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

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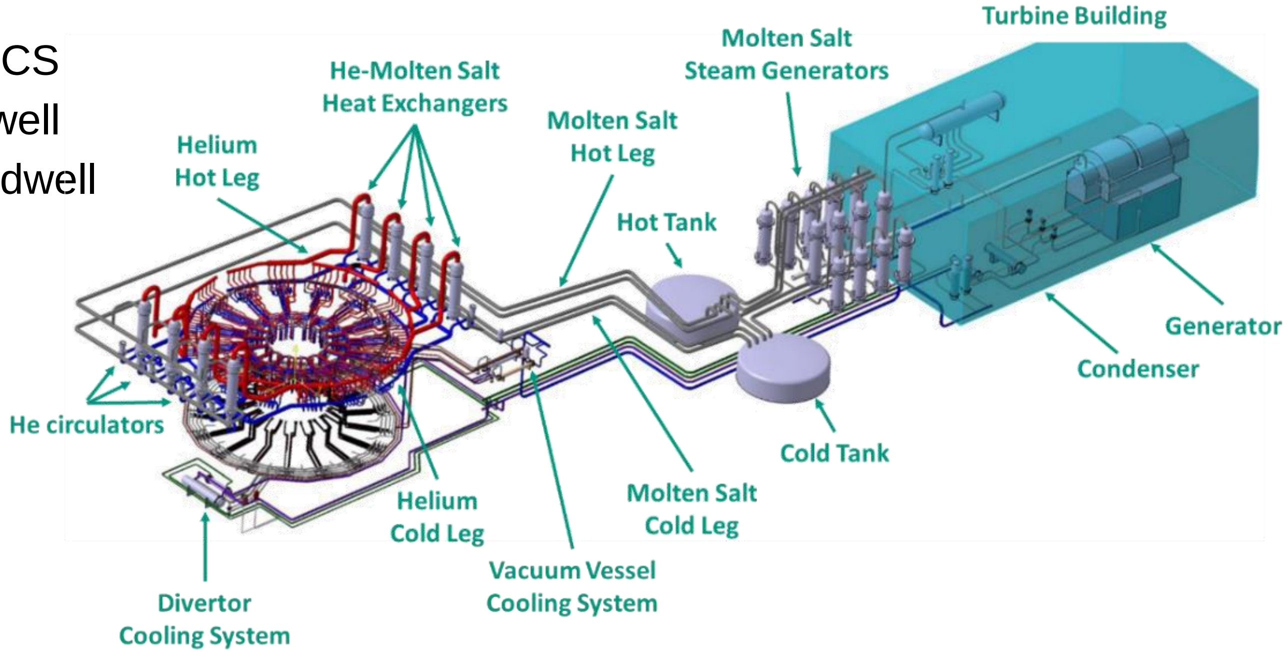
Introduction: DEMO HCPB ICD

- DEMO HCPB ICD: BOP featuring an IHTS
  - decouple the plasma intermittent heat source from the PCS
  - IHTS buffers energy during pulse and releases during dwell
  - constant PCS steam load and electrical power in pulse&dwell



- Strengths:
  - mitigate frequent plasma pulse operation effects
  - high ranked technology readiness systems/components

- Tasks to be performed to consolidate the Conceptual Design:
  1. to solve issues found in FP8 and continue with the **Conceptual Design Development**
  2. to assess the BOP functional feasibility by **evaluating the maturation** of the industrial components
  3. to **validate experimentally** the ICD in a dedicated facility

T1. Conceptual Design Development

- Ranking table:
  - summary of main characteristics/features
  - variant comparison and down-selection
  - identify critical issues
- Further optimization of BOP architecture:
  - allow operations according to latest Energy Map
  - solve integration aspects regarding VV-PHTS
  - Plant Regulation System based on plasma states
- Critical issues in DEMO HCPB ICD → R&D
  - **Plant Regulation System**
  - He compressor
  - He-MS HX

PHTS	BB PHTS SG/HX	He-MS HX
		He compressor
	PHTS Techn. Derivation	Gas Nuclear Reactor and CSP
	BB PHTS HX/SG Pressures	High-~Atmospheric
IHTS	IHTS/ESS Fluid	HITEC
	IHTS/ESS Storage Capacity	2x3000m^3
	Other Thermal Storage	-
	Auxiliary Heating System	-
	Gas Fired Boiler Supply	-
	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 / -
Safety	Inherent Safety Barriers (T, ACP)	2
Summary	**Critical components**	·He compressor ·He-MS HX · MS Steam Generator
	Preliminary Feasibility Assessment	TBI

🟥 Critical issue due to component size&integration, functional feasibility, market readiness or strategic aspects

🟦 Market readiness: producible but not in shelf

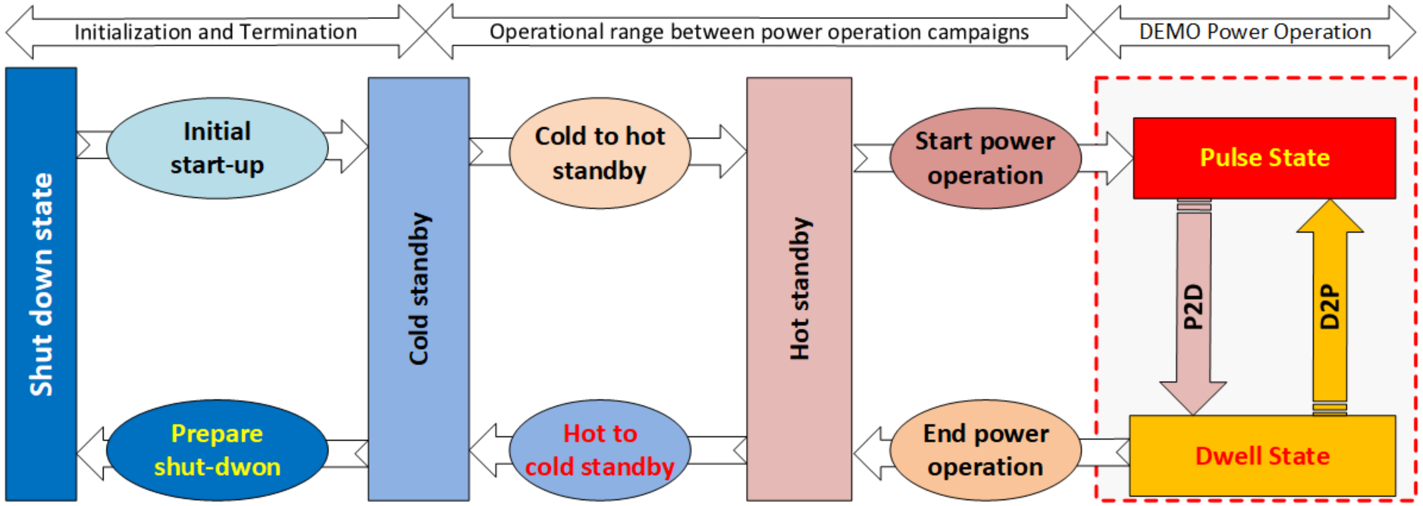
🟨 Market readiness: near or at present feasible and producible

🟩 Market readiness: component from shelf/ technology available

T1. DEMO Plant Regulation System

PHTS & IHTS & PCS controlled in a coordinated regime. Plasma power first priority → PHTS-IHTS in "plasma following mode"

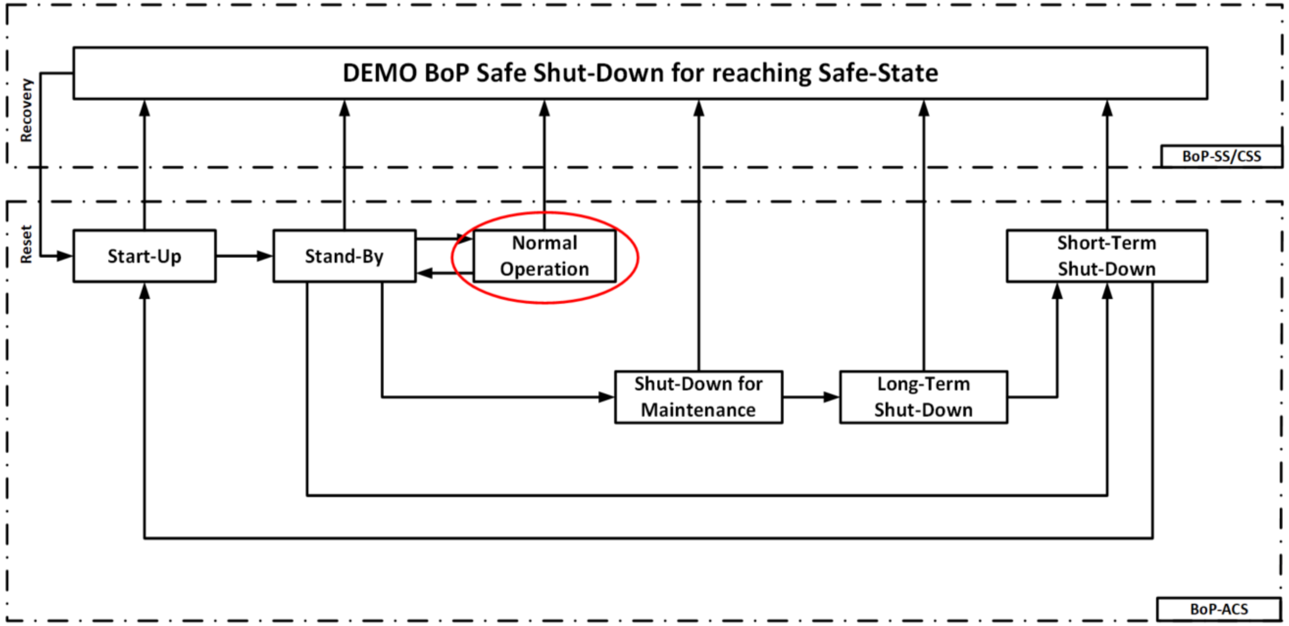
	BOP specificity
Plasma operation st.	Normal power operation
Standby	Cold/Hot Standby
Flat top	Pulse state
Dwell	Dwell state
Testing & conditioning st.	Cold standby
Tokamak commissioning	Cold or hot standby
Overall plant commis. w/o plasma	Cold or hot standby
Overall plant commis. w. plasma	Hot standby
Maintenance st.	Shut-down/cold standby
In-vessel maintenance	Cold standby
Ex-vessel maintenance	Cold & hot standby
Failed st.: (unscheduled maintenance st.)	(in work)



BOP operation modes

T1. DEMO Plant Regulation System

- BoP Automated Control System: responsible for the entire system and every single operation state incl. transitions
- BoP Safety System or Central Safety System: bringing in a safe state in case of incident/off-design condition



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
		FW Coord. Control	PCS FW Pump
			DIV1 HX Bypass Valve
			Deaerator Hot Cond. Control Valve
			PCS Pump 1
			DIV2 HX Bypass Valve
			FW 3-Way Valve
			PCS Pump 4

Preliminary DEMO HCPB ICD BoP Control Hierarchy
(performed by our industrial partner KAH)

- **HELOKA-US** tests: vital for improving the readiness level of the DEMO HCPB BoP ICD Regulation Scheme

T2. Critical Components: He compressor

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

- Preliminary market survey: potential suppliers for DEMO compressor fulfilling main requirements:
  - working pressure (80 bar)
  - volume flowrate (126,000 m^3/h)
  - other requirements not yet assessed (i.e. Helium, fluid density, work temperature, power, nuclear codes & standards).

- Proposed compressors technologies:
  - integrally geared, radial, geared turbo-compr., piston, GT-series centrifugal and multi-stage centrifugal

- **Threads**: No relevant current market is demanding such large compressors → low interest for industrial companies.

- **Opportunities:** If FPP considered for future scenarios (e.g. ITER) → + interested manufacturers (large compressors)

- Very positive recent involvement of Howden (historic supplier of AGR reactors compressor) in ITER Project.

T2. Maturation evaluation: He compressor

Readiness of the He compressor with respect to …

- Past experience (e.g fission gas-cooled react.)
Ranking: 9
- More actual nuclear reactors (NGNP)
Ranking: 4
- Fluid (He)
Ranking=9
- Operation (st-st & trans. performance)
Ranking=4

- Example NGNP project: Howden concept. design (from 3-7 and up to 16 MW) 5.8 MW (centrifugal) & 13 MW (axial)

	NGNP Project Two MCs parallel	**NGNP Project Single MC**	**HCPB PHTS He compressor**
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

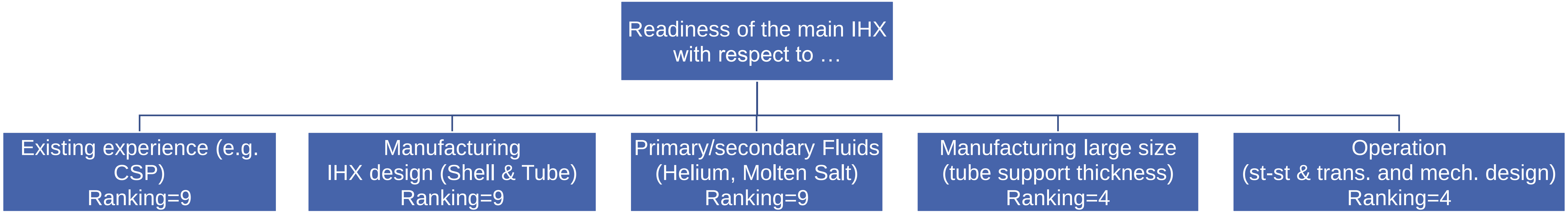
- Path for DEMO compressor to reach TRL 6/7 (as in NGNP NPR compressors): supplier identification & performance tests in scaled mock-up under relevant DEMO conditions (P2D and D2P) → Maturity expected with **HELOKA-US** tests (Phase 2).

T2. Maturation evaluation: He-MS IHX

- Validation of a Once Through Shell & Tube He-MS HX design fulfilling basic DEMO BOP requirements

	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

- Main challenges:
  - high coolant temperature and related implications on materials strength, lifetime and fabrication related factors
  - tritium migration allowance and purification capability (i.e., removal of tritium) → IHX design and secondary fluid selection



Readiness of the main IHX with respect to …

Existing experience (e.g. CSP)
Ranking=9

Manufacturing
IHX design (Shell & Tube)
Ranking=9

Primary/secondary Fluids
(Helium, Molten Salt)
Ranking=9

Manufacturing large size
(tube support thickness)
Ranking=4

Operation
(st-st & trans. and mech. design)
Ranking=4

- Experimental facility to test a He-MS HX mock-up → **HELOKA-US**

T3. HELOKA-US

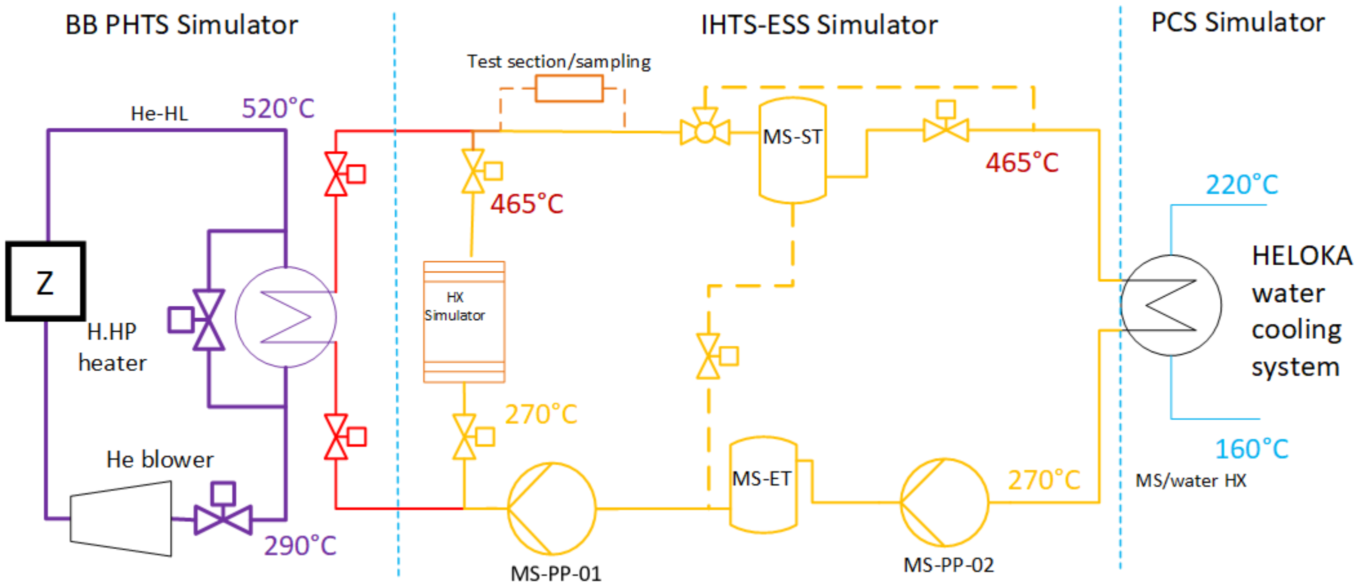
- **What:** R&D infrastructure to demonstrate exp. HCPB ICD BOP (mock-up of the DEMO PHTS and IHTS)

- **How:**
  - Ph. 1: prototyp. components (HX and MS loop operation) and testing & developing control strategies for DEMO HCPB ICD
    - Ph. 1a: MS loop using an electrical simulator of the real He-MS HX.
    - Ph. 1b: upgrade with a real He-MS HX (high temperature, high pressure He from HELOKA-HP)
  - Ph. 2: DEMO relevant helium compressor integration to prove and validate the solutions

- **Composition:** three coupled heat transfer loops:
  - High pressure & temperature He loop (repr. PHTS)
  - Low pressure MS loop (repr. IHTS)
  - Water cooling loop (heat sink of the MS loop)

- **Where:** at KIT Campus North Building 660.

- **Financing:** partially funded by EUROfusion (FP9)



More info: poster session “Design features and simulation of the new-build HELOKA-US facility for the validation of the DEMO HCPB IHTS system” X. Gaus-Liu et al.

Summary

- DEMO HCPB ICD BOP: high ranked design where further R&D is needed for
  - Plant Regulation System
  - He compressor
  - He-MS IHX

- **HELOKA-US** experimental facility:
  - Vital for demonstrating the feasibility of the DEMO HCPB ICD concept (PHTS-IHTS)
  - Validation of He-MS HX design and possible HX optimization
  - He compressor assessment for DEMO HCPB needs
  - Experimental insights for DEMO Plant Regulation System optimization

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