ECC-SMART

Joint European-Canadian-Chinese Development of Small Modular Super-Critical Water-cooled Reactor Technology

CVŘ Centrum výzkumu Řež

HORIZON 2020

Skupina ÚJV
TECHNOLOGIE | INOVACE | LIDÉ

Coordinator contacts:

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Project introduction

Duration: September 2020 – August 2024

Total budget: 8 911 950 €

EC contribution: 3 997 237,50 €

CORDIS: https://cordis.europa.eu/project/id/945234

Consortium: 15 European, 1 Canadian, 3 Chinese and 1 Ukrainian partners

Project partners

1) **CENTRUM VYZKUMU REZ SRO** (CVR)
2) **JOINT RESEARCH CENTRE** (JRC)
3) **CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT** (CIEMAT)
4) **INSTITUT JOZEF STEFAN** (JSI),
5) **UNIVERSITA DI PISA** (UNIPi),
6) **UNIVERSITY OF SHEFFIELD** (USFD),
7) **SLOVENSKA TECHNICKA UNIVERZITA V BRATISLAVE** (STUBA),
8) **EUROPEAN NUCLEAR EDUCATION NETWORK** (ENEN),
9) **BUDAPESTI MUSZAKI ES GAZDASAGTUDOMANYI EGYETEM** (BME),
10) **UNIVERSITY OF NOTTINGHAM** UNOTT),
11) **REGIA AUTONOMA TEHNOLOGII PENTRU ENERGIA NUCLEARA** (RATEN),

Project partners

12) **IPP CENTRE LLC** (IPP),

13) **TEKNOLOGIAN TUTKIMUSKESKUS VTT OY** (VTT),

14) **CANADIAN NUCLEAR LABORATORIES LTD** (CNL)

15) **SHANGHAI JIAO TONG UNIVERSITY** (SJTU)

16) **KARLSRUHER INSTITUT FUER TECHNOLOGIE** (KIT),

17) **KUNGLIGA TEKNISKA HOÖGSKOLAN** (KTH),

18) **VYSOKA SKOLA CHEMICKO-TECHNOLOGICKA V PRAZE** (VSCHT),

19) **UNIVERSITY OF SCIENCE AND TECHNOLOGY BEIJING** (USTB),

20) **NUCLEAR POWER INSTITUTE OF CHINA** (NPIC).

Evolution of the project

EU:

- High Performance Light Water Reactor (5th framework programme 8/2000 – 7/2002)
- High Performance Light Water Reactor Phase 2 (6th framework programme 9/2006 – 2/2010)
- SCWR-FQT (7th framework programme 1/2011 – 12/2014)

Canada:

- National Canadian programmes
- Cooperation under GIF umbrella

China:

• China SCWR TH&S R&D Project in support of GIF international activities (2020-2022), funded by the MOST.

• China SCWR M&C R&D Project in support of GIF international activities (2020-2022), funded by the MOST

• China SCWR Project (2012-2014) – China SCWR technology development Phase 1. In this project, the China Supercritical Water-Cooled Reactor design (CSR1000) was proposed.

• China-EU joint project SCWR-FQT-SCRIPT (2011–2014) – Supercritical Water Reactor - Fuel Qualification Test.

• China MOST Project (2012 - 2014) – China SCWR fundamental technology research funded by the China Ministry of Science and Technology (MOST)

Evolution of the project

E-SMART

- EU project
- Applied in 2016
- science-based recommendations and standards for a SCW-SMR to competent bodies in the EU
- **rejected**

MACHETE

- Joint EU-Canada-China
- Applied in 2018
- Research on Materials, Corrosion and Turbulent Heat and Mass Transfer Issues in high Pressure
- **rejected**

ECC-SMART

- Joint EU-Canada-China-Ukraine
- Applied in 2019
- Joint European Canadian Chinese development of Small Modular Reactor Technology
- **Approved&supported**

Previous cooperation + support of the project

- GIF Round Robin test nr.1: Corrosion testing I
- GIF Round Robin test nr.2: Corrosion testing II
- IAEA CRP: Understanding and Prediction of Thermal Hydraulics Phenomena Relevant to Supercritical Water Cooled Reactors

- GIF SSC/PMB
- IAEA Technical Expert Group

The project proposal was officialy supported by:

- NUGENIA/SNETP (the label was awarded in 2016 to the E-SMART project)
- GIF
- EERA JPNM (CVR, KIT, CIEMAT, KTH, JRC, VTT members, StUBA, RATEN, UNIPI associated)

Motivation - SCW cooled SMR technology

- Based on the SCWR research worldwide
- Need for flexible power source for wide range of users – the SMR
- Passive safety
- Water-cooled design
- Reaching the GIF requirements*
- Lower capital costs
- Higher efficiency

SCW-SMR

SuperCritical Water-cooled Small Modular Reactor

*Sustainability, Economics, Safety and Reliability, Proliferation Resistance and Physical Protection

Design targets

Objective: collect all experience from design studies in EU, Canada and China to derive a joint <u>design requirements document</u> following the design targets:

- The electric power output of the SMR should be around 200 to 300 MW.
- The specific plant erection costs (€/kW installed electric power) should be less 30% compared with SMR concepts based on a PWR.
- The power plant shall remove the residual heat without the need of electric power at least within a time period of 3 days.
- The specific fuel cost (€/MWh electric power) shall be smaller than those of SMR concepts based on a PWR, which may be accomplished by a higher efficiency compensating higher fuel production costs.

Project goals

- To define the design requirements for the future SCW-SMR technology
- Harmonisation and fostering of the trans-continental cooperation in the advanced nuclear technology to gain the most effective multi-national scientific and technical cooperation and gather the knowledge relevant to the SMR-SCWR development
- Harmonisation of the laboratory procedures and tools for effective research and development in the field of SMR-SCWR environment
- To keep and support the EURATOM to be active member of the multinational scientific platforms related to the SCWR/SMR-SCWR research
- Organize the events providing the interaction with regulatory bodies, vendors, operators and other end-users to spread the information of the SMR (especially the SCWR)
- Identify the key obstacles for the future SMR licencing and propose strategy for this process based on the findings on multinational level

Project goals

- Complete the understanding of the corrosion behaviour of the most promising candidate materials at different conditions to support the qualification procedure of the future SCW-SMR constructional materials and assess the relation to the existing standards and guidelines
- Provide Reactor physics analysis of preliminary core layout
- Verification and validation and further development of the selected thermo-hydraulic system-, subchannel-, safety-, and CFD-codes and assessment of the proposed SMR-SCWR concepts by applying these codes
- Develop pre-licensing study and guidelines for the demonstration of the safety in the further development stages of the SCWR-SMR concept.

Ambition

- To define the methodologies and tools for future innovative SMR assessment to provide the legislation environment ready for the future SMR-type reactors

- The selected phenomena from the each of the key fields covered by the project (constructional materials and radiation resistance, thermal-hydraulics and neutronics/reactor physics) should illustrate the safety and licensing relevant processed affecting the smooth licensing process for future reactors.

Major assumptions

- **Intrinsically and passively safe operation**: Particular focus will be put on the conceptual design of a core with a low power density, which allows in principle core cooling based only on the laws of physics (i.e. conduction and irradiation), and in any case assessing the most significant accident scenarios.
- In conjunction with the previous point, participants of the proposed project aim to define design requirements to a system with a neutron spectrum and economy, which will **minimize the minor actinides production** and will be potentially suitable for fertile nuclides fertilization (e.g. thorium resources exploitation).
- **Decommissioning**: Particular attention will be given to neutron fluency minimization outside the reactor core, in order to reduce the amount of activated materials for the dismantling of the reactor after the operational life of the reactor. Technical solutions, which will reduce the complexity of the reactor will be carefully considered.
- **Competitiveness**: The choice of SCW instead of conventional light water as coolant allows to increase reactor efficiency and reduce the capital costs, thus adopting an innovative technology which represents the natural evolution of common LWRs.
- **Cogeneration**: The adoption of SCW technologies, given the better heat conversion exploitation, will also facilitate the implementation of cogeneration in the industrial field, e.g. for water desalination (which represent a critical problem in some areas of the world, even more than energy availability).

Project bodies (AB and PMB as proposal of members to be appointed by the Genneral assembly Tommorow)

Project management board

- Coordinator (Markéta Kryková, CVR)+WP leaders (Alberto Saéz, CIEMAT; Ivan Otic, KIT; Szabolcs Czifrus, BME, Leon Cizelj, JSI; Francisco Suárez Ortiz, ENEN)

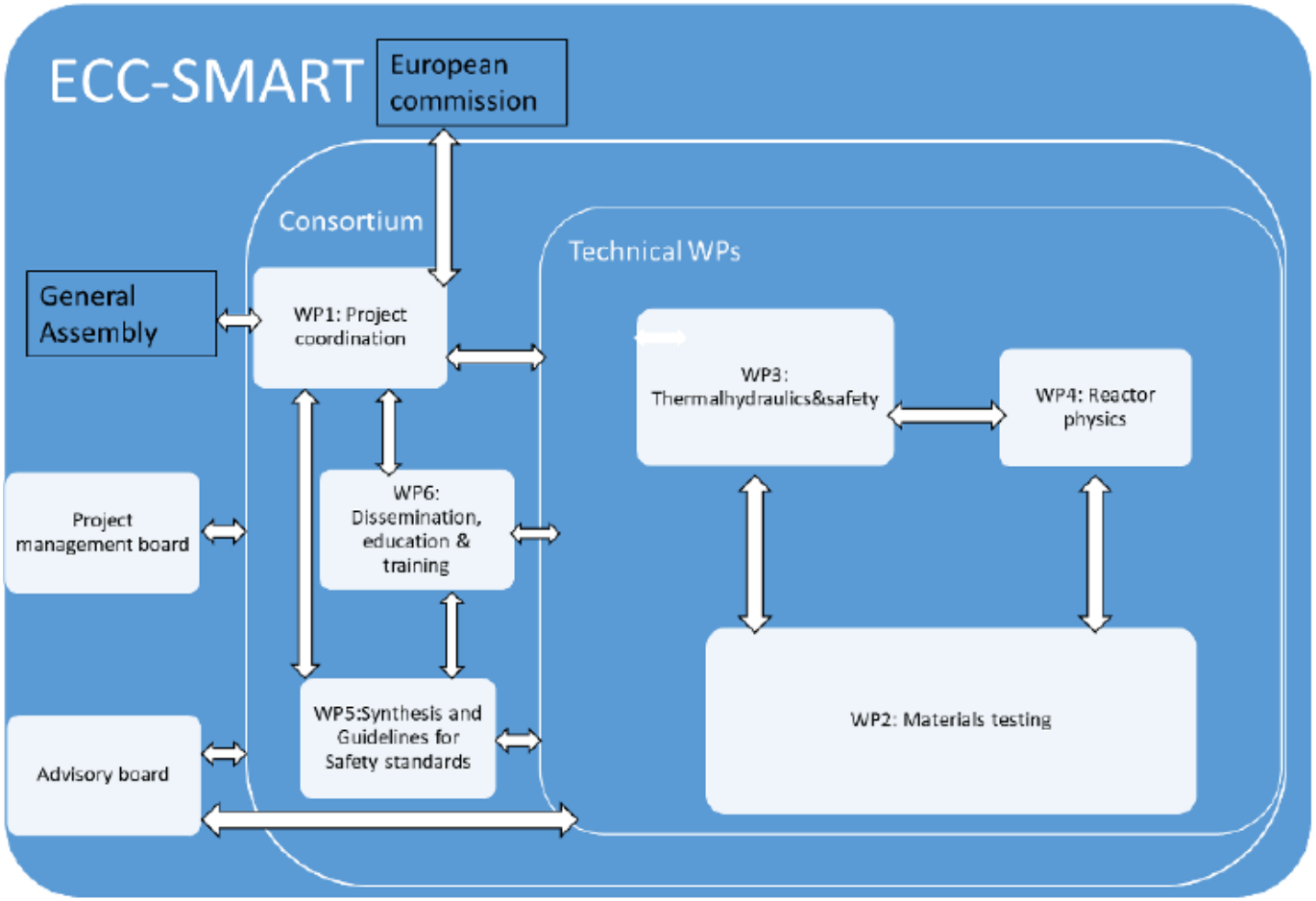
Advisory board

- Prof. Dr.-Ing. Thomas Schulenberg, Dr. Laurence Leung, Dr. David Guzonas, Katsumi Yamada, Karel Bednář (Škoda Nuclear Machinery, Czech Republic), Ján Štuller (Ministry of industry and Trade, Czech Republic), Dr. Nithy Nitheananadan (CNSC)

General assembly

- Each partner already nominated the GA member (1 member/partner)

Project structure



WP1 – Project Coordination

Leader: CVR – Markéta Kryková (marketa.krykova@cvr[illegible],

Total efforts = 21 PM

WP / Task overview and GANTT

RP1 RP2 RP3

WP/ Task			Year 2020				Year 2021												Year 2022												Year 2023												Year 2024							
			September-20	October-20	November-20	December-20	January-21	February-21	March-21	April-21	May-21	June-21	July-21	August-21	September-21	October-21	November-21	December-21	January-22	February-22	March-22	April-22	May-22	June-22	July-22	August-22	September-22	October-22	November-22	December-22	January-23	February-23	March-23	April-23	May-23	June-23	July-23	August-23	September-23	October-23	November-23	December-23	January-24	February-24	March-24	April-24	May-24	June-24	July-24	August-24
No	Title	Lead	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36	M37	M38	M39	M40	M41	M42	M43	M44	M45	M46	M47	M48
WP1	**Project coordination**	**CVR**																																																
D1.1	Project presentation	CVR																																																
D1.2	Project quality plan - draft	CVR																																															
D1.3	Project risk management - plan	CVR																																															
D1.4	Dissemination plan - final	CVR																																															
MS1	Constitution of Advisory Board	CVR																																															
MS20	State-of-the-art meeting	CVR																																															

WP 2 – Materials testing

Leader: CIEMAT – Alberto SAEZ (alberto.saez@ciemat.e

Participants: CVR, JRC, STUBA, ENEN, RATEN, VTT, CNL, SJTU, VSCHT, USTB

Total efforts: 430,20 PM

WP 2.1: Selection and characterization of materials. **Task Leader: CVR**

WP 2.2: Study of the corrosion and EAC behaviour of selected alloys out-of-pile. **Task Leader: JRC**

WP 2.3: Study of the corrosion and EAC behaviour of selected pre-irradiated alloys in SCW. **Task Leader: CVR**

WP 2.4: Study of the effect of SMR-SCW chemistry and changes in the chemical properties of SCW in the behaviour of candidate materials. **Task Leader: CNL**

WP2 – Materials testing
Main goals:

- to identify the licensing-related issues and knowledge gaps by gain more in-depth knowledge into the corrosion behaviour of candidate materials for the Small Modular Reactor cooled by Supercritical Water under non-irradiated and irradiated conditions.
- To perform electrochemical measurements in-situ to understand how changes in the physicochemical properties can affect the corrosion mechanismsin SCW
- To perfrom new tests focused on the radiolysis processes in supercritical water

WP 2 – Materials testing

Leader: CIEMAT - Alberto SAEZ (alberto.saez@ciemat.e

WP / Task overview and GANTT

RP1 RP2 RP3

WP/ Task			Year 2020				Year 2021												Year 2022												Year 2023												Year 2024							
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WP1	**Project coordination**	**CVR**																																																
WP2	**Materials Testing**	**CIEMAT**																																																
D2.1	Test matrix based on available materials	CIEMAT																																																
D2.2	Report summarizing the basic characterization of	CVR																																																
D2.3	Report summarising the results of out-of-pile cor	JRC																																															
D2.4	Report summarising the results of corrosion tests	CVR																																															
D2.5	Report summarising the results on the SCW SMR	CNL																																															
MS2	Test matrix determination and approval	CIEMAT																																																
MS3	Characterization of materials and machining of sp	CVR																																															
MS4	Out-of-pile corrosion and EAC tests completed	JRC																																															
MS5	Corrosion tests with preirradiated materials	CVR																																															
MS6	Study of the radiolysis in SCW and electrochemica	CVR																																															

WP 3 - Thermal Hydraulics and Safety of the SCW-SMR

Leader: KIT – Ivan OTIC (ivan.otic@kit.edu)

Main goals:

- To provide a database using experimental and numerical data
- Improvement, implementation and validation of engineering CFD models for turbulent heat and mass transfer
- Development and validation of heat transfer correlations and models for applications in system codes
- Safety and design analysis of the SCW-SMR concept
- Derivation of European-Canadian-Chinese (ECC) design requirements for a ECC SCW-SMR design concept; This design requirement document shall serve as a basis for a future conceptual design project.

WP 3 - Thermal Hydraulics and Safety of the SCW-SMR

Leader: KIT – Ivan OTIC (ivan.otic@kit.edu)

Participants: CVR, UNIPI, USFD, ENEN, BME, UNOTT, IPP, CNL, KTH, NPIC
Total efforts: 358,70 PM

Task 3.1: Conceptual design requirements of ECC SMR SCWR **Task Leader: CNL**
Task 3.2: Reference database **Task Leader: KIT**
Subtask 3.2.1. Experimental investigations of turbulent heat transfer along corroded surfaces **Subtask Leader: KIT**
Subtask) 3.2.2. Experimental investigations of turbulent flows along corroded surface **Subtask Leader: CNL**
Subtask 3.2.3. Exposition of experimental specimens **Subtask Leader: CVR**
Subtask 3.2.3. Direct numerical simulations of flow over rough surfaces. **Subtask Leader: USFD**
Subtask 3.2.4. Direct numerical simulations of flow induced corrosion **Subtask Leader: KIT**
Subtask 3.2.5. Assembling the existing experimental data base **Subtask Leader: IPP**

WP 3 - Thermal Hydraulics and Safety of the SCW-SMR

Leader: KIT – Ivan OTIC (ivan.otic@kit.edu)

Task 3.3: Development and improvement of system-, subchannel- and CFD-codes for SCW-SMR. **Task Leader: UNIPI**

Subtask 3.3.1. Contribution to establish heat transfer correlations and CFD models appropriate for postulated operating conditions. **Subtask Leader: UNIPI**

Subtask 3.3.2. Benchmarking of system codes under SCW-SMR conditions. **Subtask Leader: BME**

Subtask 3.3.3. Investigation and implementation of heat transfer correlations. **Subtask Leader: CNL**

Subtask 3.3.4. Improvement, implementation and validation of engineering models for turbulent heat transfer undersupercritical conditions. **Subtask Leader: IPP**

Subtask 3.3.5. CFD modeling and validation of supercritical water heat transfer along corroded rough surfaces. **Subtask Leader: KTH**

Subtask 3.3.6. Two and more equation RANS modelling of turbulent heat and mass transfer along corroded surfaces **Subtask Leader: UoN**

WP 3 - Thermal Hydraulics and Safety of the SCW-SMR

Leader: KIT – Ivan OTIC (ivan.otic@kit.edu)

Task 3.4: Study of a pre-conceptual core layout and passive safety concept for SCW-SMR. **Task Leader: UNIPI**
Subtask 3.4.1. Thermalhydraulics safety assessment of a proposed SCW-SMR for supporting the design requirements matrix. **Subtask Leader: CNL**

Subtask 3.4.2. Safety and design analysis of the SCW-SMR concept. **Subtask Leader: IPP**

Subtask 3.4.3. Analysis of pre-conceptual core layout and passive safety concept for SCW-SMR. **Subtask Leader: BME**

Subtask 3.4.4. Analysis of passive safety aspects **Subtask Leader: UNIPI**

WP 3 - Thermal Hydraulics and Safety of the SCW-SMR

Leader: KIT – Ivan OTIC (ivan.otic@kit.edu)

WP / Task overview and GANTT

RP1 RP2 RP3

WP/ Task			Year 2020				Year 2021												Year 2022												Year 2023												Year 2024							
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WP1	Project coordination	CVR																																																
WP2	Materials Testing	CIEMAT																																																
WP3	Thermal Hydraulics and Safety of the SCW-SMR	KIT																																															
D3.1	Report summarisingthe newly generatedreference	KIT																																															
D3.2	Report on the results ofthe benchmark exercise	KIT																																															
D3.3	Report on the preconceptual studies onthe core l	UNIPI																																															
D3.4	Report on the improved system codes describing	CNL																																															
D3.5	Report on CFD modelling and simulations in corr	KIT																																															
D3.6	Report on preconceptual design requirements for	CNL																																															
MS7	Reference database generated	CNL																																															
MS8	Additional experimental data provided for modeld	CVR																																															
MS9	Additional DNS data on flow, heat & mass transfe	KIT																																															
MS10	Benchmarking completed	UNIPI																																															
MS11	Heat transfer correlation development and validat	KIT																																															
MS12	Core layout and passivesafety concept of the SCW	UNIPI																																															
MS13	System code development and implementation co	CNL																																															
MS14	Conceptual design requirements completed	CNL																																															

WP4 - Neutron physics of SCW-SMR

Leader: BME – Czifrus SZABOLCS (czifrus@reak.bme.hu)

WP4 aims at studying the design- and safety-related neutronic parameters and reactor physics behavior of SCW-SMR in order to support the pre-conceptual design

Main goals:

1. Selection of proper neutron/reactor physics code for modelling the complex behaviour of SCW-SMR
2. Calculation of safety related neutron physics parameters
3. Reactor physics analysis of preliminary core layouts

WP4 - Neutron physics of SCW-SMR

Leader: BME – Czifrus SZABOLCS (czifrus@reak.bme.hu)

Participants: UNIPI, ENEN, RATEN, CNL

Total efforts: 87,90 PM

WP4.1 Assess the effect of code selection by comparing different neutron-physics codes and cross-section sets **Task Leader: CNL**

WP4.2 Analytical investigation of neutron physics parameters relevant to the safety and feasibility of the SCW-SMR **Task Leader: RATEN**

WP4.3 Preliminary/pre-conceptual core design calculations **Task Leader: BME**

WP4 - Neutron physics of SCW-SMR

Leader: BME – Czifrus SZABOLCS (czifrus@reak.bme.hu)

WP / Task overview and GANTT

RP1 RP2 RP3

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WP1	Project coordination	CVR																																																
WP2	Materials Testing	CIEMAT																																																
WP3	Thermal Hydraulics and Safety of the SCW-SMR	KIT																																															
WP4	Reactor Physics of the SCW-SMR	BME																																															
D4.1	Report summarising the neutron physics code sel	CNL																																															
D4.2	Report summarizing the calculated safety relevant	RATEN																																															
D4.3	Report summarizing the results of pre-conceptua	BME																																															
MS15	Neutron physics parameters	BME																																															

WP 5 - Synthesis and Guidelines for Safety Standards

Leader: JSI – Leon CIZELJ (Leon.Cizelj@ijs.si)

Main goals:

- Develop generic and specific safety criteria and requirements for the SCW-SMR concept;
- Synthesize the main safety related findings and conclusions of the WPs 2-4;
- Develop a pre-licensing study demonstrating the feasibility of the design to be licensed;
- Develop guidelines for the demonstration of the safety in the further development stages of the SCW-SMR concept.

WP5 - Synthesis and Guidelines for Safety Standards

Leader: JSI – Leon CIZELJ (Leon.Cizelj@ijs.si)

Participants: CVR, JRC, CIEMAT, ENEN, BME, IPP, VTT, KIT

Total efforts: 34,40 PM

WP 5.1 Generic and specific safety criteria and requirements. **Task Leader: JSI**

WP 5.2 Safety-related findings and conclusions of the WPs 2-4. **Task Leader: BME**

WP 5.3 Pre-licensing study. **Task Leader: JSI**

WP 5.4 Guidelines for the demonstration of safety in the further development stages. **Task Leader: CVR**

WP 5 - Synthesis and Guidelines for Safety Standards

Leader: JSI – Leon CIZELJ (Leon.Cizelj@ijs.si)

WP / Task overview and GANTT

RP1 RP2 RP3

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WP1	Project coordination	CVR																																																
WP2	Materials Testing	CIEMAT																																																
WP3	Thermal Hydraulics and Safety of the SCW-SMR	KIT																																																
WP4	Reactor Physics of the SCW-SMR	BME																																																
WP5	Synthesis and Guidelines for Safety Standards	JSI																																																
D5.1	Safety criteria and requirements for the scw-smr c	JSI																																																
D5.2	Safety related features of the SCW-SMR concept	BME																																																
D5.3	Pre-licensing study	JSI																																																
D5.4	Guidelines for the demonstration of the safety of	CVR																																																
MS16	Safety criteria and requirements for the SCW-SMR	JSI																																																
MS17	Pre-licensing study completed	JSI																																																

WP 6 - Dissemination and communicatio

Leader: ENEN – Francisco Suaréz Ortiz (francisco.suarez@enen.eu

Main goals:

- **Inform the nuclear community and the public about the Project.**
- Provide proper **communication and dissemination** (documents and deliverables)
- **Publication** of Project results
- Organization of **Events:**
- Project findings and advancements
- Interaction with regulatory bodies, vendors, operators and end users to spread info of the SMR
- Organization of **Training** courses + setup exchange program (PhD, postdocs/young scientists)
- Communication channel with stakeholders and authorities

WP 6 - Dissemination and communicatio

Leader: ENEN – Francisco Suaréz Ortiz (francisco.suarez@enen.eu

Participants: CVR, JRC, CIEMAT, JSI, BME, IPP, VTT

Total efforts: 26,00 PM

Task T.6.1 Project website, database and new media **Task Leader: ENEN**

Task T.6.2 Data management **Task Leader: ENEN**

Task T.6.3 Dissemination of scientific results **Task Leader**: **ENEN**

Task T.6.4 Training and exchange program for researchers **Task Leader: ENEN**

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WP / Task overview and GANTT

RP1 RP2 RP3

WP/ Task			Year 2020				Year 2021												Year 2022												Year 2023												Year 2024							
			September-20	October-20	November-20	December-20	January-21	February-21	March-21	April-21	May-21	June-21	July-21	August-21	September-21	October-21	November-21	December-21	January-22	February-22	March-22	April-22	May-22	June-22	July-22	August-22	September-22	October-22	November-22	December-22	January-23	February-23	March-23	April-23	May-23	June-23	July-23	August-23	September-23	October-23	November-23	December-23	January-24	February-24	March-24	April-24	May-24	June-24	July-24	August-24
No	Title	Lead	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36	M37	M38	M39	M40	M41	M42	M43	M44	M45	M46	M47	M48
WP1	Project coordination	CVR																																																
WP2	Materials Testing	CIEMAT																																																
WP3	Thermal Hydraulics and Safety of the SCW-SMR	KIT																																															
WP4	Reactor Physics of the SCW-SMR	BME																																															
WP5	Synthesis and Guidelines for Safety Standards	JSI																																															
WP6	Dissemination and Communication	ENEN																																															
D6.1	Issuing of first version of data management plan	ENEN																																															
D6.2	Proceedings of workshop on materials and online	ENEN																																															
D6.3	Proceedings of workshop on thermal hydraulics a	ENEN																																															
D6.4	Proceedings of the ISSCWR	CVR																																															
D6.5	Training material - booklet & presentations	ENEN																																															
D6.6	Report on visit of PhD students/post-docs/young	ENEN																																															
MS18	Document exchange server established and runni	ENEN																																															
MS19	Project website established and running	ENEN																																															

ISSCWR-10

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15th – 19th March, 2021

Prague, Czech Republic

ECC smart

CVŘ Centrum výzkumu Řež

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We are looking forward to working together on the ECC-SMART project !

In case you have any questions, don‘t hesitate to contact us!