



Ricerca di Sistema elettrico

ALFRED-SGBT. Preliminary characterization by the HERO test section

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V. Narcisi, D.V. Di Maio, F. Giannetti, G. Caruso



ALFRED-SGBT. PRELIMINARY CHARACTERIZATION BY THE HERO TEST SECTION

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Report Ricerca di Sistema Elettrico

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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

Linea: Collaborazione internazionale per il nucleare di IV Generazione

Obiettivo: Termoidraulica del refrigerante

Responsabile del Progetto: Mariano Tarantino, ENEA

Il presente documento descrive le attività di ricerca svolte all'interno dell'Accordo di collaborazione Sviluppo competenze scientifiche nel campo della sicurezza nucleare e collaborazione ai programmi internazionali per il nucleare di IV Generazione

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Titolo

ALFRED-SGBT. Preliminary characterization by the HERO test section

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Sommario

Il rapporto è diviso in 2 parti. La prima parte del report, documenta la fase di design, approvvigionamento e strumentazione del circuito secondario della sezione di prova Heavy liquid metal – pReSSurized water cOoled tube (HERO), già installata su CIRCE. Esso consiste in un loop aperto alimentato da acqua demineralizzata che pressurizza la stessa e la riscalda alle condizioni nominali di ingresso alla sezione di prova HERO: 172bar, 335°C. La seconda parte del report, riporta l'engineering handbook della facility CIRCE con sezione di prova HERO.

Note

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Autori:

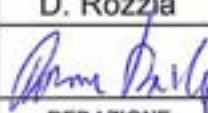
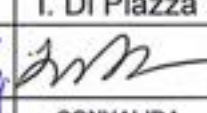
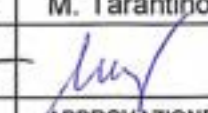
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PART-I: design and construction of the HERO secondary loop

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1 Introduction

1.1 Objective of the activity

In the framework of the Lead-cooled European Advanced DEMonstration Reactor (LEADER) project a new configuration of Steam Generator (SG) has been proposed for ALFRED (Advanced Lead Fast Reactor European Demonstrator): the super-heated steam double wall bayonet tube type with leakage monitoring. This concept allows the double physical separation between the primary lead in the pool and steam-water primary coolant that flows in the tubes.

There are two primary reasons for this separation. The first is to increase the safety margin of the NPP by reducing the probability of interaction coolant-hot fluid. The second is that this configuration allows the possibility to monitor eventual leakages from the coolant or from the hot fluid by pressurizing the separation region (i.e by helium). On the other hand, since it is required to monitor the leakages (using a low conductivity material as a gas) and get high thermal performance of the unit, the annular space that separates the fluids should be filled with a porous heat transfer enhancer (i.e. powder).

Due to the innovative features of this concept, R&D is mandatory to develop, investigate and improve double wall bayonet tube bundle SGs as well as to establish a comprehensive database for code validation.

To these purposes, ENEA has designed and constructed the HERO (Heavy liquid mETal pRessurized water cOoled tubes) test section. This device is actually located in CIRCE and consists of seven double wall bayonet tubes that represent, as much as possible, the ALFRED SG tubes (1:1 in length).

The present document summarizes the advancements achieved during this year and deals with the design and construction of the secondary loop.

1.2 HERO-CIRCE test section

CIRCE consists of a cylindrical vessel (Main Vessel S100) filled with about 70 tons of molten Lead-Bismuth Eutectic (LBE) with argon cover gas and recirculation system, LBE heating and cooling systems, several test sections welded to and hung from bolted vessel heads for separate-effects and integral testing, and auxiliary equipment for eutectic circulation^{[1][2][3][4]}. The facility is completed by a LBE storage tank (S200), a small LBE transfer tank (S300) and the data acquisition system (see *Fig. 1*). During the loading operations, the LBE is gradually transferred from the storage tank (S200) to the S300 vessel. Then, by pressurization of the S300 cover gas, the liquid metal gradually fills the test vessel (S100) from the bottom.

The main vessel S100 consists of a vertical vessel 8500 mm height, connected by gates to the other vessels. It is externally equipped with electrical heating cables, installed at the bottom and on the lateral surface. This heating system operates in a temperature range of 200-400°C.

In order to guarantee the LBE top level and to prevent accidental overpressure, the main vessel is equipped with a skimming line and a passive pressure safety system. The S100 parameters are summarized in *Tab. 1*.

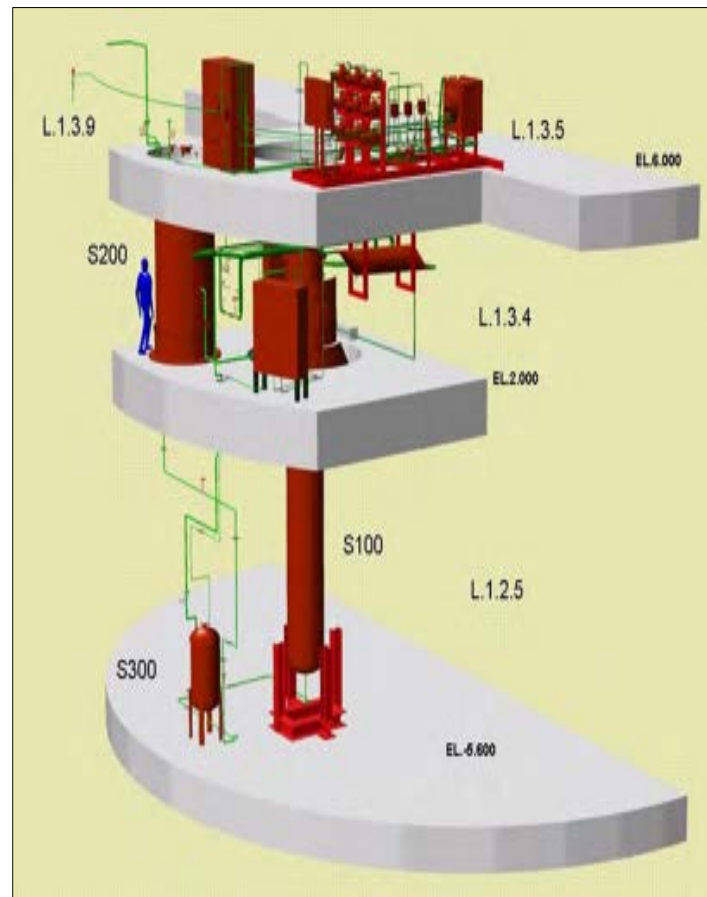


Fig. 1 – CIRCE isometric view.

Parameter	Value
Outside Diameter	1200 mm
Wall Thickness	15 mm
Material	AISI 316L
Max LBE Inventory	90000 kg
Electrical Heating	47 kW
Cooling Air Flow Rate	3 Nm ³ /s
Temperature Range	200-550°C
Operating Pressure	15 kPa (gauge)
Design Pressure	450 kPa (gauge)
Nominal Argon Flow Rate	15 NI/s
Argon Injection Pressure	600 kPa (gauge)

Tab. 1 – CIRCE S100 main parameter.

The Heavy liquid mEtal – pRessurized water cOoled tube (HERO) aims to study a 1:1 bayonet tube/s under conditions that represent, as much as possible, the operation of the ALFRED SG^{[5][6]}. The facility is expected to be a suitable tool to support the validation process of TH-Sy codes and CFD codes coupled simulations. Schematic views of HERO test section, placed in the CIRCE main vessel (S100), is depicted in *Fig. 2*.

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- *Down-comer*: It is the volume between the test section and the main vessel, which allows the hydrodynamic connection between the outlet section of the HERO-SGBT and the inlet section of the feeding conduit.
- *Feeding Conduit*: it is the inlet pipe of the test section, which allows the hydrodynamic development of the upward primary flow rate towards the flow meter.
- *Flow Meter*: it is a Venturi-nozzle flow meter. Bubble tubes are adopted to measure the pressure difference through the throat of the nozzle. The flow meter is directly connected to the HS, without a bypass, thus measuring the primary flow rate through the pin bundle.
- *Fuel Pin Simulator* (FPS): it is a mechanical structure needed to take on the Heat Source (HS). It is connected in the lower section to the flow meter and in the upper section to the insulation volume by means of the coupling flange. The coupling flange assures the sealing, avoiding the insulation volume flooding by LBE. In the upper section, the FPS is hydraulically linked to the fitting volume, ensuring continuity of the main flow path.
- *Fitting Volume*: it is placed in the middle part of the test section, allowing the hydraulic connection between the HS and the riser.
- *Riser*: it is an insulated pipe (double wall pipe with air in the gap) connecting the fitting volume with the separator. A nozzle is installed in the lower section to allow the argon injection inside this pipe^{[7][8]}.
- *Separator*: it is a volume needed to connect the riser with the HERO-SGBT. It allows the separation of the LBE flowing downward into the HX from the Argon flowing in the test section cover gas through the free surface. Moreover, the separator assures that the overall LBE flow rate flows directly into the HX (shell – side) before falling down in the down-comer. In addition, the separator works as an expansion vessel, allowing for fluid expansion during transient operations.
- *HERO-SGBT*: it corresponds to the heat sink of the system. It consists in seven double-walls bayonet tubes (with stainless steel powder filling the gap) with intermediate leakage monitoring fed by pressurized water (180 bar). It has a thermal duty of about 500 kW. It is an innovative heat exchanger mock-up (1:1) representative of a steam generator of a prototypical GEN IV lead cooled nuclear power the plant (ALFRED - Advanced Lead Fast Reactor European Demonstrator). Its main tasks are to characterize its thermal hydraulics performances and to provide a consistent database for code validation. For this purpose the HX is deeply instrumented allowing to obtain accurate measurements in order to investigate all the phenomena of interest in different operational conditions (head losses, conductive and convective flow regimes, thermo-hydraulic instability etc.). The SGBT main data are reported in *Tab. 2* and *Tab. 3*.
- *Dead Volume*: it is a component made of two concentric pipes. The inner pipe is connected, by bolted junctions, to the FPS (by the coupling flange) and to the cover head. The volume inside the inner pipe is called Insulation Volume. The outer pipe is welded to the inner pipe in the lower end by a flange which allows a bolted connection between the dead volume and the fitting volume. It extends to the cover gas, above the free level. The annulus between the inner and outer pipes, kept melt-free by design, is linked to the cover gas and filled by a thermal insulator in order to reduce the radial heat flux towards the insulation volume.
- *Decay Heat Removal System*: it corresponds to the heat sink of the system in the case of DHR scenario, when the HX is unavailable. It is hydraulically de-coupled by the primary system being placed into the down-comer. The DHR heat exchanger has been designed to have a thermal duty of 40 kW.
- *Oxygen control system*: The oxygen control system basically consists in a solid phase mass

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exchanger based on PbO spheroids for the control of the oxygen content and in three oxygen sensor based on YSZ electrolyte cell installed in the CIRCE main vessel at three different positions for the on-line measurement of the oxygen content dissolved in the melt. Moreover an extractive oxygen gas analyser is installed for on-line monitoring of the oxygen content in the cover gas. Two filtering devices are installed in the coldest and hottest region of the pool respectively. One of the filtering sections, placed at the outlet section of the main Heat Exchanger is coupled with a suitable differential pressure transducer aiming to get information related to the plugging of the filtering section during the CIRCE operation

- **Secondary loop:** the secondary loop is presently under commissioning and consists of an open cycle. The feed-water line is fed by demineralized water at service pressure. Its main task is to provide sub-cooled water at 335°C, 180 bar to the HERO-HX by means of a pump and a pre-heating system. It consists of a pump, an electrically heated spiral pipe, a collector a by-pass line and a main seam line. The system is equipped with a main control valve to pressurize the test section at the start up and a bypass valve to perform an initial pre-heating.

Description	Unit	Steam line	Helium line	LBE side
Fluid	--	Water - steam	Helium	LBE
Circulation mechanism	--	Axial pump + accumulator	Storage tank for leakage refilling	Gas enhanced
Main components	--	7 bayonet tubes, steam chamber	Helium chamber	SGBT unit shell
Bundle type and P/D	-	Triangular	--	Shell
Operating inlet temperature	°C	335	--	480
Operating mass flow	kg/s	0.330785	stagnant	44.573529
Design pressure	bar	172	5.0	As CIRCE
Operating pressure	bar	170	4.5	Hydraulic head
Hydraulic head in design condition	bar	0.7	--	--
Hydraulic head in test condition	bar	0.7	--	--
Test pressure	bar	180	--	--
Design temperature	°C	432	432	As CIRCE
Volume	m ³	0.0083	0.0054	--
Empty weight	kg	135	--	--
Code	--	EN13445	--	--
Welding joint efficiency	--	1	--	--
Notified body	--	TUV0948	--	--
Welding specification	--	WKF/3479/1	--	--
Serial number	--	13173	--	--
CE - PED	--	III Category	B1+F Module	--

Tab. 2 – HERO-CIRCE SGBT unit, main data.

Label	Inner diameter [mm]	Outer diameter [mm]	Thickness [mm]	Material
Feed-water slave tube	7.09	9.53	1.22	AISI-304
Feed-water tube gap	9.53	15.75	3.11	Slight vacuum
Feed-water outer tube	15.75	19.05	1.65	AISI-304
Annular riser gap	19.05	21.18	1.07	Water-steam
Second tube	21.18	25.40	2.11	AISI-304
Annular gap	25.40	26.64	0.62	AISI 316 powder
Third tube	26.64	33.40	3.38	AISI-304

Tab. 3 – HERO-CIRCE SGBT unit, tube design.

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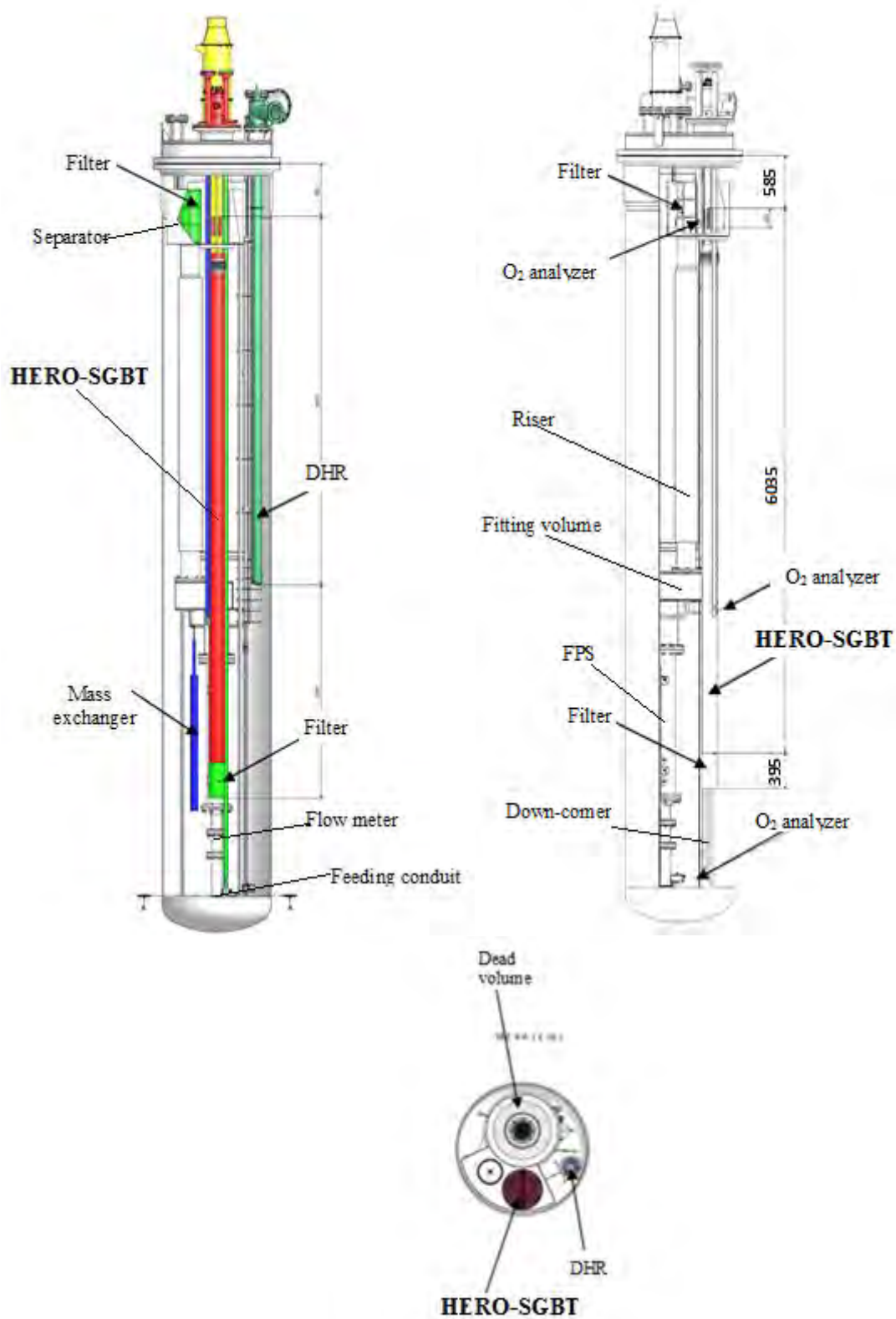


Fig. 2 – CIRCE HERO test section.

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2 Design and construction of the secondary loop

2.1 Description

The secondary loop is an open cycle loop fed by demineralized water. It pressurizes and preheats the water that fed the HERO SGBT unit and discharge the superheated steam that leaves the HERO-SGBT to the environment.

The conceptual scheme is depicted in *Fig. 3*. It is constituted by these main components:

- The demineralizer (already installed in the experimental hall)
- The pumping system
- The preheating system
- The collector
- The main pipeline (PIPE-50, PIPE-100, PIPE-200 and PIPE-300)
- The bypass pipeline (PIPE-400)
- Valves to pressurize and operate the facility
- The discharge.

Start-up:

- Valves V-200-01 and V-300-01 are closed valve V-200-01 is opened: un-pressurized water (at environmental temperature, 10-20% of the nominal rate), flows into the circuit and is discharged.
- The spiral pre-heater is activated and the facility runs in this status up to the achievement of steam at its outlet ($>100^{\circ}\text{C}$, >1 bar).
- When only steam flows in the circuit, V-200-01 and V-300-01 are gradually opened and V-400-01 is closed. CIRCE pool conditions are set from the beginning to avoid thermal stresses in the tubes once the steam enters the SGBTs.
- From this point, pressurization and feed-water heat-up start by gradually closing valve V-300-01 and adapting the power to the spiral preheater and to the CIRCE FPS.
- The start-up ends with the feed-water inlet at 335°C , 172 bar and nominal flow rates (water and LBE in CIRCE).

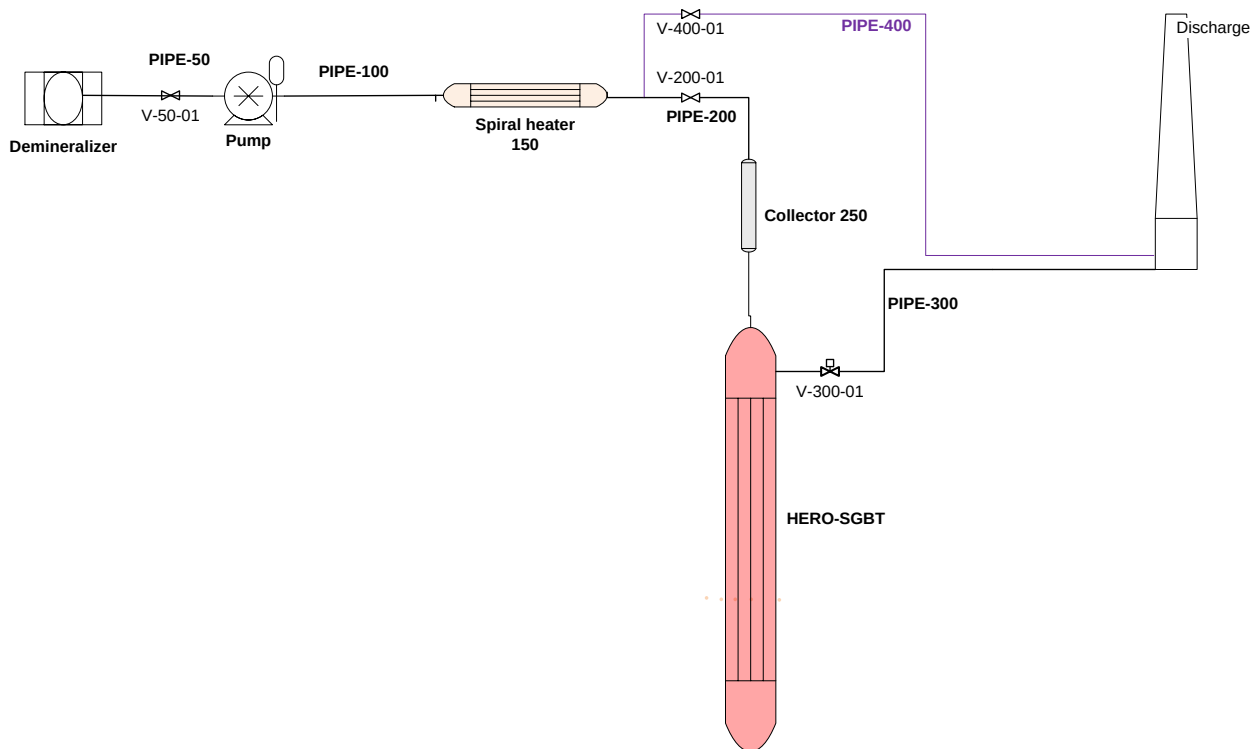


Fig. 3 – CIRCE HERO secondary loop scheme.

2.2 Pre-heater, collector and pump

The construction/acquisition of the spiral pre-heater, the collector and the pump were assigned to LIMAIOX. These components will be delivered together at Brasimone.

2.2.1 Spiral pre-heater

The spiral pre-heater supplies the power to the feed-water in order to achieve adequate conditions to enter the HERO-SGBT units (from 15°C up to 335°C, 172 bar). Since the required power is in the order of 500 kW, it is necessary to adopt a system to preheat the feed-water which was finally decided to be based on electrical heating of the feed-water tube. RELAP-5 calculations were performed and the heating tube length was estimated to be 24 m (considering a 3/4" SCH-80 – AISI-316 tube). In order to make it compact, spiral geometry has been selected. The construction of the spiral heater was assigned according to these requirements.

- Design data given in

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- ;
- Designed and constructed according to *Fig. 4*;
- To be thermally insulated by means of a cylindrical containment whose design was in charge to the supplier that should be able to guarantee an HTC less than $5.5 \text{ W}/(\text{m}^2 \text{ K})$;
- To be anchored with an opportune system whose design was in charge to the supplier that should be electrically insulated.

LIMAINOX provided the constructive design reported in *Fig. 5*. The components have been constructed and are going to be delivered to ENEA CR Brasimone, *Fig. 6*.



a) Spiral heater.



b) Spiral heater containment.

Fig. 6 – Spiral heater fabrication.

2.2.2 Collector

The collector should distribute the feed-water to seven bayonet tubes. The design and construction of this component has been assigned to LIMAINOX according to these requirements.

- The component should be designed in order to achieve as uniform as possible distribution of the feed-water to the seven bayonet tubes (this is expected to impact the component length, the distribution of the outlet nozzles and the introduction of dedicated grids).
- The working fluid in nominal conditions is water at 335°C, 170 bar, 0.33 kg/s..
- The material is AISI-316 or AISI-304.

The component has been designed (*Fig. 7*) and constructed. It is going to be delivered to ENEA CR Brasimone.

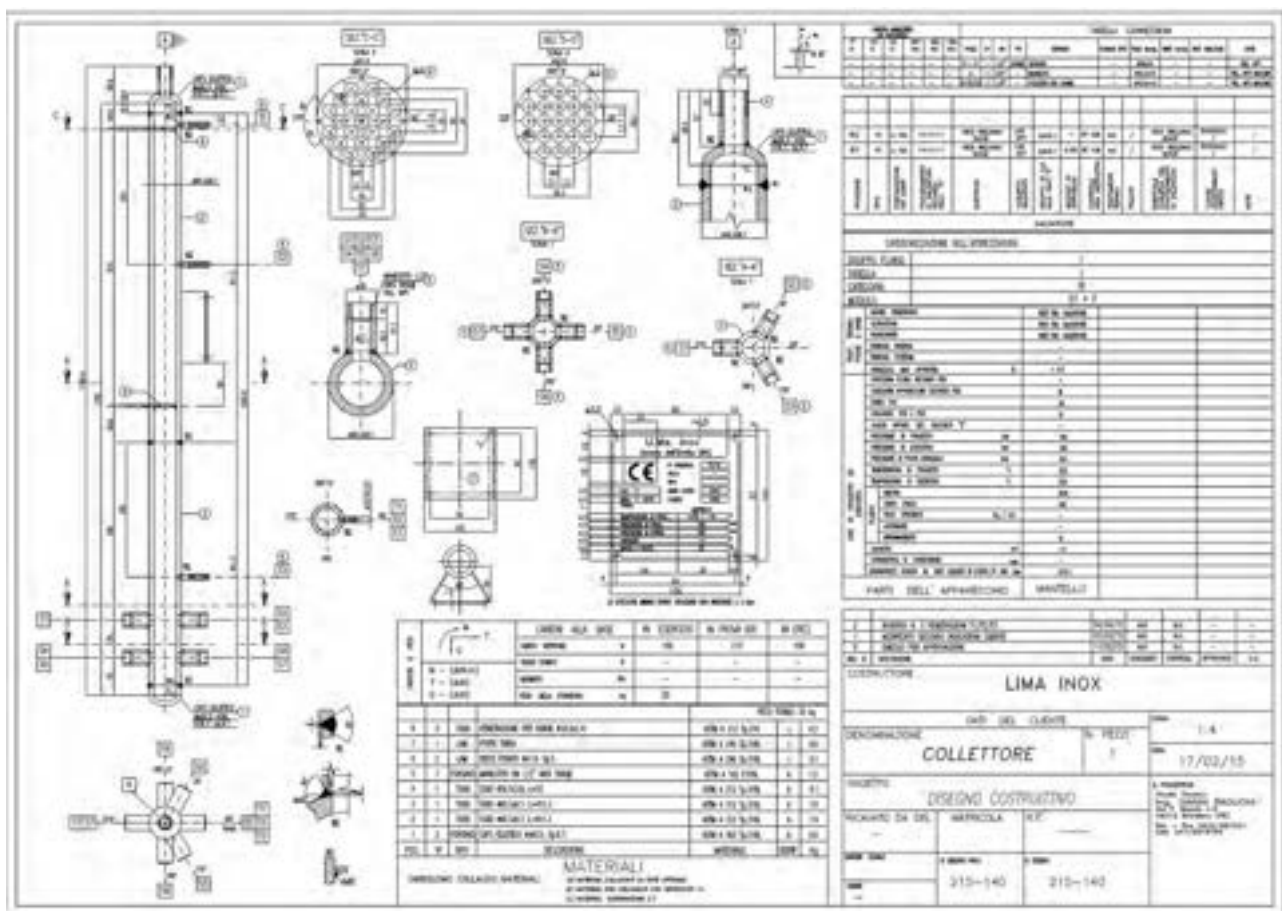


Fig. 7 – Collector design.

2.2.3 Pump

The pump has in charge to pressurize the feed-water from the service pressure up to 172 bar. Since it is required to operate at constant pressure and constant mass flow rate (into a range +10/-50 of the nominal flow rate), a piston pump with electric motor plus an accumulator to reduce its oscillations has been selected.

The pump should fulfill the following requirements:

- Motor – pump group with adequate number of rpm (es. 1400 rpm) including its regulating pressure valve and manometer, without electrical box.

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- Design data according to *Tab. 5*.
- Accumulator mounted at the pump outlet. It should be able to reduce oscillations down to 1% both at Pn and 0.5 Pn.

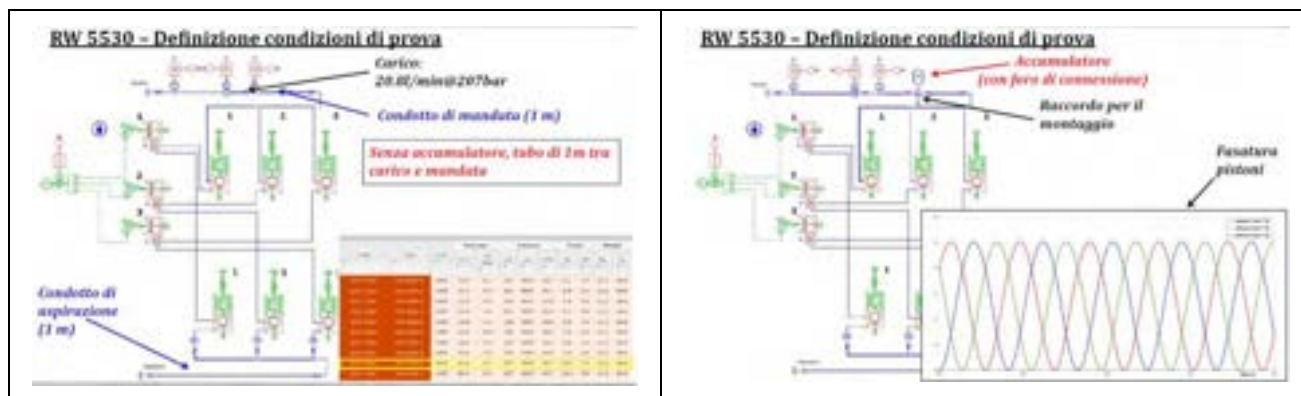
The pump triplex RW 5530 has been identified among those reported in *Tab. 6*. The accumulator was designed as reported in *Fig. 8*.

<i>Id</i>	<i>Description</i>	<i>Note</i>
Max pressure	200 bar	--
Operating pressure	180 bar	--
Nominal flow rate, Pn	19.85 l/min	--
Flow rate range	+10%Pn, -50%Pn	--
Operating temperature	20°C	--
Type	Motor-pump piston	--
Accumulator	yes	It should reduce oscillations below 1% Pn

Tab. 5 – Pump requirements.

Code	Type	RPM	Flow rate		Pressure			Power		Weight	
			l/min	US GPM	bar	psi	MPa	hp	kW	kg	lb.
6517 0200	RW 3035 S	1450	11,4	3,0	241	3500	24,1	6,9	5,1	11,2	24,6
6517 0201	RW 3040 S	1450	11,4	3,0	276	4000	27,6	7,9	5,8	11,2	24,6
6517 0300	RW 3530 S	1450	13,0	3,4	207	3000	20,7	6,7	5,0	11,2	24,6
6517 0400	RW 4022 S	1450	15,6	4,1	152	2200	15,2	5,9	4,4	11,2	24,6
6517 0500	RW 5022 S	1450	18,8	5,0	152	2200	15,2	7,2	5,3	11,2	24,6
6517 0600	RW 5030 S	1450	18,8	5,0	207	3000	20,7	9,8	7,2	11,2	24,6
6517 0700	RW 5522 S	1450	20,8	5,5	152	2200	15,2	7,9	5,8	11,2	24,6
6517 0800	RW 5530 S	1450	20,8	5,1	207	3000	20,7	10,8	7,9	11,2	24,6
6517 0900	RW 6030 S	1450	23,4	6,2	207	3000	20,7	12,1	8,9	11,2	24,6
6517 1000	RW 3535 S	1450	13,0	3,4	241	3000	24,1	7,9	5,8	11,2	24,6
6517 1001	RW 3540 S	1450	12,6	3,3	276	4000	27,6	8,7	6,4	11,2	24,6
6517 1100	RW 4030 S	1450	15,6	4,1	207	3000	20,7	8,1	5,9	11,2	24,6
6517 1100	RW 4035 S	1450	15,6	4,1	241	3500	24,1	9,4	6,9	11,2	24,6
6517 1101	RW 4540 S	1450	16,8	4,4	276	4000	27,6	11,6	8,6	11,2	24,6
6517 1200	RW 5035 S	1450	18,8	5,0	241	3500	24,1	11,4	8,4	11,2	24,6
6517 1201	RW 5040 S	1450	19,9	5,0	276	4000	27,6	13,1	9,6	11,2	24,6
6517 1300	RW 5535 S	1450	20,1	5,3	241	3500	24,1	12,6	9,3	11,2	24,6
6517 1400	RW 4040 S	1450	15,6	4,0	276	4000	27,6	10,6	7,8	11,2	24,6

Tab. 6 – Pump catalogue.



RW 5530 - Tabella risultati

Non-uniformity grade is defined as :

$$\delta_Q = \frac{Q_{max} - Q_{min}}{Q_{mi}}$$

Configurazione	Regime	Picco max	Picco min	Pressione media	Picco max	Picco min	Portata media	Grado irregolarità	Portata teorica	Rend. Vol.
	rpm	bar	bar	bar	l/min	l/min	l/min	%	l/min	%
no accumulatore	1450	254	136.1	207	23.1	16.9	20.8	30	21.9	95.13
no acc. con tubo	1450	216	188	207	21.3	18.8	20.8	7	21.9	95.13
0.15l - 40 bar	1450	206.6	205.5	206	20.83	20.78	20.6	<1	21.9	94.21
no accumulatore	725	241.7	148.2	207	11.6	9	10.7	25	10.9	97.87
no acc. con tubo	725	214	195	207	10.9	10.4	10.7	5	10.9	97.87
0.15l - 40 bar	725	206.5	205.7	206	10.72	10.69	10.7	<1	10.9	97.87

Fig. 8 – Influence of the accumulator.

2.3 Control and operational valves

The control valves have been supplied by SAMSON according the following requirements:

- Operating pressure [1-172 bar]
- Operating temperature [20-450°C]
- Fluid: water, water/steam mixture, superheated steam
- One valve (V-300-01) 3" with possibility to regulate 0.3-1.1 of nominal flow rate (which is 0.33 kg/s)
- Two valves (V-200-01 and V-400-01) 1".

The components are under acquisition, *Tab. 7* and *Tab. 8*.

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Ns. offerta n°	Ns. riferimento	Cod. Cliente	Numero
161062062 3	IT-AGN	IT16124	161062062 3
Pos.	Codice e descrizione articolo	Quantità	Prezzo cad.
001.00	Valvola di regolazione Tipo 3251-7	1,00	18.378,88
001.01	Valvola di regolazione Tipo 3251 3"; ANSI Class 2500; Corpo acciaio carbonio 1.7357 / A 217 WC6; Flange: RF - Raised Face ASME B16.5, rugosità Ra 3,2...6,3 µm; Con suddivisore di flusso I; Materiale 1.4571; Kvs 3,6 / Cv 4,2; Caratteristica equipercentuale; Corsa 15 mm; tenuta otturatore metallica (classe IV); Materiale otturatore Stellite 6 B; Materiale seggio 1.4006; tenuta con seggio stellitato; Pacco tenuta PTFE-carbonio, caricato a molla; Conn. attuatore ø 30 mm; con elemento isolante (per castello in acciaio) Var-ID: 4757550	1,00	
001.02	Attuatore pneumatico Tipo 3277 Corsa operativa 15 mm; Tipo 3277, superficie della membrana 700 cm²; Materiale della membrana NBR; Attacco segnale di comando ISO 228-1 , filettatura G; Campo segnale di comando 0,4...2,0 bar; Forza molle: asta attuatore in uscita; Campo operativo 1,6...2,4 bar Var-ID: 1074980	1,00	
001.03	Posizionatore e/p tipo 3725 con display LCD e AUTOTUNE, variabile di riferimento 4...20 mA Versione hardware GI: 00; Versione software xxx Var-ID: 4098517	1,00	
001.04	Kit di montaggio per tipo 3725 costituito da; Accessori di montaggio per montaggio diretto su tipo 3277, 240 fino 700 cm² (1402-0240); Blocco di connessione 1/4NPT (1402-0242); 2 manometri (1400-6950) Var-ID: 3496724	1,00	
001.05	Filtro riduttore Tipo 4708 riduttore di pressione tipo 4708-64, solo su blocco di connessione obliquo (montaggio diretto su tipo 3277, 240...700 cm²); Attacchi filettati 1/4-18 NPT; Campo di set point 0,5...6,0 bar, senza manometro; Custodia alluminio; Filtro nel serbatoio del riduttore di pressione nero - corpo in plastica Var-ID: 3276038	1,00	

Tab. 7 – V-300-01.

OFFERTA

Ns. offerta n°	Ns. riferimento	Cod. Cliente	Numero	
161062062 3	IT-AGN	IT16124	161062062 3	3

Pos.	Codice e descrizione articolo	Quantità	Prezzo cad.	
002.00	Valvola di regolazione Tipo 3251-7	1,00	8.795,19	-
002.01	Valvola di regolazione Tipo 3251 1"; ANSI Class 2500; Corpo acciaio carbonio 1.7357 / A 217 WC6; Flange: RF - Raised Face ASME B16.5, rugosità Ra 3,2...6,3 µm; Kvs 10 / Cv 12; Caratteristica On/ Off; Corsa 15 mm; tenuta otturatore metallica (classe IV); Materiale otturatore Stellite 6 B; Materiale seggio 1.4006; tenuta con seggio stellato; Pacco tenuta PTFE-carbonio, caricato a molla; Conn. attuatore ø 30 mm; con elemento isolante (per castello in acciaio) Var-ID: 4790680	1,00		
002.02	Attuatore pneumatico Tipo 3277 Corsa operativa 15 mm; Tipo 3277, superficie della membrana 700 cm²; Materiale della membrana NBR; Attacco segnale di comando ISO 228-1 , filettatura G; Campo segnale di comando 1,4...2,3 bar; Forza molle: asta attuatore in uscita; Campo operativo 1,85...2,3 bar Var-ID: 1065868	1,00		
002.03	Elettrovalvola Tipo 3963 Protezione Ex: II 2G EEx ia IIC T6 ATEX, Zona 1; Segnale nominale: 24 V DC; Funzione di commutazione: 3/2 vie; Montaggio: interfaccia NAMUR; Kvs: 0,32; Diametro nominale: G 1/4"; Attacco elettrico: pressacavo nero M 20x1,5; Protezione elettrica: IP 65 bugscreen con filtro in poliammide Var-ID: 1267776	1,00		
002.04	Kit di montaggio per elettrovalvola Tipo 3963 Per attuatori lineari; Costituito da: Elementi di fissaggio: staffa di montaggio per montaggio di una elettrovalvola - attuatore (0300-0998); Tubazione: acciaio zincato 10x1 per Kvs 0,16 e 0,32 Var-ID: 1114886	1,00		
002.05	Filtro riduttore Tipo 4708 Riduttore di pressione Tipo 4708-11; Attacchi filettati 1/4-18 NPT; Campo di set point 0,5...6,0 bar, senza manometro; Custodia alluminio; Filtro nel serbatoio di plastica trasparente, non allineabile Var-ID: 1620341	1,00		

2.4 Thermocouples instrumentation

The secondary loop has been mapped with 37 thermocouples whose description is given in *Tab. 9*, *Fig. 9* and *Fig. 10*.

#	ID	Location	Elev / Position	Type	Diameter	Length	Operating range
1	TF-100-01	PIPE-100	After the pump	K-type	3 mm	0.5 m	[5-50]°C, [1-200] bar
2	TF-100-02	PIPE-100	Twin to TF-100-01	K-type	3 mm	0.5 m	[5-50]°C, [1-200] bar
3	TF-100-03	PIPE-100	Spiral pipe inlet	K-type	3 mm	0.5 m	[5-50]°C, [1-200] bar
4	TF-100-04	PIPE-100	Twin to TF-100-03	K-type	3 mm	0.5 m	[5-50]°C, [1-200] bar
5	TW-100-05	PIPE-100	Spiral pipe inlet- tube surface	K-type	1 mm	0.5 m	[50-500]°C, [1] bar
6	TW-150-01	SPIRAL-PIPE-150	3 rd spire from the inlet, outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
7	TW-150-02	SPIRAL-PIPE-150	5 th spire from the inlet, outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
8	TW-150-03	SPIRAL-PIPE-150	8 th spire from the inlet, outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
9	TW-150-04	SPIRAL-PIPE-150	11 th spire from the inlet, outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
10	TW-150-05	SPIRAL-PIPE-150	12 th spire from the inlet, outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard

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#	ID	Location	Elev / Position	Type	Diameter	Length	Operating range
							OSTW. Lunghezza 1 metro
11	TW-150-06	SPIRAL-PIPE-150	Electric joints	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
12	TW-150-07	SPIRAL-PIPE-150	Electric joints	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
13	TW-150-08	SPIRAL-PIPE-150	Electric joints	K-type	1 mm	2m	[50-500]°C, 1bar giunzione isolata, cavi isolati in fibra ceramica
14	TW-150-09	SPIRAL-PIPE-150	Electric joints	K-type	1 mm	2m	[50-500]°C, 1bar giunzione della termocoppia di stile a terra a bullone, spina di termocoppia a dimensioni standard OSTW. Lunghezza 1 metro
15	TF-200-01	PIPE-200	Spiral pipe outlet	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
16	TF-200-02	PIPE-200	Twin to TF-200-01	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
17	TW-200-03	PIPE-200	Spiral pipe outlet, outer surface	K-type	1 mm	0.5 m	[50-500]°C, 1bar
18	TF-200-04	PIPE-200	Collector inlet	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
19	TF-200-05	PIPE-200	Twin to TF-200-04	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
20	TW-200-06	PIPE-200	Collector inlet, outer surface	K-type	1 mm	0.5 m	[50-500]°C, 1bar
21	TW-250-01	Collector-250	Outer surface top	K-type	1 mm	1 m	[50-500]°C, [1] bar
22	TC-250-02	Collector-250	Heating cable top	K-type	1 mm	1 m	[50-500]°C, [1] bar
23	TW-250-03	Collector-250	Outer surface middle	K-type	1 mm	1 m	[50-500]°C, [1] bar
24	TC-250-04	Collector-250	Heating cable middle	K-type	1 mm	1 m	[50-500]°C, [1] bar
25	TW-250-05	Collector-250	Outer surface bottom	K-type	1 mm	1 m	[50-500]°C, [1] bar
26	TC-250-06	Collector-250	Heating cable bottom	K-type	1 mm	1 m	[50-500]°C, [1] bar
27	TF-250-07	Collector-250	After the last grid	K-type	3 mm	1 m	[50-450]°C, [1-200] bar
28	TF-SGT-01	HERO-SGBT	Steam plenum outlet nozzle	K-type	1 mm	1 m	[50-450]°C, [1-200] bar
29	TF-SGT-02	HERO-SGBT	120° to TF-SGT-01	K-type	1 mm	1 m	[50-450]°C, [1-200] bar
30	TF-SGT-03	HERO-SGBT	240° to TF-SGT-01	K-type	1 mm	1 m	[50-450]°C, [1-200] bar
31	TW-SGT-04	HERO-SGBT	Nozzle outer surface	K-type	1 mm	1 m	[50-500]°C, 1bar

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#	ID	Location	Elev / Position	Type	Diameter	Length	Operating range
32	TF-300-01	PIPE-300	After VC-300-01	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
33	TF-300-02	PIPE-300	Twin to TF-300-01	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
34	TF-300-03	PIPE-300	Outer surface	K-type	1 mm	0.5 m	[50-500]°C, 1bar
35	TF-400-01	PIPE-400	After VB-400-01	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
36	TF-400-02	PIPE-400	Twin to TF-400-01	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
37	TW-400-03	PIPE-400	Outer surface	K-type	1 mm	0.5 m	[50-500]°C, 1bar
38	T3-001-01	Reserve	Outer surfaces	K-type	1 mm	0.5 m	[50-500]°C, 1bar
39	T3-001-02	Reserve	Outer surfaces	K-type	1 mm	1 m	[50-500]°C, 1bar
40	T3-001-03	Reserve	Outer surfaces	K-type	1 mm	1 m	[50-500]°C, 1bar
41	T3-001-04	Reserve	Outer surfaces	K-type	1 mm	1 m	[50-500]°C, 1bar
42	T3-001-05	Reserve	Outer surfaces	K-type	1 mm	1 m	[50-500]°C, 1bar
43	T3-002-01	Reserve	Spiral heater outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione isolata, cavi isolati in fibra ceramica
44	T3-002-02	Reserve	Spiral heater outer surface	K-type	1 mm	2m	[50-500]°C, 1bar giunzione isolata, cavi isolati in fibra ceramica
45	T3-002-03	Reserve	Spiral heater outer surface	K-type	1 mm	2m	[50-500]°C, 1bar
46	T3-002-04	Reserve	Fluid	K-type	1 mm	1 m	[50-500]°C, 1bar
47	T3-002-05	Reserve	Fluid	K-type	1 mm	1 m	[50-500]°C, 1bar
48	T1-001-01	Reserve	Fluid	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
49	T1-002-01	Reserve	Fluid	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar
50	T1-003-01	Reserve	Fluid	K-type	3 mm	0.5 m	[50-450]°C, [1-200] bar

Tab. 9 – HERO-CIRCE secondary loop, temperature mapping.

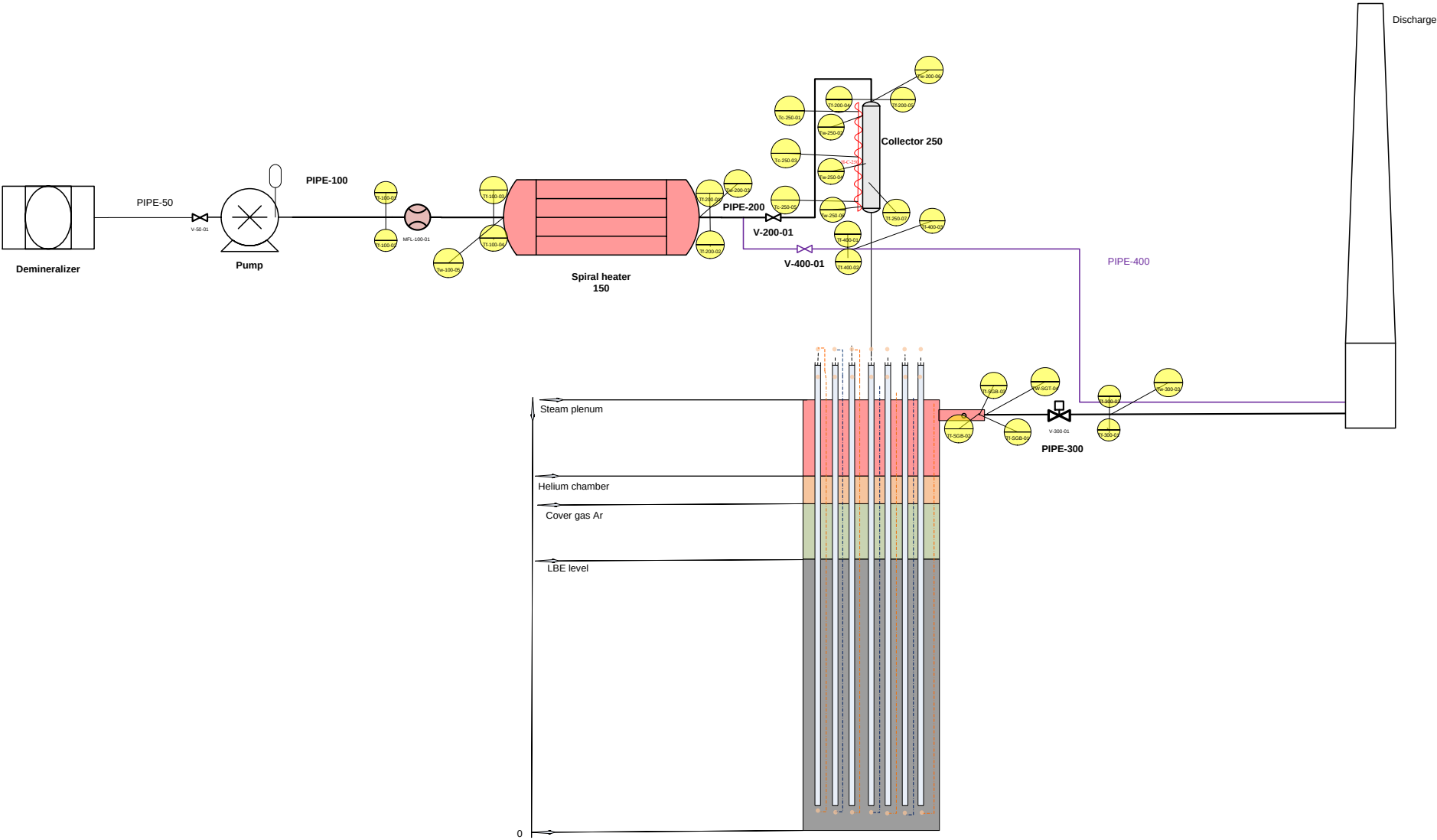


Fig. 9 – Secondary loop thermocouples.

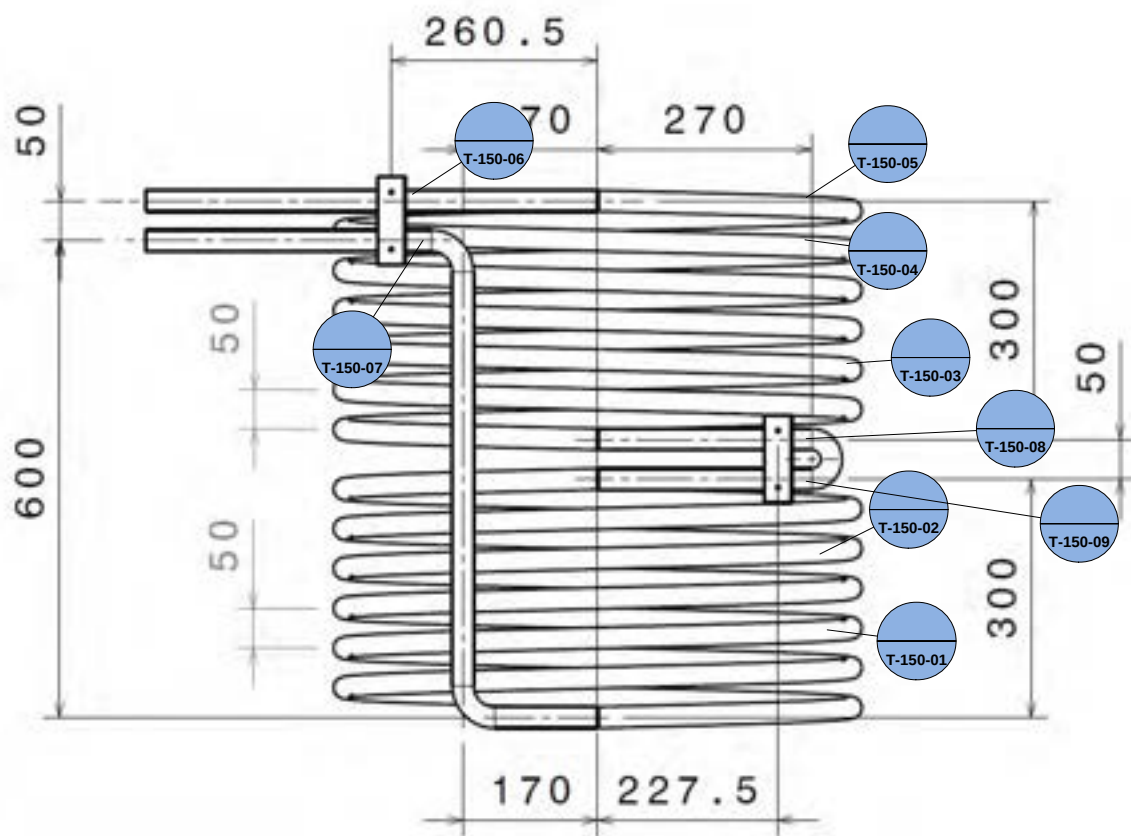


Fig. 10 – Spiral heater instrumentation.

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PART-II: HERO-CIRCE engineering handbook

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1 Introduction

The experimental test section HERO (Heavy liquid mEtal pRessurized water cOoled tube) will be installed into the CIRCE (CIRColazione Eutettica) experimental facility. The main purpose of the HERO test section is to study the behavior of the bayonet tubes of the ALFRED steam generator, in scale 1:1 and as much as possible at the ALFRED operating conditions.

The present document is aimed at providing a detailed description of the whole facility giving all the input parameters required for modeling and simulating the system through computer programs.

1.1 CIRCE conceptual design

The CIRCE facility is an experimental test section dedicated to the study of innovative nuclear systems cooled by liquid heavy metal. It consists of a main vessel (S100), inside which is installed the HERO test section, and two auxiliary tanks S200 and S300.

The vessel is filled with about 70 tons of a lead-bismuth eutectic alloy (LBE) and above the free level an argon cover is present. The S200 auxiliary tank is used for the liquid metal storage during maintenance phases. During the charging phase of the vessel, the LBE passes from the S200 storage tank to the intermediate S300 tank. Through the S300 tank, the LBE is subsequently introduced from the bottom, into the S100 vessel.

The facility is shown in the Figure 1 while the main parameters are reported in Table 1.

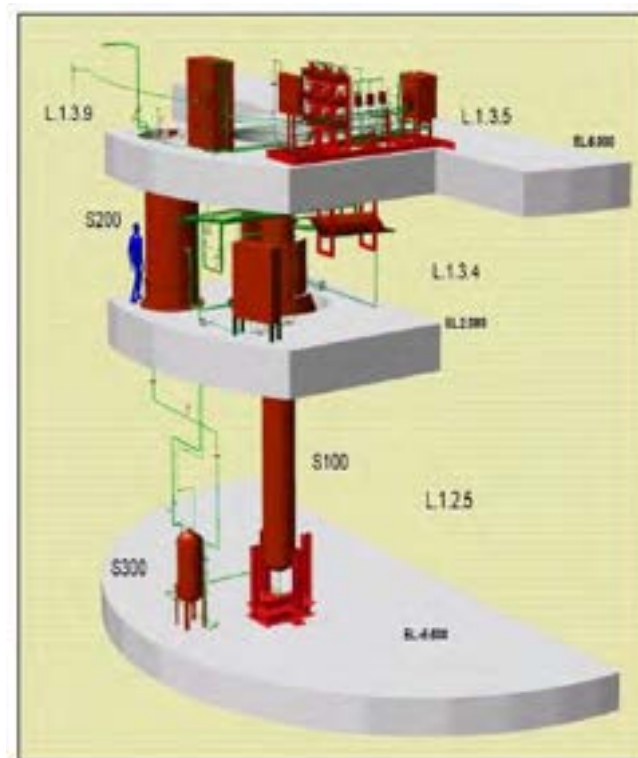


Figure 1 – CIRCE isometric view.

Parameters	Value
Outside diameter [mm]	1200
Wall thickness [mm]	15
Material	AISI 316L
Max LBE Inventory [kg]	90000
Electrical Heating [kW]	47
Cooling Air Flow Rate [Nm ³ /s]	3
Temperature Range [°C]	200 to 500
Operating Pressure [kPa]	15 (gauge)
Design Pressure [kPa]	450 (gauge)
Argon Flow Rate [Nm/s]	15
Argon Injection Pressure [kPa]	600 (gauge)

Table 1 – CIRCE S100 main parameters.

1.2 HERO conceptual design

The HERO test section is composed by a hexagonal shell in which 7 bayonet tubes (SGBT Steam Generator Bayonet Tube) are included. The bayonet tubes have the same geometrical configuration, included the dimensions (1:1 scale), of those foreseen in the ALFRED steam generators.

The HERO test section is installed into the CIRCE main vessel. The LBE enters the HERO test section from the upper part, flows into the subchannels (6 meters long) and exits at the bottom of the heat exchanger reaching again the CIRCE pool.

A simplified scheme of the bayonet tubes layout is shown in Figure 2.

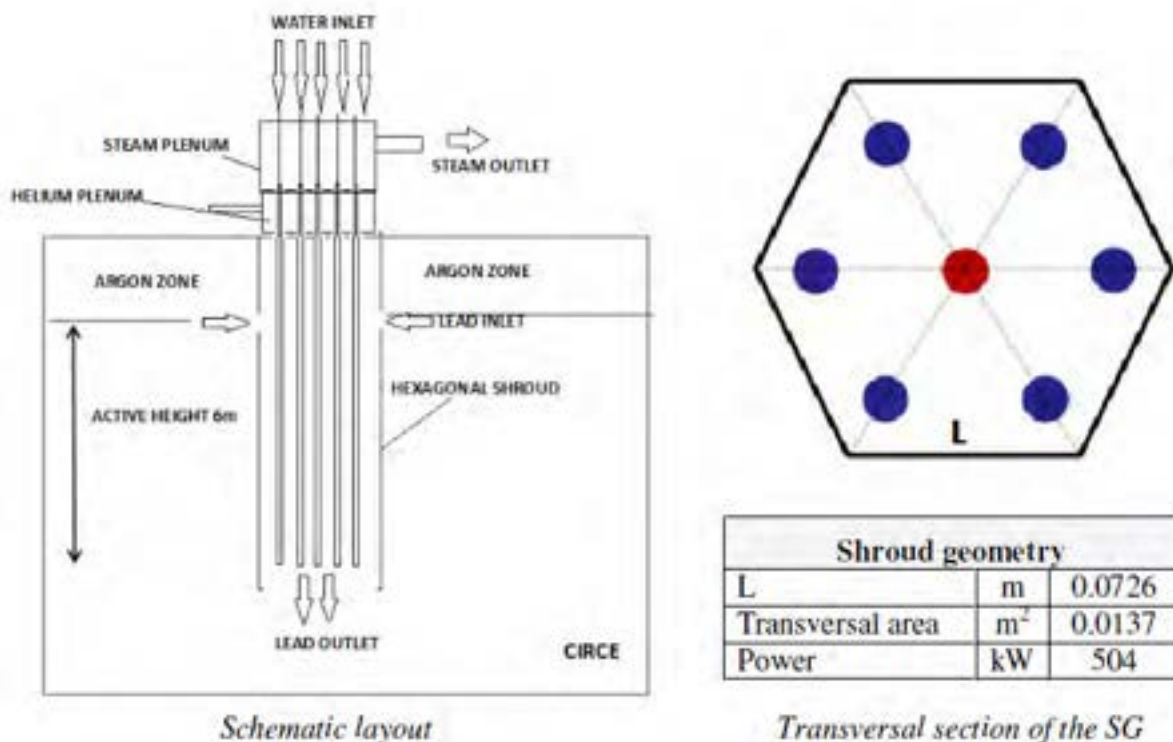


Figure 2 – Arrangement and geometry of the seven tubes and the hexagonal box.

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2 CIRCE and HERO Overview

The present chapter is aimed at providing a brief overview of the CIRCE primary loop with the HERO test section installed into it.

In the next chapter, a more detailed description of each component, included the main geometrical parameters, position and type of the instrumentation and all the information required for the system nodalization, are reported.

2.1 Primary loop

The primary loop is characterized by:

- the LBE pool;
- the riser;
- the fuel pin simulator (FPS);
- the steam generator (HERO);
- the DHR (Decay Heat Removal).

All the primary circuit components are submerged in the LBE pool; above the LBE free level there is the argon cover gas. Starting from the pool, the liquid metal is pushed into the feeding conduit, where a Venturi-nozzle flow meter is installed. The LBE, flowing upward, increase its temperature passing through the FPS, which is characterized by 37 electrically heated pins with a maximum thermal power of about 25 kW each.

After flowing into the FPS, the LBE reaches a fitting volume and hence the riser that bring the LBE at the separator, placed in the upper region of the main vessel. Into the fitting volume there is a nozzle that injects argon at the riser bottom section in order to enhance the upward circulation of the LBE coolant (gas-injection enhanced circulation). At the top of the riser, the separator allows the separation of the LBE and the argon previously injected; the argon gas comes back into the cover gas.

From the top of the main vessel, the LBE enters the HERO test section passing through the bayonet tube sub-channels. Once the LBE is cooled, it exits from the heat exchanger reaching the CIRCE main pool.



Figure 3 – HERO – CIRCE SGBT unit.

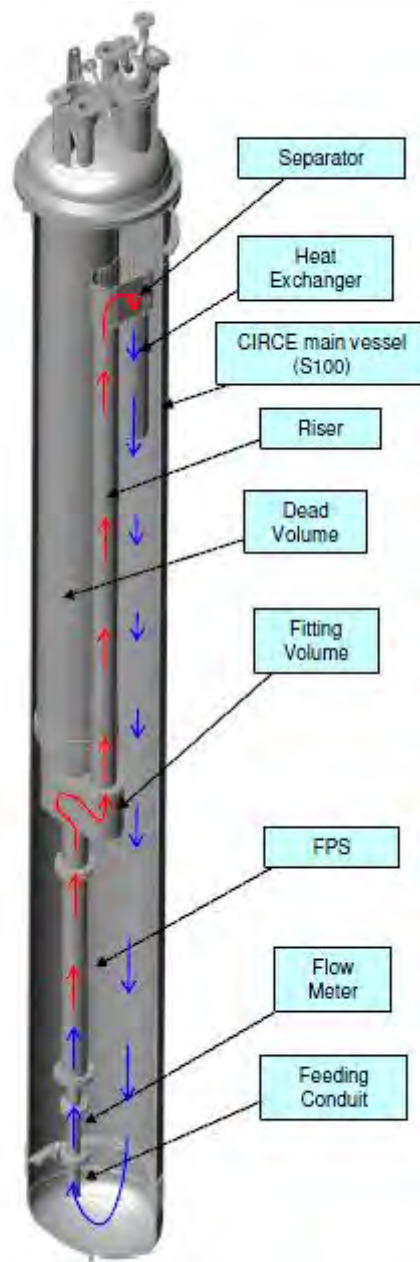


Figure 4 – CIRCE primary flow path.

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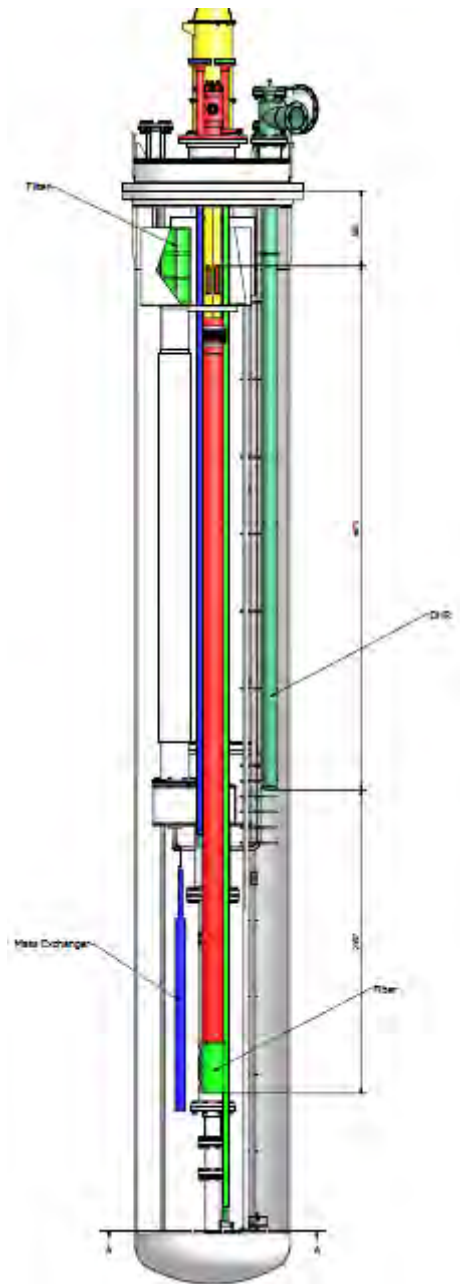


Figure 5 – CIRCE – HERO test section.

In Figure 4 there is dead volume that performs two main functions: the first one is to guarantee the placement of the FPS and the location of power and instrumentation cables; the second one is to limit the volume that has to be filled with the LBE.

3 Primary System

This chapter provides a detailed descriptions of the components belonging to the test facility primary loop. For each component, all geometrical parameters, instrumentation location and typology and all information needed for the plant nodalization are reported.

The whole system consists of: feeding conduit, fuel pins simulator, fitting volume, riser, separator, heat exchanger and pool.

At the end of the present chapter a table with the main geometrical parameters is reported.

3.1 Feeding Conduit

The feeding conduit is composed by three parts; two of these (the bottom and the upper ones) are 4 "sch. 40 tubes with a respectively length of 300 and 270 mm. Between these two parts is foreseen a Venturi flow meter (Venturi - Nozzle), 300 mm long. The three components are connected each other by 4" flanges.

Concerning the flow meter performance, it has been shown, through experimental activity previously carried out on the CIRCE facility, that a pressure drop of about 9 kPa is expected for the nominal LBE flow.

The flow measurement is performed through two pressure measurement lines. A further pressure line is foreseen in the upper tube of the feeding conduit.

3.2 Fuel Pin Simulator (FPS)

Once the LBE passes through the feeding conduit, it reaches the system heat source: named Fuel Pin Simulator (FPS).

The FPS is characterized by 37 electrically heated pins and by a rated power of about 800 kW. The design of the FPS is aimed at providing, with the LBE having an average speed of 1 m/s, a coolant temperature gradient of 100 °C/m and a pin power density of 500 W/cm³.

The electrically heated pins are characterized by a hexagonal lattice with a pitch to diameter ratio equal to 1.8.

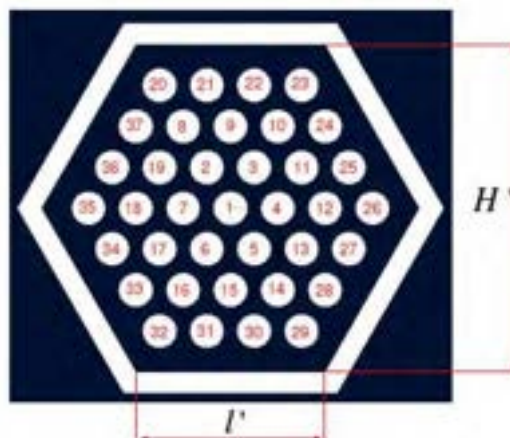


Figure 6 – FPS cross section.

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Each pin is characterized by an outer diameter equal to 8.2 mm, a maximum thermal power of about 25kW and by a heat flux, at the pin wall, of 1 MW/m². The FPS pins length is 1885 mm; the heat source is limited to the central 1000 mm. The other 885 mm constitute the upstream and downstream mixing zones, placed immediately below and over the heating region. These two mixing zones are respectively characterized by a length of 300 and 485 mm.

The pins are kept in their correct position, along their height, by means of three spacer grids (for the locations see Figure 7). Moreover, a lower grid, which guarantees the LBE inlet, and an upper grid, which acts as FPS cap, are placed at the bottom and upper pins edges.

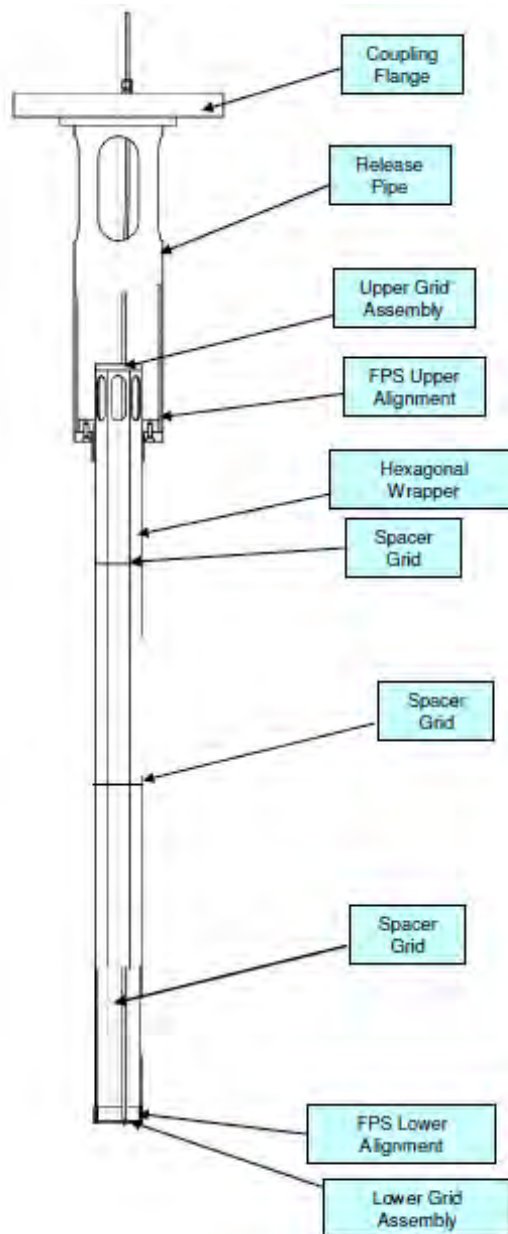


Figure 7 – FPS mechanical drawing.

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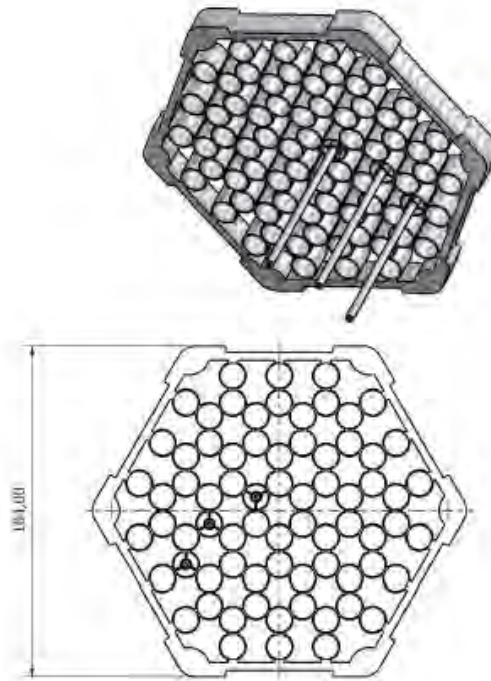


Figure 8 – Spacer grid.

The three spacer grids are located as follow:

- The first and the third ones are located at heights corresponding to the interfaces of the heating region and the mixing zones.
- The second spacer grid is located at the center of the heating zone.

The FPS geometrical parameters, reported in the Table 6, are evaluated taking into account the actual position of each grid. The pressure drop coefficients corresponding to the grids have been evaluated through the Rehme correlation.

The FPS hexagonal wrapper is included in a cylindrical shroud, where holes for the instrumentation connections are obtained. The gap, between the inner hexagonal wrapper and the outer cylindrical shroud, is filled with stagnant LBE.

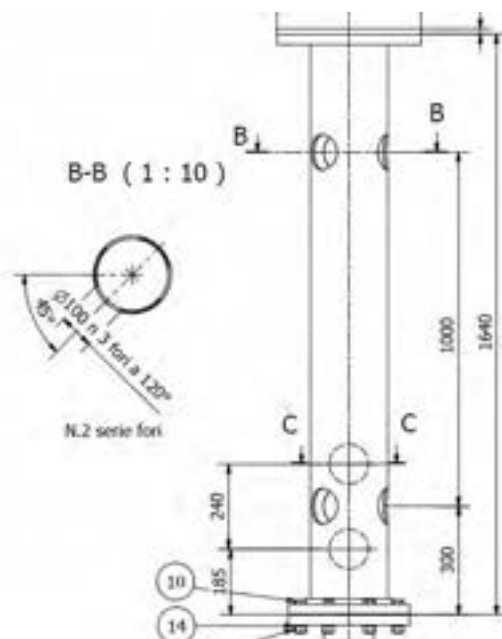


Figure 9 – Cylindrical wrapper.

The FPS instrumentation is characterized by:

- three TCs at the active zone inlet: placed, at 120° , at 20 mm above the first spacer grid;
- three TCs at the active zone outlet: placed, at 120° , at 20 mm below the third spacer grid;
- pressure outlet line at 223 mm from the FPS inlet;
- pressure outlet line at 463 mm from the FPS inlet (240 mm above the previous one).

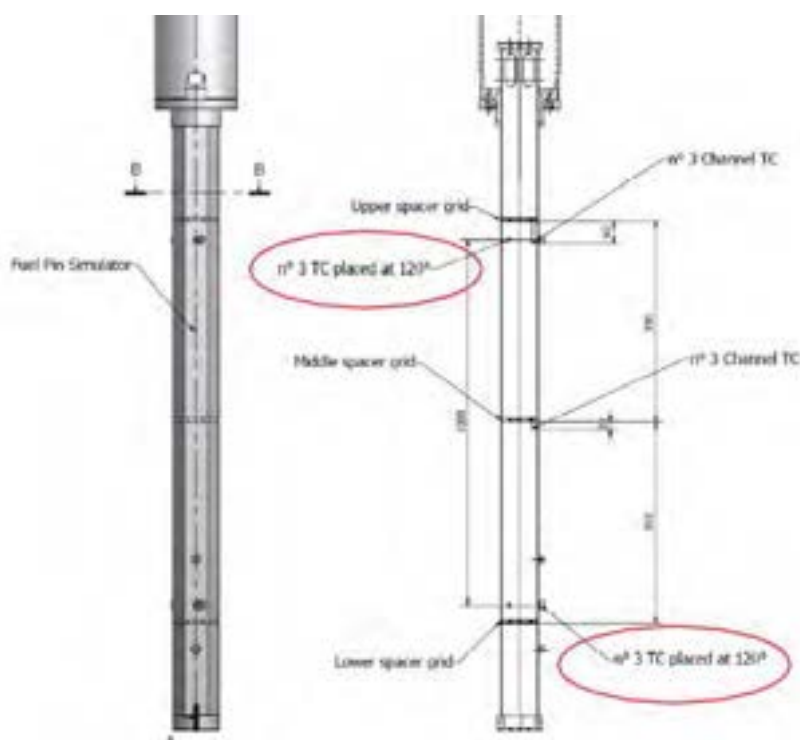


Figure 10 – Fuel Pin Simulator overview.

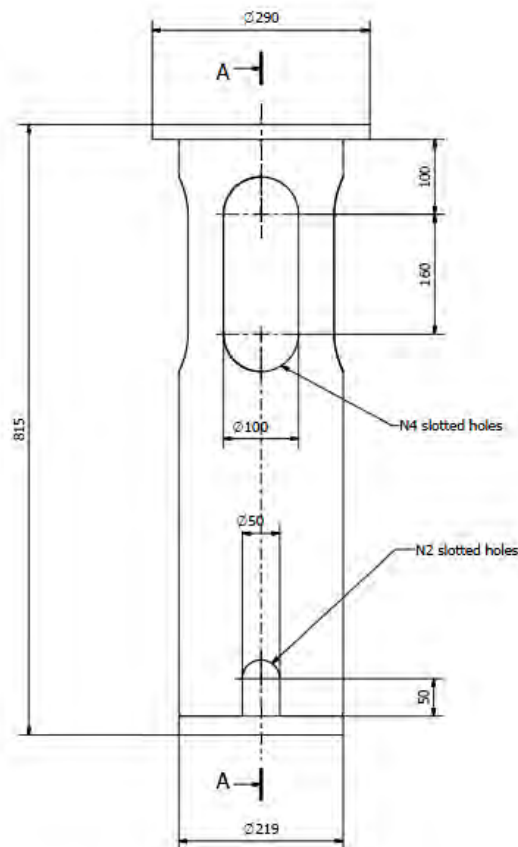


Figure 13 – Release pipe.

In the bottom region there are two openings to guarantee the LBE flow. The release pipe can be internally subdivided into two regions:

- the first 115 mm long,
- the second 645 mm long.

The first region has a flow area equal to the annular zone included between the inner wall of the release pipe and the FPS outer wall (the FPS enters into the release pipe). This flow area is evaluated to be 229.985 cm^2 .

The second region has a flow area equal to the difference between the release pipe inner section and the zone occupied by the electrically heated pins of the FPS. The upper part of the electrically heated pins exit from the FPS through the upper grid and they reach the dead volume up to the connection flange. The flow area of the second region was evaluated to be equal to 304.115 cm^2 . Three thermocouples are placed in the openings that connect the release pipe to the fitting volume.

3.4 Fitting Volume

The main task of the fitting volume (see Figure 14) is to connect the release pipe to the riser. Once the LBE, exiting from the release pipe, reaches the fitting volume, it is driven to the riser inlet.

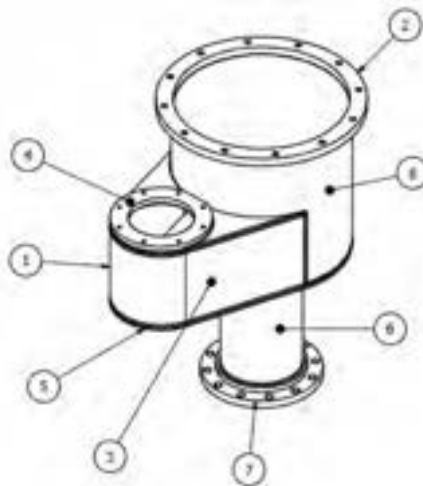


Figure 14 – Fitting volume.

8	1	Cylinder th.8 d600 L525 [mm]	AISI304
7	1	Flange SO RF150 10"	AISI304
6	1	Pipe 10" Sch.40	AISI304
5	1	Sheet th.15 [mm]	AISI304
4		Flange riser support d340 th.20 [mm]	AISI304
3	1	Sheet th.15 [mm]	AISI304
2	1	Flange d700 th.30 [mm]	AISI304
1	1	Folded sheet th.8 [mm]	AISI304
POS.	Q.TY	DESCRIPTION	MATERIAL

Table 2 – Fitting volume.

The fitting volume can be divided into the two following zones (see Figure 16):

- the first, at the bottom, where the LBE is driven towards the coupling flange with the riser (see position 4 in Figure 14);
- the second is the cylindrical upper region where the LBE is stagnant.

The flow area of the first region has been evaluated subtracting areas of the release pipe and of the gas injection nozzle to the fitting volume section. This is represented in the Figure 15.

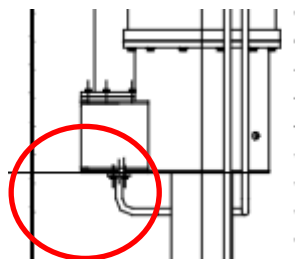


Figure 15 – Argon injector.

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The first zone is characterized by the flow area equal to 0.3214 m² and the length equal to 290 mm. The second zone is almost entirely occupied by the dead volume structure, which penetrates into the fitting volume (see Figure 17). In particular, dividing the area into two volumes, the following geometrical parameters can be obtained:

- volume 1: length of 142.5 mm and flow area of 0.0549 m²;
- volume 2: length of 142.5 mm and flow area of 0.1854 m².

At half height of the first zone is placed a pressure outlet line.

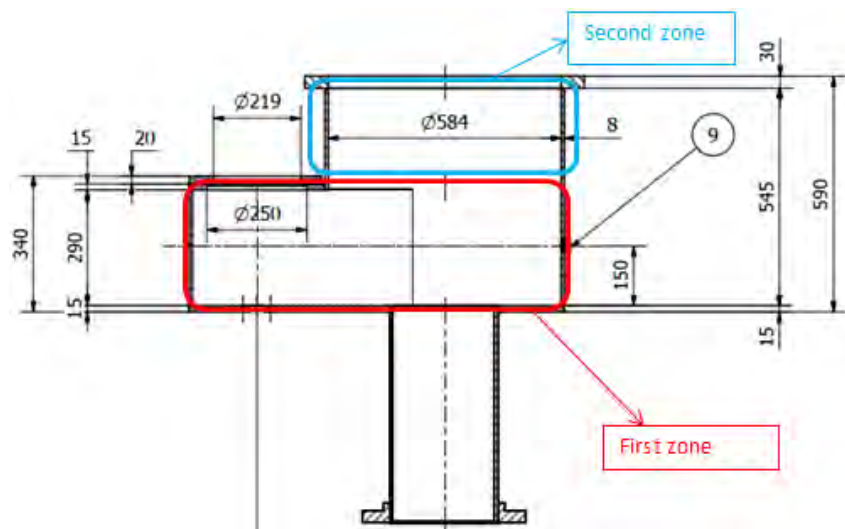


Figure 16 – Fitting volume: zones.

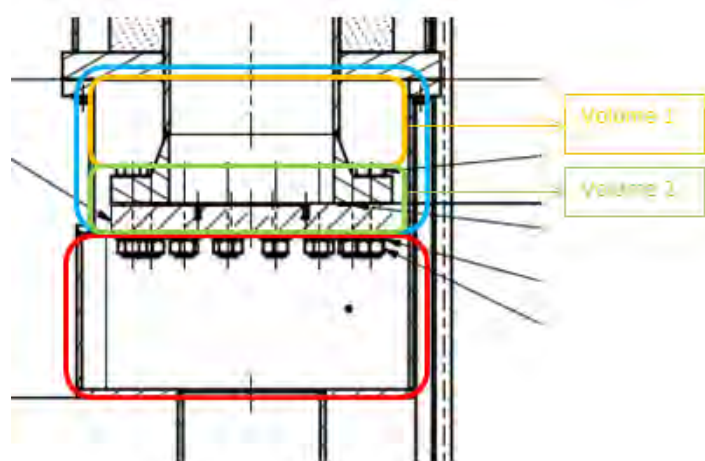


Figure 17 – Fitting volume: zones and volumes.

3.5 Riser

The riser is a double-wall pipe characterized by an overall length of 3.81 m. It allows the LBE to flow upward, thanks to the gas-injection enhanced circulation, from the fitting volume to the separator.

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In order to reduce the hot fluid heat loss towards the main pool, a double-wall pipe has been selected for the riser. The inner tube has an inner diameter of 203 mm and it is included, for a length of 3020 mm, into a larger tube, as shown in Figure 18.

The gap between the two pipes is filled with air in order to reduce the heat loss. The riser is equipped by an axial bellow with a maximum length of 310 mm. The upper edge of the riser, which reaches the separator penetrating it of 102 mm, is coupled with a filter.

The pressure drop due to the filter can be taken into account through a K coefficient equal to 7. Moreover, the riser is equipped with two pressure gauges located at the inlet and at the outlet of the inner tube.

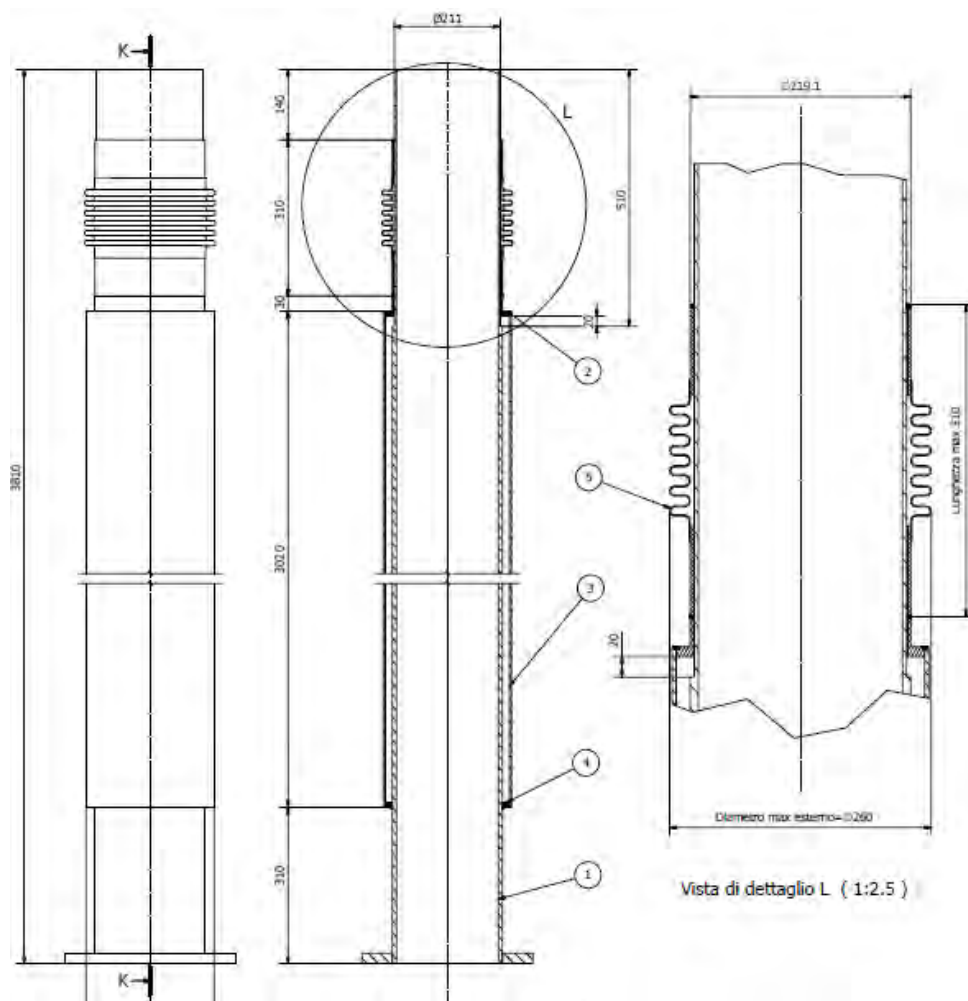


Figure 18 – Riser overview.

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Figure 19 – Filter.

3.6 Separator

The separator, made by metal sheets, creates a volume dedicated to the separation of the hot LBE and the argon gas. The separation occurs since the hot LBE is driven downward, towards the heat exchanger inlet, while the argon can flow upward reaching the cover gas upper volume.

At the same time the separator guarantees the connection between the riser and the HERO-SGBT test section. The flow path connection is obtained through 6 openings present on the heat exchanger shroud; each of them is characterized by a flow area of 84.566 cm^2 .

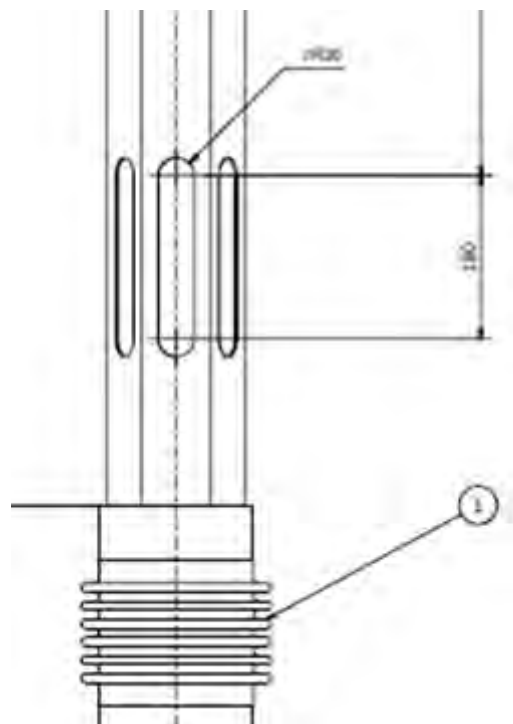


Figure 20 – HERO inlet.

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The separator walls force the LBE to flow through the heat exchanger sub channels for reaching the down comer. In order to avoid that LBE would overcome the separator, the separator walls have a height of 0.608 m.

Moreover, the separator has the function of an expansion tank, allowing the LBE to change its volume during transients.

Because of many pipes and components are into the separator volume, the flow area has been evaluated splitting the separator volume into two different zones along the vertical.

The first zone includes the riser, which penetrates into the separator, and from the steam generator hexagon wrapper. It corresponds to a flow area of 0.2338 m² for a height of 102 mm. The upper edge of the riser is included in this zone. The second zone is affected by the presence of the hexagonal HERO wrapper and it is characterized by a flow area of 0.2715 m² and height of 498 mm.

In the first zone two holes are foreseen for pressure lines and thermocouples installation.

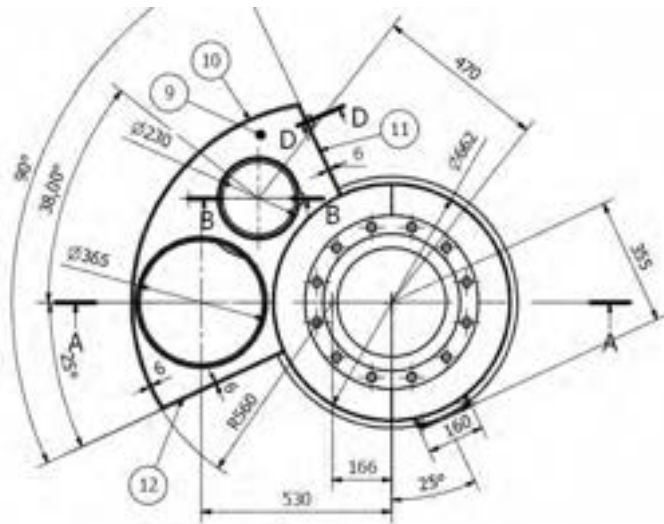


Figure 21 – Separator overview.

3.7 Pool

The CIRCE pool is characterized by the vessel inner volume, specifically volumes that are not occupied by circuit and/or auxiliary components.

For simplicity, the pool has been subdivided in 14 zones; each of them presents specific geometrical parameters, which depend on equipment placed within the S100.

The first three volumes are the upper ones; they are placed above the separator walls. The volume of these three zones are only partially filled with LBE. The rest of the space is occupied by the argon gas, which constitutes the cover gas volume. Of these three volumes, the first and second include the zone from the separator walls up to the connection flange with the S100 upper head. They respectively have lengths of 70 and 230 mm and flow areas of 0.7252 and 0.987 m². The third

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In the Figure 24 the CIRCE-HERO bundle is shown; for further details concerning the geometrical arrangement are see Figure 2.



Figure 24 – HERO – CIRCE unit: bundle arrangement.

The assembly is characterized by a 14” flange with a thickness of 30 mm (see position 1 in the Figure 23), which connects the test section to the CIRCE experimental facility. On the flange 7 holes for the bayonet tubes and 1 for the instrumentation are obtained. The flange has also to support the Helium chamber, the steam chamber, the bayonet tubes and hexagonal wrapper. The Helium chamber is slightly pressurized in order to increase the heat transfer from the primary LBE to the steam flowing inside the bayonet tubes and, at the same time, to make easier the

detection of possible leakage. The helium chamber, which is made of a 6" sch. 40 pipe, is welded at its bottom edge to the flange while the upper edge is welded to a septum that guarantees the separation of helium chamber and steam chamber. On both the flange and the septum, the 7 holes for passing the bayonet tubes are obtained.

The steam chamber, which has to collect the superheated steam (170 bar and 430°C) coming from the steam generator, is made by a 6" sch.120 pipe. At the top of the steam chamber, there is a plate that seals the HERO test section; on this plate the bayonet tube upper edges are fixed. The superheated steam is extracted from the chamber through a 2 ½" sch.80 outlet nozzle.

Both chambers are equipped with 1" sch.40 radial nozzles to connect cables to the internal instrumentation (i.e. thermocouples installed on the bayonet tubes).

The feed water reaches the 7 bayonet tubes through Swagelok connections that pass through the test section upper plate and through a changeable orifice plate. The bayonet tubes consist of four concentric tubes, as shown in Figure 25. In particular Figure 25 shows a detail of the bottom region of a bayonet tube (see also Figure 27).

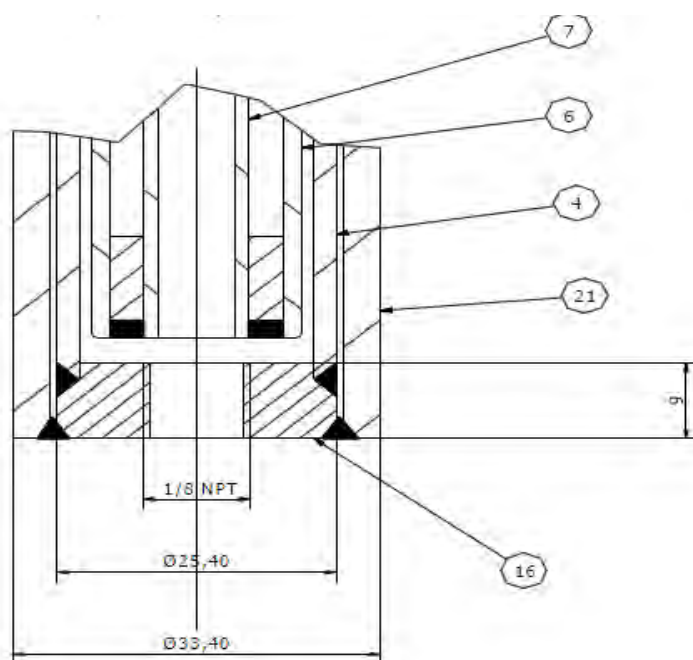


Figure 25 – Section of a bayonet tube bottom end.

21	1	Third tube: OD 33.4 th.3.38 [mm]
16	1	Plate: OD 25.4 th.9 [mm]
7	1	Slave tube: OD 9.53 th.1.22 [mm]
6	1	Inner tube: OD 19.05 th.1.65 [mm]
4	1	Second tube: OD 25.4 th.2.11 [mm]
POS.	Q.TY	DESCRIPTION

Table 3 – SGBT main dimensions.

The slave and the inner tubes pass through the steam chamber while the helium chamber is crossed by the slave, the inner and the second tubes. Hence the bayonet tubes enter the main vessel S100 through the connection flange, at which the third tube is connected through a bellows. Inside the slave tube the feed water (cold) flows downward; during the descendent path, the water is preheated.

Once the bottom edge of the slave tube is reached, the water changes its direction of 180° flowing upward between the outer wall of the inner tube and the inner wall of the second tube. In this zone the water vaporizes reaching the superheated state before entering the steam chamber. The primary coolant, the LBE, flows downward in contact with the outer wall of the third.

Two gaps are present in each bayonet tube:

- between the slave and the inner tubes;
- between the second and the third tubes.

The first gap (i.e. between the slave and inner tubes) is filled with a thermal insulator, the ZIRCOFOAM 250, in order to minimize the heat transfer between the cold feed water and the hot superheated steam; it allows to increase the thermodynamic efficiency of the steam generator. The thermal conductivity of the ZIRCOFOAM 250 as a function of the temperature is shown in Table 4. The second gap (i.e. between the second and third tubes) is filled with SiC powder and slightly pressurized helium. These materials have been selected to guarantee good heat transfer performance (i.e. SiC thermal conductivity) and at the same time to possibility of detecting any leakage (i.e. connection with the helium chamber). The mutual position of the four tubes that constitute the bayonet tube is guaranteed by spacer grids (see Figure 26); they also have to maintain the correct thermocouples position in the operating conditions.

Temperature [K]	Thermal Conductivity [W / m K]
423.15	0.060
523.15	0.071
673.15	0.088
873.15	0.113

Table 4 – Zircofoam 250 thermal conductivity.

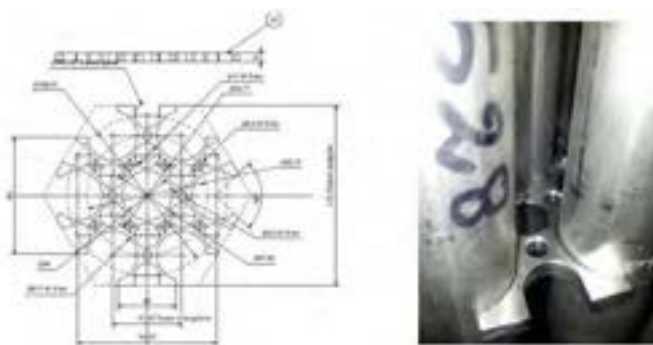


Figure 26 – HERO – CIRCE unit: spacer grid.

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At the bayonet tube bottom edge, on the lower plate (see position 16 in Figure 25), a 1/8" NPT penetration is foreseen to allow the connection of a pressure gauge transducer; if not needed it can be sealed with a swagelok cap. In Figure 27 a view of the bayonet tube bottom end is shown.



Figure 27 – HERO – CIRCE unit: end of bayonet tubes.

The 7 bayonet tubes are located into a hexagonal wrapper, which is thermally insulated from the CIRCE pool through a tube placed, concentric, around the wrapper. The gap between the hexagonal wrapper and the cylindrical shroud is filled with air. The final section of the steam generator is coupled with a mechanical filter; a representation of the mechanical filter is shown in Figure 28. For the test section modelization, the filter has been considered through a K coefficient equal to 7.



Figure 28 – SG filter.

On the connection flange there are three 2" nozzles, each equipped with a connection flange. These nozzles are needed for installing the oxygen probes.

The test section is characterized by the following instrumentation:

- 75 thermocouples;
- 13 pressure gauges;

- 2 absolute pressure transducers placed at the inlet and at the outlet of the test section;
- 8 flow meters, 1 placed upstream of the test section to measure the overall mass flow, the others placed at the inlet of each bayonet tube.

A complete list of the test section instrumentation is reported in Table 5.

3.9 Geometrical data summary

The test section geometrical data, required for the nodalization of the overall experimental facility, are reported in Table 6. All the elevations reported in the table are referred to the LBE free level, assumed to be equal to 0, as reported in the CAD drawings; this is also represented in the Figure 29.

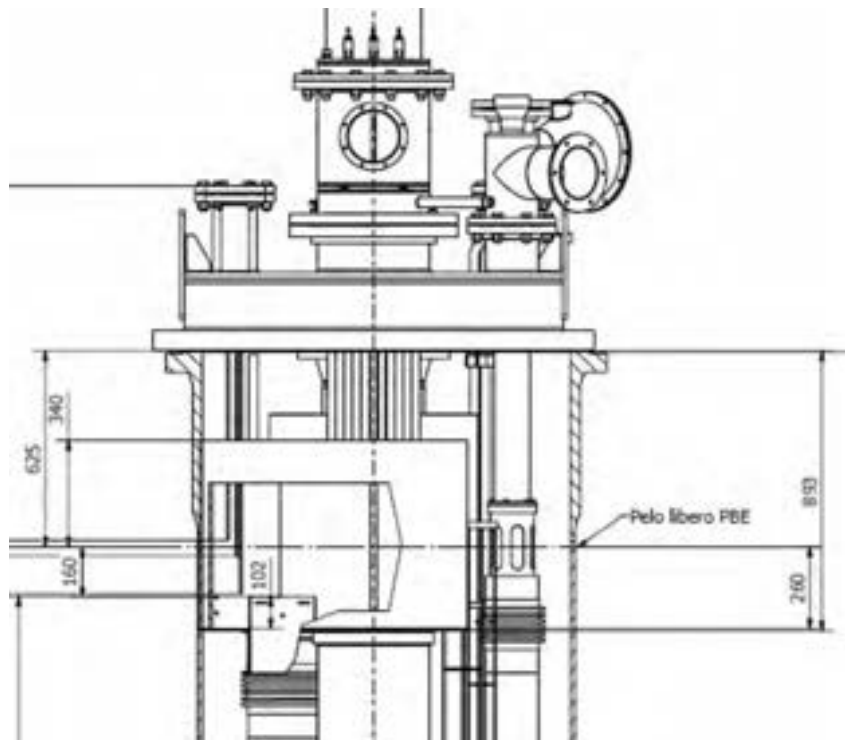


Figure 29 – LBE free surface.

At the end of the present data collection, due to errors and approximations, a vertical difference in the height equal to 1.2 cm has been identified. In order to obtain a closed loop, this difference has been compensated reducing the height of the component Pool 1. This component has been selected because of its large hydraulic diameter; this allows at minimizing errors in the simulation results.

3.10 Nodalization scheme

In the Figure 30 an example of the test section nodalization is shown. This model can be directly obtained from the data available in the present document.

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#	ID	Instrument location			Measurement		Notes
		Zone	Elevation(1)/Position	Medium	Quantity	Dim	
1	TC-C0-I00	Tube 0 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
2	TC-C0-I01	Tube 0 – Inner tube	Outlet	Water	Temperature	°C	D=0.5mm
3	TC-C0-O15	Tube 0 – Second tube	1500mm	Water	Temperature	°C	D=0.5mm
4	TC-C0-O18	Tube 0 – Second tube	1800mm	Water	Temperature	°C	D=0.5mm
5	TC-C0-O21	Tube 0 – Second tube	2100mm	Water	Temperature	°C	D=0.5mm
6	TC-C0-O24	Tube 0 – Second tube	2400mm	Water	Temperature	°C	D=0.5mm
7	TC-C0-O27	Tube 0 – Second tube	2700mm	Water	Temperature	°C	D=0.5mm
8	TC-C0-O30	Tube 0 – Second tube	3000mm	Water	Temperature	°C	D=0.5mm
9	TC-C0-O33	Tube 0 – Second tube	3300mm	Water	Temperature	°C	D=0.5mm
10	TC-C0-O36	Tube 0 – Second tube	3600mm	Water	Temperature	°C	D=0.5mm
11	TC-C0-O39	Tube 0 – Second tube	3900mm	Water	Temperature	°C	D=0.5mm
12	TC-C0-O42	Tube 0 – Second tube	4200mm	Water	Temperature	°C	D=0.5mm
13	TC-C0-O60	Tube 0 – Second tube	6000mm	Water	Temperature	°C	D=0.5mm
14	TC-C0-O70	Tube 0 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
15	TC-W0-W68	Tube 0 – Inner tube	6800mm	Wall – Water	Temperature	°C	D=0.5mm
16	TC-W0-P15	Tube 0 – Second tube	1500mm / 0°	Wall – SiC	Temperature	°C	D=0.5mm- Broken
17	TC-W0-P30	Tube 0 – Second tube	3000mm / 0°	Wall – SiC	Temperature	°C	D=0.5mm Broken
18	TC-W0-P40	Tube 0 – Second tube	4200mm / 0°	Wall – SiC	Temperature	°C	D=0.5mm Broken
19	TC-W0-P60	Tube 0 – Second tube	6000mm / 0°	Wall – SiC	Temperature	°C	D=0.5mm Broken
20	TC-W0-L10	Tube 0 – Third tube	1500mm / 0°	Wall – LBE	Temperature	°C	D=1mm
21	TC-W0-L11	Tube 0 – Third tube	1500mm / 120°	Wall – LBE	Temperature	°C	D=1mm
22	TC-W0-L12	Tube 0 – Third tube	1500mm / 240°	Wall – LBE	Temperature	°C	D=1mm
23	TC-W0-L30	Tube 0 – Third tube	3000mm / 0°	Wall – LBE	Temperature	°C	D=1mm
24	TC-W0-L31	Tube 0 – Third tube	3000mm / 120°	Wall – LBE	Temperature	°C	D=1mm
25	TC-W0-L32	Tube 0 – Third tube	3000mm / 240°	Wall – LBE	Temperature	°C	D=1mm
26	TC-W0-L40	Tube 0 – Third tube	4200mm / 0°	Wall – LBE	Temperature	°C	D=1mm
27	TC-W0-L41	Tube 0 – Third tube	4200mm / 120°	Wall – LBE	Temperature	°C	D=1mm
28	TC-W0-L42	Tube 0 – Third tube	4200mm / 240°	Wall – LBE	Temperature	°C	D=1mm
29	TC-W0-L60	Tube 0 – Third tube	6000mm / 0°	Wall – LBE	Temperature	°C	D=1mm
30	TC-W0-L61	Tube 0 – Third tube	6000mm / 120°	Wall – LBE	Temperature	°C	D=1mm
31	TC-W0-L62	Tube 0 – Third tube	6000mm / 240°	Wall – LBE	Temperature	°C	D=1mm
32	TC-C1-I00	Tube 1 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
33	TC-C1-O70	Tube 1 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
34	TC-C2-I00	Tube 2 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
35	TC-C2-O70	Tube 2 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm

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#	ID	Instrument location			Measurement		Notes
		Zone	Elevation(1)/Position	Medium	Quantity	Dim	
36	TC-C3-I00	Tube 3 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
37	TC-C3-O70	Tube 3 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
38	TC-C4-I00	Tube 4 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
39	TC-C4-O70	Tube 4 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
40	TC-C5-I00	Tube 5 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
41	TC-C5-O70	Tube 5 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
42	TC-C6-I00	Tube 6 – Inner tube	Inlet	Water	Temperature	°C	D=0.5mm
43	TC-C6-O70	Tube 6 – Second tube	7016mm	Water	Temperature	°C	D=0.5mm
44	TC-W1-L11	Tube 1 – Third tube	1500mm / 120°	Wall – LBE	Temperature	°C	D=1mm
45	TC-W2-L12	Tube 2 – Third tube	1500mm / 240°	Wall – LBE	Temperature	°C	D=1mm
46	TC-W1-L31	Tube 1 – Third tube	3000mm / 120°	Wall – LBE	Temperature	°C	D=1mm
47	TC-W2-L32	Tube 2 – Third tube	3000mm / 240°	Wall – LBE	Temperature	°C	D=1mm
48	TC-W1-L41	Tube 1 – Third tube	4200mm / 120°	Wall – LBE	Temperature	°C	D=1mm
49	TC-W2-L42	Tube 2 – Third tube	4200mm / 240°	Wall – LBE	Temperature	°C	D=1mm
50	TC-01-L15	Sub-channel 1 centre	1500mm	LBE	Temperature	°C	D=1mm
51	TC-07-L15	Sub-channel 7 centre	1500mm	LBE	Temperature	°C	D=1mm
52	TC-09-L15	Sub-channel 9 centre	1500mm	LBE	Temperature	°C	D=1mm
53	TC-11-L15	Sub-channel 11 centre	1500mm	LBE	Temperature	°C	D=1mm
54	TC-01-L30	Sub-channel 1 centre	3000mm	LBE	Temperature	°C	D=1mm
55	TC-07-L30	Sub-channel 7 centre	3000mm	LBE	Temperature	°C	D=1mm
56	TC-09-L30	Sub-channel 9 centre	3000mm	LBE	Temperature	°C	D=1mm
57	TC-11-L30	Sub-channel 11 centre	3000mm	LBE	Temperature	°C	D=1mm
58	TC-01-L42	Sub-channel 1 centre	4200mm	LBE	Temperature	°C	D=1mm
59	TC-07-L42	Sub-channel 7 centre	4200mm	LBE	Temperature	°C	D=1mm
60	TC-09-L42	Sub-channel 9 centre	4200mm	LBE	Temperature	°C	D=1mm
61	TC-11-L42	Sub-channel 11 centre	4200mm	LBE	Temperature	°C	D=1mm
62	TC-SL-W01	Steam-chamber outlet	--	Water	Temperature	°C	D=1mm
63	TC-SL-W02	Steam-chamber outlet	--	Water	Temperature	°C	D=1mm
64	TC-SL-W03	Steam-chamber outlet	--	Water	Temperature	°C	D=1mm
65	TC-SL-W04	Steam-chamber outlet	--	Water	Temperature	°C	D=1mm
1	DP-C0-W00	Tube 0	Overall	Water	Press. diff.	kPa	dp
2	DP-C0-W01	Tube 0	Descending	Water	Press. diff.	kPa	dp
3	DP-C0-W02	Tube 0	Ascending	Water	Press. diff.	kPa	dp
4	DP-C1-W00	Tube 1	Overall	Water	Press. diff.	kPa	dp
5	DP-C1-W01	Tube 1	Descending	Water	Press. diff.	kPa	dp

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#	ID	Instrument location			Measurement		Notes
		Zone	Elevation(1)/Position	Medium	Quantity	Dim	
6	DP-C1-W02	Tube 1	Ascending	Water	Press. diff.	kPa	dp
7	DP-C2-W00	Tube 2	Overall	Water	Press. diff.	kPa	dp
8	DP-C2-W01	Tube 2	Descending	Water	Press. diff.	kPa	dp
9	DP-C2-W02	Tube 2	Ascending	Water	Press. diff.	kPa	dp
10	DP-C3-W00	Tube 3	Overall	Water	Press. diff.	kPa	dp
11	DP-C3-W01	Tube 3	Descending	Water	Press. diff.	kPa	dp
12	DP-C3-W02	Tube 3	Ascending	Water	Press. diff.	kPa	dp
13	DP-C4-W00	Tube 4	Overall	Water	Press. diff.	kPa	dp
14	DP-C4-W01	Tube 4	Descending	Water	Press. diff.	kPa	dp
15	DP-C4-W02	Tube 4	Ascending	Water	Press. diff.	kPa	dp
16	DP-C5-W00	Tube 5	Overall	Water	Press. diff.	kPa	dp
17	DP-C5-W01	Tube 5	Descending	Water	Press. diff.	kPa	dp
18	DP-C5-W02	Tube 5	Ascending	Water	Press. diff.	kPa	dp
19	DP-C6-W00	Tube 6	Overall	Water	Press. diff.	kPa	dp
20	DP-C6-W01	Tube 6	Descending	Water	Press. diff.	kPa	dp
21	DP-C6-W02	Tube 6	Ascending	Water	Press. diff.	kPa	dp
22	PC-00-I00	FW collector	--	Water	Pressure	MPa	p
22	PC-00-O00	Steam collector	--	Water	Pressure	MPa	p
1	MF-00-I00	Tube 0 – inlet	Orifice ends	Water	Mass flow	g/s	dp
2	MF-01-I00	Tube 1 – inlet	Orifice ends	Water	Mass flow	g/s	dp
3	MF-02-I00	Tube 2 – inlet	Orifice ends	Water	Mass flow	g/s	dp
4	MF-03-I00	Tube 3 – inlet	Orifice ends	Water	Mass flow	g/s	dp
5	MF-04-I00	Tube 4 – inlet	Orifice ends	Water	Mass flow	g/s	dp
6	MF-05-I00	Tube 5 – inlet	Orifice ends	Water	Mass flow	g/s	dp
7	MF-06-I00	Tube 6 – inlet	Orifice ends	Water	Mass flow	g/s	dp
8	MF-FW-I00	FW collector	Orifice ends	Water	Mass flow	g/s	dp

Table 5 – HERO – CIRCE unit: instrumentation.

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m ²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m ²]
1	Feeding conduit 1	-7,4450	0,3000	0,0082	0,3213	- N/A -	- N/A -
		-7,1450					
2	Venturi - Nozzle	-7,1450	0,4000	0,0082	0,3213	- N/A -	- N/A -
		-6,7450					
3	Feeding conduit 2	-6,7450	0,2150	0,0082	0,3213	- N/A -	- N/A -
		-6,5300					
	LOWER GRID ⁽¹⁾						
4	Hexagonal wrapper (lower align.)	-6,5300	0,3000	0,0060	1,2857	- N/A -	- N/A -
		-6,2300					
	MIDDLE GRID ⁽¹⁾						
5	Hexagonal wrapper (lowhot)	-6,2300	0,5500	0,0060	1,2857	0,9532	0,4766
		-5,6800					
	MIDDLE GRID ⁽¹⁾						
6	Hexagonal wrapper (uphot)	-5,6800	0,5500	0,0060	1,2857	0,9532	0,4766
		-5,1300					
	MIDDLE GRID ⁽¹⁾						
7	Hexagonal wrapper (up align.)	-5,1300	0,4850	0,0060	1,2857	- N/A -	- N/A -
		-4,6450					
	N6 SLOTTED HOLES 36 ⁽¹⁾						
8	Release pipe 1	-4,7650	0,1150	0,0230	0,9980	- N/A -	- N/A -
		-4,6500					
9	Release pipe 2	-4,6500	0,6450	0,0304	1,5909	- N/A -	- N/A -
		-4,0050					
	N4 SLOTTED HOLES 100 ⁽¹⁾						
10	Fitting volume 1	-4,2950	0,2900	0,3214	3,1848	- N/A -	- N/A -

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m ²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m ²]
		-4,0050					
11	Fitting volume 2	-4,0050	0,1425	0,0549	3,4705	- N/A -	- N/A -
		-3,8625					
12	Fitting volume 3	-3,8625	0,1425	0,1854	0,1854	- N/A -	- N/A -
		-3,7200					
13	Riser	-4,0050	3,8450	0,0324	0,6377	- N/A -	- N/A -
		-0,1600					
14	Separator 1	-0,2620	0,1020	0,2338	3,3995	- N/A -	- N/A -
		-0,1600					
15	Separator 2	-0,1600	0,4980	0,2715	2,7115	- N/A -	- N/A -
		0,3380					
16	Upper plenum 1	0,3380	0,0700	0,7252	6,7404	- N/A -	- N/A -
		0,4080					
17	Upper plenum 2	0,4080	0,2300	0,9870	5,6786	- N/A -	- N/A -
		0,6380					
18	Upper plenum 3	0,6380	0,2100	0,9593	5,6312	- N/A -	- N/A -
		0,8480					
19	Pool 1	0,3380	0,5880	0,4471	7,5192	- N/A -	- N/A -
		-0,2500					
20	Pool 2	-0,2500	0,1687	0,6804	7,4285	- N/A -	- N/A -
		-0,4187					
21	Pool 2 (I)	-0,4187	3,2814	0,6804	7,4999	- N/A -	- N/A -
		-3,7000					
22	Pool 3	-3,7000	0,3400	0,2290	7,3051	- N/A -	- N/A -
		-4,0400					
23	Pool 3 (I)	-4,0400	0,2500	0,7418	7,1849	- N/A -	- N/A -

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m ²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m ²]
		-4,2900					
24	Pool 4	-4,2900	0,1325	1,0221	5,5901	- N/A -	- N/A -
		-4,4225					
25	Pool 4 (I)	-4,4225	0,3975	1,0037	5,1095	- N/A -	- N/A -
		-4,8200					
26	Pool 5	-4,8200	1,1571	1,0429	4,9398	- N/A -	- N/A -
		-5,9771					
27	Pool 5 (I)	-5,9771	0,5269	1,0429	4,4111	- N/A -	- N/A -
		-6,5040					
28	Pool 6	-6,5040	0,9410	1,0926	4,0819	- N/A -	- N/A -
		-7,4450					
29	Lower plenum	-7,4450	0,3500	- N/A -	- N/A -	- N/A -	- N/A -
		-7,7950					
	N6 SLOTTED HOLES 20 ⁽¹⁾						
30	HERO 1	0,1259	0,1500	0,0076	1,1710	0,7345	0,1102
		-0,0241					
31	HERO 2	-0,0241	0,1780	0,0076	1,1710	0,7345	0,1307
		-0,2021					
32	HERO 3	-0,2021	0,1500	0,0076	1,1710	0,7345	0,1102
		-0,3521					
33	HERO 4	-0,3521	0,1500	0,0076	1,1710	0,7345	0,1102
		-0,5021					
34	HERO 5	-0,5021	0,1500	0,0076	1,1710	0,7345	0,1102
		-0,6521					
	GRID A ⁽¹⁾						
35	HERO 6	-0,6521	0,1500	0,0076	1,1710	0,7345	0,1102

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m²]
		-0,8021					
36	HERO 7	-0,8021	0,1500	0,0076	1,1710	0,7345	0,1102
		-0,9521					
37	HERO 8	-0,9521	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,1021					
38	HERO 9	-1,1021	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,2521					
39	HERO 10	-1,2521	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,4021					
40	HERO 11	-1,4021	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,5521					
41	HERO 12	-1,5521	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,7021					
42	HERO 13	-1,7021	0,1500	0,0076	1,1710	0,7345	0,1102
		-1,8521					
43	HERO 14	-1,8521	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,0021					
	GRID B ⁽¹⁾						
44	HERO 15	-2,0021	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,1521					
45	HERO 16	-2,1521	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,3021					
46	HERO 17	-2,3021	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,4521					
47	HERO 18	-2,4521	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,6021					

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m ²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m ²]
48	HERO 19	-2,6021	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,7521					
49	HERO 20	-2,7521	0,1500	0,0076	1,1710	0,7345	0,1102
		-2,9021					
50	HERO 21	-2,9021	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,0521					
51	HERO 22	-3,0521	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,2021					
	GRID C ⁽¹⁾						
52	HERO 23	-3,2021	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,3521					
53	HERO 24	-3,3521	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,5021					
54	HERO 25	-3,5021	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,6521					
55	HERO 26	-3,6521	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,8021					
56	HERO 27	-3,8021	0,1500	0,0076	1,1710	0,7345	0,1102
		-3,9521					
57	HERO 28	-3,9521	0,1500	0,0076	1,1710	0,7345	0,1102
		-4,1021					
58	HERO 29	-4,1021	0,1500	0,0076	1,1710	0,7345	0,1102
		-4,2521					
59	HERO 30	-4,2521	0,1500	0,0076	1,1710	0,7345	0,1102
		-4,4021					
60	HERO 31	-4,4021	0,1500	0,0076	1,1710	0,7345	0,1102

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N	Region	Elevation (from / to) [m]	Axial Length [m]	Flow Area [m ²]	Wetted Perimeter [m]	Heated Perimeter [m]	Heat Transfer Surface [m ²]
		-4,5521					
61	HERO 32	-4,5521	0,1500	0,0076	1,1710	0,7345	0,1102
		-4,7021					
	GRID D ⁽¹⁾						
62	HERO 33	-4,7021	0,1500	0,0076	1,1710	0,7345	0,1102
		-4,8521					
63	HERO 34	-4,8521	0,1500	0,0076	1,1710	0,7345	0,1102
		-5,0021					
64	HERO 35	-5,0021	0,1500	0,0076	1,1710	0,7345	0,1102
		-5,1521					
65	HERO 36	-5,1521	0,1500	0,0076	1,1710	0,7345	0,1102
		-5,3021					
66	HERO 37	-5,3021	0,1500	0,0076	1,1710	0,7345	0,1102
		-5,4521					
67	HERO 38	-5,4521	0,1313	0,0076	1,1710	0,7345	0,0964
		-5,5834					
68	HERO 39	-5,5834	0,1313	0,0076	1,1710	0,7345	0,0964
		-5,7146					
69	HERO 40	-5,7146	0,1313	0,0076	1,1710	0,7345	0,0964
		-5,8459					
	GRID E ⁽¹⁾						
70	HERO 41	-5,8459	0,1313	0,0076	1,1710	0,7345	0,0964
		-5,9771					

(1) For spacer grids pressure drop details see Table 7

Table 6 – HERO – CIRCE facility: geometrical parameters.

The head loss coefficients corresponding to the CIRCE-HERO facility grids are reported in Table 7. These coefficients are referred to both the forward and the reverse flows. The position of each grid can be obtained from Table 6 where they are highlighted.

Grid	Forward K coefficient	Reverse flow K coefficient
LOWER GRID	2,0000	2,0000
MIDDLE GRID	0,1481	0,1481
MIDDLE GRID	0,1481	0,1481
MIDDLE GRID	0,1481	0,1481
N6 SLOTTED HOLES 36	1,6462	1,2731
N4 SLOTTED HOLES 100	2,2844	1,5922
N6 SLOTTED HOLES 20	1,7315	2,5630
GRID A	13,3000	13,3000
GRID B	13,3000	13,3000
GRID C	13,3000	13,3000
GRID D	13,3000	13,3000
GRID E	13,3000	13,3000

Table 7 – Energy loss coefficients.

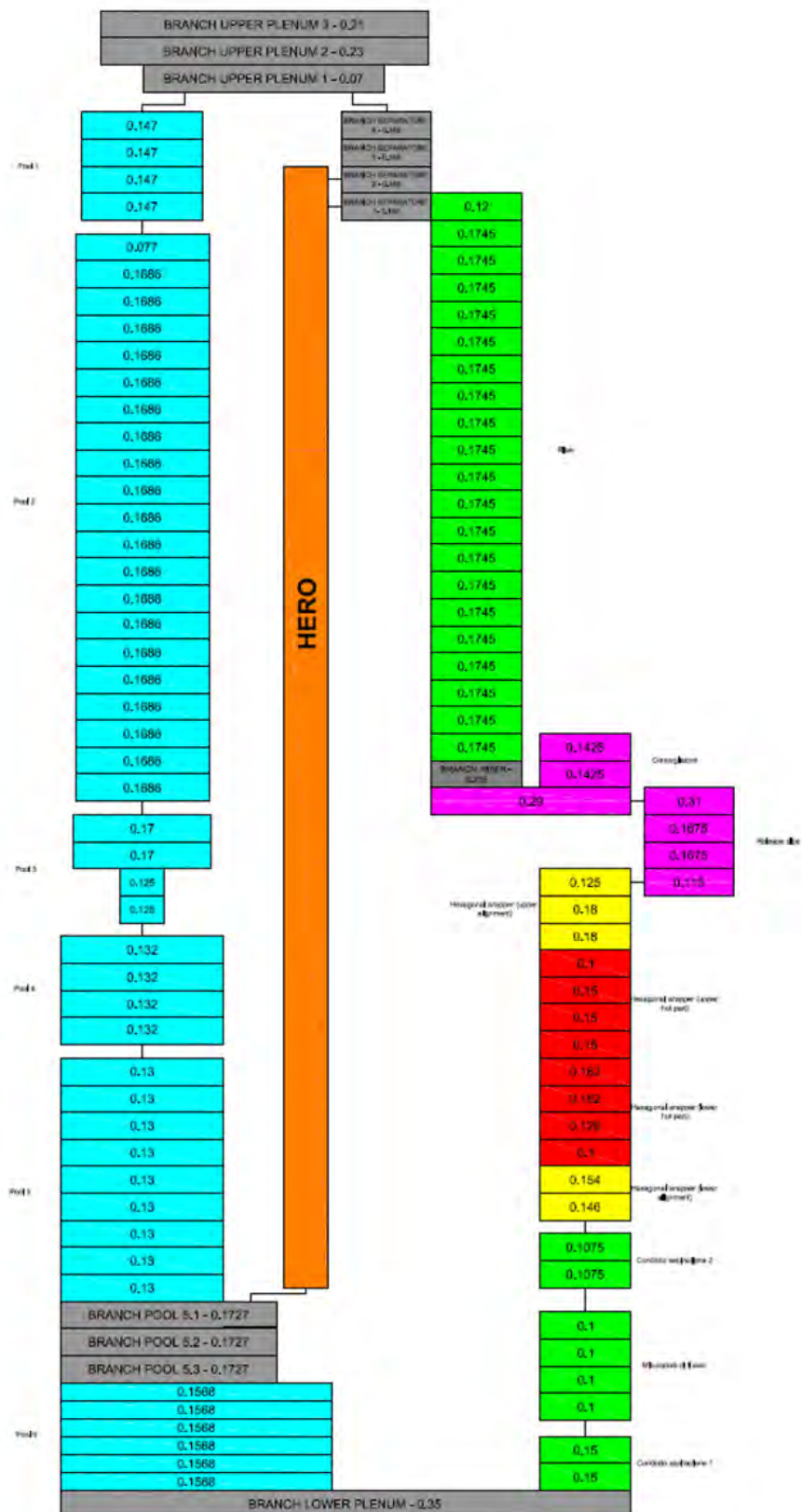


Figure 30 – Nodalization scheme of primary circuit.