EU DEMO cryogenic system and cryo-distribution: pre-conceptual design for an optimal cooling of the superconducting magnets and the thermal shields

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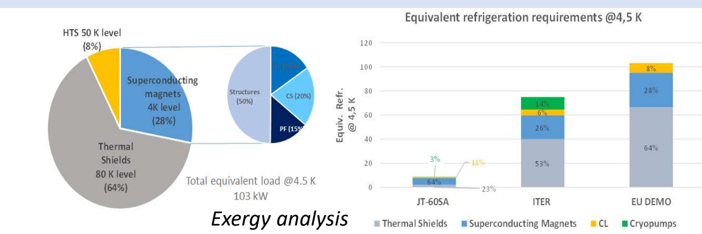
ABSTRACT

- Innovative approach to find an optimized process with interactions between designers, cryogenic experts and industry
- Review of the cooling parameter for the superconducting magnets , for the High Temperature Superconductor Current Leads and for the thermal shields
- Trade-off studies on several process options
- Conceptual design of a novel process architecture with Helium and He-Ne cycles
- Technology maturity and the R&D strategy

BACKGROUND

- The pre-conceptual study elaborated the design of the European demonstrator EU DEMO in the framework of the EUROfusion consortium collaboration
- EU DEMO would demonstrate the production of electricity and the operation of the closed fuel cycle with the development and integration of key fusion technologies, among them, the NbSn3 and Nb-Ti superconducting magnets requiring a large-scale cryogenic system
- Cooling capacity for the superconducting magnets a about 4 K, for the high temperature superconductor current leads at about 50 K and the thermal shields at about 80 K.
- Objective of an overall integrated system, with cost effective solutions for both capital and operation expenditures



Exergy analysis

CHALLENGES / METHODS / IMPLEMENTATION

REVIEW OF THE COOLING REQUIREMENTS

Parametric studies on temperature, pressure and pressure drop for all the cryogenic users

TRADE-OFF STUDIES ON THE DESIGN ANALYSIS at 4 K and 80 K levels

- ITER-like He +LN2 precooling
- He + Mixed Refrigertion cycles [He+ Ne]

CONCEPTUAL DESIGN: HELIUM AND MIXED REFRIGERATION CYCLES

- Warm centrifugal compressor for MP/HP helium cycle (8 stages) and for MR cycles (5 stages) : 1,3 to 15 bar
- Turbine recovery system for warm turbines > 100 kW (LN2 and MR turbines)

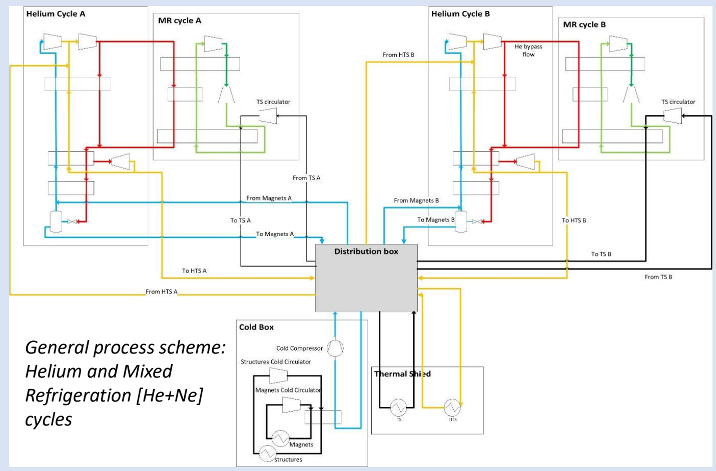
Cryogenic users	Loads (W)	Mass flows (g/s)	Supply Temperature (K)	Supply Pressure (bar)	Pressure drops (bar)
Toroidal Field coils TF	3200	[1000-3000]	[4.1- 4,6]	[4,10]	<1 bar
Central Solenoid CS	5200	[1600-3100]	[4.1- 4,6]	[4,10]	<1 bar
Poloidal Field coils PF	3200	1600	[4.1- 4,6]	[4,10]	<1 bar
Structures	13900	2700	[4.1- 4,6]	[4,10]	<1 bar
HTS	n.a	250	[48-52]	[4-6]	<3 bar
Thermal shields	1400000/ 590000	13200	[60-150]	[15-20]	<1 bar

Main cooling requirements for EU DEMO cryoplant &cryo-distribution
In nominal operation

OUTCOME

Process architecture & layout :

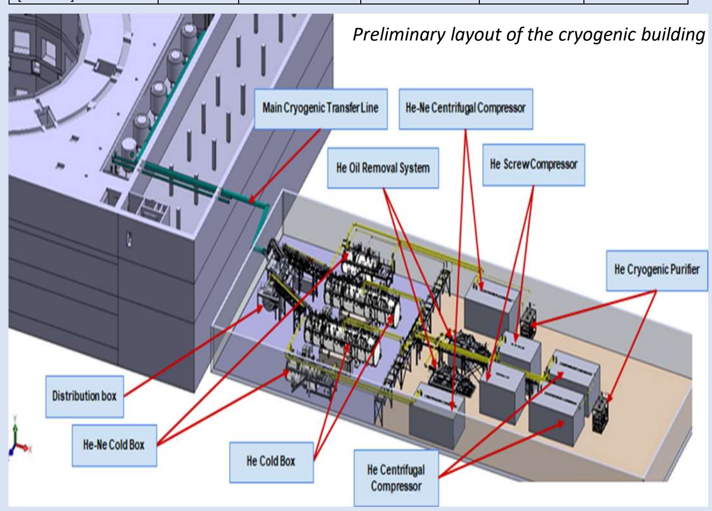
robustness, efficiency and mature technologies



General process scheme: Helium and Mixed Refrigeration [He+Ne] cycles

Electrical consumption and Carnot efficiency for the 2 precooling options

Options	Pre-cooling	Electrical consumption (%) without PR	Carnot Efficiency (%) without PR	Electrical consumption (%) with PR	Carnot Efficiency (%) with PR
ITER-like –[He-LN2]	LN2	100	25	94	26.
[He +MR]	He+Ne	83	29	76	31



Preliminary layout of the cryogenic building

CONCLUSION

- The involvement of industry at the early stage of the pre-conceptual design is an innovative approach to the anticipated cooling requirements and to identify some paths of investigations for novel process architectures
- Trade-off studies led to compare two process solutions: ITER-like [He+LN2] or Mixed Refrigeration and helium cycles [He+MR]
- The Mixed refrigeration and helium cycles offers better efficiency and flexibility in the range of 60-150 K for the thermal shield cooling and the precooling of the helium cycle
- The conceptual design of the Mixed Refrigeration cycles led to an estimated Carnot efficiency of 31%, thanks to the use of mature advanced technologies based on centrifugal compressors and turbine recovery systems.

ACKNOWLEDGEMENTS / REFERENCES

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