sCO2-4-NPP: Innovative sCO2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants

Deliverable 5.1

Design concept with auxiliary systems

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Type		
R	Document, report excluding the periodic and final reports	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	
Dissemination level		
PU	PUBLIC, fully open, e.g. web	X
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1 List of Acronyms

Abbreviation / Acronym	Description / meaning
CHX	Compact Heat Exchanger
DUHS	Diverse Ultimate Heat Sink
NPP	Nuclear Power Plant
sCO2	Supercritical Carbon Dioxide

2 Executive Summary

The present deliverable presents an architecture of the sCO2 system developed in the sCO2-4-NPP project.

Based on the work in progress, the sCO2-4-NPP project team has worked on a lightweight, modular architecture, as compact as possible, in order to demonstrate the possibility of integrating the sCO2 system into a nuclear power plant, without the need for a large footprint.

The system, studied in this deliverable, is presented with a push-up type start-up solution, requiring pressurized CO2 storage tanks, and presenting the interest of not requiring additional equipment for start-up. If another start-up solution were to be considered later, the addition of other equipment (battery, pump, etc.) would be possible and without impact on the footprint because it could be integrated into the current building.

3 Introduction

In the framework of the sCO2-4-NPP project, the consortium aims to continue the development of the sCO2 system, developed in the sCO2-HeRo project. The role of WP5 is to study the full scale-up of the sCO2 system and its possible integration in a nuclear power plant.

The main objective of deliverable D5.1 related to task T5.1 of the sCO2-4-NPP project is to present a typical architecture for the sCO2 system as studied in the sCO2-4-NPP project. We therefore present this typical architecture in this deliverable and also a reflection on possible developments to improve the performance and integration of the sCO2 system. These adjustments would then be made with a view to adapting the sCO2 system to a particular type of nuclear power plant.

4 General installation

General installation is a generic term that can be used both to talk about very macroscopic studies, such as positioning buildings and equipment on the same layout plan as well as detailed studies up to a 3D digital twin, which is an exact reflection of the installation.

The sCO2-Based Heat Removal Technology has been subject of a detailed 3D modelling with all the functional links specific to the CO2 loop for the main equipment. In this case, the “**Proposed design**” deliverable is in between in terms of general installation as several pieces of equipment, auxiliary systems and process principles are still under development. Said “**Proposed design**” is achieved through the integration of the installation constraints of each of its parts.

4.1 sCO2-4-NPP Installation constraints

4.1.1 Project constraints

The project constraints are the specifications the general installation needs to respect in order to fulfil the project requirements. The sCO2-Based Heat Removal Technology project constraints are as followed:

- **Compact**:
  The sCO2-Based Heat Removal Technology ought to be installed on multiple sites, both existing and future. Therefore and given the layout differences between each site, its implantation needs to have as minimum a footprint as possible to reduce the installation constraints on its environment.

- **Modular**:
  The sCO2-Based Heat Removal Technology is designed to dissipate 10 Mw of thermal power. The thermal dissipation needs for the various sites this technology can be installed on being different, its implantation must allow the installation of 1 up to 6 modules in series.

- **Transportable**:
  The sCO2-Based Heat Removal Technology requires the installation to be swappable for maintenance purposes and ease of transportation to other sites where such technology is already deployed.

4.1.2 Conflicting constraints

A constraint conflict is a generic term that is used to describe project requirements which diverge from each other. In this case, the installations constraints “**compact**” and “**transportable**” are in direct interference.

A “**transportable**” installation requires its size to respect the standard road gauge. If the installation dimensions exceed said gauge, multiple standard modules need to be designed. Each of those modules then requires to be easily disconnectable both on its mechanical and electrical interfaces to ease its transportation. On top of that, a dedicated loading/unloading area close to a road on ground level also needs to be designed to accommodate this constraint. To release those constraints while respecting safety guidelines, free space is required which is in direct opposition with the “**compact**” installation constraint.

To reduce the feasibility risk of the project and to ease the implantation of the sCO2-Based Heat Removal Technology on existing sites where free space is rarely available, the “**compact**” installation constraint must then take priority over the “**transportable**” one.

4.1.3 Equipment list

The sCO2-Based Heat Removal Technology rests on four main pieces of equipment whose installation requirements determine the design of the general installation. These equipment’s dimensions are as follows:

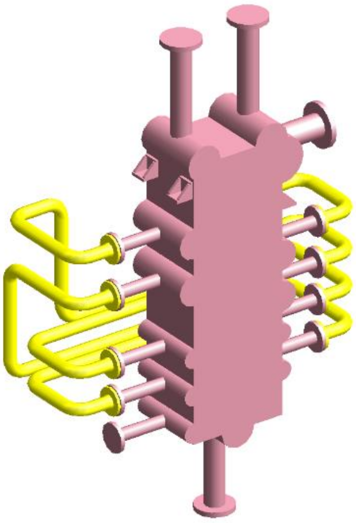
- 1 x **CHX Exchanger**:
  Length=512mm; Width=700mm; Height=2 000mm
- 20 x **DUHS Exchanger**:
  Length=640mm; Width=2 000mm; Height=987mm
- 2 x **CO2 Start-up Tank (for the push-up start)**:
  Volume: 63 m^3
- 1 x **Turbomachine**:
  Length=958.98mm; Width =1 200mm; Height=811.2mm

4.1.4 Constraints and equipment list analysis

The main installation constraint of the sCO2-Based Heat Removal Technology is its “**compact**” footprint followed closely by its “**transportability**”. The “**modular**” constraint is solved by having all the mechanical and electrical interfaces on the same side of the installation to ease the connections between the modules and the power plant.

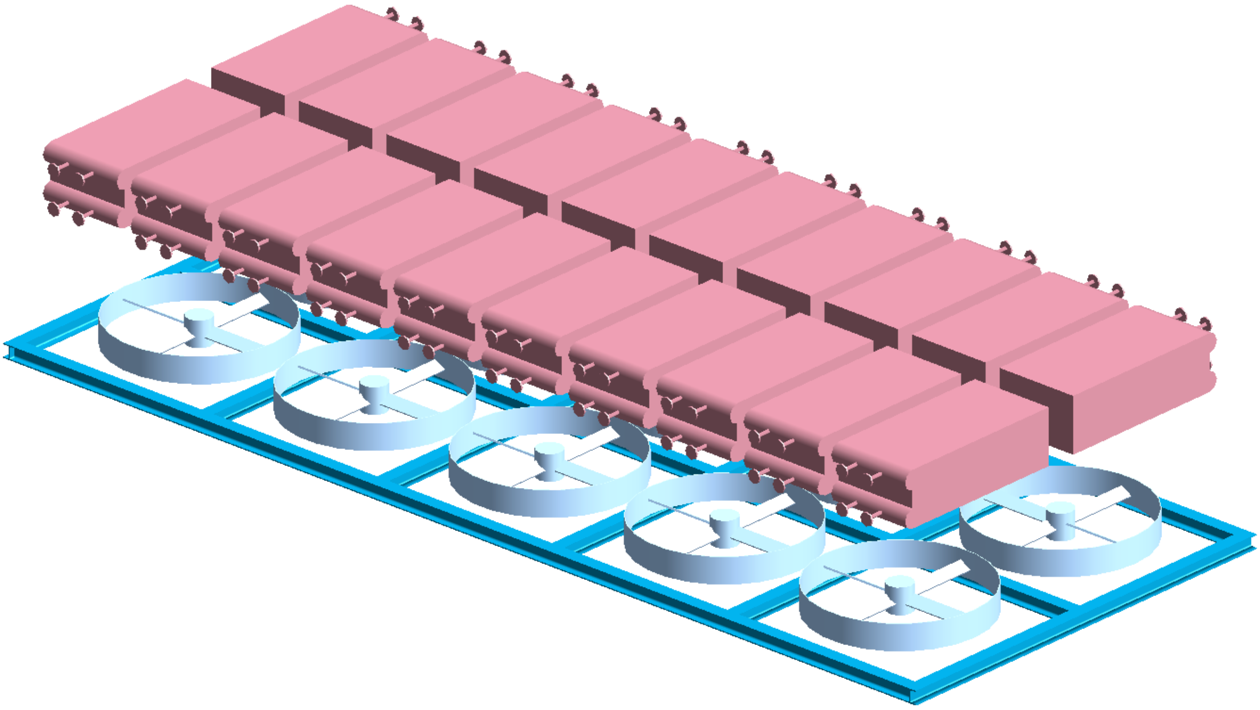
The **CHX Exchanger** represented in Figure 1 is a Steam/CO2 exchanger and must be installed vertically to ensure its heat exchange performance. The main body of the CHX Exchanger is 2 000mm high and goes up to 3 481mm when integrating its nozzles and connected piping systems.

Figure 1 : CHX Exchanger



The **DUHS Exchanger** is a CO2/Air exchanger and must be placed outside to ensure its heat exchange performance. Twenty DUHS cores must be installed to dissipate the thermal output of the sCO2-Based Heat Removal Technology. These 20 **DUHS Exchangers** must be installed in pairs and outside to allow the implantation of the fin-fan coolers required for the forced ventilation system to operate. The overall dimensions of the 20 **DUHS Exchangers** represented in Figure 2 and their respective fin-fan coolers are: Length=11 517mm; Width=5 000mm; Height=2 350mm.

Figure 2 : DUHS Exchangers with fin-fan coolers

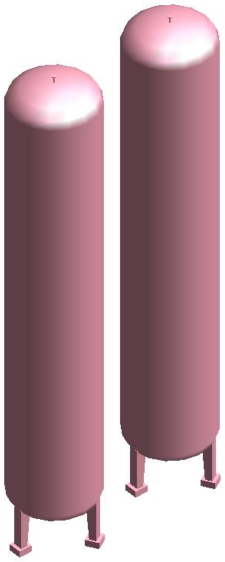


The start-up process requires two 63 m^3 tanks of CO2. The **CO2 Start-up Tanks** represented in Figure 3 must be placed outside due to the risk associated with the CO2 gas for the safety of personnel. To reduce the installation footprint of these tanks as well as follow industrial standards on high pressure gas tanks, vertical tanks with the following dimensions have been selected for the storage tank:

Diameter = 2 600mm; Height = 12 000mm.

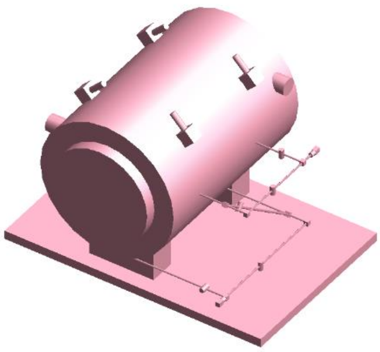
If another solution for the start-up of the system is chosen, these tanks will be more compact, but still necessary in order to fill and operate the system.

Figure 3 : CO2 Start-up Tanks



The **turbomachine** represented in Figure 4 is a compact piece of equipment whose only constraint is to be installed inside a structure to protect it from potential damage and degradations from the environment.

Figure 4 : Turbomachine



To enable the transportability of the installation, the equipment must be placed inside a container for ease of transportation. The standard dimensions for a 40” High Cube (HC) Container following the standard road gauge are as follows: Length=12 192mm; Width=2 438mm; Height=2896mm. The height of the **CHX Exchanger**, the overall dimensions of the **DUHS Exchangers** as well as the size of **CO2 Start-up Tanks** being higher than those values, the transportability of a full sCO2-Based Heat Removal Technology in a single standard road gauge HC Container cannot be ensured.

4.2 sCO2-4-NPP proposed design

The constraints and equipment list analysis highlighted that the **DUHS Exchangers** and their fin-fan coolers have the largest footprint of the main equipment outside of the **CO2 Start-up Tanks** and requires to be implanted on the outside. To limit the footprint of the sCO2-Based Heat Removal Technology beyond that, the principal solution is to install the remaining equipment in a structure as shown below.

Added to that, the fin-fan coolers of the **DUHS Exchanger** also require free space both above and below them where no bulky equipment can be installed to allow proper air passage. This constraint added to the 3 481mm height of the **CHX Exchanger** suggests said structure to be 3 storeys high. One for the main mechanical and electrical equipment, one for the **CHX Exchanger** clearance and air flow passage for the **DUHS Exchangers,** then one for the **DUHS Exchangers** themselves.

The **CO2 Start-up Tanks**’ size prevent them from being implanted in the same structure and requires them to be installed nearby.

The Figure 5, Figure 6 and Figure 7 represent the final integration of this design for the **sCO2-Based Heat Removal Technology** whose overall dimensions of are as follows:

- Main module:
  Length=13 570mm; Width=6240mm; Height=9860mm
- Two CO2 Start-up Tanks:
  Length=2 600; Width=6 500mm; Height=15 200mm

Figure 5 : sCO2-Based Heat Removal Technology - General Installation - Isometric view 1

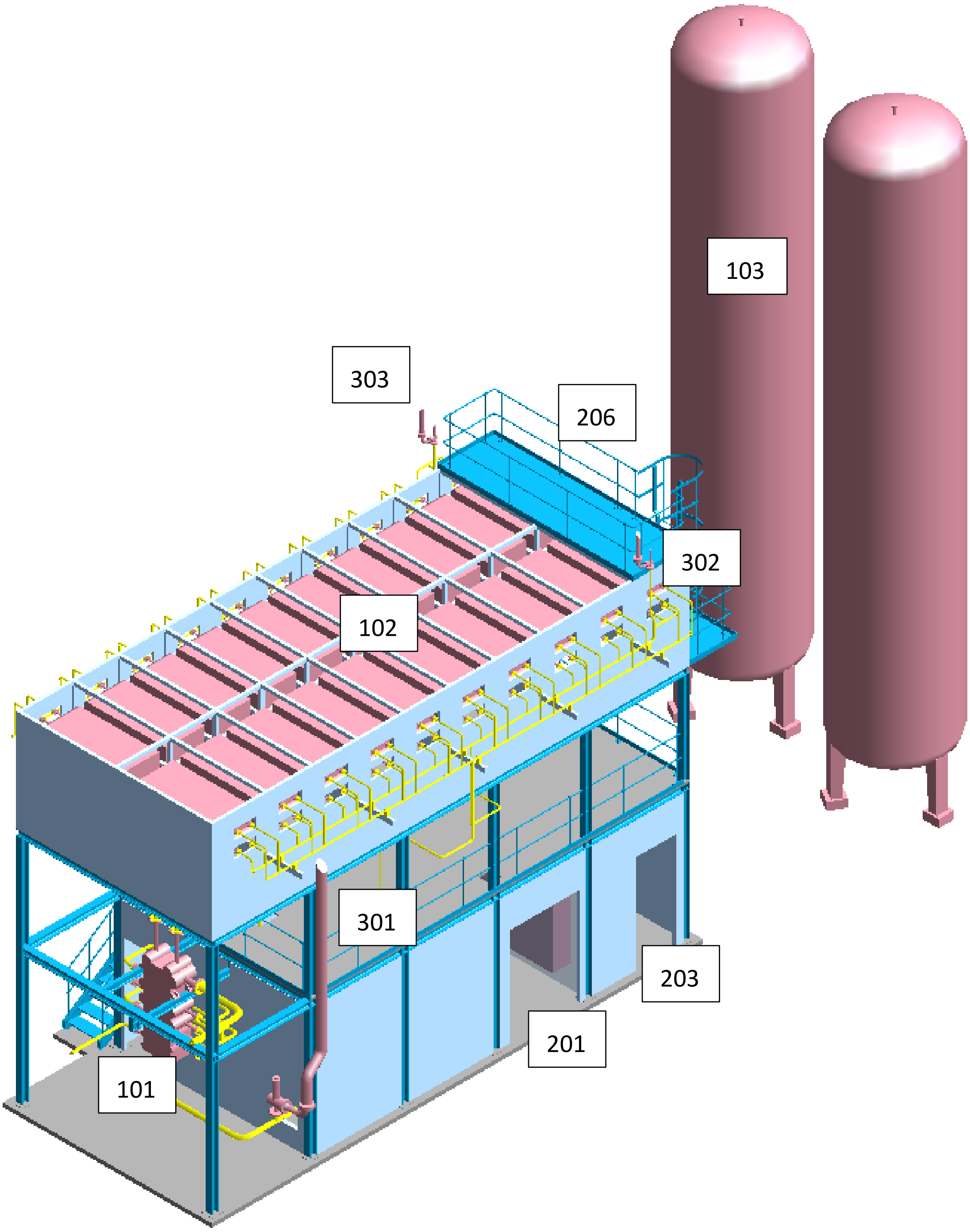


Figure 6 : sCO2-Based Heat Removal Technology General Installation - Isometric view 2

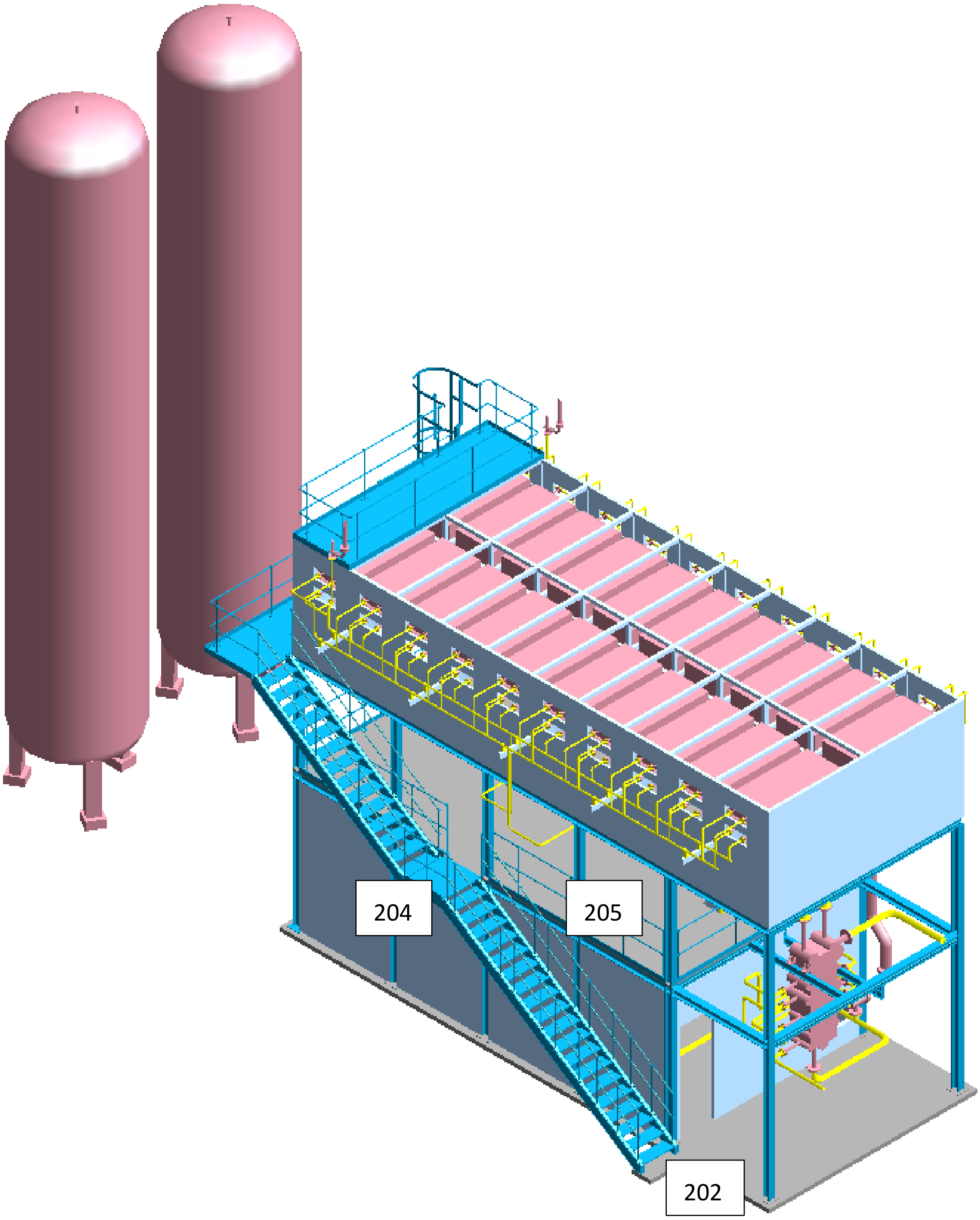
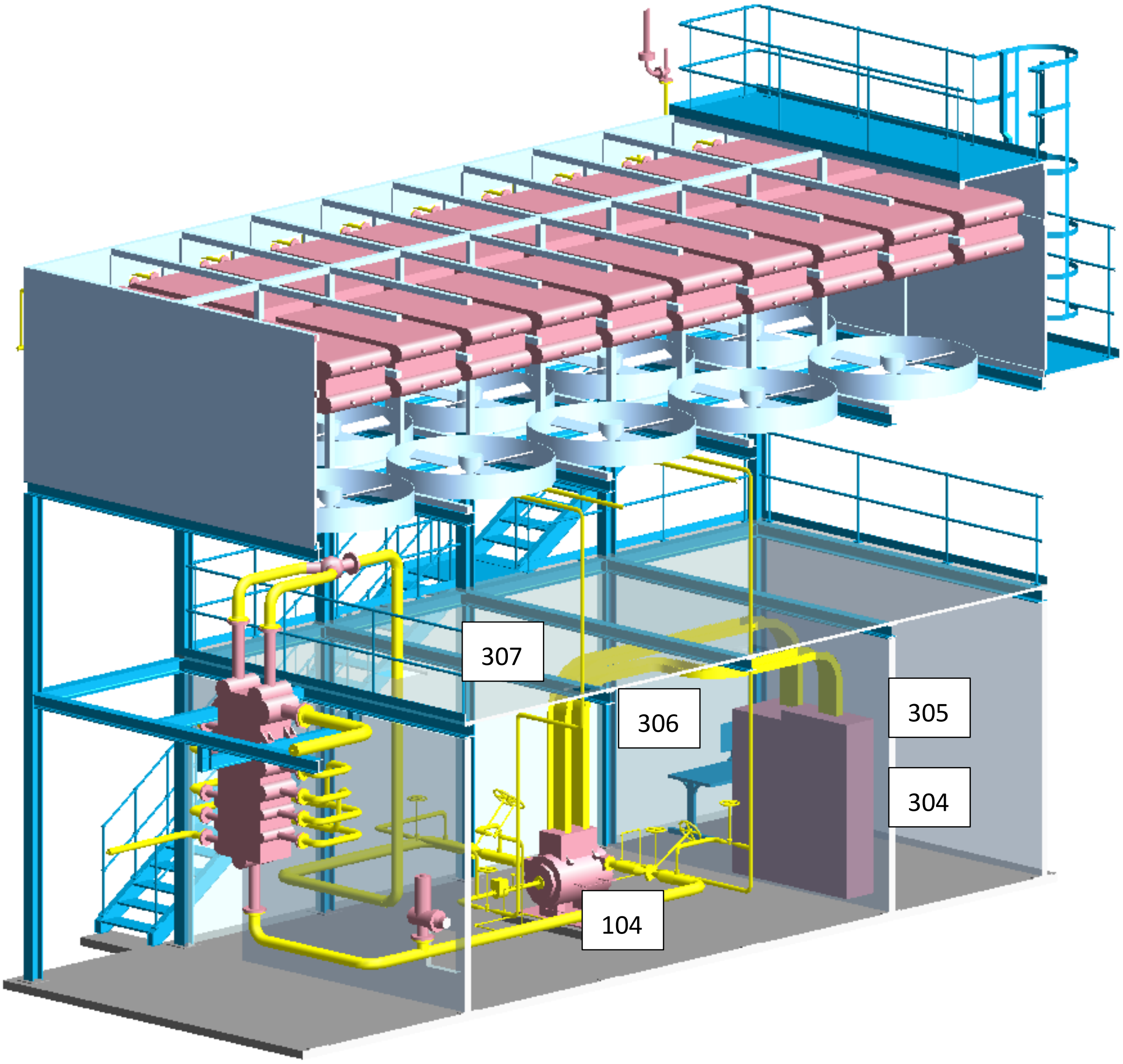


Figure 7 : sCO2-Based Heat Removal Technology - General Installation - Interior section view



Main equipment:

- 101: CHX Exchanger
- 102: DUHS Exchangers
- 103: CO2 Start-up Tanks
- 104: Turbomachine

Auxiliary equipment:

- 301: Start-up CO2 vent
- 302 & 303: CO2 loop safety vents
- 304: Electrical & Batteries cabinet
- 305: Control & Command cabinet
- 306: Control & Command post
- 307: Turbomachine electrical interface

Access:

- 201: Mechanical room main access
- 202: Mechanical room secondary access
- 203: Electrical, Control & Command room main access
- 204: Stairs to intermediary and DUHS Platform
- 205: Intermediary platform
- 206: DUHS access platform

5 sCO2-4-NPP General installation follow-up

5.1 Auxiliaries and installation complementation

The sCO2-Based Heat Removal Technology studies focused on the four pieces of equipment required for the main process. This equipment requires auxiliary systems to function properly which have yet to be designed. To ensure due consideration, a non-exhaustive list of the required auxiliary systems, some of which have been taken into account in the current design, is detailed below:

Electrical:

- Electrical cabinet
- Control & Command cabinet
- Control & Command interface
- Electrical Interface
- Battery storage for blackstart
- Power transformer

Mechanical:

- Pipework diameters
- Instrumentation & Valve systems
- Pipework conditioning
- CO2 Start-up vent
- CO2 Safety-vents
- CO2 Stripping
- CO2 Conditioning
- HVAC & Safety ventilation systems

5.2 Consideration for NPP integration

Some of the elements mentioned above could be integrated in the global architecture of the sCO2 system, but other elements, such as the instrumentation and the diameters of the pipes will be dependent on the type of plant on which the sCO2 system will be installed.

With regard to the CO2 storage tank, it should be noted that such equipment does not exist off-the-shelf to date and will be subject to specific development. In addition, an in-depth design will be required including:

- The stability of regulations
- Regulatory constraints
- The exact CO2 volume of the final configuration selected
- Start-up impact on mechanical equipment

This component is also dependant on the start-up option presented in this deliverable. Based on the current work in WP5 of sCO2-4-NPP, we present a push-up start-up with pressurized storage tank. If this start-up option will not be considered in the future, some components like the storage tanks will be modified.

Other elements will also depend on the nuclear power plant considered. Indeed, some operators may choose to use wet cooling, in order to gain in compactness for the sCO2 system (this type of cooling is more compact than dry cooling), or they may want an installation protected by a concrete building, (this deliverable presents it in a light, metallic structure in order to show the compactness). The choice of an installation of the sCO2 system on an existing plant or on a future plant will allow a more or less advanced integration.

The regulations will also be an influential factor in the architecture of the sCO2 system. Indeed, depending on the regulatory requirements, the qualification, operation, and maintenance constraints of the sCO2 system, some of the equipment presented will have to be modified (redundancy, linked instrumentation) or others will have to be added.

6 Conclusion

In this deliverable, we present an architecture of the sCO2 system. This architecture is intended to be simple and as compact as possible in order to demonstrate the small footprint of the system and thus the ease of installation near nuclear power plants.

Some auxiliary components still need to be better defined, as they depend on the regulatory requirements that will be associated with the sCO2 system and the choice of installing it on an existing plant or on a new plant design.