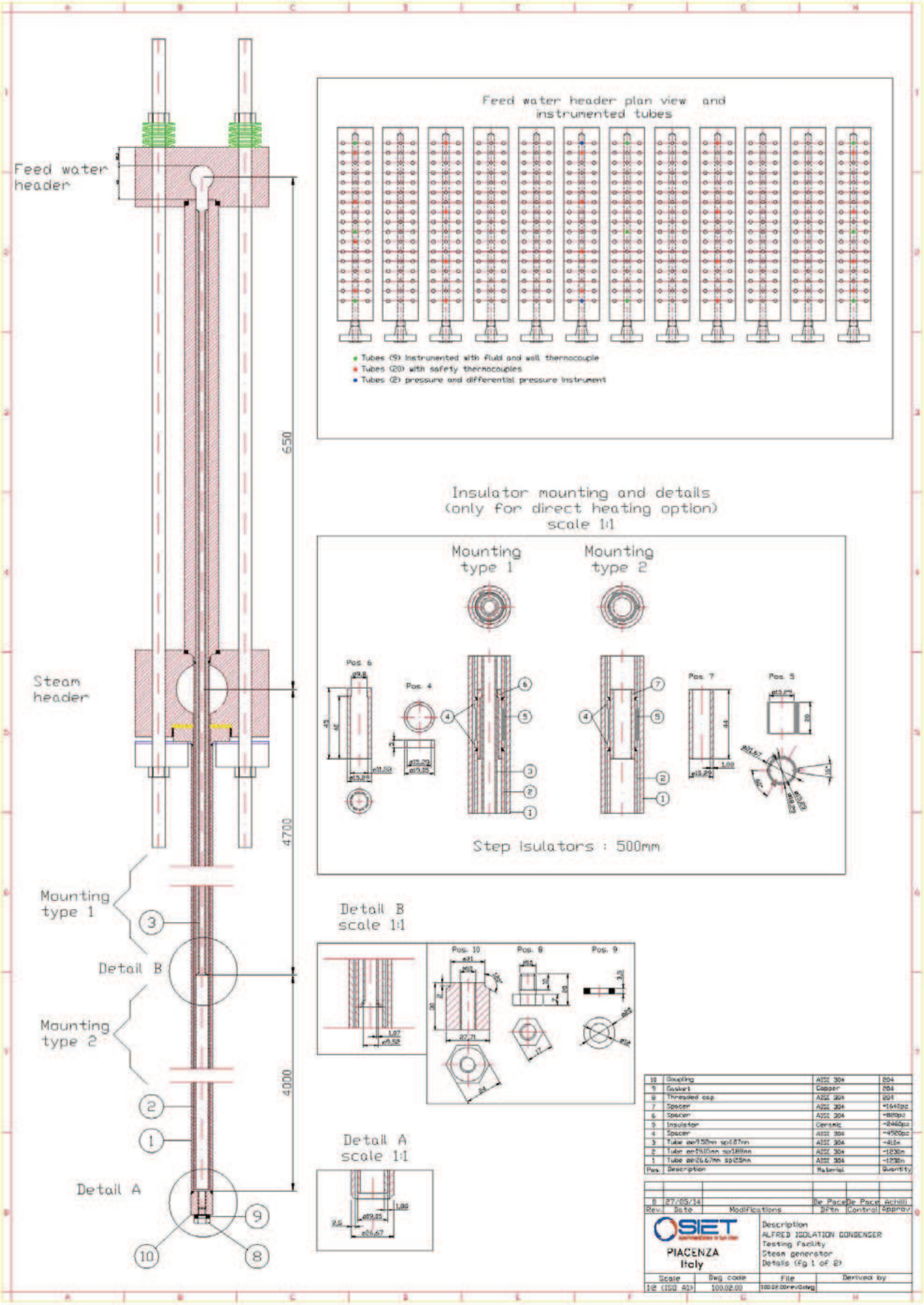
Annex 1/a - ALFRED Isolation Condenser testing facility: P&I (sheet 1 of 2)



Annex 1/b - ALFRED Isolation Condenser testing facility: P&I (sheet 2 of 2)



Annex 2/a - ALFRED isolation condenser testing facility: SG with direct heating (sheet 1 of 2)



Pos.	Description	Material	Quantity
10	Coupling	AISI 304	204
9	Gasket	Copper	204
8	Threaded cap	AISI 304	204
7	Spacer	AISI 304	~1640pz
6	Spacer	AISI 304	~880pz
5	Insulator	Ceramic	~2460pz
4	Spacer	AISI 304	~4920pz
3	Tube øe9.58mm sp1.07mm	AISI 304	~410m
2	Tube øe19.05mm sp1.88mm	AISI 304	~1230m
1	Tube øe26.67mm sp2.5mm	AISI 304	~1230m

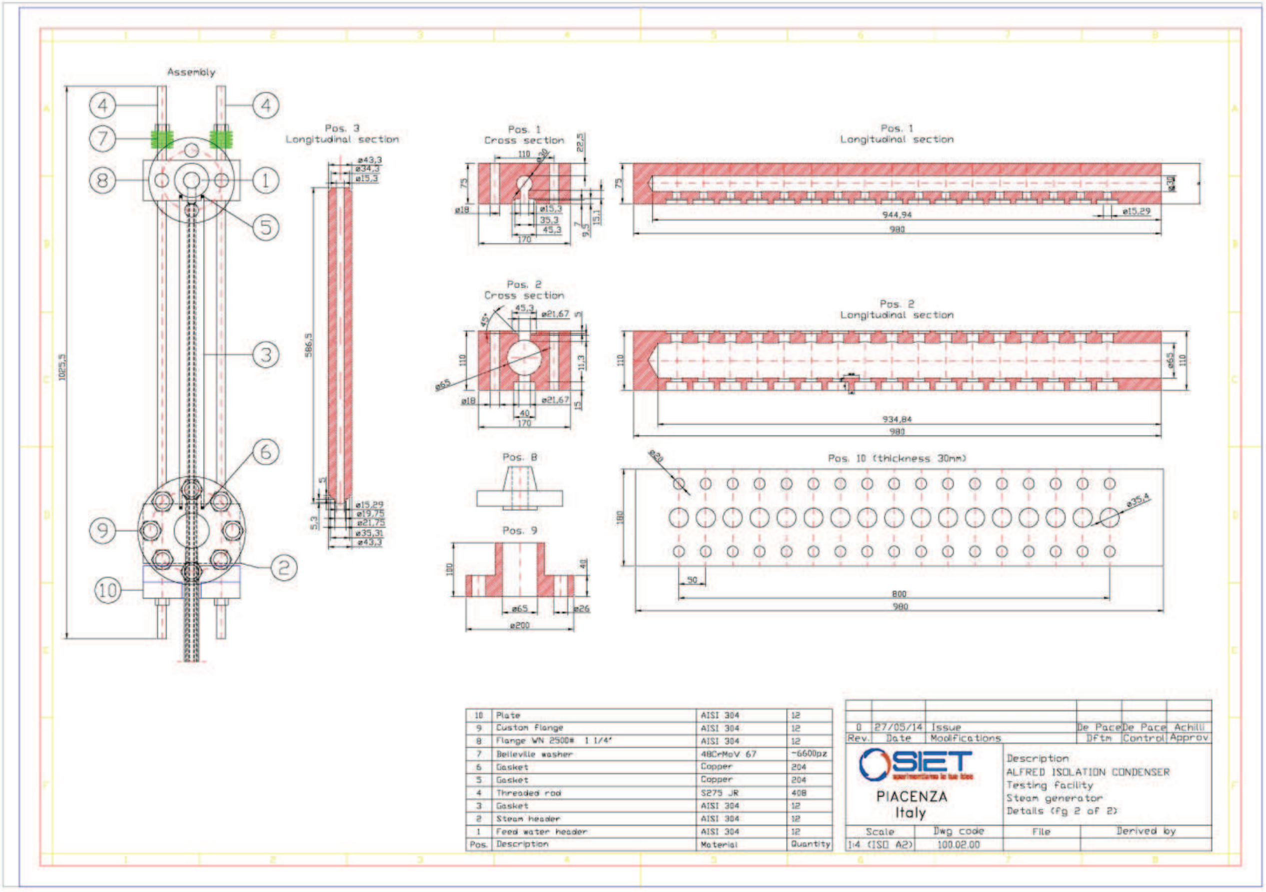
Rev.	Date	Modifications	Dftn	Control	Approv.
0	27/05/14		De Pace	De Pace	Achilli

SIET
PIACENZA
Italy

Description
ALFRED ISOLATION CONDENSER
Testing Facility
Steam generator
Details (fg 1 of 2)

Scale	Dwg code	File	Derived by
1:2 (ISO A1)	100.02.00	100.02.00rev0.dwg	

Annex 2/b - ALFRED isolation condenser testing facility: SG with direct heating (sheet 2 of 2)



10	Plate	AISI 304	12
9	Custom flange	AISI 304	12
8	Flange WN 2500# 1 1/4"	AISI 304	12
7	Belleville washer	48CrMoV 67	~6600pz
6	Gasket	Copper	204
5	Gasket	Copper	204
4	Threaded rod	S275 JR	408
3	Gasket	AISI 304	12
2	Steam header	AISI 304	12
1	Feed water header	AISI 304	12
Pos.	Description	Material	Quantity

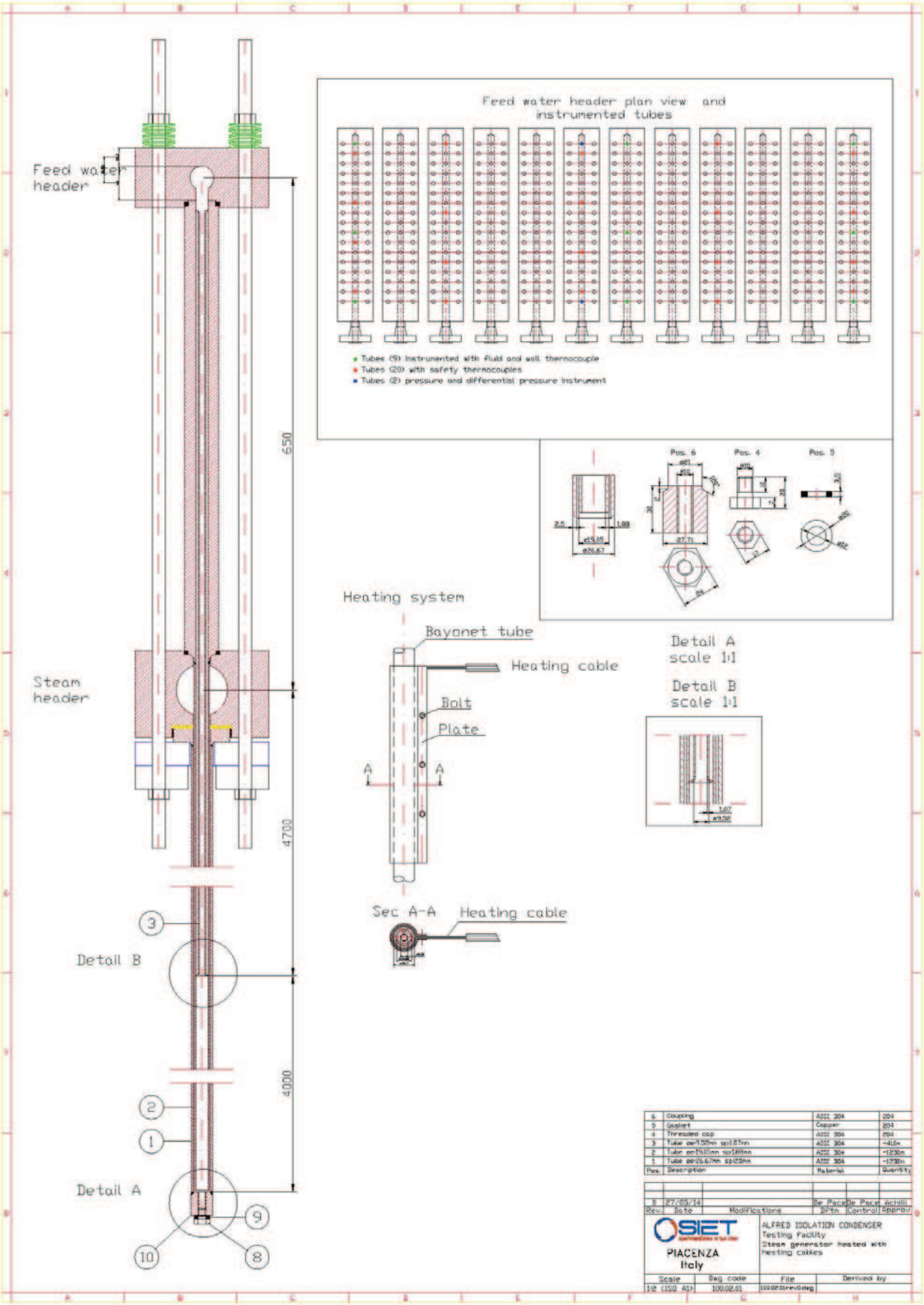
0	27/05/14	Issue	De Pace	De Pace	Achilli
Rev.	Date	Modifications	Dftm	Control	Approv

SIET
PIACENZA
Italy

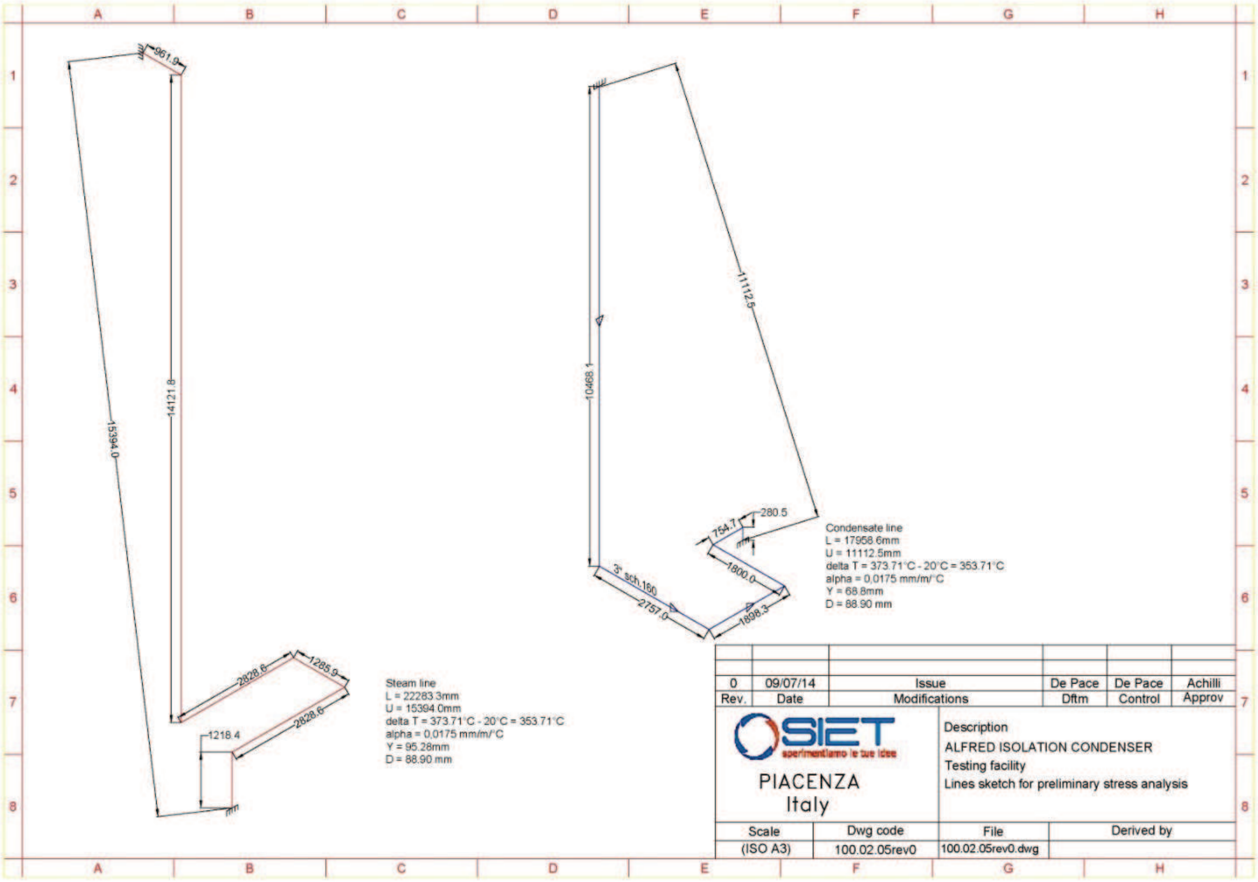
Description
ALFRED ISOLATION CONDENSER
Testing facility
Steam generator
Details (fg 2 of 2)

Scale	Dwg code	File	Derived by
1:4 (ISO A2)	100.02.00		

Annex 2/c - ALFRED isolation condenser testing facility: SG with indirect heating



Annex 3 - ALFRED isolation condenser testing facility: condensate and steam line isometrics



Steam line
L = 22283.3mm
U = 15394.0mm
delta T = 373.71°C - 20°C = 353.71°C
alpha = 0,0175 mm/m/°C
Y = 95.28mm
D = 88.90 mm

Condensate line
L = 17958.6mm
U = 11112.5mm
delta T = 373.71°C - 20°C = 353.71°C
alpha = 0,0175 mm/m/°C
Y = 68.8mm
D = 88.90 mm

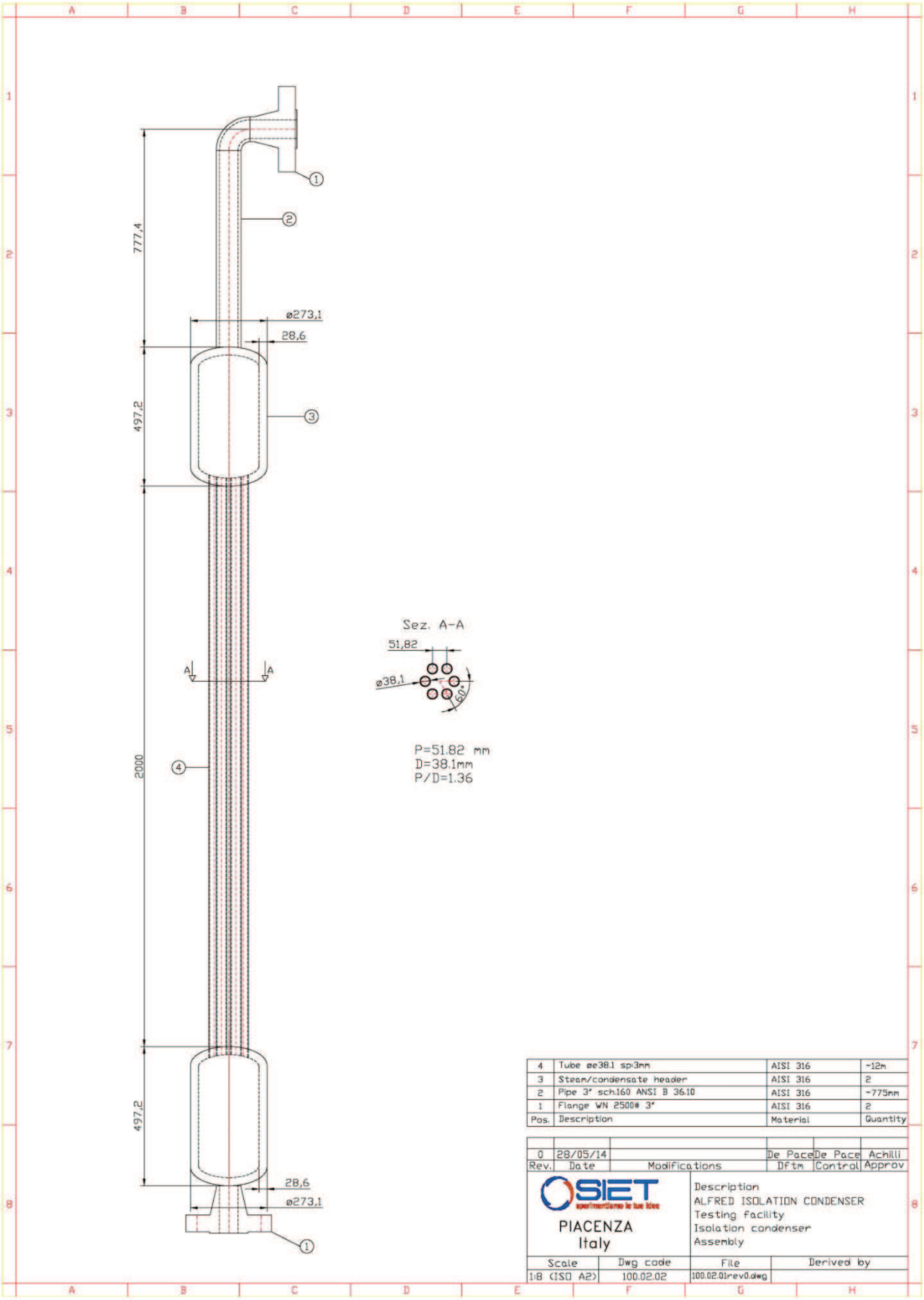
0	09/07/14	Issue	De Pace	De Pace	Achilli
Rev.	Date	Modifications	Dftm	Control	Approv

PIACENZA
Italy

Description
ALFRED ISOLATION CONDENSER
Testing facility
Lines sketch for preliminary stress analysis

Scale	Dwg code	File	Derived by
(ISO A3)	100.02.05rev0	100.02.05rev0.dwg	

Annex 4 - ALFRED isolation condenser testing facility: Isolation Condenser



Pos.	Description	Material	Quantity
4	Tube øe38.1 sp:3mm	AISI 316	~12m
3	Steam/condensate header	AISI 316	2
2	Pipe 3" sch.160 ANSI B 36.10	AISI 316	~775mm
1	Flange WN 2500# 3"	AISI 316	2

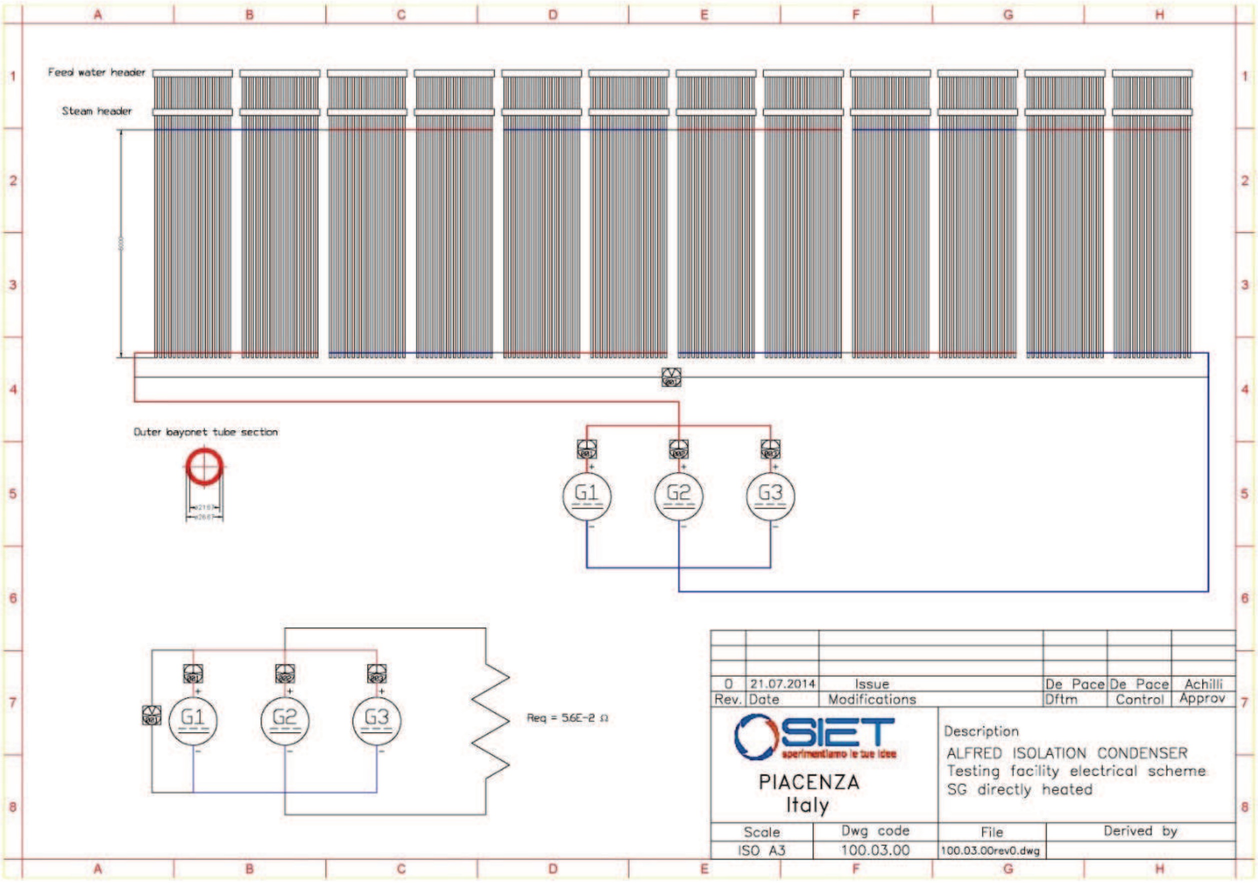
Rev.	Date	Modifications	Dftm	Control	Approv
0	28/05/14		De Pace	De Pace	Achilli

PIACENZA
Italy

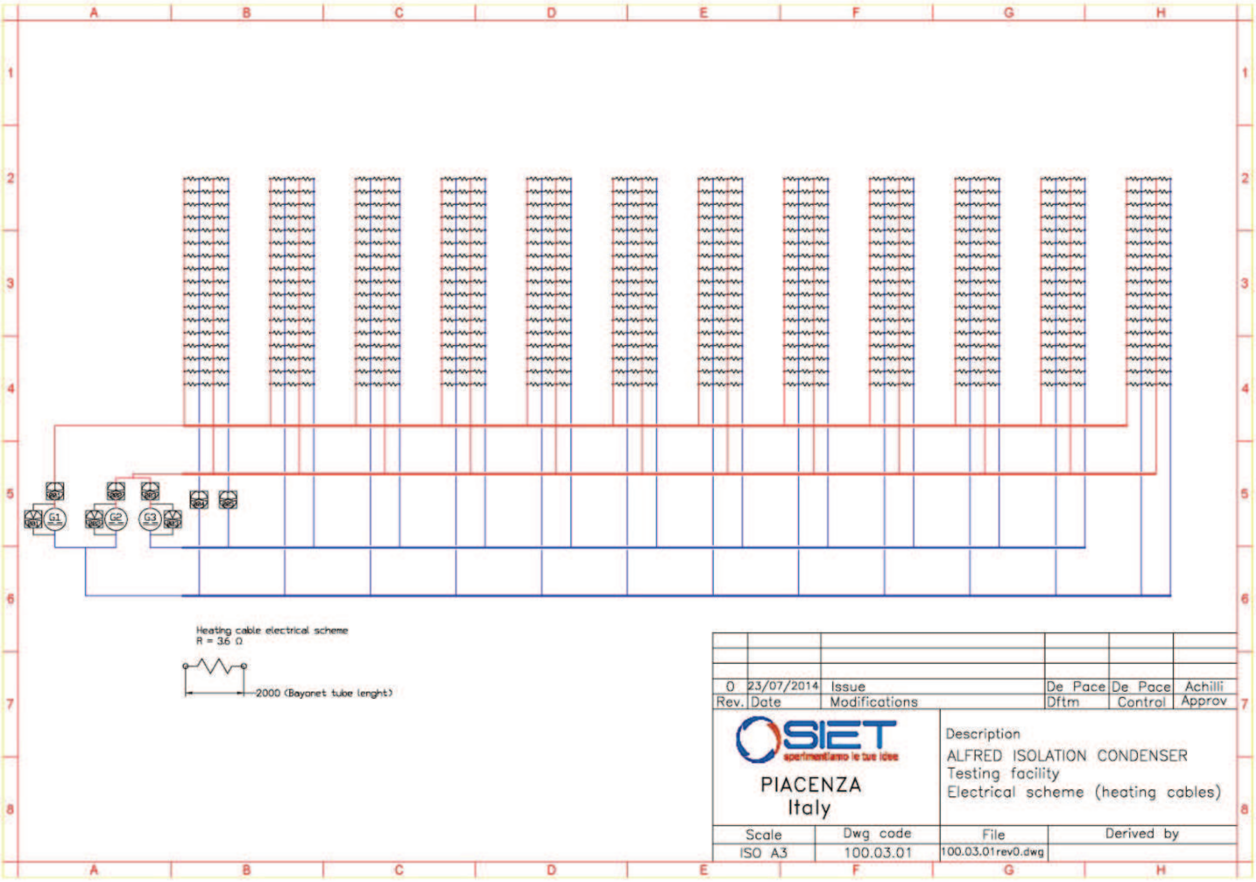
Description
ALFRED ISOLATION CONDENSER
Testing facility
Isolation condenser
Assembly

Scale	Dwg code	File	Derived by
1:8 (ISO A2)	100.02.02	100.02.01rev0.dwg	

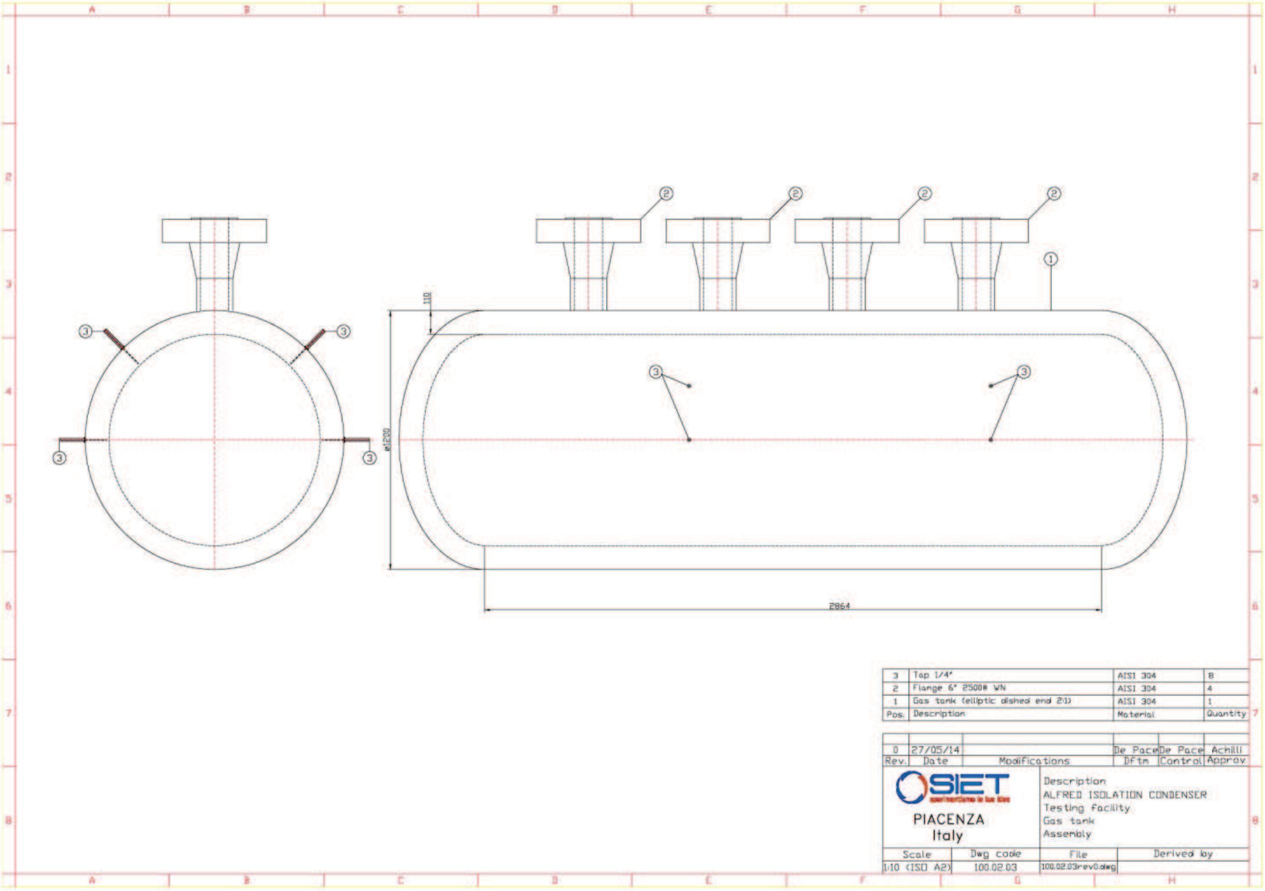
Annex 5 - ALFRED isolation condenser testing facility: electrical scheme of directly heated SG



Annex 6 - ALFRED isolation condenser testing facility: electrical scheme of indirectly heated SG



Annex 7 - ALFRED isolation condenser testing facility: forged gas tank

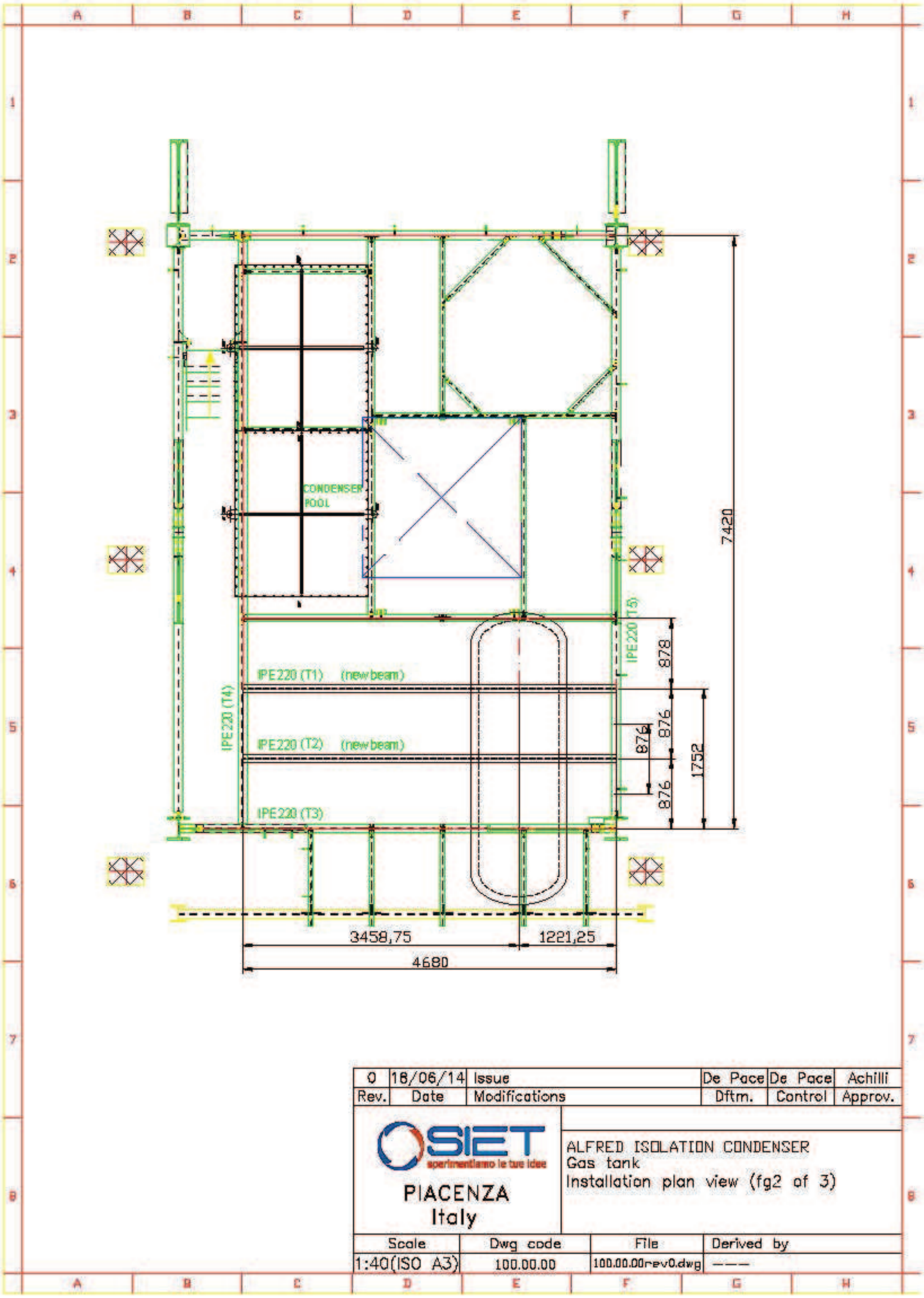


Pos.	Description	Material	Quantity
3	Tap 1/4"	AISI 304	8
2	Flange 6" 2500# WN	AISI 304	4
1	Gas tank (elliptic dished end 2:1)	AISI 304	1

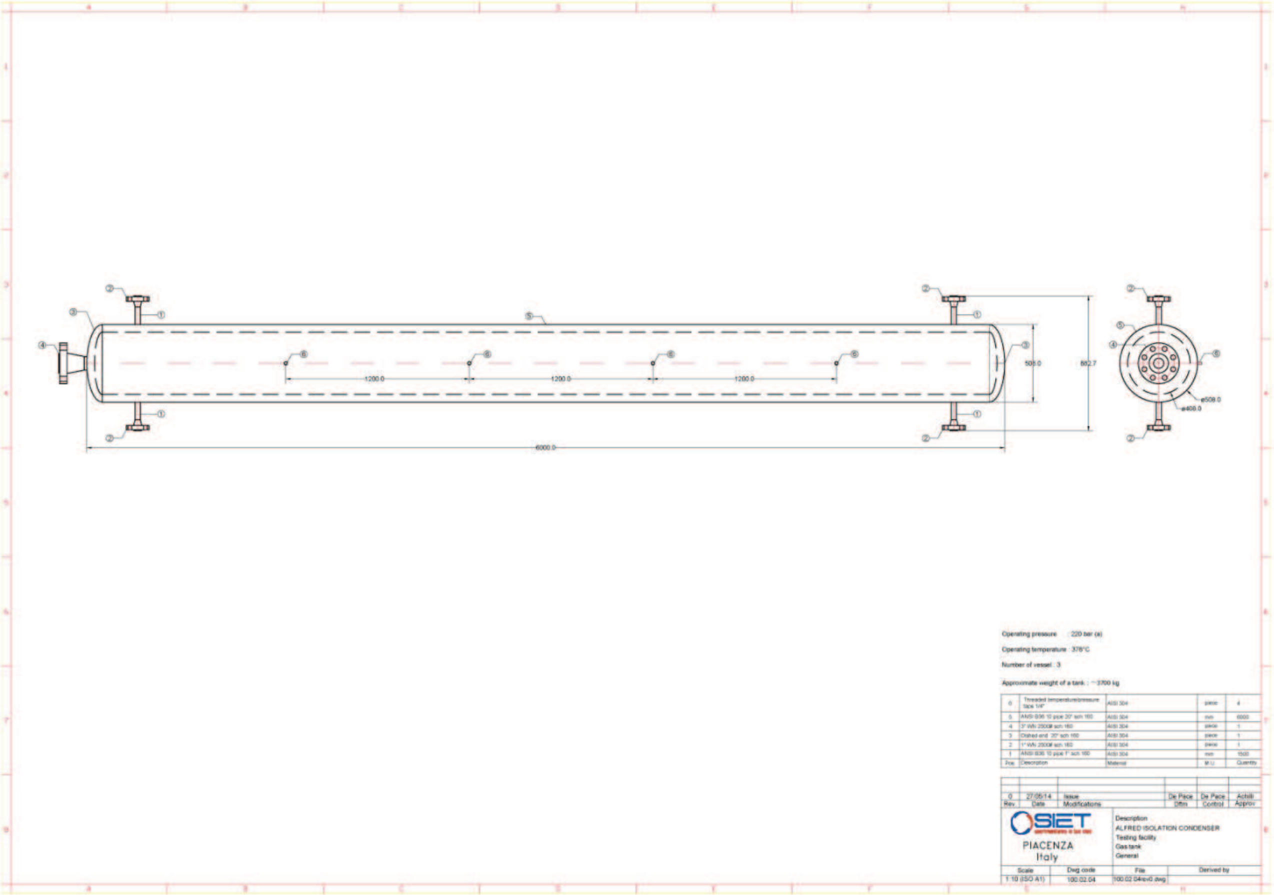
Rev.	Date	Modifications	Dftm	Control	Approv
0	27/05/14		De Pace	De Pace	Achilli

Scale	Dwg code	File	Derived by
1:10 (ISO A2)	100.02.03	100.02.03rev0.dwg	

Annex 8 – ALFRED isolation condenser testing facility: installation of forged gas tank



Annex 9 - ALFRED isolation condenser testing facility: gas tank manufatured with standard pipe



Operating pressure : 220 bar (a)

Operating temperature : 378°C

Number of vessel : 3

Approximate weight of a tank : ~3700 kg

Pos.	Description	Material	M.U.	Quantity
6	Threaded temperature/pressure taps 1/4"	AISI 304	piece	4
5	ANSI B36.10 pipe 20" sch 160	AISI 304	mm	6000
4	3" WN 2500# sch 160	AISI 304	piece	1
3	Dished end 20" sch 160	AISI 304	piece	1
2	1" WN 2500# sch 160	AISI 304	piece	1
1	ANSI B36.10 pipe 1" sch 160	AISI 304	mm	1500

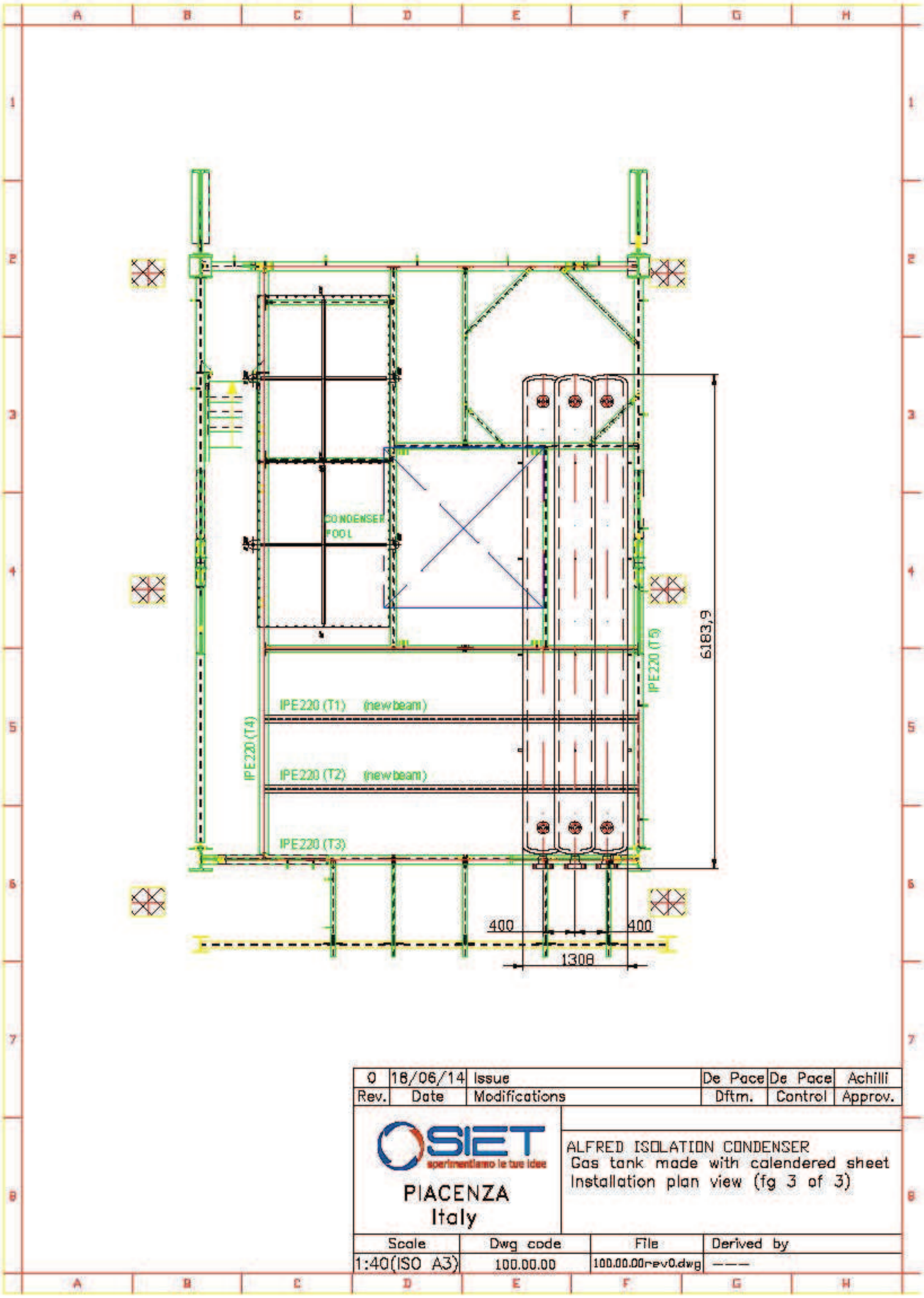
Rev.	Date	Modifications	Dftm	Control	Approv
0	27/05/14	Issue	De Pace	De Pace	Achilli

SIET
PIACENZA
Italy

Description
ALFRED ISOLATION CONDENSER
Testing facility
Gas tank
General

Scale	Dwg code	File	Derived by
1:10 (ISO A1)	100.02.04	100.02.04rev0.dwg	

Annex 10 - ALFRED IC testing facility: installation of gas tank manufactured with standard pipe



0	18/06/14	Issue	De Pace	De Pace	Achilli
Rev.	Date	Modifications	Dftm.	Control	Approv.

PIACENZA
Italy

ALFRED ISOLATION CONDENSER
Gas tank made with calendered sheet
Installation plan view (fg 3 of 3)

Scale	Dwg code	File	Derived by
1:40(ISO A3)	100.00.00	100.00.00rev0.dwg	———

Annex 11 - ALFRED IC testing facility: gas tank support structure preliminary calculation

The forged gas tank is mounted on an existing steel structure which must be modified to support the weight of the tank.

A structural analysis of this structure is needed to identify at least the order of magnitude of the loads resulting from the installation of non-condensable gas tank. For the calculation of the forces acting on the structure, we assumed that the tank is full of water even if this is an event arising from a wrong action of the plant operation.

Furthermore, for service need, a further generic load of 200 kg/m^2 is considered on the structure grating.

The tank is mounted on three IPE220 beams with a step of 876 mm.

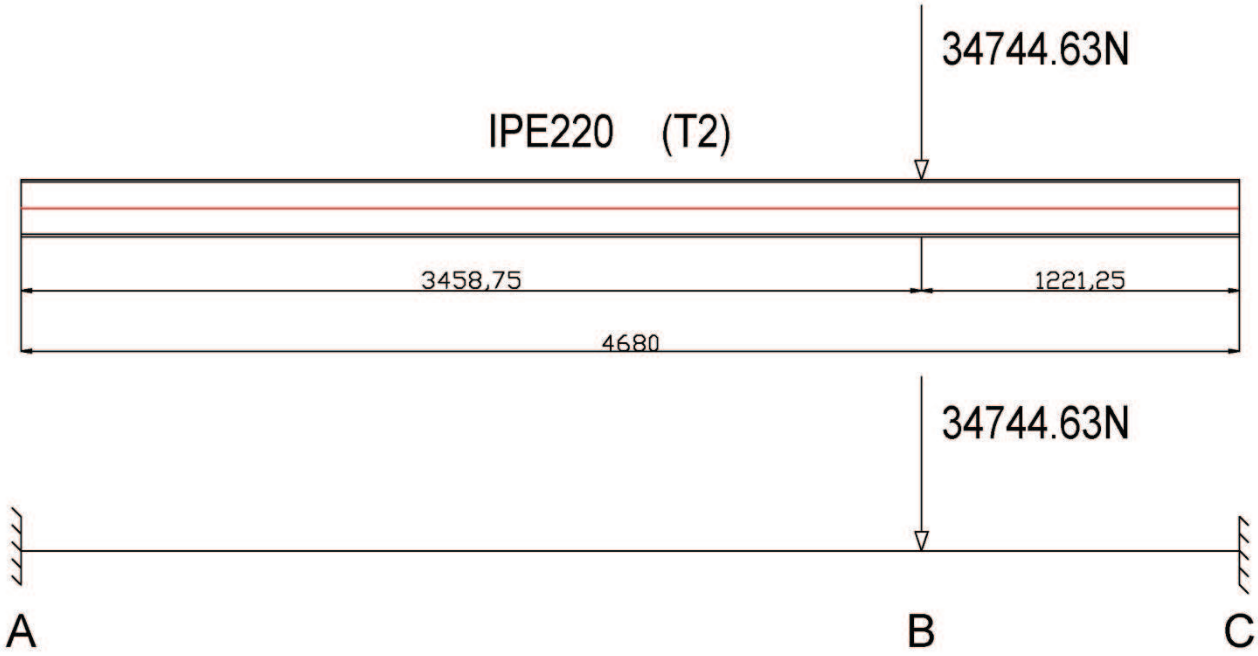
The distributed specific load along the axis of the beam is therefore (see IPE 220 T2):

$$q = 200\frac{kg}{m^2} * \frac{9.81\frac{m}{s^2} * 4680\,mm * 876\,mm}{4680mm} = 1.72\,N/mm$$

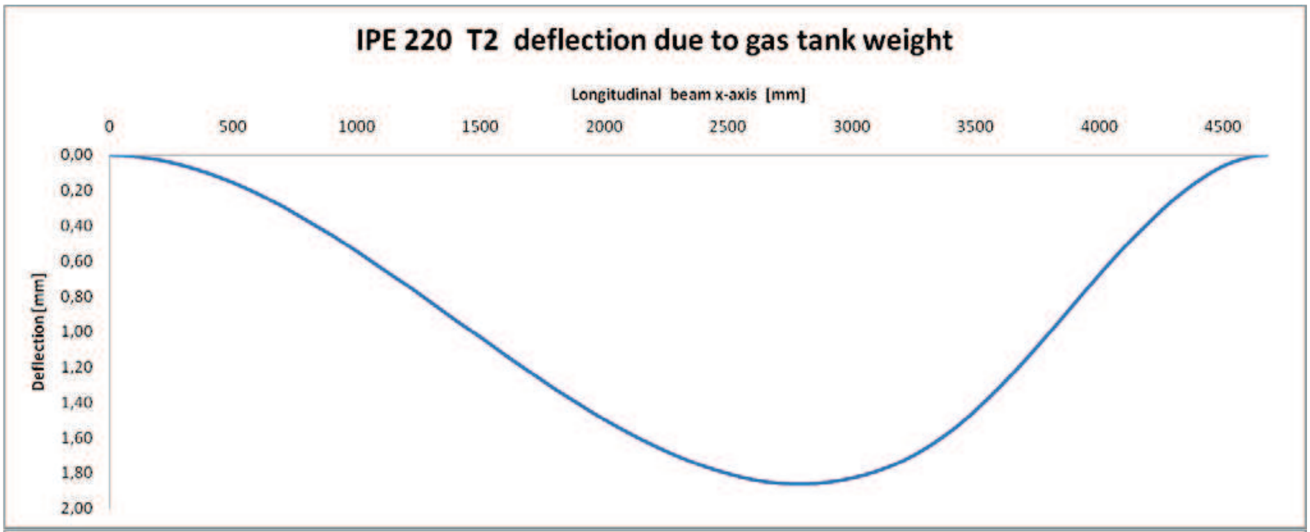
The loads on the structure are considered acting individually.

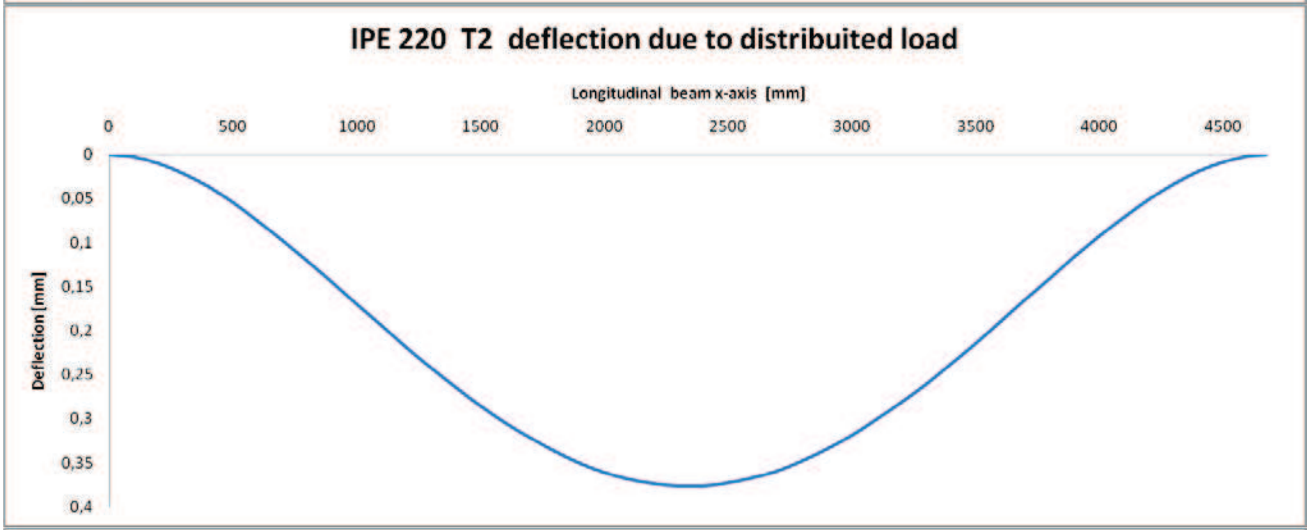
As a first approximation we assume that each IPE220 supports one-third of the total weight of the tank filled with water. Subsequently, their effects (stresses and strains) are summed to obtain the overall effect on the steel structure.

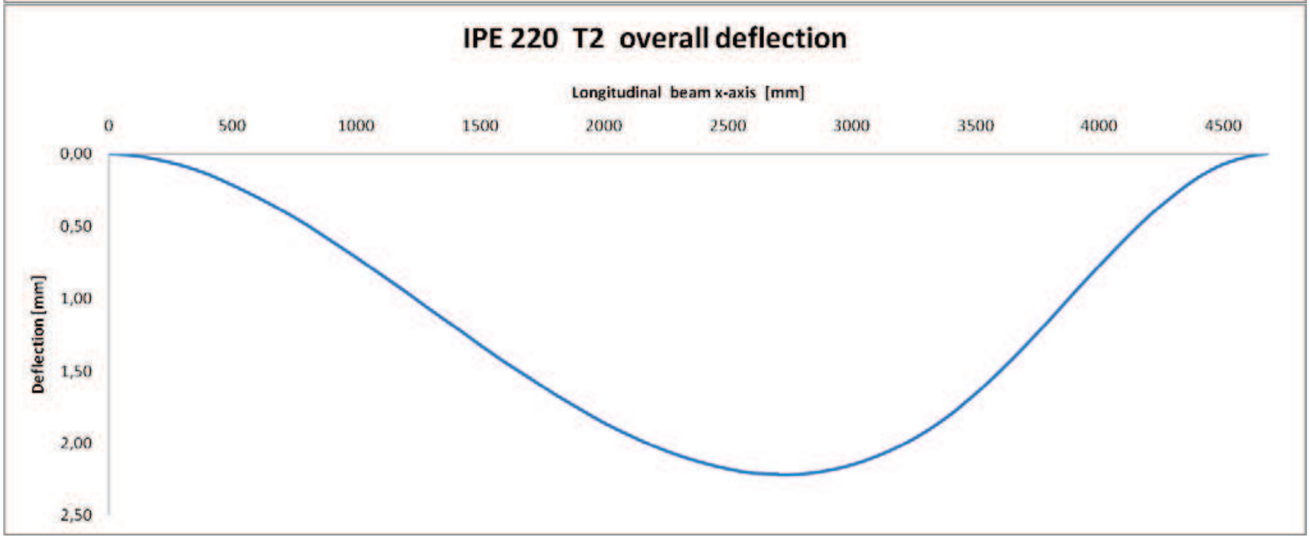
This is the structural scheme of the calculation for the IPE 220 T2 beam.

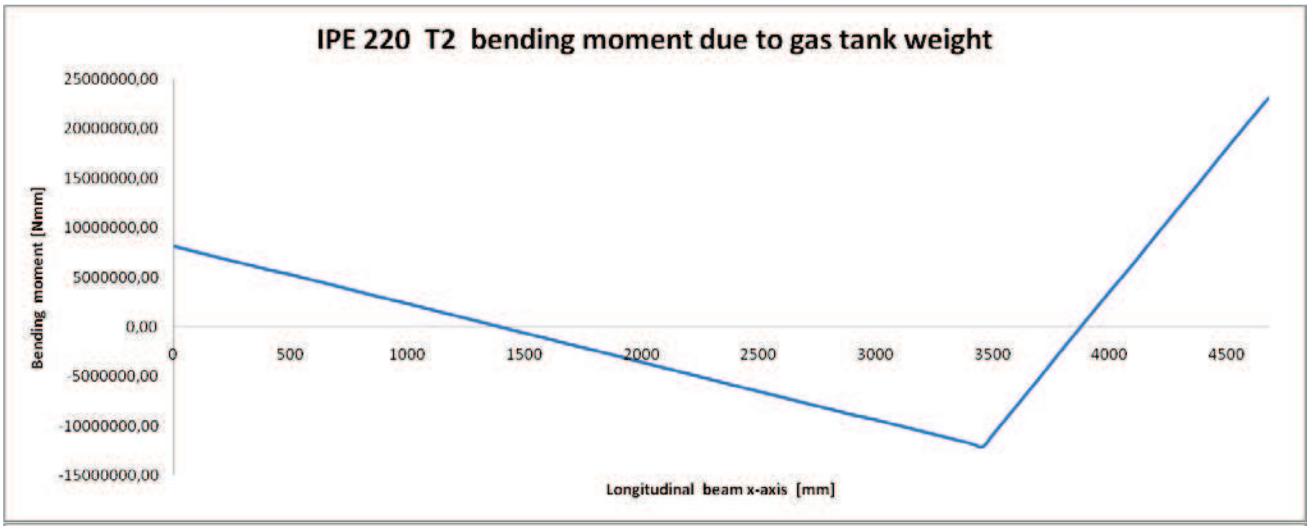


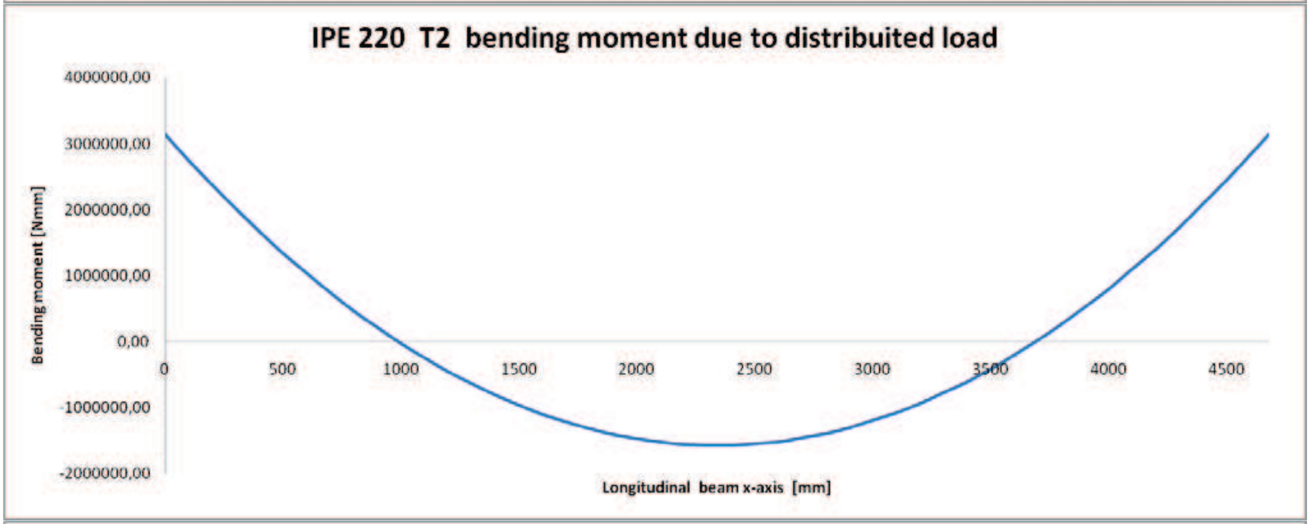
The results of the calculations relating to the supporting IPE 220 T2 beam are shown in the following graphics.

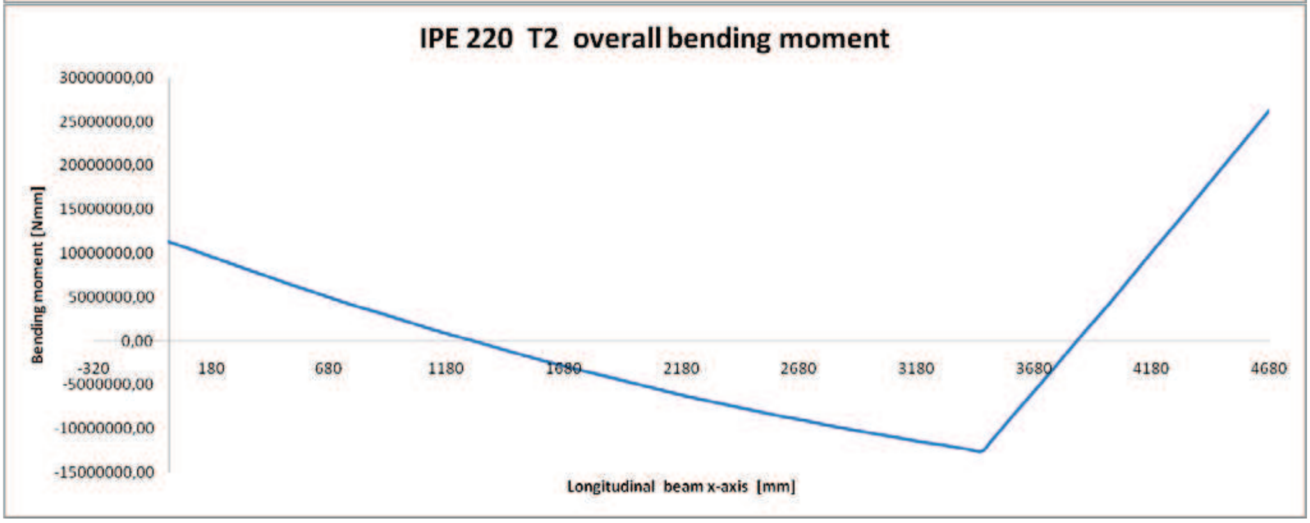

IPE 220 T2 deflection due to gas tank weight
Longitudinal beam x-axis [mm]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Deflection [mm]
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
1,60
1,80
2,00

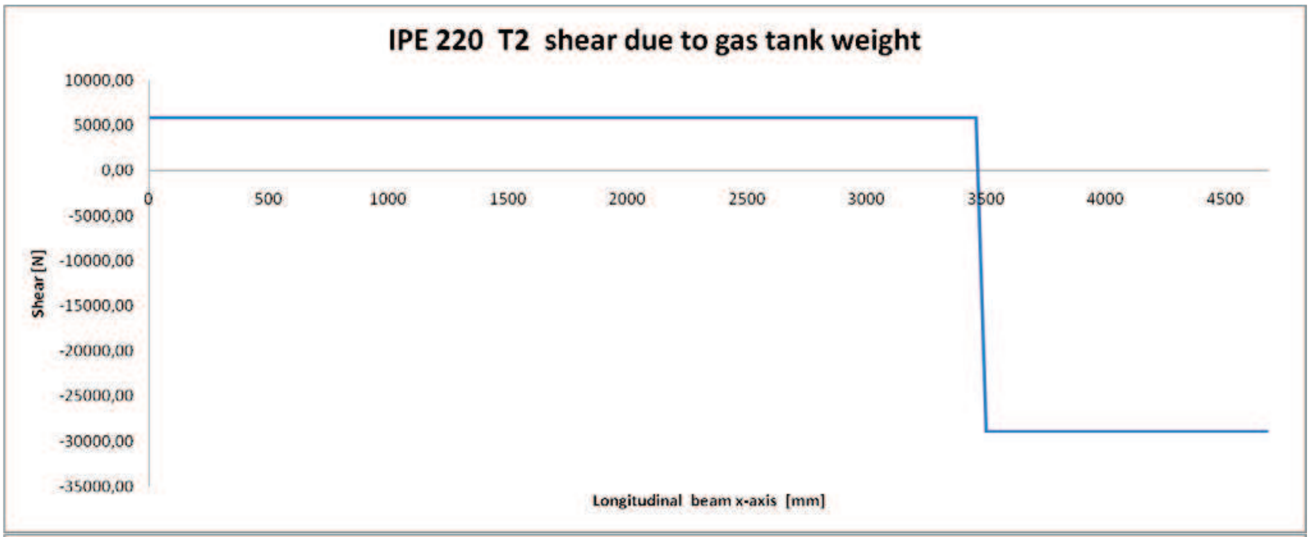

IPE 220 T2 deflection due to distribuited load
Longitudinal beam x-axis [mm]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Deflection [mm]
0
0,05
0,1
0,15
0,2
0,25
0,3
0,35
0,4

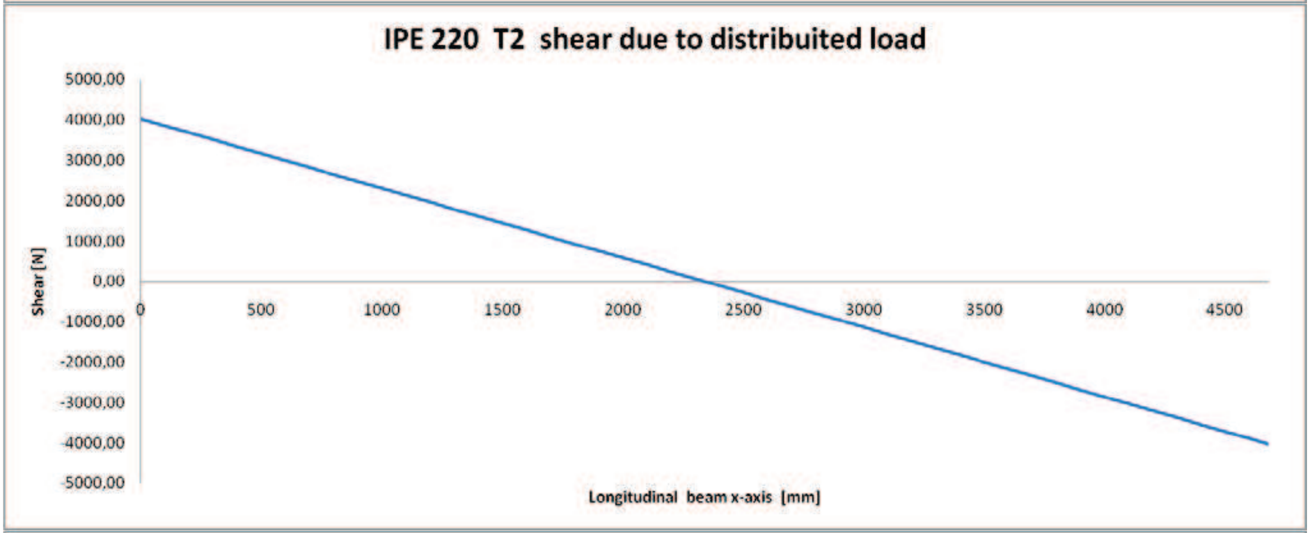

IPE 220 T2 overall deflection
Longitudinal beam x-axis [mm]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Deflection [mm]
0,00
0,50
1,00
1,50
2,00
2,50

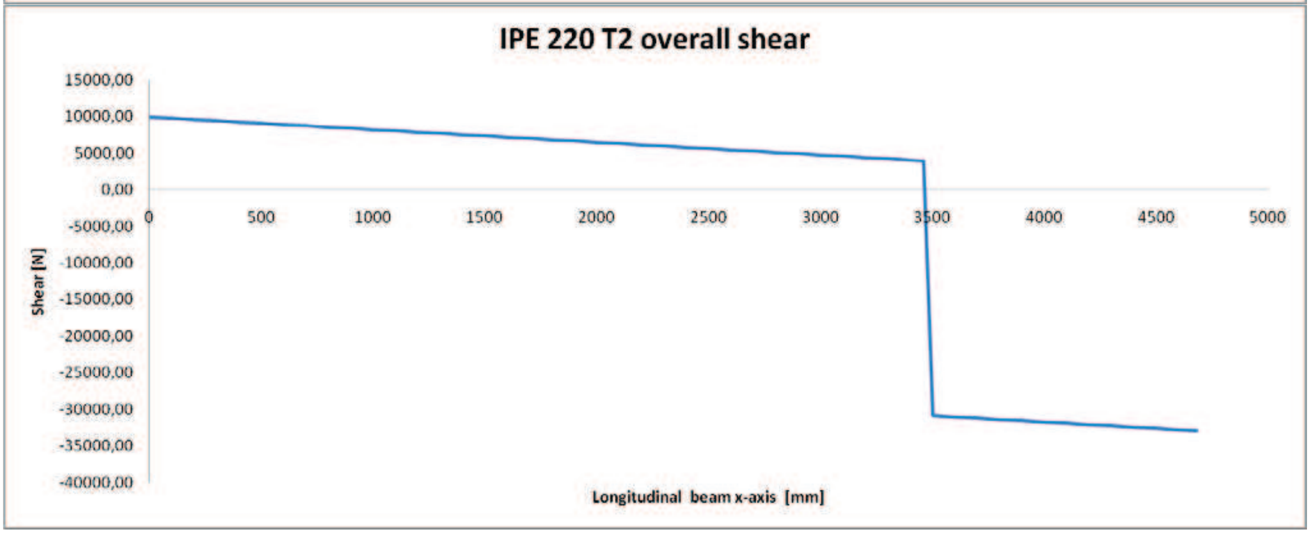

IPE 220 T2 bending moment due to gas tank weight
Bending moment [Nmm]
25000000,00
20000000,00
15000000,00
10000000,00
5000000,00
0,00
-5000000,00
-10000000,00
-15000000,00
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Longitudinal beam x-axis [mm]


IPE 220 T2 bending moment due to distribuited load
Bending moment [Nmm]
4000000,00
3000000,00
2000000,00
1000000,00
0,00
-1000000,00
-2000000,00
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Longitudinal beam x-axis [mm]


IPE 220 T2 overall bending moment
Bending moment [Nmm]
30000000,00
25000000,00
20000000,00
15000000,00
10000000,00
5000000,00
0,00
-5000000,00
-10000000,00
-15000000,00
-320
180
680
1180
1680
2180
2680
3180
3680
4180
4680
Longitudinal beam x-axis [mm]







The most stressed section of the beam is the C section in which the characteristics of stress assume the following values:

M_c = 26315524 Nmm (bending moment)

T_c = -32906,58 N (shear)

The beams are made of S 275 JR steel with an allowable stress (σ_{amm}) of 275 MPa and the following features:

Area = 3340 mm^2

Section modulus W = 252000 mm^3

The normal and shear stress are respectively:

$\sigma = M_c / W = 104.426$ MPa

$\tau = T_c / A = 9.85$ MPa

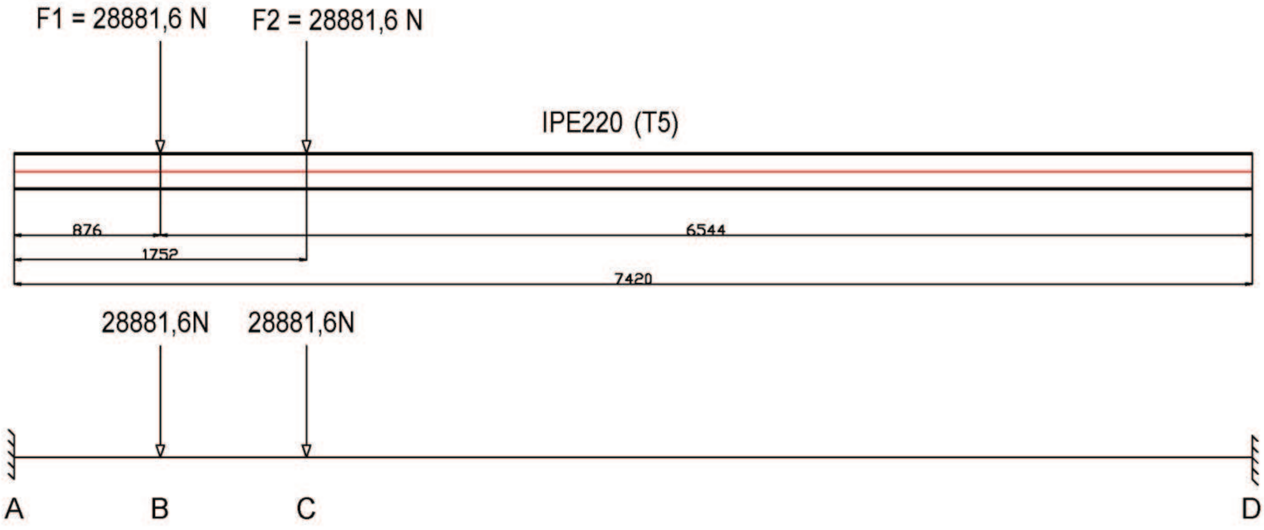
and according to Tresca criterion the equivalent stress is:

$$\sigma eq = \sqrt{\sigma^2 + 4 * \tau^2} = 106.3 \text{ MPa} < \sigma_{amm} = 275 \text{ MPa}$$

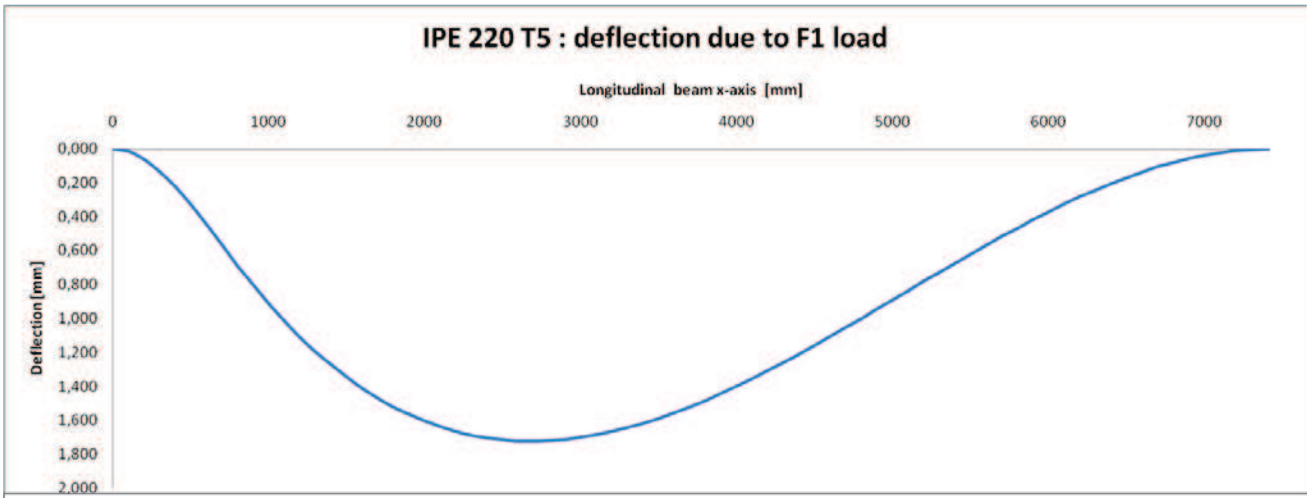
The beam lenght L is 4680 mm and its maximum deflection is $f_{max} = 2.21 < 9.36$ (1/500 L)

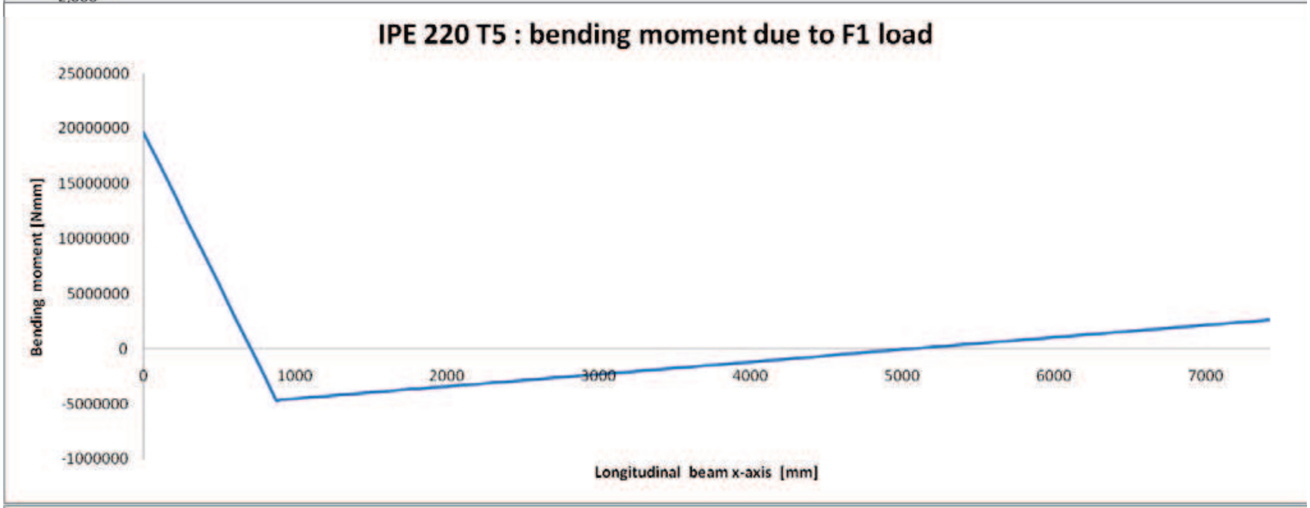
Also the beam IPE 220 T5 need to be verified.

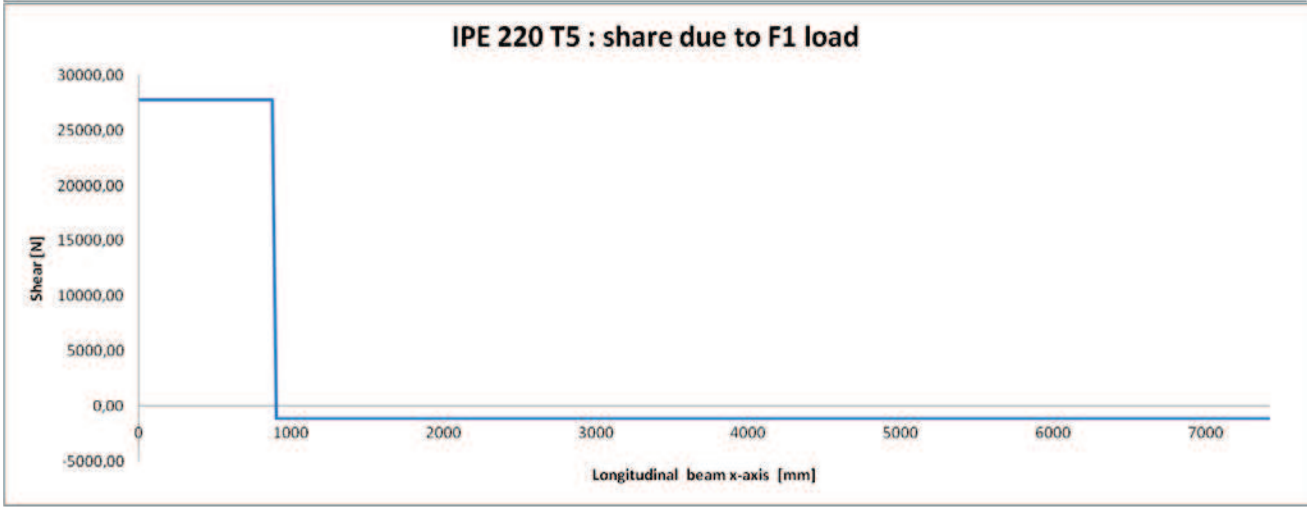
The structural scheme of the calculation for the IPE 220 T2 beam is reported here below.

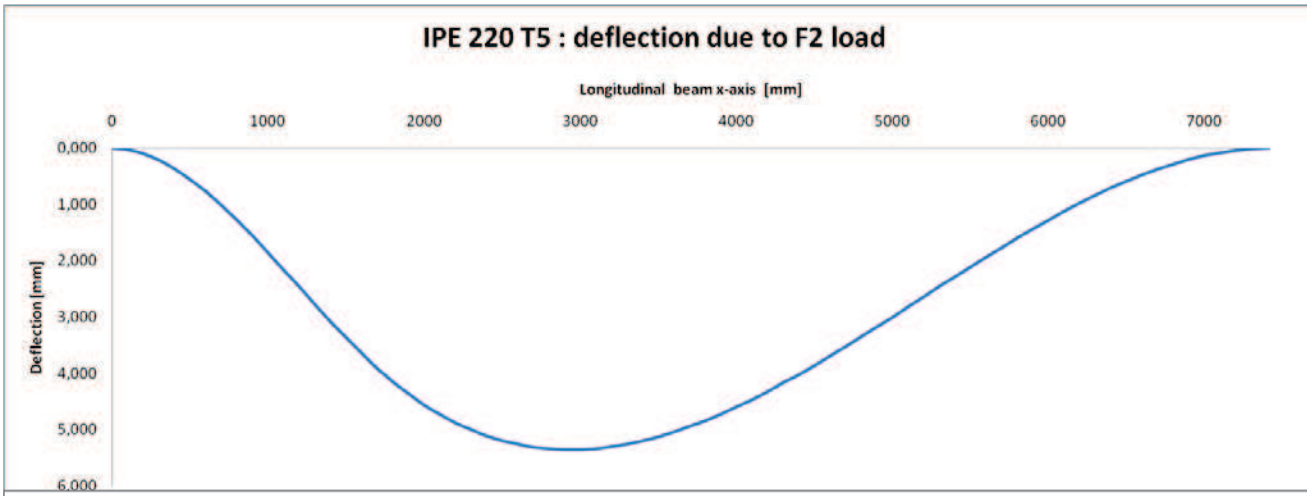


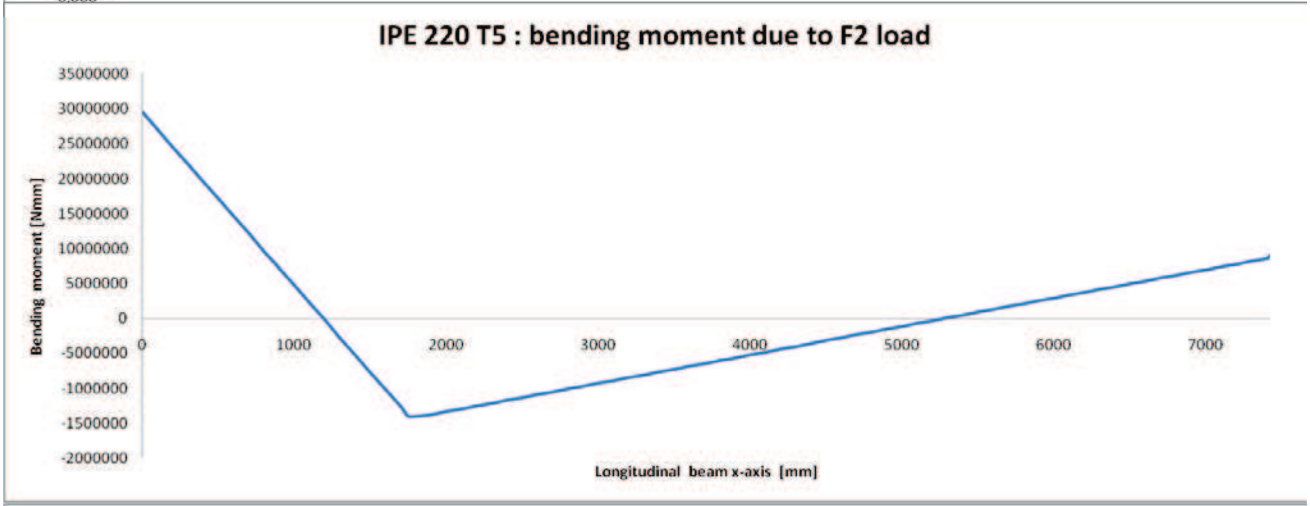
The results of the calculation relevant to IPE 220 T2 beam are shown in the following graphics.

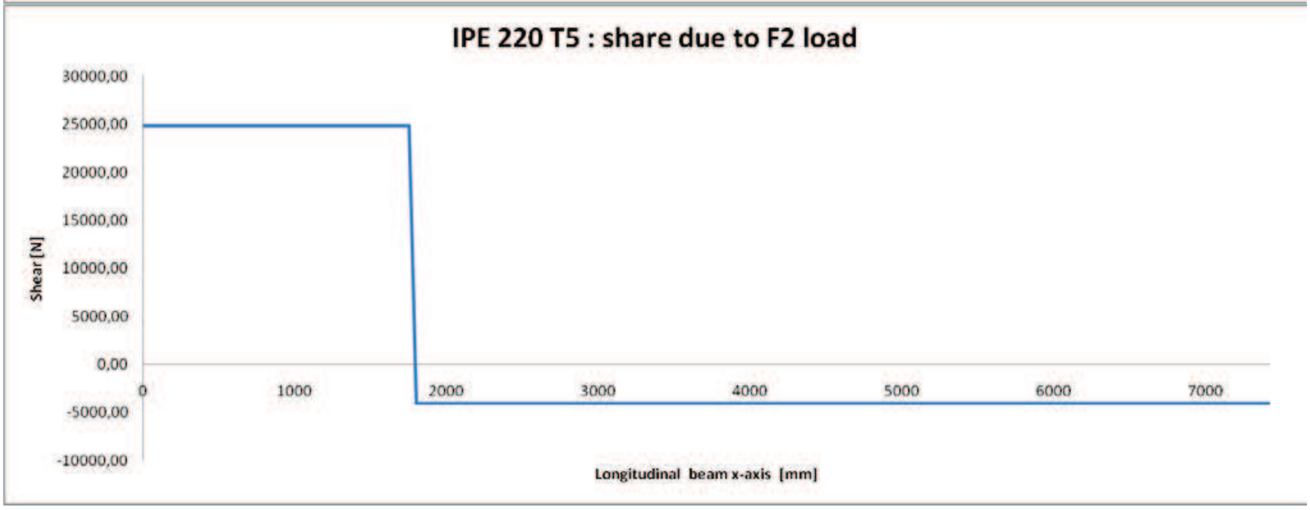

IPE 220 T5 : deflection due to F1 load
Longitudinal beam x-axis [mm]
0
1000
2000
3000
4000
5000
6000
7000
Deflection [mm]
0,000
0,200
0,400
0,600
0,800
1,000
1,200
1,400
1,600
1,800
2,000

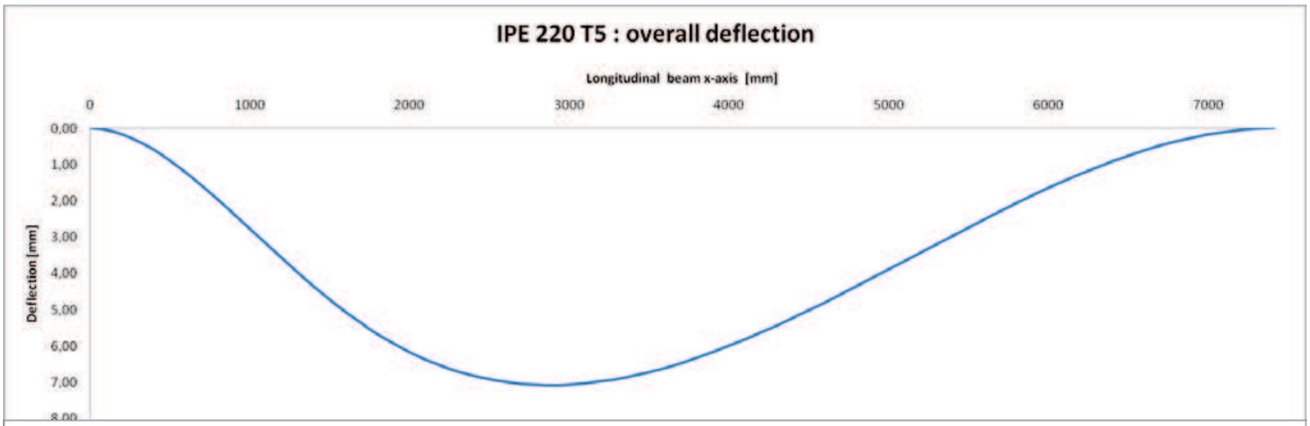

IPE 220 T5 : bending moment due to F1 load
Bending moment [Nmm]
25000000
20000000
15000000
10000000
5000000
0
-5000000
-1000000
0
1000
2000
3000
4000
5000
6000
7000
Longitudinal beam x-axis [mm]

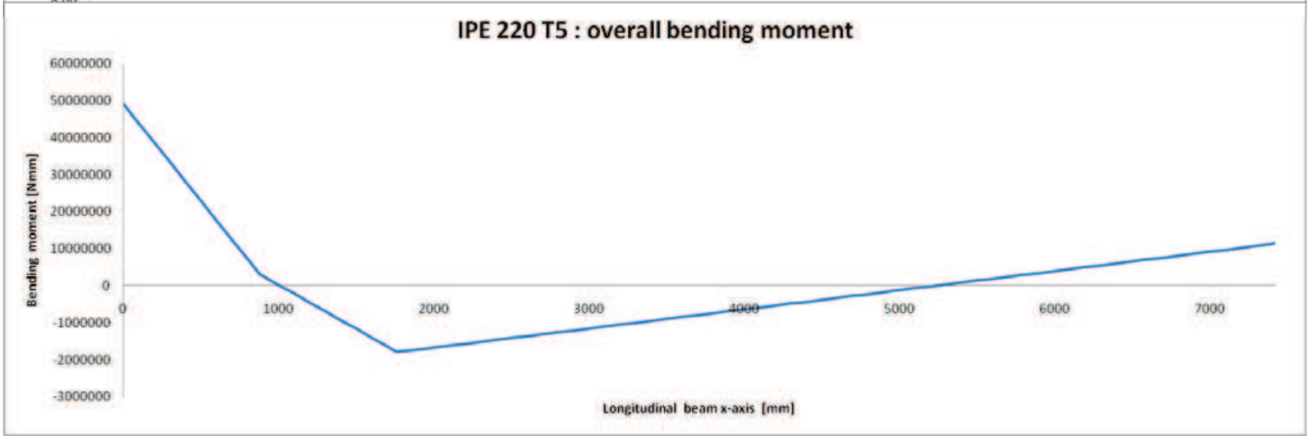

IPE 220 T5 : share due to F1 load
Shear [N]
30000,00
25000,00
20000,00
15000,00
10000,00
5000,00
0,00
-5000,00
0
1000
2000
3000
4000
5000
6000
7000
Longitudinal beam x-axis [mm]

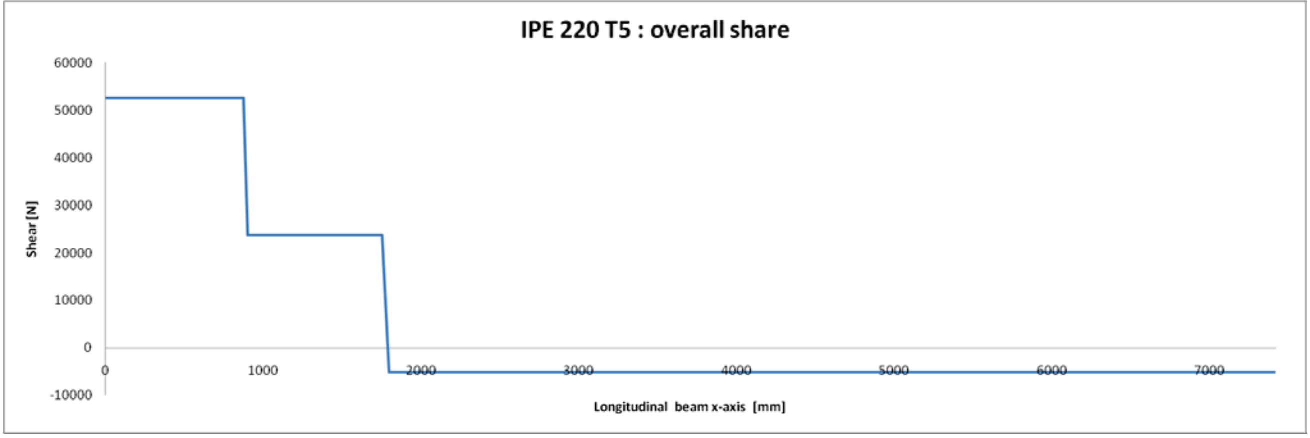

IPE 220 T5 : deflection due to F2 load
Longitudinal beam x-axis [mm]
0
1000
2000
3000
4000
5000
6000
7000
Deflection [mm]
0,000
1,000
2,000
3,000
4,000
5,000
6,000


IPE 220 T5 : bending moment due to F2 load
Bending moment [Nmm]
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
-5000000
-1000000
-1500000
-2000000
0
1000
2000
3000
4000
5000
6000
7000
Longitudinal beam x-axis [mm]


IPE 220 T5 : share due to F2 load
Shear [N]
30000,00
25000,00
20000,00
15000,00
10000,00
5000,00
0,00
-5000,00
-10000,00
0
1000
2000
3000
4000
5000
6000
7000
Longitudinal beam x-axis [mm]


IPE 220 T5 : overall deflection


IPE 220 T5 : overall bending moment


IPE 220 T5 : overall share

The most stressed section of the beam is the A section in which the characteristics of stress assume the following values:

M_A	=	49205191	Nmm	(bending moment)
T_A	=	52580	N	(shear)

The beams are made of S 275 JR steel with an allowable stress (σ_{amm}) of 275 MPa and the following features:

Area = 3340 mm^2
Section modulus W = 252000 mm^3

The normal and shear stress are respectively:

$\sigma = M_A / W = 195$ MPa

$\tau = TA / A = 15{,}7$ MPa

and according to Tresca criterion the equivalent stress is:

$$\sigma_{eq} = \sqrt{\sigma^2 + 4 * \tau^2} = 197.8 \text{ MPa} < \sigma_{amm} = 275 \text{ MPa}$$

The beam lenght L is 7420 mm and its maximum deflection is $f_{max} = 7.07 < 14.84$ (1/500 L)