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Article

R&D Needs for the Design of the EU-DEMO HCPB ICD Balance of Plant in FP9

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Abstract: During the Pre-Conceptual Design Phase of the EU-DEMO, two BOP solutions for WCLL and HCPB were elaborated, as close as possible to industrial standards. Nevertheless, each solution has open issues to be investigated, analytically and experimentally, in the Conceptual Design Phase (CDP). For the HCPB, the functionality and operability of the Helium-Molten Salt Heat Exchanger, and the coupling to a helium loop with a prototypic helium blower, is of primary interest. In addition, the operation of the pulse, dwell and transitions will be investigated within the new build infrastructure, HELOKA-US (Upgrade Storage), to be erected at KIT. The design requires a certain flexibility, since the final parameters of the Primary Heat Transfer System of DEMO may vary, due to plasma optimizations during CDP. HELOKA-US benefits from the high-pressure helium loop HELOKA-HP, erected to test HCPB-Breeding Blanket and First Wall modules, as well as from the competencies of preparing, handling and testing of various molten salts used for heat transfer optimization and natural convection.

Keywords: EU-DEMO; HCPB; BOP; HELOKA-US; helium compressor; He-MS Heat Exchanger; Energy Storage System

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1. Introduction

The current European Framework Program (FP) to support the DEMO project (FP9) has the goal to perform the conceptual design of the DEMO baseline selected in the Gate Review G1 among the options studied during the previous Framework Program FP8. For the DEMO Helium Cooled Pebble Bed (HCPB) Breeding Blanket (BB) concept, the Balance of the Plant system, featuring an Intermediate Heat Transfer System (IHTS) to decouple the plasma intermittent heat source from the Power Conversion System (PCS), was the selected reference option, the so-called HCPB Indirect Coupling Design (ICD) Balance of Plant (BOP).

Among all BOP concepts presented in the Gate Review G1 (2020), including water- and helium-cooled BB, as well as PHTS-to-PCS direct and indirect (i.e., using an IHTS) couplings, the DEMO HCPB ICD BOP was rated as the most promising concept able to achieve the DEMO BOP future goals. This conclusion was based not only on the way this concept is able to mitigate the effects of the frequent plasma pulse operation (2 h pulse followed by 10 min dwell), but also on the highly ranked technology readiness level of its systems and components.

After the Gate Review G1, the outcomes and feedback from the review panel were considered and a strategic plan established by the Work Package BOP, so that the identified issues could be solved before the next Gate Review in 2024. During the period until 2024, a deeper analysis of the HCPB ICD BOP will be performed, seeking to further optimize the conceptual design.

One key activity to support this strategic plan is the experimental demonstration of the HCPB ICD BOP. The HELOKA-US project, representing a mock-up of the DEMO

PHTS+IHTS (energy scaling 1:1000), will provide insights into the real operation of a Helium-Molten Salt Heat Exchanger (He-MS HX), as well as of a scaled helium compressor with similar characteristics to that operating in DEMO HCPB PHTS.

The tasks foreseen for the FP9 period (2021–2027), to consolidate the path towards the conceptual design of this DEMO HCPB ICD Plant, are presented in the following sections: (i) to solve issues encountered in FP8 and continue with the conceptual design development (Section 2); (ii) to assess the BOP functional feasibility by evaluating the maturation of the industrial components (Section 3), and (iii) to experimentally validate the ICD in a dedicated facility (Section 4).

2. Conceptual Design Development

The HCPB ICD BOP architecture (see Figure 1) thermally decouples the PCS from the BB PHTS via an IHTS equipped with an Energy Storage System (ESS) that buffers energy during pulse operation and releases it during dwell operation [1]. This concept mitigates the intermittent generated power profile, so that PCS operation is enabled with a constant steam load and electrical power output to the grid in both pulse and dwell phases. The IHTS, which is composed of a charging loop, interfacing the PHTS through the Main Heat Exchanger, and a discharging loop, interfacing the PCS through the Steam Generator, is equipped with an ESS, operating with HITEC Molten Salt, using qualified technology coming from Concentrated Solar Power (CSP) plants. The ESS, in turn, includes a hot tank and a cold tank that represent the start and end points of the IHTS charging and discharging circuits. The BOP work was supported by the industry and focused on investigating different PHTS and PCS architectures (i.e., feedwater train optimization for pulse and dwell conditions) leading to quite a robust design.

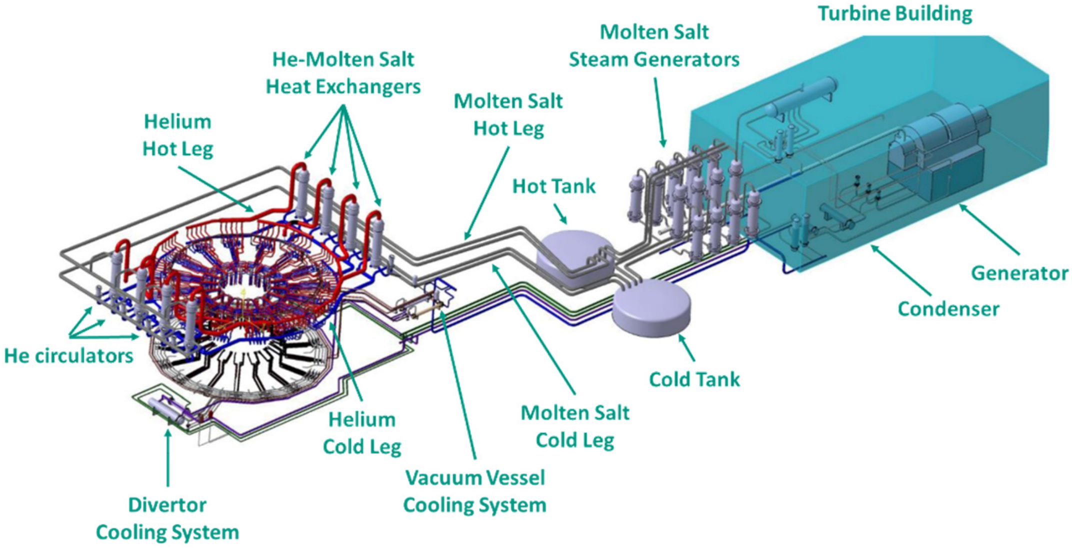

Figure 1. Layout of the HCPB ICD BOP configuration.

During the previous EUROfusion Framework Program FP8, all variants studied were assessed by using a ranking table in order to do the following: (i) to summarize the main characteristics and features, (ii) to facilitate a variant comparison and down-selection and (iii) to identify critical issues. Table 1 presents the results for the DEMO HCPB ICD BOP [2,3]. The colors used are related to the market readiness level associated with the corresponding components.

Table 1. Summary of the DEMO HCPB ICD BOP Configuration.

PHTS	BB PHTS key components	He-MS HX
		He compressor
	PHTS Technology Derivation	Gas Nuclear Reactor and CSP
	BB PHTS HX Pressures	High-~Atmospheric
IHTS	IHTS/ESS Fluid	HITEC
	IHTS/ESS Storage Capacity	2 × 3000 m^3
	Other Thermal Storage	- (not needed)
	Auxiliary Heating System	- (not needed)
	Gas Fired Boiler Supply	- (not needed)
	Space for IHTS (+Storage)	Large (IHTS + Large ESS)
PCS	Turbine for operation at dwell	Yes
	Tolerant to frequent transients	Yes
Variant	Power output/Suppl. power needed	Almost constant/No
Safety	Inherent Safety Barriers (T, ACP)	2
Summary	Critical components	He compressor
		He-MS HX
		MS Steam Generator
	Feasibility Assessment	TBI

Background colors stand for the following: Red: Critical, due to component size/integration, functional feasibility or market readiness; White: Market readiness, producible but not on shelf; Yellow: Market readiness, near or at present feasible and producible; Green: Market readiness, component from shelf/technology available.

Currently further optimization of the BOP architecture is on-going to allow operations according to the updated Energy Map provided by DEMO DCT in 2021, as well as to solve integration aspects regarding the new Vacuum Vessel (VV) PHTS.

The critical issues in DEMO HCPB ICD BOP, needing further R&D, are the following systems and components:

- Development of the Plant Regulation System based on plasma states
- Maturity assessment and technology verification of the helium compressor
- Experimental validation of the Helium-Molten Salt Heat Exchanger

The description of the current R&D activities related to these three aspects is presented in the following section.

3. Main R&D Topics Considered for FP9

A close contact with the industry is pursued in order to select the most suitable technology for the various HCPB ICD BOP components, such as the helium compressor, and the He-MS HX, as well as the MS Steam Generator (SG), coupling IHTS to PCS. Additionally, KIT is performing design and engineering activities to develop and validate the DEMO BOP Regulation System for both normal power operation, as well as preparatory plant states.

3.1. BOP Control System

The baseline of the Plant Control Concept for the PHTS/IHTS interaction is under development thanks to cooperation between KIT and Kraftanlagen Heidelberg (KAH). The normal operation (i.e., pulse and dwell sequences) presents a certain challenge to the design of the I&C system; therefore, PHTS and IHTS must be controlled in a coordinated regime where possible fluctuations in flat top operation should be considered. The proposed control system ensures reliable and safe operation of the two systems in interaction where a "plasma following mode" is used, meaning that an almost constant electrical output is achieved by a suitable regulation in cascade of PHTS and IHTS (charging loop) on the basis of the instantaneous value of the plasma power, while minor regulation has to be set for the Power Conversion System, constantly loaded by the flow of energy accumulated in ESS and provided to it through the IHTS discharging circuit. Changes in plasma power, or of plasma operation, have to be followed primarily by PHTS and then by IHTS (charging loop). The I&C requirement profile, as well as the approval process for such a reactor cooling system, is, therefore, highly sophisticated, due to both possible short reaction time and large power level changes.

The development of the BOP Logic Control System is based on DEMO plasma states and their operational requirements (i.e., supply of power, cooling, etc.), so that consistent BOP operational modes are first defined, then elaborated and, finally, tested in an experimental facility. The initial plant states considered for establishing BOP operational modes are depicted in Figure 2. Although very schematic, this representation shows four plant states (in rectangles), namely, shut-down, cold stand-by, hot stand-by and power operation, with their corresponding transitions (oval shapes). They are all grouped into the following three blocks: (i) initiation and termination, (ii) testing and conditioning between power operation campaigns and (iii) power operation. This scheme will be further extended once the requirements of the DEMO Plant for BOP are provided by the DEMO Central Team, so that BOP auxiliary functions and systems are clearly defined. For instance, the restrictions or limitations of the system and components (such as tolerable temperature, pressure variations, material properties, limitations by licensee, etc.) have to be known, as they may limit operational transitions.

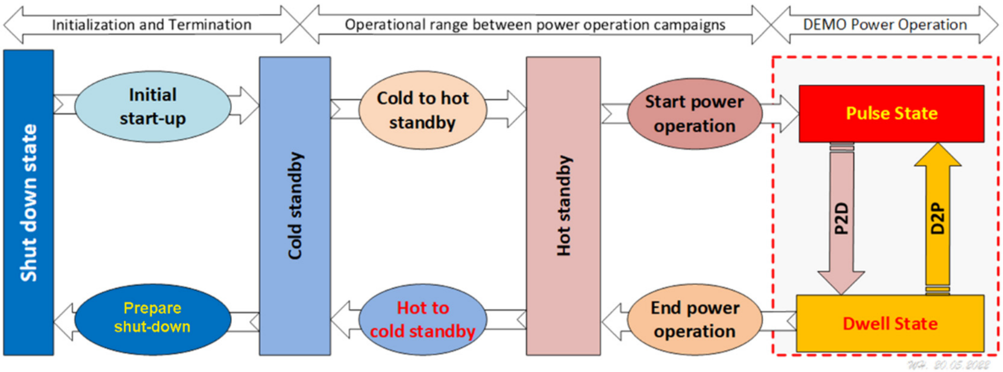

Figure 2. DEMO BOP operation modes, including states and transitions.

For other DEMO systems interfacing BOP (e.g., Plant Electrical System, Auxiliary Cooling System, etc.), a more detailed version is of especial advantage, to allow for an easier alignment. For instance, DEMO internal power demand can be easily supplied using the thermal energy stored in the ESS.

The operational mode diagram allows safe transitions to be defined, in case of accidental mitigation procedures, so that the plant is brought into a safe state in an effective and quick way. Currently, the separation between states and transitions is only preliminary, as well as the indicated names. They will be adapted and modified as soon as the DEMO overall plant state concept is approved. For instance, it is necessary to define the initiation of stable operation (pulse and dwell) as a transition or a state. If the state starts with fusion initiation in the plasma, then the ramp-up is part of the state. Such details have to be defined during on-going CDP. Some early ideas are also under development for the emergency transitions to be applied in most relevant scenarios investigated in the Work Package Safety and Environment (WPSAE).

Based on the preliminary list of plant states presented in the Design Description Document (DDD), Table 2 gives the alignment between DEMO and BOP states. The plasma operation states fit perfectly with BOP states because, so far, the operation states were the main goals of BOP design. However, testing and conditioning states still have to be arranged, following their requirements (e.g., temperature needs in the First Wall and Breeding Blanket for backing). In all cases, it should be taken into account that the achievement of temperature levels in in-vessel and BOP components requires much more time, compared to, for example, plasma preparation. The maintenance states are allocated depending on the requirements in shut-down, cold stand-by or hot stand-by. The rationale behind this is that, if, for instance, the VV has to be opened, a backing phase at hot stand-by is required.

Table 2. Alignment between DEMO and BOP states.

DEMO Plant State	BOP State	Status of Alignment
Plasma operation state	Normal power operation	✓
Stand-by	Cold/hot Stand-by	✓
Flat top	Pulse state	✓
Dwell	Dwell state	✓
Testing & conditioning state	Cold stand-by	To be defined
Tokamak commissioning	Cold or hot stand-by	To be defined
Plant commissioning w/o plasma	Cold or hot stand-by	To be defined
Plant commissioning w. plasma	Hot stand-by	To be defined
Maintenance state	Shut-down/cold stand-by	✓
In-vessel maintenance	Cold stand-by	✓
Ex-vessel maintenance	Cold & hot stand-by	✓
Failed state	(in work)	To be defined

DEMO plant operation modes have to be aligned and acceptable to all plant subsystems. For this to be the case, the plant states and transitions (as listed in the DEMO Plant DDD) are taken as the basis and adapted to BOP needs. Generally, the thermal inertia of the FW, BB and the PCS limits the transition times so that thermally governed states take the leading role in the time frame. Other states can be arranged at different temperature stages for simplification of the operation. For example, the requirements of vacuum generation and/or baking are taken into account in the hot stand-by state.

Regarding the BOP Control System, Table 3 shows the hierarchy and interdependence of PHTS and IHTS systems, including the physical control element used for each task. For the improvement of the readiness level of the Control System it is vital to integrate HELOKA-US tests (see Section 4) into the DEMO Conceptual Design Phase. Further, the control of normal operation, as well as the simulation of the transitions, must be extensively tested under DEMO conditions. Only by integrating the results of HELOKA-US tests into the conceptual design can the next System Readiness Level (SRL), or Integration Readiness Level (IRL), be achieved.

3.2. Helium Compressor

To start the development of a helium circulator for the DEMO BB PHTS to be compliant with the architecture and machine operational data foreseen by the BB PHTS, a market survey of helium compressor manufacturers was performed during FP8. It identified six potential suppliers, each of which submitted their best pumping solution fulfilling the two main requirements, namely the working pressure (80 bar, abs) and volume flow

(126,000 m^3/h). Companies from the Czech Republic, Germany, Sweden and the USA provided information about their blower technologies, including integrally geared compressors, radial compressors, geared turbocompressors, piston compressors, and GT-series centrifugal compressors, as well as multi-stage centrifugal compressors. In all cases, the blower group performance covered the DEMO requirements for mass flow and outlet pressure. This first survey helped in assessing current market availability, as well as identifying the gaps between what is commercially available and DEMO needs and, thus, in determining the direction for the current R&D program. The responses to the first survey were positively received, since it demonstrated that industrial companies could provide preliminary compressor technologies able to fulfil DEMO HCPB ICD BOP needs.

Table 3. Control Hierarchy in PHTS, IHTS and PCS.

Control Hierarchy			Physical Control Element
PHTS Coord. Control	He Loop Control		He Compressor
	IHTS Cold Side Control		MS Pump Set 2
	IHTS Thermal Load Control		MS Pump Set 1
			SG Bypass Valve
			Hot Tank Bypass Valve
	PCS Coord. Control	Turbine Control	Turbine Control Valve
			Non-Return Valves
			Seal Steam/Leak-Off Steam Valve
		Feedwater Control	PCS Feedwater Pump
			DIV1 HX Bypass Valve
			Deaerator Hot Cond. Control Valve
			PCS Pump 1
			DIV2 HX Bypass Valve
			Feedwater 3-Way Valve
			PCS Pump 4

Now other compressor requirements, such as helium as the working fluid, its density and working temperature, or the nuclear codes and standards, as well as the single (large) DEMO blower requirement, according to the PHTS architecture, were not checked in the first survey, and have to be included in the technical requirements for the design criteria.

Since currently no commercial solution is available, large R&D activities are still needed to bring such components to the required level of readiness. If fusion power plants start being considered, then, in future market scenarios with solid fundamentals (e.g., ITER experimental demonstration), more companies will be interested in manufacturing such large compressors and the time needed to close that existing gap will become quicker. One example of this gap bridging is the involvement of Howden, the historic supplier of helium compressors to AGR reactors, in ITER Project in 2020.

After the update of the Energy Map in 2021 the PHTS characteristics for the DEMO HCPB ICD configuration are presented in Table 4. The BB PHTS includes two helium compressors in parallel in each of the eight PHTS loops, meaning that each helium compressor develops a power of 5.5 MW. It is planned to check the advantages of serial or parallel arrangement of the helium circulators, with respect to operational and safety requirements.

Table 4. Characteristics of the BB PHTS of the DEMO HCPB ICD configuration.

	DEMO HCPB ICD
Total BB Thermal Power (MWth)	2117
# of BB-PHTS loops	8
Thermal Power per PHTS loop (MWth)	265
# of helium compressors per PHTS loop	2
Compressor power (MW)	5.5
Total helium volume (m^3)	1735
Total pipework length (m)	6300

One of the Howden conceptual designs presented for the Next Generation Nuclear Plant (NGNP) project (see Table 5), is similar to the DEMO HCPB helium compressor, where two concepts were under consideration from 3–7 MW and up to 16 MW, one of 5.8 MW of centrifugal-type and another one of 13 MW axial-type.

Table 5. Characteristics of the compressor for the NGNP project and DEMO HCPB ICD.

	NGNP Two MCs	**NGNP Single MC**	**HCPB PHTS Two MCs**
He mass flowrate (kg/s)	112	224	232
Compressor inlet pressure (MPa)	6.996	6.996	7.81
Compressor inlet temperature (°C)	480	480	290
Compressor pressure rise (kPa)	176	176	266
Power of a single compressor (MW)	5.8/2	5.8	5.5

Currently, ATEKO is supporting KIT in evaluating the various technological options that best fit the DEMO HCPB helium compressor requirements. The preliminary conclusion presents a horizontal turbocompressor arrangement, featuring an Induction Machine and Active Magnetic Bearings, as the recommended option.

The readiness assessment of the helium compressor for DEMO HCPB ICD Variant should, however, consider not only the current status of such a precise component, but also aspects such as past experience with similar characteristics of the working fluid, power levels, pressure and temperature conditions, as well as nuclear code and standards. With respect to the past experience, for instance, in fission gas-cooled reactors, such as Fort Saint Vrain, THTR 300 and Peach Bottom, helium compressors are at the top (Ranking: 9, using the Technology Readiness Assessment Guide GAO-20-48G) since the gas blowers successfully perform the cooling functions as expected. As for more actual nuclear reactors, such as the already mentioned NGNP project, the large helium blower was assessed as 4, since the conceptual design of the technology is available, but it still needs to be tested in similar environmental conditions as DEMO. Regarding helium as cooling fluid, it is also at the top ranking (9) because helium blowers are commercially available for many industrial applications. Finally, focusing on the operation (pulse and dwell operation, including the frequent transitions) further experimental tests are needed to increase the ranking from current 4 (as in Howden concept), postulating that the DEMO blower will be developed using the same technology.

The path for the DEMO helium compressor to reach TRL 6/7 (as in NGNP NPR compressors) should first identify potential compressor suppliers, select the best technology fulfilling DEMO helium requirements and, finally, conduct experimental performance tests in a scaled mock-up under relevant DEMO conditions (P2D and D2P). The HELOKA-US facility, under construction at KIT, will provide confirmation of the maturity level expected in the experimental campaign programmed into Phase 2 of the project (see Section 4).

3.3. He-MS HX

The current reference design of the Helium-Molten Salt Heat Exchanger is a Once Through Shell and Tube HX (OTHX). During the Pre-Conceptual Design Phase, the main design parameters and the preliminary thermal–hydraulic performance were investigated (see Table 6).

Table 6. Characteristics of the IHX for DEMO HCPB ICD configuration.

	Tube Side	**Shell Side**
Coolant	helium	HITEC®
Thermal Power (MW)	265.6 (BB + 2 compressors per loop)	
Inlet temperature (°C)	520	270
Outlet temperature (°C)	290	465
Inlet pressure (bar)	78	6
Mass flowrate (kg)	222	873

Due to the complexity of the Tokamak reactor, PHTS components should be as compact and simple as possible to prevent integration issues, and safety issues (because of potential permeation of contaminants through its surface), while requiring as little maintenance as possible. The current He-MS HX design should, thus, be re-evaluated in order to reduce the heat transfer area and improve the operational performance level, while decreasing life maintenance attention and increasing lifetime. Alternatives to the He-MS OTHX could be the following: (i) a more compact helical design (Coil-Wound Heat Exchanger, CWHX) with several helical coils integrated module-wise, improving maintenance (e.g., single modules can be replaced), (ii) a Plate and Shell HX (PSHX) design combining Tube and Shell Heat Exchanger (TSHX) advantages (high temperatures, pressures etc.) and regular plate HX characteristics (compact design avoiding gasket sealing due to welded plates), or (iii) Printed Circuit HX (PCHX) designs using innovative manufacturing processes (e.g., diffusion bonding) reducing the volume by ~4–6 times, compared to Tube and Shell Heat Exchanger (TSHX) type, and providing very high overall thermal efficiency (>95%). Should a change be pursued from the qualified S&T technology, a suitable component qualification program for nuclear application must be envisaged for such technologies never before deployed.

Beyond the frequent power level changes in normal operation, other challenges the He-MS HX has to tackle are the following: the high coolant temperature and related implications on materials strength, and factors related to lifetime and fabrication, as well as the tritium migration allowance and coolant purification capability (i.e., removal of tritium).

The readiness of the main IHX (S&T technology), with respect to existing experience, is at the top (Ranking = 9), since they are currently under commercial operation in Concentrating Solar Power Plants. As for manufacturing aspects, the Shell and Tube HX design is also at the top (Ranking = 9), as this is a well-proved HX type. However, due to the large size and the tube support thickness needed for this precise He-MS HX case, the ranking is assessed as 4, since its manufacturability should be confirmed. Regarding the primary and secondary heat transfer fluids (helium, Molten Salt), these are well used in industrial application, and, thus, the ranking is at the top (9). Overall, the present main IHX ranking could be placed at 4. Similarly, as in the case of the helium compressor, DEMO operation implies severe power transients not yet experienced in any commercial power plant or industrial application, and, therefore, the thermal–hydraulic and mechanical performance have to be validated experimentally in order to upgrade the current ranking, assessed as 4.

After considering all pros and cons of the previously mentioned HX design, as well as aspects of the technology readiness assessment, it is necessary to validate, experimentally, the selected design in an experimental facility where DEMO operating conditions are applied. This will be performed in the HELOKA-US experimental facility.

4. Experimental R&D Activities in HELOKA-US Facility

The HELOKA-Upgrade Storage (US) facility will investigate the DEMO HCPB ICD BOP configuration, and, in particular, the coupling between PHTS and IHTS. The main focus of the facility and of the experimental campaigns will be to replicate the expected modes of operation of such a DEMO concept, namely the power transitions from pulse to dwell (P2D) and from dwell to pulse (D2P).

As mentioned in the previous sections, two critical aspects are of importance: (1) test of DEMO specific components, such as the He–MS HX, as well as the DEMO specific helium blower, and (2) test of regulation strategies developed for DEMO.

The HELOKA-US facility will consist of three coupled heat transfer loops:

- A high-pressure and high-temperature helium loop, representing one of the eight DEMO HCPB BB PHTS
- A low-pressure Molten Salt loop, representing a scaled DEMO IHTS
- A water loop acting as the heat sink of the previous MS loop (not representing PCS conditions, but operated at 220 °C and 46 bar, since an existing cooling system is used)

The various phases of the HELOKA-US Project (see Figure 3) will be the following:

Phase 1: testing prototypical components such as He-MS HX, as well as the operation of the MS loop.

Phase 1a: setting up a complete functioning MS loop, hosting an electrical simulator of the real He-MS HX with a representative shell side, which supplies the power expected to be transferred from the Helium PHTS to the Molten Salt side of the heat exchanger, and representing the heat source of the MS loop during this initial phase (260 kW). This phase consists of setting into operation the complete MS loop in order to get HX MS side heat transfer experimental data to validate solution and computing codes.

Phase 1b: upgrading of the MS loop, by substituting the electrical HX simulator with a scaled mock-up He-MS HX to be fed with the high temperature, high pressure helium supply from the HELOKA-HP facility for component qualification.

Phase 2: testing of the coupling of the MS loop with a new helium loop, featuring a helium DEMO-representative blower under DEMO power operation (pulse and dwell sequences).

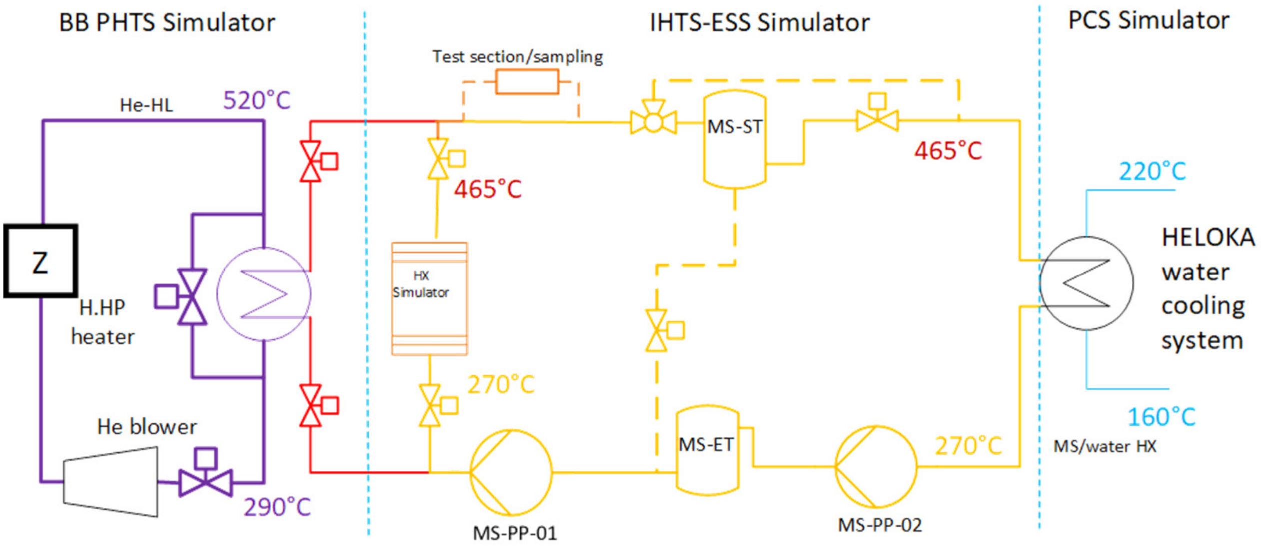

Figure 3. Schematic diagram of HELOKA-US.

Another important aspect is that HELOKA-US will be used to verify DEMO BOP operational modes and the Plant Logic Control System. Based on the experimental feedback from HELOKA-US tests, important hints for non-operational modes, such as initialization, ramp-up/ramp-down and preparation of maintenance will be developed and verified.

HELOKA-US is currently under construction at the Karlsruhe Institute of Technology (KIT) in Germany with the financial support of EUROfusion and the KIT FUSION program. More details of the project can be found in [4].

5. Conclusions

The DEMO HCPB ICD BOP is the reference configuration for the He-cooled DEMO Plant, and is classified as the most promising concept capable of achieving the DEMO BOP future goals, according to the conclusions from the Gate Review G1 panel members. The high-ranking classifications were based on the way this concept is able to mitigate the effects of the frequent plasma pulse operation, as well as on the high technological readiness of its systems and components.

The current R&D activities being performed for the Conceptual Design Phase of the DEMO HCPB ICD BOP are mainly related to: (i) the DEMO BOP Plant Logic Control System and the He-MS HX design, where both activities are being supported by the industrial partner KAH, as well as (ii) the helium compressor technology selection being supported by the industrial partner ATEKO. They are on-going activities which will continue in the coming years.

The HELOKA-US experimental facility will be vital for demonstrating the feasibility of the DEMO HCPB ICD concept (PHTS-IHTS), since it will provide the following: (i) the validation of the He-MS HX design and possible HX optimization; (ii) the helium compressor assessment for DEMO HCPB needs and (iii) experimental insights for DEMO Plant Regulation System optimization.

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Abbreviations

ACP	Activated Corrosion Products
AGR	Advanced Gas Reactors
ATEKO	Compressor manufacturer from the Czech Republic
BB	Breeding Blanket
BOP	Balance of Plant
CDP	Conceptual Design Phase
CDT	Central Design Team
CSP	Concentrating Solar Power
CWHX	Coil-Wound Heat Exchanger
D2P	Dwell to Pulse
DCT	DEMO Central Team
DDD	Design Description Document

DIV	Divertor
ESS	Energy Storage System
EU	European Union
FP	Framework Program
FPP	Fusion Power Plant
FW	First Wall
HCPB	Helium Cooled Pebble Bed (BB design)
HELOKA-US	Helium Loop Karlsruhe—Upgrade Storage
HX	Heat Exchanger
I&C	Instrumentation and Control
ICD	Indirect Coupled Design
IHTS	Intermediate Heat Transport System
IHX	Intermediate Heat Exchanger (He-MS)
IRL	Integration Readiness Level
KAH	Kraftanlage Heidelberg
KIT	Karlsruhe Institute of Technology
MC	Main Compressor
MS	Molten Salt
NGNP	Next Generation Nuclear Plant
NPR	New Production Reactor
OTHX	Once Through Shell and Tube Heat Exchanger
P2D	Pulse to Dwell
PCHX	Printed Circuit Heat Exchanger
PCS	Power Conversion System
PHTS	Primary Heat Transport System
PSHX	Plate and Shell Heat Exchanger
R&D	Research and Development
SG	Steam Generator
SRL	System Readiness Level
T	Tritium
TRL	Technology Readiness Level
TSHX	Tube and Shell Heat Exchanger
VV	Vacuum Vessel
WCLL	Water Cooled Lead Lithium (BB design)

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