Conceptual design of an effective heat exchanger for heat removal sCO2 Brayton cycle to increase the safety of nuclear power plants

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OUTLINE

1. Context & introduction
    - s-CO2-4-NPP project
    - s-CO2 power cycles

2. Design of the Diverse Ultimate Heat Sink (DUHS)
    - Heat exchangers in Brayton cycles
    - Overview of a Plate-Fin Heat Exchanger
    - Cycle input data
    - Design results

3. Conclusion and perspectives

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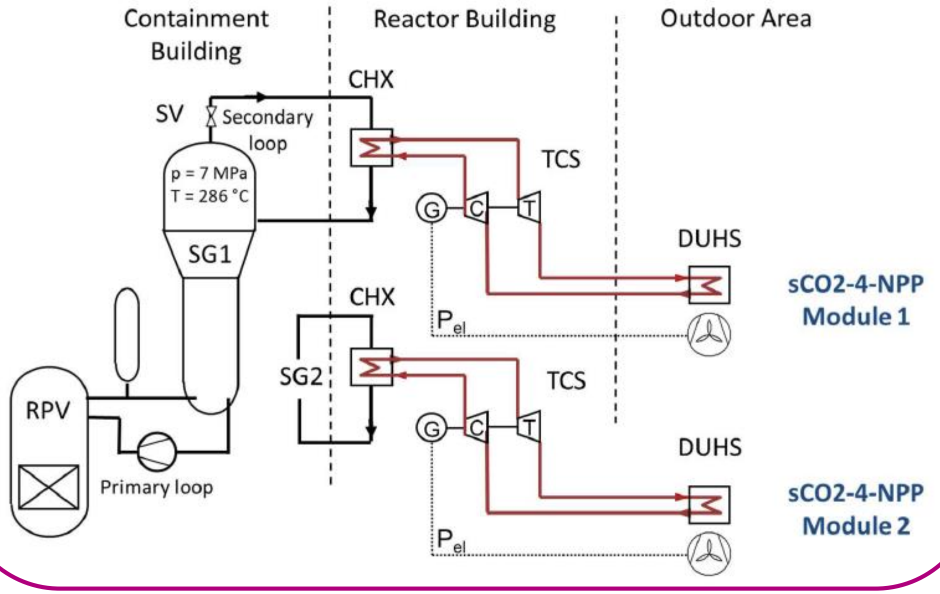
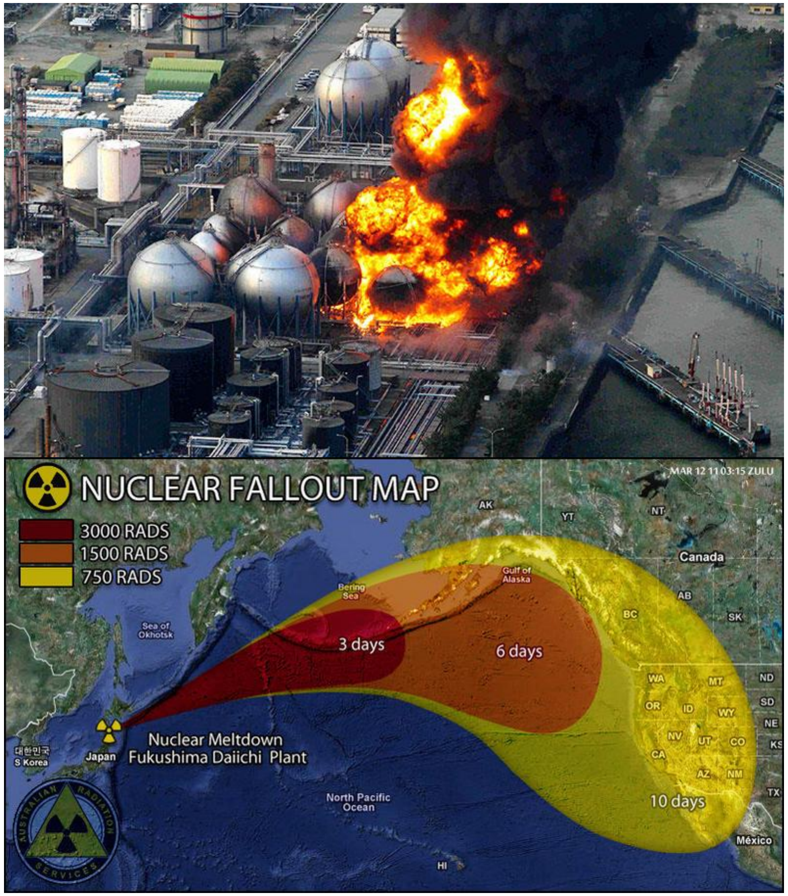
SCO2-4-NPP PROJECT

Development of efficient sCO2 heat removal Brayton cycle to increase the safety level in case of Nuclear Power Plants (NPP) accidents

Modular sCO2-4-NPP system attached to the secondary loop of a pressurized water reactor



Fukushima Daiichi disaster (2011)



Fives Cryo role in the project :

Development of CHX & DUHS heat exchangers in agreement with NPP codes and regulations

SCO2-4-NPP PROJECT

Fins geometry development

Mechanical resistance development

Corrosion resistance

Thermal/hydraulic performances

+

Fives Cryo Background in BSSHX design

- Conceptual design of heat exchangers for MW-scale sCO2-4-NPP loop
- Plan for qualification of heat exchangers

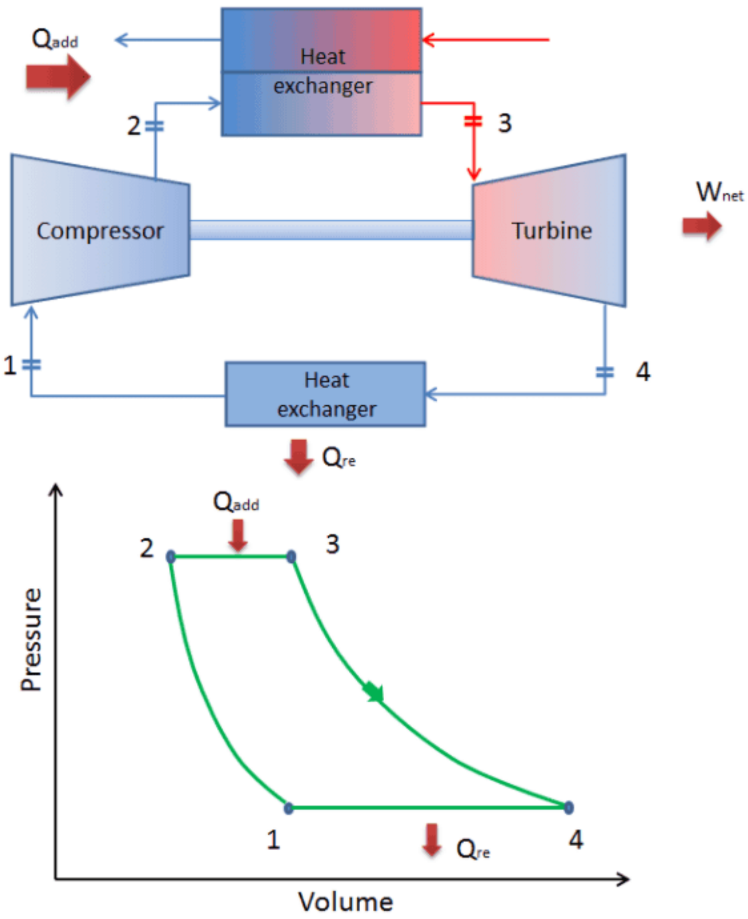
Project Coordinator

Project Partners

SCO2 POWER CYCLES

Importance of **heat exchangers** in the thermodynamic process of **closed Brayton cycles**

Compactness + ability to operate under severe mechanical and environmental constraints



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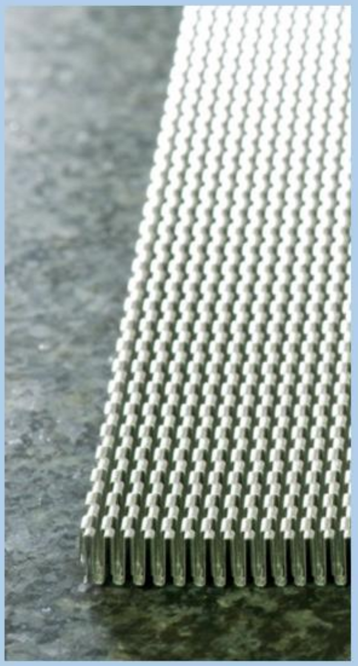
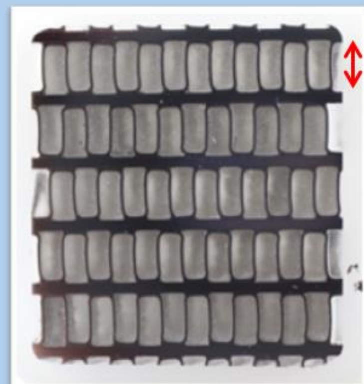
HEAT EXCHANGERS IN BRAYTON CYCLES

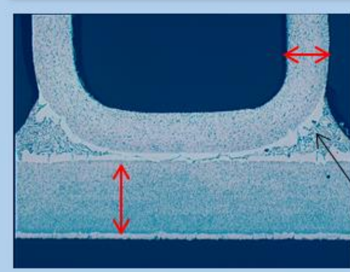
Plate-Fin Heat Exchanger

All the pieces (fins, bars, plates) of HX are brazed all together





4mm to 12mm



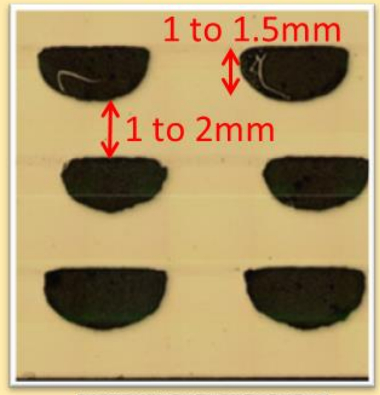
Fin thickness : 0.15 to 0.40mm

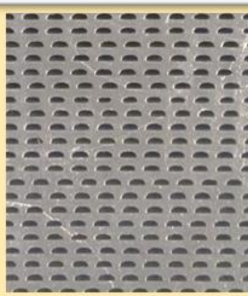
Brazed joint

plate thickness : 0.6 to 2mm

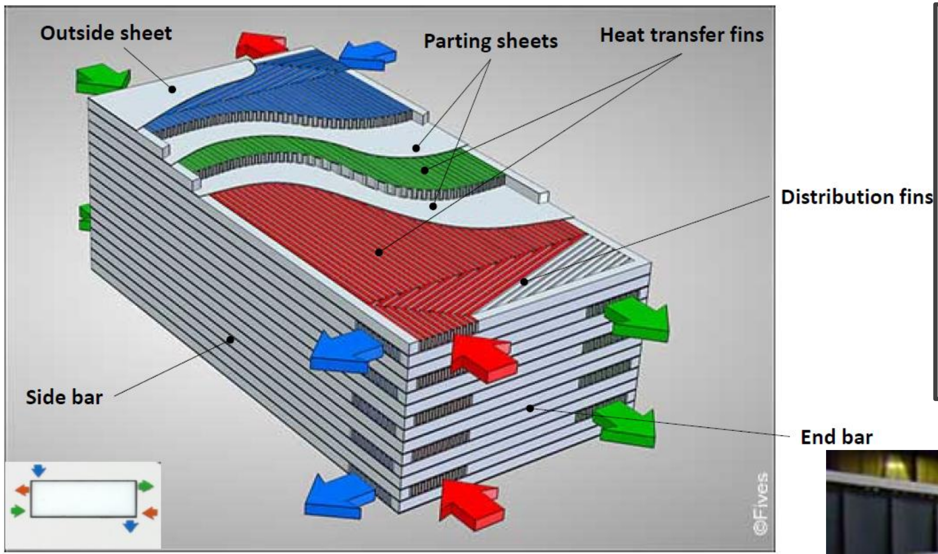
Printed Circuit Heat Exchanger

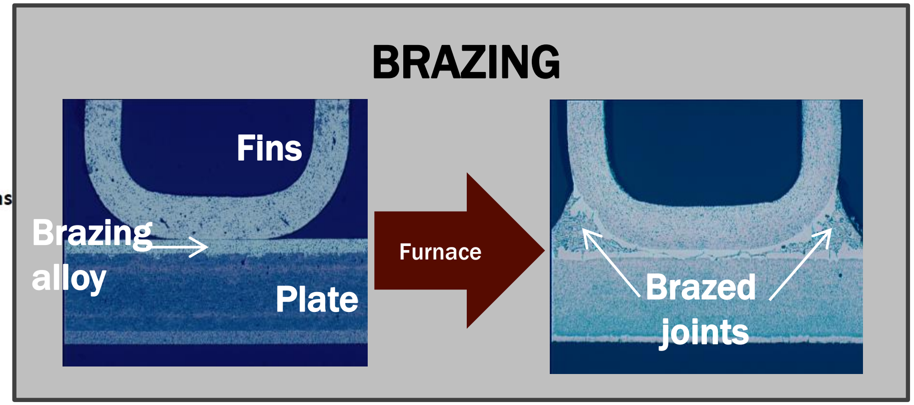
Channels are « printed » by chemical etching, and then plates are brazed or diffusion bonded

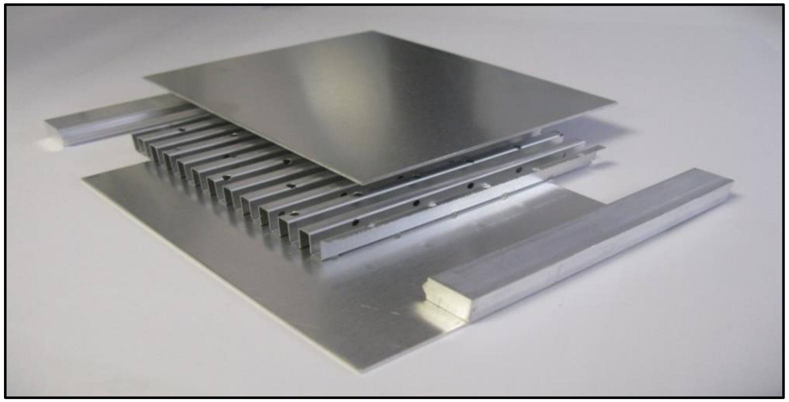




OVERVIEW OF A PLATE-FIN HEAT EXCHANGER







CYCLE INPUT DATA

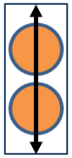
- Initial cycle design of a 10MW sCO2-Brayton cycle
  - High temperature HX
  - Very limited pressure drops on air side
  - Max ΔT fluids = 128°C

DUHS	sCO2	Air
P_in (MPa)	12.70	0.1003
P_out (MPa)	12.68	0.10
DP (mbar)	200	3
T_in (°C)	243.19	45.00
T_out (°C)	55.00	115.21
H_in (kJ/kg)	674.88	318.59
H_out (kJ/kg)	350.97	389.50
m (kg/s)	29.74	135.87
Q (MW)	9.63	

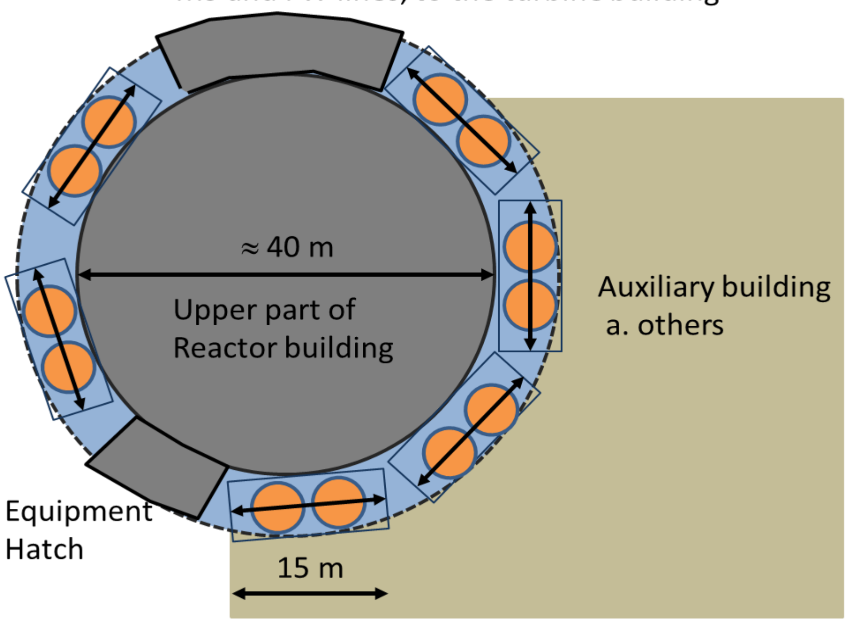
CYCLE INPUT DATA

- The construction of the DUHS needs to be adapted:
  - To avoid any breach of nuclear safety
  - To resist to heavy weather conditions and extreme situations

  - To limitate penetration of reactor safety vessel
  - to fit into existing infrastructures



Projected size of a DUHS Cell

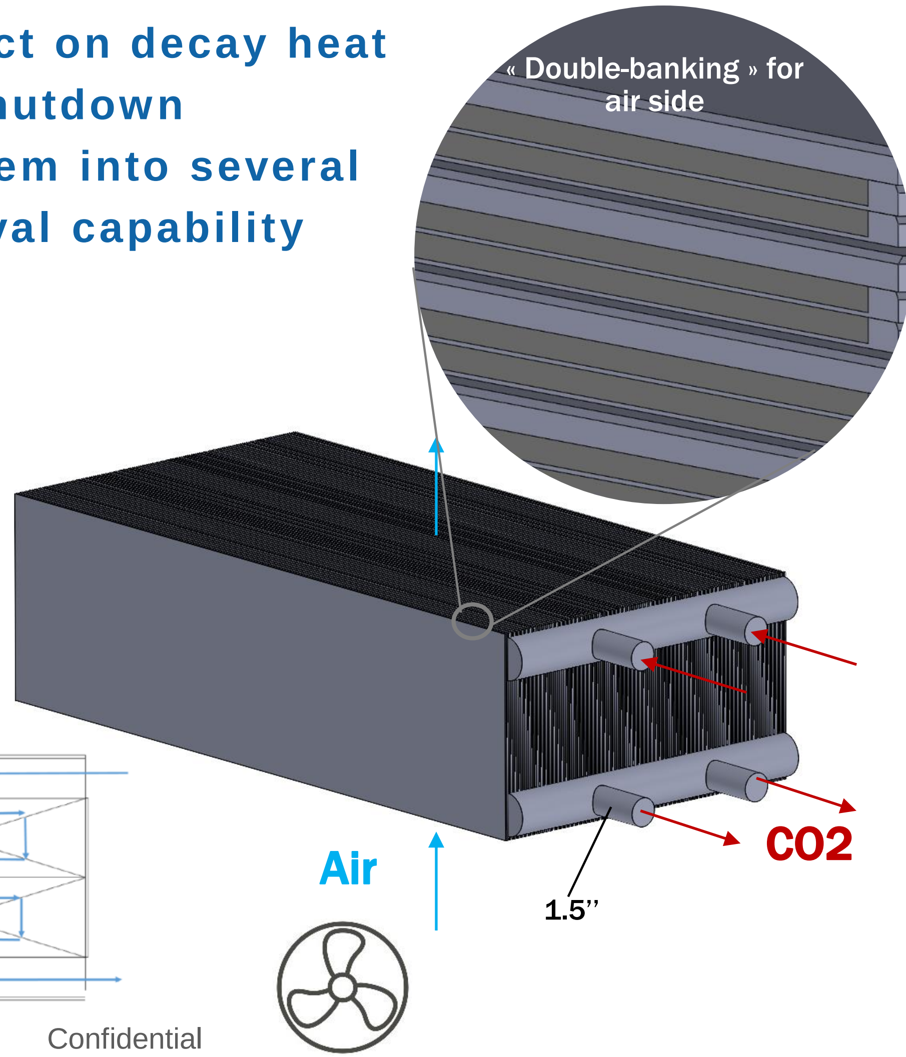


→Estimation of the available area for DUHS installation: 540m² = 15m x 36m

→6 cells instead of a massive block due to air circulation

DESIGN RESULTS

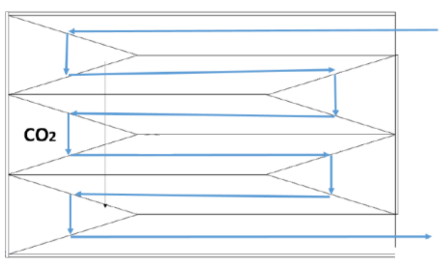
To increase the flexibility to react on decay heat decrease in the long run after shutdown
→Split up the heat removal system into several blocks of 10MW each heat removal capability



6 units of 60MW of 20 cores each
= 120 cores in total

For each core :
- Width: 2000 mm
- Height: 987 mm
- Length: 570 mm

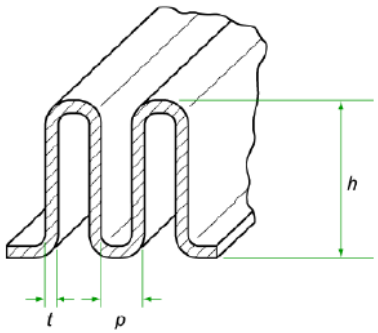
- 64 layers for CO2
- 128 layers for air
- 4"inactive" layers



DESIGN RESULTS

- Different fins are used in the layer to achieve the thermal performances

- Base material is 316Ti stainless steel
UNS S31635
W. Number 1.4571
→suitable for brazing-diffusion bonding
→withstand high T & ΔT
→high mechanical strength
→high corrosion/erosion Resistance

	CO2 side fins	Air side fins
Thickness t (mm)	0.3	0.15
Height h (mm)	4	4
FPM p (Fin Per meter)	787.4	393.7
Geometry of "plain fins"		

- Heat transfer area:

FLUID		CO2	AIR
EFFECTIVE PASSAGE WIDTH	mm	83	1928
EFFECTIVE PASSAGE LENGTH	mm	12000	560
TOTAL HEAT TRANSFER AREA	m2	9376	13581
TOTAL FREE FLOW AREA	cm2	3002	178802

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CONCLUSION AND PERSPECTIVES

- The sCO2-4-NPP project aims to develop Develop an efficient sCO2 heat removal Brayton cycle to increase the safety level in case of Nuclear Power Plants (NPP) accidents

- To that end : **Fives Cryo** is developing both DUHS and CHX

=> stainless steel plates & fins heat exchangers able to operate under severe conditions (impure sCO2, high temperature and high pressure for CHX)

- Innovative design for DUHS with double-banking air layers in the stacking
- DUHS divided into several strains (6 units of 10 MW each) to increase the efficiency of heat removal while operating

- Next steps:

- Validate DUHS design (thermal & hydraulic performances) through testing mock-ups in experimental loop
- Validate the design from nuclear power plants regulation and codes

THANK YOU FOR YOUR ATTENTION

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