sCO2-4-NPP: Innovative sCO_2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants

Deliverable D8.3

Project Public Website

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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
CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	

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Deliverable Contributors

Authors

Partner	Name
ARTTIC	Susan Barreault

Contributors

Partner	Name
ARTTIC	Florian Fromm

Internal Reviewers

Partner	Name
EDF	Albannie Cagnac
USTUTT	Jörg Starflinger

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1 List of Acronyms

Abbreviation / Acronym	Description / meaning
ATHLET	Analysis of THermal-hydraulics of LEaks and Transients. Simulation code use for the analysis of the whole spectrum of leaks and transients in PWRs and BWRs. The code is applicable for western reactor designs as well as for Russian VVER and RBMK reactors.
BWR	Boiling Water Reactor
CAD	Computer Aided Design
CATHARE	CATHARE (Code for Analysis of THermalhydraulics during an Accident of Reactor and safety Evaluation) is a two-phase thermal-hydraulic simulator used, in particular, in PWR safety analyses, the verification post-accidental operating procedures, and in research and development.
CHX	Compact Heat Exchanger
DID	Defence In Depth
DUHS	Diverse Ultimate Heat Sink
EC	European Commission
EU	European Union
GA	Grant Agreement
GDPR	General Data Protection Regulation
HX	Heat Exchanger
IP	Internet Protocol
ISP	Internet Service Provider
KONVOI	KONVOI is a standardized KWU construction line of PWR with about 1300 MW electrical power.
kW	KiloWatt
LWR	Light Water Reactor
MW	MegaWatt
NPP	Nuclear Power Plant
NUGENIA	Nuclear Generation II & III Association
PMO	Project Management Office
PWR	Pressurised Water Reactor
SBO	Station BlackOut; an accident scenario where the plant is left without alternating current electrical power
sCO2	Supercritical carbon dioxide
SEO	Search Engine Optimisation
SV	Safety Valve
TCS	Turbo-compressor system
TRL	Technology Readiness Level
URL	Uniform Resource Locator
VVER/WWER	Water-Water Energy Reactor

2 Executive Summary

The sCO2-4-NPP public website is part of the project dissemination activity. Its design, realization and updates have been assigned to WP8, led by ARTTIC.

This deliverable describes the website design and the initial site content, which has been approved by the partners of the consortium.

The website objectives, target audience, and key messages are aligned with the Dissemination and Communication Plan described in D8.1. The main target audience for the public website is the general public. As such, non-technical language is used and the focus, particularly for the homepage, are the project results which are of interest for the European citizen, and specifically how the sCO2-4-NPP system further increases the safety of NPPs.

The website visual identity is based on the project logo.

The website follows a standard format for European research projects, with subpages for describing the project ("About sCO2-4-NPP"), the consortium, project documentation (press releases, public deliverables, links to scientific publications, etc.), announcing news and events, and a form for contacting the project.

The initial website content (website section "About sCO2-4-NPP") is drawn from the Grant Agreement technical annex and summarised for a general audience with still enough technical detail to interest specialists.

Google Analytics is used to assess the website effectiveness in reaching its target audience.

The website will be updated throughout the project duration, namely with project news and events.

The sCO2-4-NPP website can be consulted at: https://www.sco2-4-npp.eu.

3 Introduction

This deliverable documents the sCO2-4-NPP public website. The website communication objectives are presented, followed by the website structure and format, and finally, the initial website content. In the appendix, screenshots of the public website are provided.

4 Public Website

The sCO2-4-NPP public website can be reached at https://www.sco2-4-npp.eu/.

4.1 Website Objectives

The main objective of the website is to inform the targeted audiences of the project objectives, approach, expected results and partners in order to raise public awareness. Specific sections will be dedicated to the different target audiences and an interrelation with the NUGENIA website is planned. Publications and public deliverables will also be made available via the website.

The website will be updated on a frequent basis, providing the latest project publications and news, and the project social media accounts will be integrated.

1) To inform: What is sCO2-4-NPP? How does sCO2-4-NPP proceed? What results does sCO2-4-NPP target/achieve?

2) To convince: Why is sCO2-4-NPP needed? What are the benefits of the results? For whom are these results relevant?

4.1.1 Target audience

For reference, the sCO2-4-NPP target audiences are listed below. The sCO2-4-NPP public website is intended to reach in particular the general public, but also provide enough technical content to interest the other target audiences.

Table 1: Target audiences

Importance	Segment	Target Audience
1	End users (NPP)	NPP (all relevant types)
2	End users (other sectors)	Other power plant and industrial sectors (fossil fuel, chemical, cement, metallurgy)
3	Components manufacturers	Industrial manufacturers of components (turbomachinery and heat exchangers) (end-users)
4	Regulatory authorities	WENRA[1]
5	Standards bodies	CCPN[2], AFNOR[3], IEC[4] and CENELEC[5]
6	Scientific community	Scientific research community (nuclear safety, sCO2, turbomachinery).
7	Related EU projects	sCO2-Flex, etc.

[1] Western European Nuclear Regulators' Association

[2] Coordination Committee for French Standardisation Policy

[3] Association Française de Normalisation (French Standardisation Association)

[4] International Electrotechnical Commission

[5] European Committee for Electrotechnical Standardization

Importance	Segment	Target Audience
8	NUGENIA[6]	all major players in the nuclear field in Europe, including industry, research and academia
9	Other relevant European and international organisations	NEA[7], WNA[8], IAEA[9]
10	General public	European citizens, science & engineering students

4.1.2 Key messages

The key message of the homepage:

- "Bringing nuclear safety solutions closer to market"

The key message of the "About the project" section:

- "sCO_2 heat removal system for a higher safety level in nuclear power plants"

4.1.3 Website Analytics and Success Criteria

Google Analytics will be used to periodically assess the effectiveness of the public website in meeting the dissemination objectives.

The success of the website will be monitored and assessed based on the number of unique visitors (at least 100) and will include more specific information when available such as dwell time, origin, contacts, etc. Interrelation with the NUGENIA website will also be assessed.

4.2 Website Structure

Table 2: Website structure

Level 1 (Navigation menu)	Level 2	Description of content
About	The project	Project rationale
	The consortium	Brief description of the partners' roles
How It Works	sCO2-based heat removal concept	Description of the sCO_2 system
	Technical objectives & methodology	Description of main technical objectives, expected results and project methodology
	Expected impact	Description of expected impact on the environment, science and industry
News & Events	N/A	List of project news and events (most recent item appears first) with image, title, short

[6] Nuclear Generation II & III Association

[7] Nuclear Energy Agency

[8] World Nuclear Association

[9] International Atomic Energy Agency

Level 1 (Navigation menu)	Level 2	Description of content
		description. "Read more" click to open full description.
Documentation	Media & downloads	List of downloadable project documents (flyers, communication kit, press kit, poster, video, etc.) with thumbnail and filename
	Scientific publications & Articles	List of scientific and popular press publications with links to abstracts, articles
	Public deliverables	List of public deliverables with links to download documents
Event Registration	N/A	Hidden page for future workshop announcements and registration.
Contact	N/A	Contact form for sending an email to the project management office

4.3 Website Format

The website development focuses on user-friendly design, effective navigation, browser consistency, fast loading pages and mobile compatibility, presenting the content in a clearly structured way and considering Search Engine Optimisation (SEO) factors.

4.3.1 Metadata (keywords)

Nuclear power plant safety, LWR, supercritical carbon dioxide, sCO_2 heat removal system, decay heat removal, roadmaps to market, validation, virtual NPP, KONVOI PWR simulator, ATHLET, CATHARE, nuclear licensing, passive safety systems.

4.3.2 Visual Identity

The website visual identity is based on the sCO2-4-NPP logo. The look and feel is designed to be professional and modern.

4.3.3 Header for all pages (navigation menu)

The header for all pages includes the sCO2-4-NPP logo and the Level 1 page titles.

4.3.4 Sidebar (social media)

The sidebar shows links to social media sites Twitter and LinkedIn so that visitors can easily share content from the sCO2-4-NPP public website.

4.3.5 Footer for all pages (legal mentions)

The footer on all pages includes:

Table 3: Page footer

European emblem:	EC acknowledgement & disclaimer: This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847606. This text reflects only the author's view and the Commission is not liable for any use that may be made of the information contained therein.	Navigation links (site map) including links to Imprint & Disclaimer, Privacy Policy, Copyright, Sitemap	Twitter live feed	Links to sCO2-4-NPP on Twitter and Linked in

4.4 Website Content

4.4.1 Home

The homepage provides essential information about the project and teasers with links to the website subpages for the reader looking for more detailed information:

The main aim of sCO2-4-NPP is to bring an innovative technology based on supercritical CO_2 (sCO_2) for heat removal in nuclear power plants (NPPs) closer to the market. sCO2-4-NPP builds on results of the previous Horizon 2020 project sCO2-HeRo (http://www.sco2-hero.eu/), where the technology was first developed and brought to experimental proof of concept (TRL3).

The sCO2-4-NPP technology will be **a backup cooling system, attached to the principal steam-based cooling system, which will considerably delay or eliminate the need for human intervention (>72 hours) in case of accidents such as station blackouts, thus replying to the need for increased safety in NPPs**.

Thanks to the compact size and modularity of the system, it can be retrofitted into existing NPPs and included in future NPPs under development.

Through a close collaboration between major industrial actors and highly-skilled academic institutions, the sCO2-4-NPP partners will bring the full system to TRL5 (technology validated in relevant environment) and parts of it to TRL7 by carrying out experiments, simulations, design, upscaling and validation of the technology in a real NPP Pressurised Water Reactor (PWR) simulator. Regulatory requirements will be considered in the conceptual design of components and the system architecture to increase the chances of acceptance by European nuclear safety authorities and speed up the time to market. Detailed technical, regulatory, financial and marketing roadmaps will be developed for bringing the technology to industrial use (TRL 9) after the project.

The sCO2-4-NPP technology will increase NPP safety, decrease the plant overall environmental footprint, and potentially lower costs for energy consumption, thus increasing the competitiveness of European NPP operators.

To achieve the objectives, the consortium will use the following test loops:

- Reactor glass model (KSG/GfS): The reactor glass model is a reproduction of a two-loop pressurised water reactor (Siemens/KWU design) at a scale of 1:10. It allows the visualisation of operational procedures, incidents and accidents as well as thermal hydraulic effects in a light water reactor. All the phenomena visible in the reactor glass model have occurred in real nuclear power plants.

- 200 kWth sCO2-HeRo loop: Developed for the sCO2-HeRo project, this loop will provide partners with all the input data necessary to carry out the MW scaling-up. It is currently coupled with the glass model at GfS and is operational.

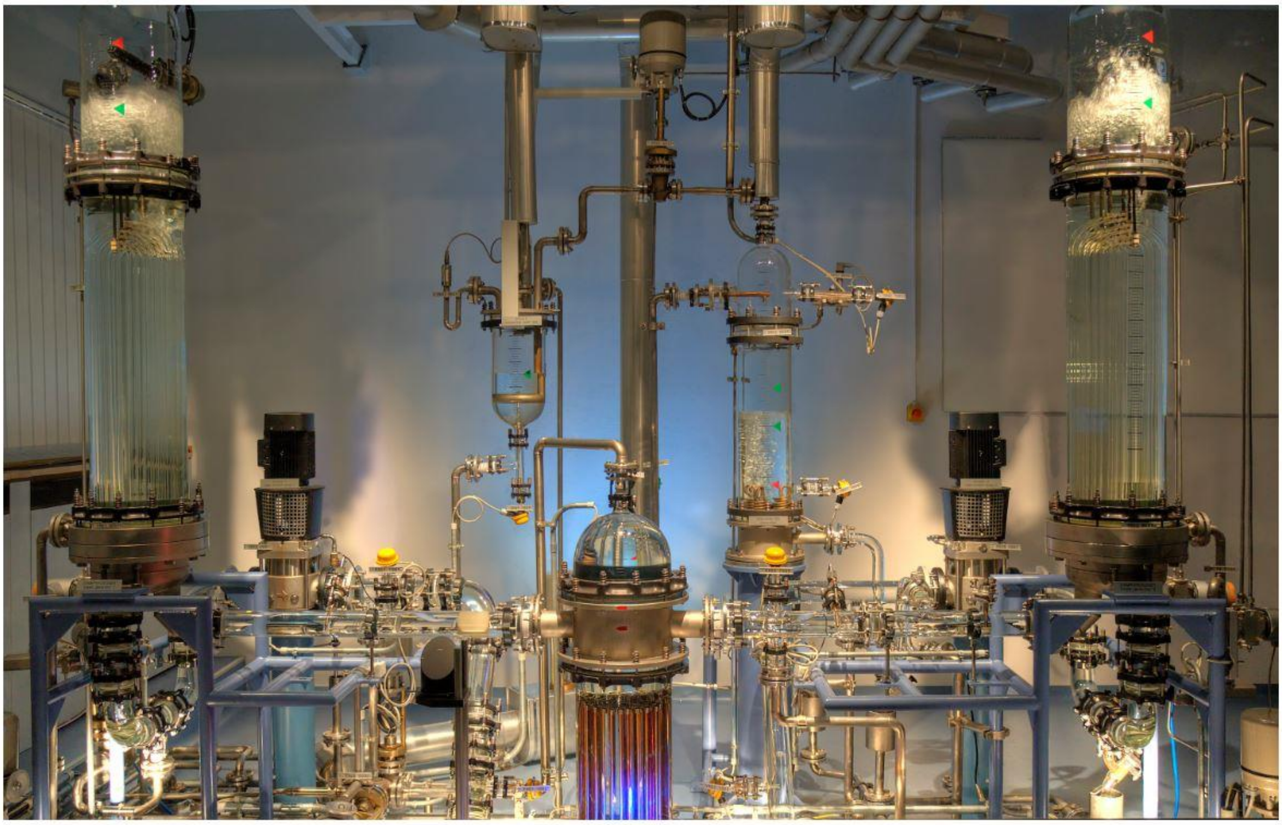

Figure 1: Glass Model (photo copyright: Gesellschaft für Simulatorschulung, 2019)

- Training simulator (KSG): The KONVOI simulator is an almost identical replica of a German KONVOI power plant (Konvoi/ pre-Konvoi class of PWR with about 3900 MW thermal power, 1300-400 MW electrical power, 4 loop primary circuit)) with respect to the control room. This implementation will allow partners to test the sCO_2 system by simulating its integration in an NPP from a control room operator's point of view.

Figure 2: Simulator control room (Image source: GfS, Photographer: Bernhard Ludewig)

4.4.2 About sCO2-4-NPP

4.4.2.1 The Project

Rationale

The Fukushima Daiichi nuclear accident demonstrated the vulnerability of nuclear power plants (NPPs) to loss of electrical power and loss of ultimate heat sink events. During the accident, the insufficient performance of the heat removal system resulted in core melt and in the spread of radioactive material into the surroundings with an overall cost of 188 billion dollars as estimated by the Japanese government. The prevention and mitigation strategies for these events were analysed and presented in multiple publications. Among the lessons learnt to overcome the vulnerability was the need for safer and more reliable fuel heat removal solutions. **Safety standards have hence been improved at an international level requiring the development of new technologies for improving the safety of both existing and future nuclear reactors**. The developed solutions are required to provide higher levels of safety in the case of accidents, while at the same time not degrading safety during normal operation. In addition, the new safety solutions must not require major modifications to existing reactor installations, workers' circulation in the building, and radiation protection measures, and should be available at reasonable installation costs.

Technologies based on the use of sCO_2 can significantly increase the level of safety in the case of accidents, since sCO_2 is non-flammable and non-toxic and, when attached to an NPP as a backup cooling system, delays the need for human intervention. In addition, it can potentially lower costs of energy production and subsequent recovery of the reactor thanks to the compact size of the equipment. The compact size and high energy density of the system also means an overall smaller plant footprint.

The Horizon 2020 project sCO2-HeRo developed and proved the concept of a heat removal backup technology based on sCO_2 that can safely, reliably and efficiently remove residual heat from nuclear fuel without the need for external power sources making it an excellent backup cooling system for the reactor core in the case of a station blackout and loss of ultimate heat sink. The concept consists of several modular sCO2-systems, attached to the existing heat removal system, to remove decay heat from the reactor.

By bringing this technology closer to market, sCO2-4-NPP will offer a new solution to NPP operators that will improve plant safety in the case of an accident with minimal impact on existing reactors, thus decreasing the negative effects on the environment, citizens and the economy. The sCO2-4-NPP solution can potentially also lead to improvements in energy efficiency in other energy (e.g. fossil, solar) and industrial sectors (e.g. aeronautics, space, cement, steel).

4.4.2.2 Partners

The sCO2-4-NPP partners are listed along with their organisations' logos, websites and their role in the project.

Table 4: List of partners

Full Name	Short Name	Website	Role in project
ELECTRICITE DE FRANCE	EDF	https://www.edf.fr/en/the-edf-group	Coordinator of the project. Definition of the operation procedures related to the new cycle. Preparation of licensing documentation.
UNIVERSITAET STUTTGART	USTUTT	https://www.uni-stuttgart.de/en/	Technical coordinator of the project, ensuring the link between the former project sCO2-HeRo and sCO2-4-NPP. Numerical simulations of the sCO2-4-NPP System with ATHLET. Support of FIVES to design heat exchangers and thermodynamic behaviour of the overall solution.
NUOVO PIGNONE TECNOLOGIE SRL	NP TEC	https://www.bhge.com/	Expertise in the fields of gas turbines and compression technologies, gas re-injection for enhanced oil recovery (high pressure CO2 reinjection) and gas processing of sour and acid gases.
FIVES CRYO	FIVES CRYO	https://cryogenics-energy.fivesgroup.com/	Expertise in the design and improvement of the heat exchangers.
GFS GESELLSCHAFT FUR SIMULATORSCHULUNG MBH	GfS	https://simulatorzentrum.de/en/	Testing the technology in a combined steam and sCO2-cycle for different relevant environmental conditions. Validation of the sCO2-4-NPP cycle in a virtual PWR.
KSG KRAFTWERKS-SIMULATORGESELLSCHAFT MBH	KSG	https://simulatorzentrum.de/en/	Operation of the Glass Model and the KONVOI NPP Simulator. Simulation in a virtual NPP environment.

Full Name	Short Name	Website	Role in project
CENTRUM VYZKUMU REZ S.R.O.	CVR	http://cvrez.cz/en/	Transient (accident) simulations of the whole system (VVER with sCO_2 heat removal system and benchmark calculation for sCO_2 heat removal at the glass model) (coupling ATHLET/CATHARE with Modelica). The thermodynamic cycle design of the sCO_2 heat removal system. Testing of the natural circulation and condensation of the steam cycle cooled by sCO2. Optimisation and testing of the sink HX. Real-time simulator of the sCO_2 heat removal system.
INSTITUT JOZEF STEFAN	JSI	https://ijs.si/ijsw/V001/JSI	Identification of the regulatory elements to be considered in the design of components and system. Independent review of the documentation addressing the compliance with licensing requirements of a possible user country. Developing regulatory roadmap to reach TRL9.
UNIVERSITAET DUISBURG-ESSEN	UDE	https://www.uni-due.de/en/index.php	Turbomachine dynamic behaviour testing in the Glass Model and evaluation of the results. Improving the design to achieve industrial requirements for robustness based on the results.
UJV REZ, a. s.	NRI	https://www.ujv.cz/en	Transient (accident) simulations of the whole system (VVER with sCO_2 heat removal system and benchmark calculation for sCO_2 heat removal at the glass model) (coupling ATHLET/CATHARE with Modelica), responsible for the ATHLET part. Production and review of licensing documents. Supporting the task of safety requirements.
ARTTIC	ARTTIC	http://www.arttic.eu/pages/en/home.php	Project management and communication.

4.4.3 How It Works

4.4.3.1 sCO2-based Heat Removal Concept

The sCO2-HeRo system is an innovative heat removal concept that has the potential to improve the safety of both currently operating and future Nuclear Power Plants (NPP) in Europe. The system is independent of NPP type and can be easily retrofitted to existing reactors. **There is to date no such heat removal system with sCO_2 as working fluid applied in the nuclear industry today**, despite ongoing research on sCO2-power cycles as the main system in generation IV reactors. Based on this system, sCO2-4-NPP will develop a scaled-up sCO_2-based heat removal system using real NPP dimensions and specifications for integration and validation in a real NPP (KONVOI PWR type). The sCO2-4-NPP technology will be implemented as an independent complement to the existing water-based systems and will have a very compact design, which will not require any major modifications to the existing NPP infrastructure.

The sCO2-4-NPP system will safely remove heat from the reactor core through the use of several highly compact, self-propellant, self-sustaining, and self-launching cooling system modules where each module is powered by an integrated Brayton-cycle using sCO_2 as its working fluid. At the time of an accident, all the sCO2-4-NPP system modules will be turned on for a maximum nominal power to remove decay heat. As decay heat, after reactor shutdown, decreases monotonically in the days following the accident, the need for heat removal decreases accordingly and hence one module after the other is turned off.

In general, a simple Brayton cycle consists of a heat exchanger (CHX) to the heat source, a turbo-compressor system (TCS) consisting of a turbine, compressor and generator, and a heat exchanger to the diverse ultimate heat sink (DUHS). The sketch shows one Brayton cycle attached to a Boiling Water Reactor. In case of accident, the containment isolation valves will close and the safety valves (SV) will open. The steam from the generator will flow into the CHX, which must be compact in size to fit into the limited space available in existing reactor containments. Inside the CHX the CO2 is heated up. The sCO_2 then flows through the turbine (T) which is located on the same shaft as the compressor (C) and generator (G). Downstream of the turbine, the sCO_2 is cooled by means of air and is delivered to the compressor and back to the CHX.

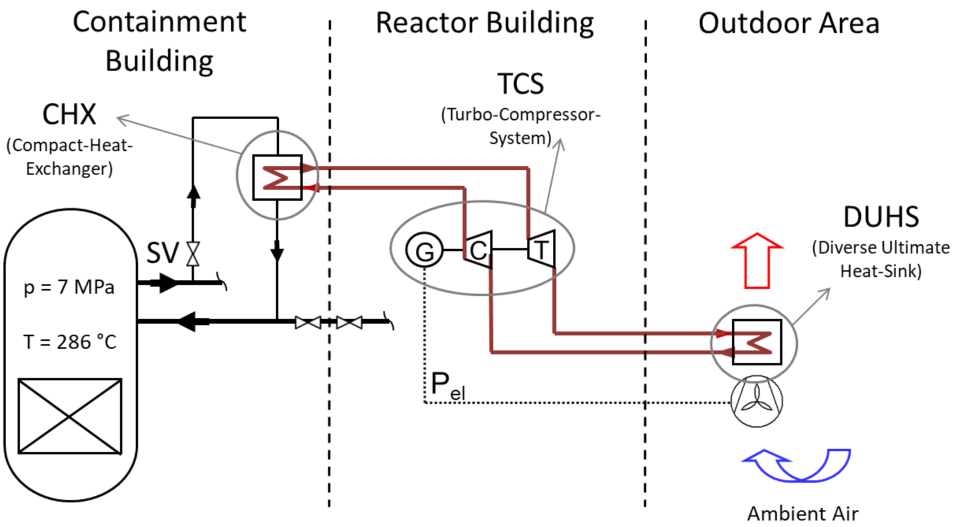

Figure 3: Schematic sketch of sCO2-HeRo system attached to a BWR. The coloured lines correspond to the sCO_2 circuit. (Source: Venker, "Development and Validation of Models for Simulation of Supercritical Carbon Dioxide Brayton Cycle and Application to Self-Propelling Heat Removal Systems in Boiling Water Reactors", University of Stuttgart, IKE2-156, ISSN 0173-6892 (2015).)

The Brayton cycle fulfils the safety goal of removing decay heat from the core to the diverse ultimate heat sink (air) while simultaneously producing electricity. Over a large operating range, the turbine of the Brayton cycle provides more power than the compressor needs to operate; the excess power is converted into electricity. This means that the sCO2-4-NPP system modules are independent from internal or external power supply raising nuclear safety to a new level. In addition, the excess electricity that is produced can be used to power additional fans for better heat removal to air or to power other systems, like batteries.

As the sCO2-4-NPP modules deliver the heat to air, safe decay heat removal is accomplished without the need for external water contributing to an increased level of safety.

The sCO2-4-NPP modules shall operate with almost no operator action (design goal). They shall start upon automated signals, e.g. magnetic valves, operate self-propellant and be self-regulating. Achieving these operational targets, **the sCO2-4-NPP system will reduce active operator interventions in case of accidents and thus reduce the probability of human error**.

Due to the similar steam parameters of a BWR and the steam generator of a Pressurised Water Reactor (PWR), from the thermodynamic point of view, **this system can be attached to both existing PWRs and BWRs, thus addressing the majority of Light Water Reactors in Europe**.

4.4.3.2 Technical Objectives and Methodology

The overall aim of sCO2-4-NPP is to contribute to an increased safety of Nuclear Power Plants (NPPs) in case of accidents by further specifying, designing and validating the sCO2-based heat removal system developed in the previous sCO2-HeRo project on a NPP and preparing the necessary roadmaps to bring it closer to industrial use.

By bringing the system closer to market, sCO2-4-NPP will provide a heat removal solution for NPPs that will increase the grace period in case of accidents to beyond 72 hours (compared to a grace period in current reactors of ~48 hours), delaying the need for human intervention in case of an accident and thus decreasing the risk of human errors and the spread of radioactive material into the surrounding environment, ultimately reducing harm to both workers and citizens. The sCO2-4-NPP solution will be independent of the type of reactor operated (BWR, PWR, VVER, HTR, etc.) and will have the possibility to be retrofitted to the majority of current reactors in Europe as well as being integrated into future reactors.

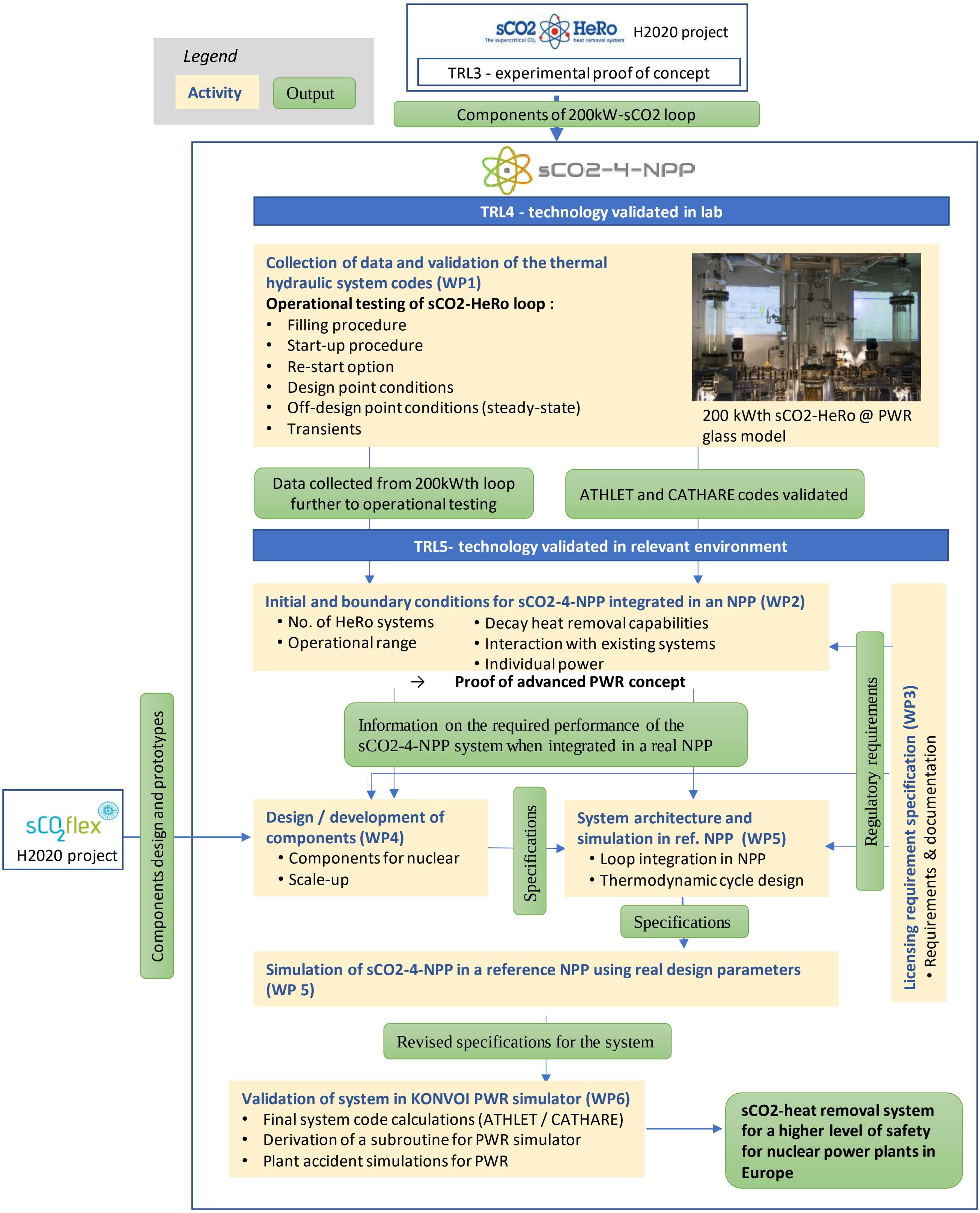

Figure 4: Project methodology

In the former sCO2-HeRo project, the concept was validated in laboratory conditions to TRL3. In sCO2-4-NPP, the complete system will be further developed to reach TRL5 (technology validated in relevant environment) and parts of it will reach TRL6-7. To achieve this, the following technological and innovation objectives have been defined:

Objective 1: Validation of sCO_2 models in thermal-hydraulic system codes on lab scale

To allow for necessary simulations of the sCO2-4-NPP system in a nuclear environment, the sCO_2 models will be validated in the thermal-hydraulic system codes ATHLET and CATHARE (system codes used for reactor transient simulations, accepted in many licensing processes) and the Modelica code (real time running code to simulate parametric studies of the sCO2-HeRo loop) by means of experiments carried out on the 200 kWth sCO2-HeRo loop installed at GfS.

In addition, the models for turbomachinery, compact heat exchangers and the control system will be assessed for ATHLET, CATHARE and Modelica as an important step of the validation procedure from TRL3 (experimental proof of concept) to TRL4 (technology validated in lab).

Targeted result: ATHLET and CATHARE reproduce data of the sCO2-HeRo loop taking into account known uncertainties related to the codes.

Objective 2: Specification of an upscaled system, boundary conditions and simulations for implementation of an sCO2-4-NPP loop in a full-scale NPP (PWR)

In the sCO2-HeRo Project, upscaling of components led to the design of an sCO_2 loop for BWR and VVER reactors. In sCO2-4-NPP, the design of the sCO_2 loop will be upgraded for implementation on a PWR-type NPP where it will be attached to the steam generator of the secondary loop to safely and reliably remove heat for conditions which would lead to severe accidents without countermeasures. It is the ambition that by implementing the sCO_2-cycle conditions the reactor can be cooled sufficiently without external grid connection, without emergency diesels, and without using the existing heat sink. The PWRs that will be concerned represent almost the entire PWR fleet of European large-scale NPPs. Based upon the results of accident simulations, specifications for the design will be available providing important boundary conditions, as well as heat removal capacity.

Targeted results: Specifications of sCO2-4-NPP system modules (number, power, expected performance) that safely and reliably remove decay heat produced by ATHLET and CATHARE simulations.

Objective 3: Preparation of a licensing roadmap of the sCO2-4-NPP system to ensure compliance with applicable regulation

This objective is critical for the adoption of the sCO2-4-NPP technology by utilities, and hence for shortening the time to market. sCO2-4-NPP will identify requirements on the system arising from licensing and regulation and ensure that they are included in the design process of components and system architecture. In addition, the partners will prepare a roadmap of future steps to achieve licensing by nuclear authorities.

The foreseen Defence in Depth (DID) level 4a will be assessed and requirements for system design will be specified. The selection of the DID level will serve as boundary conditions for the operation of the system, application of safety principles (redundancy), etc.

Targeted results: Identification of requirements for DID level 4a, initiation of licensing process, and licensing roadmap to reach TRL9.

Objective 4: Design of components for the sCO2-4-NPP loop in the context of licensing requirements (turbomachinery, heat exchanger, auxiliary systems)

As mentioned above, the design of components within the framework of nuclear licensing is an important step to enable the adoption of sCO2-4-NPP by nuclear authorities and NPP operators. This is especially true for new types of components to be attached to the steam generator of a NPP. The detailed design of the sCO2-4-NPP components (turbomachinery, heat exchangers and auxiliary systems) will therefore be specified taking into account regulatory requirements. This detailed design will define the dynamic behaviour of the sCO_2 cycle, which is required for the system architecture (objective 5) and the validation of sCO2-4-NPP loop (objective 6). Results from work on component design and prototyping in the ongoing H2020 sCO2-Flex project (https://www.sco2-flex.eu/) coordinated by EDF and with many partners also involved in sCO2-4-NPP will support the achievement of this objective. Robustness of the turbomachinery will also be improved by the development of an improved small-scale turbomachine to be included in the sCO2-HeRo loop built in the previous project.

Targeted results: CAD designs of components that comply with nuclear licensing requirements available and key performance data (dimensions, masses, efficiencies, etc.) documented.

Objective 5: Final design of the system architecture of sCO2-4-NPP integrated in a full-scale NPP

This objective will demonstrate the capability for retrofitting the sCO2-4-NPP system into existing PWRs with minimal impact on the reactors and will provide the necessary information to integrate the system into a future reactor by identifying necessary auxiliaries and the footprint. A 1:1 scale design of sCO2-4-NPP modules integrated into a PWR will be developed and numerical accident simulations will be carried out using ATHLET and CATHARE to assess the reliable heat removal of the resulting sCO2-4-NPP modules. The interaction with different active safety systems or severe accident safety measures will be simulated with ATHLET and CATHARE to demonstrate that the sCO2-4-NPP system will not negatively interact with active safety systems installed at PWRs.

Targeted results: CAD drawings of 1:1 scale design of sCO2-4-NPP modules integrated in PWR and safe heat removal of the designed system validated by ATHLET and CATHARE simulations.

Objective 6: Validation of sCO2-4-NPP loop in a virtual "relevant nuclear environment" PWR

TRL5 (technology validated in relevant environment) will be achieved by using a unique virtual relevant nuclear environment: a real scale training simulator of a German PWR. The PWR simulator that will be used provides a unique opportunity to assess the operation and interaction of the sCO2-4-NPP technology with a real NPP without neutrons. Other than testing on an operating NPP (which is not possible for safety reasons), using such a training simulator is the environment closest to reality that exists. Using the results from ATHLET/Modelica, a fast running model that will simulate the interaction of the sCO2-4-NPP cycle with the PWR will be derived and programmed into the software of the training simulator. Several accident sequences will be simulated and assessed.

Another important aspect of the virtual integration of the sCO2-4-NPP system into the training simulator is that it allows NPP operators to become familiar with the new sCO2-4-NPP system. An easier market entrance is achievable by demonstrating how the system can be retrofitted to the PWR with minimal associated changing of the plant.

Targeted results: Operation of sCO2-4-NPP integrated into the KONVOI NPP simulator without negatively interfering with the existing safety and operational systems, validation that the grace period can be extended to beyond 72 hrs and that the decay heat is safely removed from the core to the diverse ultimate heat sink (air, air cooling towers).

Objective 7: Prepare technical, regulatory, financial and organisational roadmaps to bring sCO2-4-NPP to market

To prepare the required steps after the project to bring the sCO2-4-NPP system to market, roadmaps for technical fine-tuning, demonstration activities, financial, regulatory and logistic requirements of the system will be defined. This will provide important input to the exploitation plan for the sCO2-4-NPP technology and will allow a direct continuation of activities after the end of the project to bring the system all the way to the market.

Targeted results: Detailed technical, regulatory, financial and organisational roadmaps for bringing sCO2-4-NPP to market.

4.4.3.3 Expected Impact

Impact area	How sCO2-4-NPP will reach the expected impacts
Environment & Society	The Fukushima Daiichi accident has revealed how dependent active safety systems are on a supply of energy and of water. Active safety systems often move enormous amounts of water, which must be refilled at some point in time and require an external power supply. A major difference between the sCO2-4-NPP system and active systems is its independence from external sources. **As the sCO2-4-NPP modules deliver the heat to air, safe decay heat removal is accomplished without the need of external water or power contributing to an increased level of safet**y. The sCO2-4-NPP modules shall operate with almost no operator action (design goal). They shall start upon automated signals, e.g. electro-magnetic valves, which are usually closed due to electro-magnets as long as electricity is available and open automatically, if electricity fails. Achieving these operational targets, the sCO2-4-NPP system will reduce active operator interventions in case of accidents and thus reduce the probability of human error. When attached to an NPP as a backup cooling system, the sCO2-4-NPP system **delays the need for human intervention in case of accidents to beyond 72 hours (compared to a grace period in current reactors of about 48 hours) thus decreasing the risk of human error and the spread of radioactive material into the surrounding environment**, ultimately reducing harm on both workers and citizens.
Science & Innovation	There is to date no such heat removal system with sCO_2 as a working fluid applied in the nuclear industry today. The sCO2-4-NPP project **contributes to the overall scientific and technical knowledge base in the field of sCO_2**, keeping European industrial and academic research centres at the forefront of this field. The project continues the **combination of simulation results with physical tests on loops allowing better apprehension of the real behaviour** of this type of system. The heat recovery system can be used for purposes other than backup safety systems in the nuclear power industry. **sCO_2-based heat recovery technology can be used in many industrial processes to significantly increase the energy efficiency of the system concerned.** The sCO2-4-NPP technology will be **applicable to other energy conversion systems such as fossil fuel power plants**. There are also promising heat sources under development, including several renewable energy sources such as **high temperature fuel cells, concentrated solar power, and geothermal power** which can benefit from the technology. The advances made on sCO_2-based heat recovery in this project will also be applicable to **waste heat recovery in aeronautics, space and industrial plants (cement, steel)**.
European Industry	For the nuclear power industry, a safer heat removal system also implies important **cost savings in case of accidents**, since both the reactor equipment and the environment will be less affected. Furthermore, the **initial costs for installation of the technology are expected to be low**, since the system is compact and no major changes to the existing NPP infrastructure are required. For future reactors, the increase in TRL at the end of the project will facilitate the appropriation of the system by manufacturers to integrate it into their future offers. The **operational costs are also expected to be low** since CO_2 is a relatively inexpensive chemical. The specificity of the sCO2-4-NPP system is also its **modularity**. In case of an accident, radioactive particles decrease exponentially in the days following the accident and the power needed to remove the heat decreases accordingly. Therefore, the sCO2-4-NPP system will be composed of several loops which by the time of the accident will be turned on for maximum power to remove

Impact area	How sCO2-4-NPP will reach the expected impacts
	decay heat. As the need for heat removal decreases in the days following the accident, one module after the other is turned off. This makes the system very competitive with regards to current heat removal systems and will allow NPPs to increase safety in a cost-efficient way. A modular system also makes maintenance intervention easier. The need for space or height is very low since **the system is compact**. The compact size and high energy density of the system mean an overall smaller plant footprint. Over a large operating range, the **turbine of the Brayton cycle provides more power than the compressor needs to operate; the excess power is converted into electricity**. The excess electricity that is produced can be used to power additional fans for better heat removal to air or to power other systems, such as batteries. **The sCO2-4-NPP system is designed to be retrofitted to the majority of current reactors in Europe**. Due to the similar steam parameters of a Boiling Water Reactor (BWR) and the steam generator of a Pressurised Water Reactor (PWR), from the thermodynamic point of view, this system can be attached to both existing PWRs and BWRs, thus addressing the majority of Light Water Reactors in Europe. The sCO2-4-NPP system does not require major modifications to existing reactor installations, workers' circulation in the building or radiation protection measures. **This technology will allow European NPPs and related technology equipment manufacturers to increase their competitiveness and growth** in their respective international markets. Partners NP TEC and FIVES, who develop and commercialise turbomachinery and heat exchangers respectively, will benefit from the knowledge generated in the project on the use of a sCO2-cycle as a back-up system for heat removal in a nuclear environment. This will allow them to **develop new product lines for the nuclear energy market**.

4.4.4 News & Events

This page displays a list of project news and partner participation to external events, such as scientific conferences. An image, title, date and short description is displayed for each item, with a "Read more" link, which when clicked opens the full description. The most recent item appears first.

4.4.5 Documentation

4.4.5.1 Media/downloads

This page displays a list of downloadable project documents (flyers, communication kit, press kit, poster, video, etc.) with thumbnail, description and filename.

4.4.5.2 Scientific Publications and Articles

This page displays a list of scientific and popular press publications with links to abstracts or articles. This page should be hidden until a scientific paper or press article is published.

4.4.5.3 Public Deliverables

This page displays a list of the public deliverables with links to submitted deliverables. This page should be hidden until a public deliverable becomes available.

4.4.6 Event Registration

This page should be hidden until announcement of the first workshop. The page should be adaptable to accommodate the phases of workshop planning:

- "Save the date" Announcement of date and location
- Invitation with preliminary agenda and link to reservation form.
- Summary of event with links to workshop materials (presentations, etc.).

4.4.7 Contact

This page contains a contact form to email the project management office. The email address used is contact-management@sco2-4-npp.eu which reaches the ARTTIC project team for sCO2-4-NPP.

Contact details for the Project Coordinator and the PMO are also listed.

4.4.8 Legal mentions

4.4.8.1 Imprint & Disclaimer

Imprint

Webmaster

To contact the webmaster: info-paris@eurtd.com

Webhosting and Webdesign

ARTTIC

Registration details and legal entity

ARTTIC S.A.S.

Headquarters and Publication Director

ARTTIC

58A rue du dessous des berges

75013 Paris

FRANCE

info-paris@eurtd.com

Website

Disclaimer

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Accountability for links

We will link to external sites that help us perform our mission – to inform about sCO2-4-NPP. Links to external servers do not imply any official sCO2-4-NPP endorsement of the opinions or ideas expressed therein, or guarantee the validity of the information provided. Links to commercial sites are in no way an endorsement of any vendor's products or services.

Links will be provided to external servers that are managed in a professional manner (i.e., it is fully operational, is available most of the time, does not serve inaccurate information or obscene graphics, etc.). This server will not link to external servers if such a link would appear to provide an official endorsement of fundraising efforts or lobbying for a political agenda.

Responsibility for the content of external links (to web pages of third parties) lies solely with the operators of the linked pages. No violations were evident to us at the time of linking. Should any legal infringement become known to us, we will remove the respective link immediately.

4.4.8.2 Privacy Policy

The privacy policy of ARTTIC, as webmaster, covers the topics of Information and Rights of Data Subjects, Data Collected and Purposes of Processing, Cookies, Recipients of Data, Storage of Data, Subcontracting, Procedures in Case of Security Breach Detected by ARTTIC, Cross-border and Non-EU Processing, and Control Authority. The privacy policy is implemented and available at https://www.sco2-4-npp.eu/privacy-policy/.

4.4.8.3 Copyright

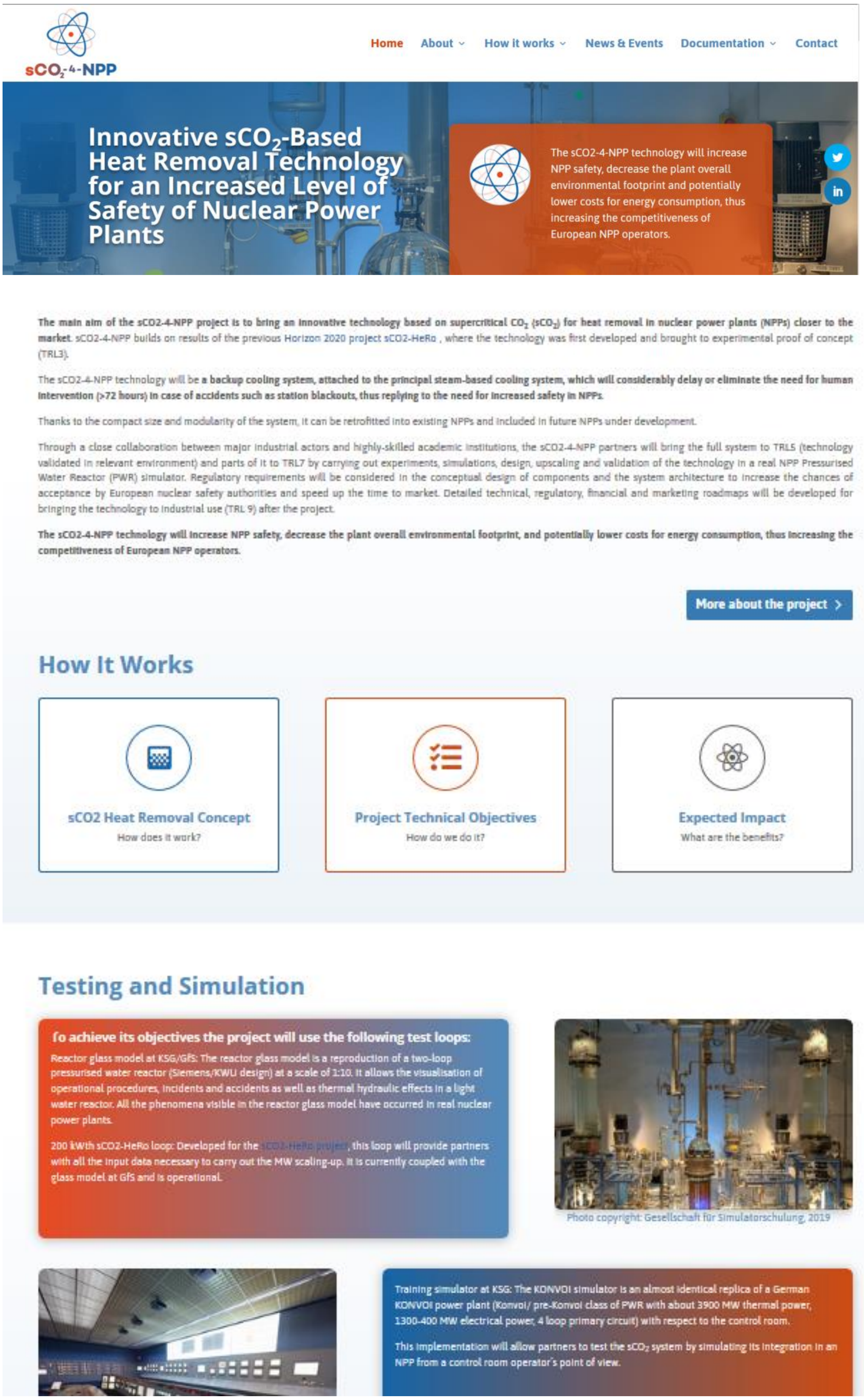
Images of individuals are the copyright of the photographer or the personal property of the person displayed. Illustrations are the property of the organisations which provided them to the webmaster. You may download, reproduce and retransmit material displayed on this web site for non-commercial, personal use. If you do so, you agree to mention the source and retain all copyright and other proprietary notices contained in the materials. You may not use, distribute, modify, transmit, or post the content of the sCO2-4-NPP website for public or commercial purposes, including any text, images, audio, or video, without the written permission of sCO2-4-NPP.

5 Conclusion

The sCO2-4-NPP public website has been launched at M6 (February 2020) and will serve as an important means for project communication and dissemination for the duration of the project. Essential project information is provided, including the consortium partners, the technical objectives, methodology, expected results and impact. The website is set up to communicate project news and events and make available project documentation such as public deliverables and scientific papers.

Appendix A Website Screenshots

A.1 Homepage



A.2 About

A.2.1 About – The project

A.2.2 About – The consortium

A.3 How it works

A.3.1 How it works – The sCO2 heat removal concept

Home About ˅ How it works ˅ News & Ev

What is the sCO_2-based heat removal concept?

The sCO2-HeRo system is an innovative heat removal concept that has the potential to improve the safety of both currently operating and future Nuclear Power Plants (NPP) in Europe. The system is independent of NPP type and can be easily retrofitted to existing reactors. **There is to date no such heat removal system with sCO_2 as working fluid applied in the nuclear industry today**, despite ongoing research on sCO_2-power cycles as the main system in generation IV reactors. Based on this system, sCO2-4-NPP will develop a scaled-up sCO_2-based heat removal system using real NPP dimensions and specifications for integration and validation in a real NPP (KONVOI PWR type). The sCO2-4-NPP technology will be implemented as an independent complement to the existing water-based systems and will have a very compact design, which will not require any major modifications to the existing NPP infrastructure.

The sCO2-4-NPP system will safely remove heat from the reactor core through the use of several highly compact, self-propellant, self-sustaining, and self-launching cooling system modules where each module is powered by an integrated Brayton-cycle using sCO_2 as its working fluid. At the time of an accident, all the sCO2-4-NPP system modules will be turned on for a maximum nominal power to remove decay heat. As decay heat, after reactor shutdown, decreases monotonically in the days following the accident, the need for heat removal decreases accordingly and hence one module after the other is turned off.

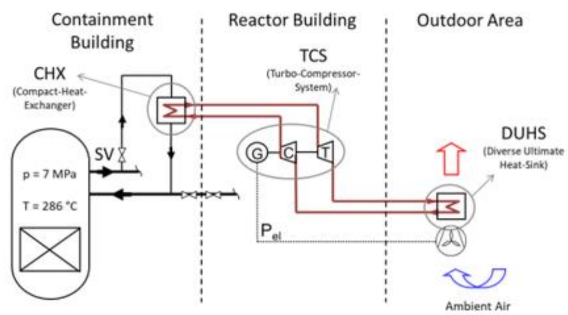
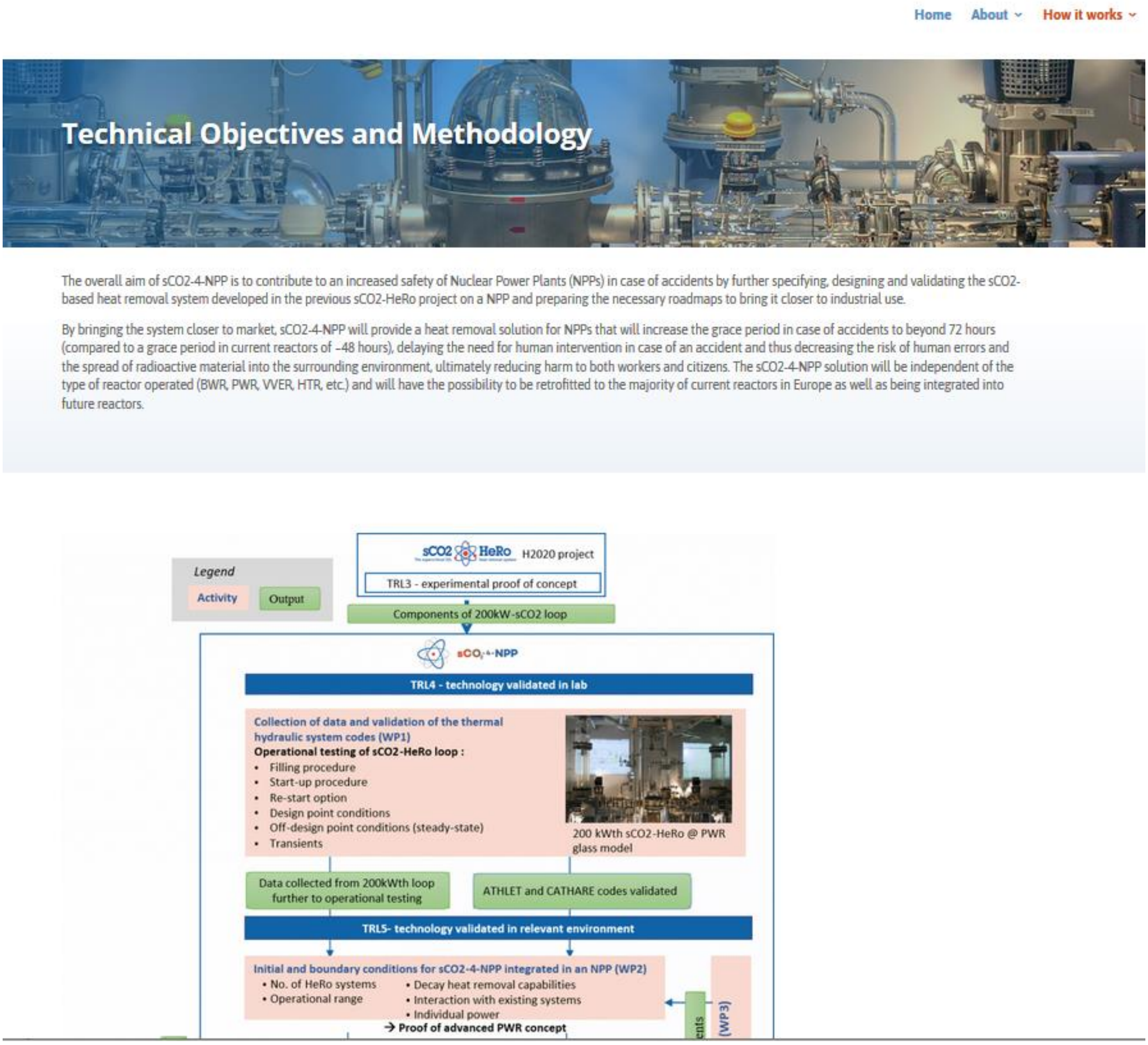


Figure: Schematic sketch of sCO2-HeRo system attached to a BWR. The red lines correspond to the sCO_2 circuit. (Source: Venker, "Development and Validation of Models for Simulation of Supercritical Carbon Dioxide Brayton Cycle and Application to Self-Propelling

In general, a simple Brayton cycle consists of a **heat exchanger (CHX)** to the heat source, a **turbo-compressor system (TCS)** consisting of a turbine, compressor and generator, and a heat exchanger to the **diverse ultimate heat sink (DUHS)**. The sketch shows one Brayton cycle attached to a Boiling Water Reactor. In case of accident, the containment isolation valves will close and the **safety valves (SV)** will open. The steam from the generator will flow into the CHX, which must be compact in size to fit into the limited space available in existing reactor containments. Inside the CHX the CO_2 is heated up. The sCO_2 then flows through the **turbine (T)** which is located on the same shaft as the **compressor (C)** and **generator (G)**. Downstream of the turbine, the sCO_2 is cooled by means of air and is delivered to the compressor and back to the CHX.

A.3.2 How it works – Technical objectives



A.3.3 How it works – Expected impact

Home About How it works

Impact areas

Environment & Society

Science & Innovation

European Industry

Environment & Society

The Fukushima Daiichi accident has revealed how dependent active safety systems are on a supply of energy and of water. Active safety systems often move enormous amounts of water, which must be refilled at some point in time and require an external power supply. A major difference between the sCO2-4-NPP system and active systems is its independence from external sources. **As the sCO2-4-NPP modules deliver the heat to air, safe decay heat removal is accomplished without the need of external water or power contributing to an increased level of safety**.

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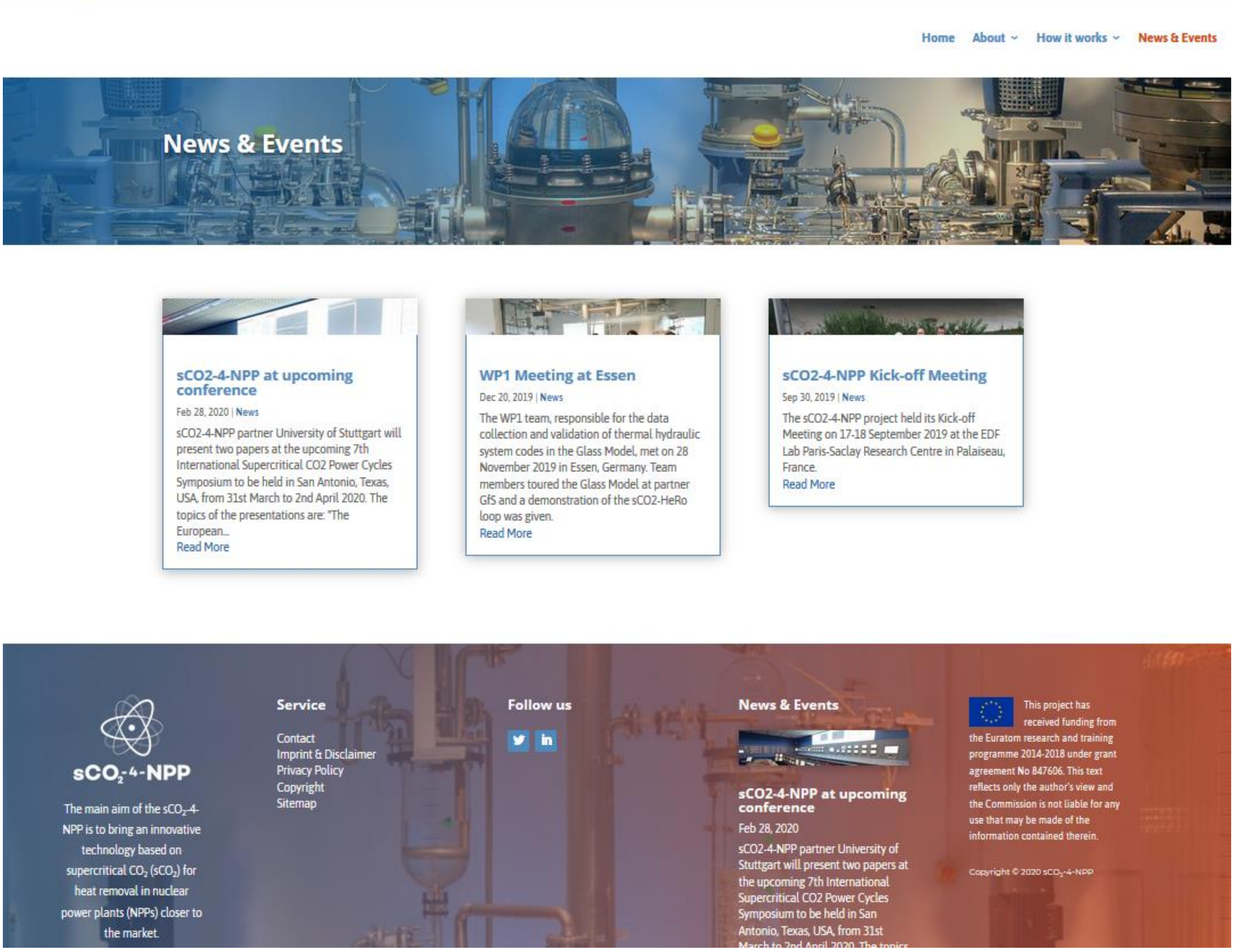
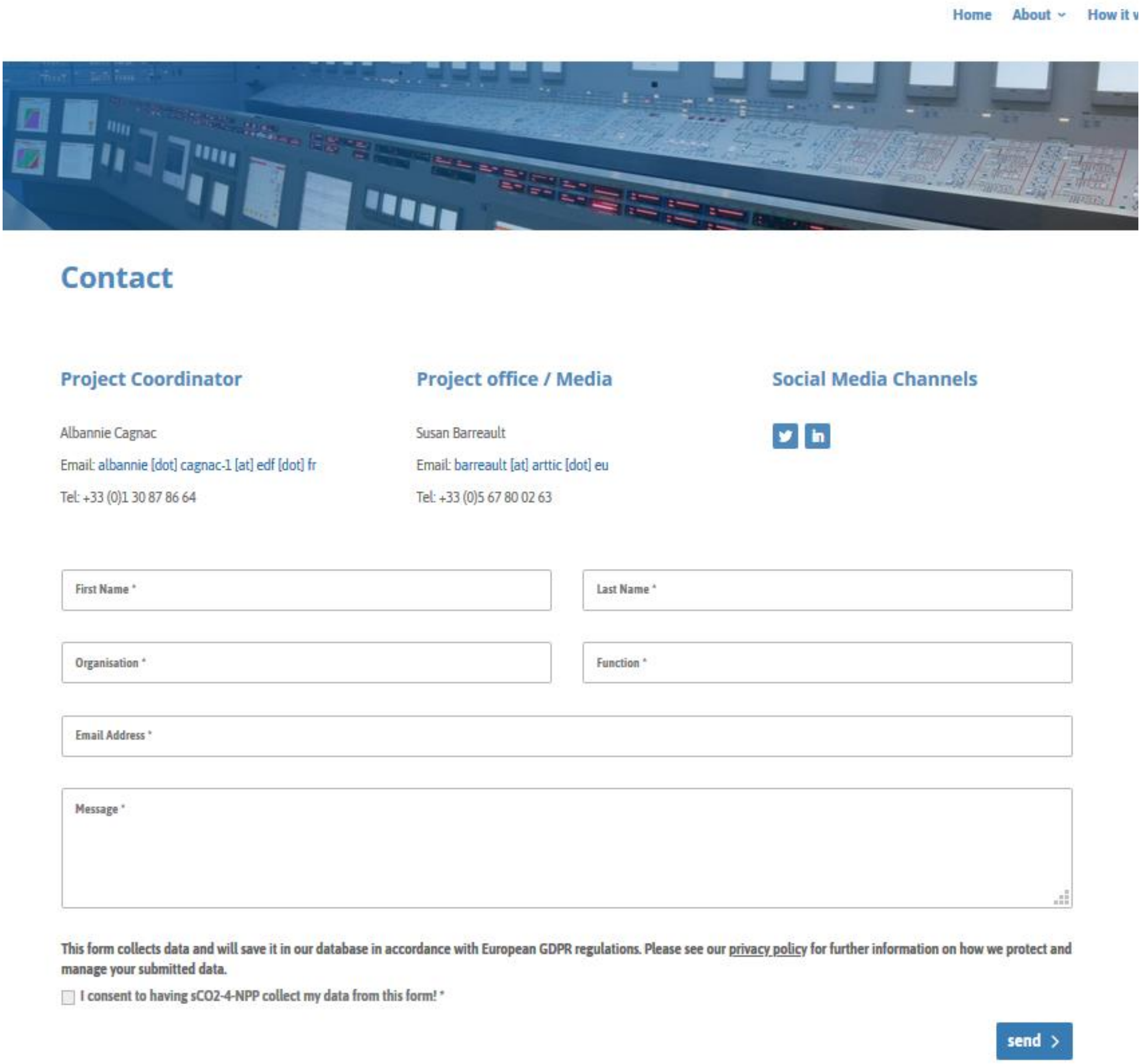
Science & Innovation

There is to date no such heat removal system with sCO_2 as a working fluid applied in the nuclear industry today. The sCO2-4-NPP

A.4 News & Events



A.5 Contact



Home About How it w

Contact

Project Coordinator

Albannie Cagnac

Email: albannie [dot] cagnac-1 [at] edf [dot] fr

Tel: +33 (0)1 30 87 86 64

Project office / Media

Susan Barreault

Email: barreault [at] arttic [dot] eu

Tel: +33 (0)5 67 80 02 63

Social Media Channels

First Name *

Last Name *

Organisation *

Function *

Email Address *

Message *

This form collects data and will save it in our database in accordance with European GDPR regulations. Please see our privacy policy for further information on how we protect and manage your submitted data.

I consent to having sCO2-4-NPP collect my data from this form! *

send