ECC-SMART PROJECT

Joint European Canadian Chinese development of Small Modular Reactor Technology

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Abstract:
This deliverable presents the experience and research activities of PhD students, postdoctoral researchers, and young scientists supported by the ECC-SMART Project with an overview of the long and short-term visits. This document also includes researcher profiles, summarizing their background, research focus, and main findings. Deliverable D6.6 highlights the ECC-SMART project's commitment to education by providing young researchers access to advanced laboratories, workshops, and international experts. This enhances technical expertise and nurtures future leaders in the nuclear field. Moreover, educational events and mobilities foster young researchers' growth, encourage innovation, and facilitate interdisciplinary skill development.

The ECC-SMART project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945234.

Executive Summary

This deliverable D6.6, *Report on visits of PhD students/post-docs/young scientists*, provides an overview of the research and development activities undertaken by PhD students, postdoctoral researchers, and early-career scientists with support from the ECC-SMART Project. This report highlights their laboratory visits, collaborative research, and professional development engagements in key facilities across Europe, Canada, and China, focusing on specialized areas such as corrosion in supercritical water environments, code validation, benchmarking, code modification, etc. These researchers contribute significantly to addressing challenges in nuclear energy and materials durability.

The deliverable details specific experiments conducted at renowned institutions. Each researcher's profile includes a summary of their background, research focus, experimental findings, and knowledge shared at workshops and conferences.

This deliverable supports the ECC-SMART project's overarching objectives by serving multiple crucial functions. It disseminates knowledge through the sharing of valuable research findings and best practices, advancing understanding in critical areas of nuclear technology within both the scientific community and industry stakeholders. Additionally, it promotes research opportunities by providing access to international facilities and specialized workshops, thereby fostering the growth of young researchers, encouraging innovation, and facilitating interdisciplinary skill development. The deliverable enhances ECC-SMART's visibility by showcasing its dedication to scientific progress and collaboration, strengthening its profile and demonstrating its significant impact within the field of nuclear research and development

In particular, deliverable 6.6 underscores the ECC-SMART project's commitment to education and capacity-building in nuclear science and technology. By enabling young researchers to access cutting-edge laboratories, participate in advanced workshops, and engage with international experts, the project not only enhances technical expertise but also nurtures the next generation of leaders in the nuclear field. These educational opportunities emphasize hands-on learning, interdisciplinary collaboration, and the development of critical skills essential for addressing complex challenges in nuclear energy and materials science. Moreover, the project's focus on mentorship and knowledge transfer ensures that young scientists are equipped to contribute meaningfully to the global nuclear community, driving innovation and sustainability in the sector.

Table of contents

List of acronyms and abbreviations

Acronym/Abbreviation	Definition
AFA	Alumina Forming Austenitic
AMALIA Lab	Name for specific lab at JRC Petten
BME	Budapest University of Technology and Economics
CCS	Carbon Capture and Storage
CFL	Computational Fluid Dynamics
CNL	Canadian Nuclear Laboratories
COMAT	International Conference on Recent Trends in Structural Materials
CVŘ	Research Centre Řež
DNS	Direct Numerical Simulation
ECC-SMART	European Canadian Chinese development of Small Modular Reactor Technology
EDS	Energy Dispersive X-ray Spectroscopy
ENEN	European Nuclear Education Network
GEN IV	Generation IV (reactor concepts)
IHTC	International Heat Transfer Conference
IPP	IPP Centre LLC in Ukraine
ISSCWR	International Symposium on Supercritical Water-Cooled Reactors
JRC	Joint Research Centre
KIT	Karlsruhe Institute of Technology
MSc	Master of Science
METAL	International Conference of Metallurgy and Materials

NENE	International Conference on Nuclear Energy
NURETH	Nuclear Reactor Thermal Hydraulics Conference
PDRA	Postdoctoral Research Assistant
PIE	Post-Irradiation Examination
SCW	Supercritical Water
SCWR	Supercritical Water Reactor
SCW-SMR	Supercritical Water-cooled Small Modular Reactor
USFD	University of Sheffield
SJTU	Shanghai Jiao Tong University
UCT	University of Chemistry and Technology
UNIPI	University of Pisa
UoN	University of Nottingham
USTB	University of Science and Technology Beijing
WWER	Water-Water Energy Reactor
XPS	X-ray Photoelectron Spectroscopy

List of Annexes

Annex 1: Presentations and Posters
Annex 2: Publications

Access the annexes through the following link: Annex - D.6.6

Introduction

1.1 Project summary

The Joint European Canadian Chinese development of Small Modular Reactor Technology (ECC-SMART) is a multinational project focused on the development and licensing of the future Supercritical Water-cooled Small Modular Reactor (SCW-SMR).

The ECC-SMART project main objectives are:

- to provide science-based recommendations and methodologies for performing safety evaluations and safety improvements fostering the safety standards, including the experimental validation of essential items for safety demonstrations related to the SCW-SMR,
- to derive the most economical safety-driven SCW-SMR design requirements by identifying adequate solutions to key technical issues which drive cost and safety and their influence to the future licensing process,
- to increase the level of knowledge as well as the interest of the industrial partners and demonstrate the benefits of the SCW-SMR concept.

1.1.1 Purpose of this document

This document is a deliverable of Work Package 6 “Dissemination and communication” led by ENEN. The purpose of deliverable 6.6 is to document and assess the research activities, international laboratory visits, and contributions of PhD students, postdoctoral researchers, and early-career scientists supported by the ECC-SMART Project.

By showcasing the achievements of these emerging scientists, this report highlights the project’s commitment to expanding knowledge and fostering innovation in the field of SCW-SMR technology. It supports ECC-SMART's objectives by sharing science-based insights and research that underpin safety evaluations, drive cost-effective safety-driven design, and strengthen the engagement of industrial partners in advancing SCW-SMR development.

As per the Grant Agreement, the contribution of the PhD students/postdocs/trainees can be divided into 3 groups: (1) participation in the research tasks, (2) participation at the events organized by the consortium and (3) student internships organized by the consortium members.

To provide a clear structure, the deliverable is organized into two main sections: one focusing on short-term stay visits and participation in events and the other on long-term stay visits diving deep into the participation in events organized by the consortium, activities, research tasks and experiments to demonstrate the benefits of the SCW-SMR concept. In this context, short-term

refers to participation in activities or stays lasting up to and including one week. Conversely, long-term refers to activities or stays exceeding one week in duration.

1.1.2 Involved students and young researchers

The ECC-SMART project has fostered significant collaboration among its partners, including UNIPI, IPP, KIT, UoN, UCT Prague, CVR, JRC and USFD.

At **UNIPI**, three students contributed to the project: Sara Kassem (PhD student at the time, currently a postdoc and grant holder), Alessandro De Angelis (former MSc student, currently a PhD student outside ECC-SMART), and Omar Chaaraoui (MSc student in Nuclear Engineering).

IPP engaged three young researchers in workshops: Oleksii Ishchenko (PhD), Konstantin Lukianenko (PhD), and Zahar Yaskovets (Postdoc), with their participation documented in ECC-SMART newsletters.

KIT contributed by involving two promising researchers, Fabian Wiltschko and Gürel Özesme. Both participated in the Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors, actively engaging in discussions and showcasing their expertise.

At **UoN**, PhD students Chunyu Jin and Yuhao Xu, along with postdoc Dr. Jivan Khatry, worked on CFD simulations for ECC-SMART.

Yuhao's research focuses on conducting CFD studies to analyze the thermal-hydraulic properties of supercritical working fluids in tubes. While not conducting experiments in external laboratories as part of the ECC-Smart Project, Yuhao contributed to advancing the understanding of energy-efficient systems in sustainable technologies.

UCT Prague involved six students in total: PhD candidates Jaromír Valtr, Petr Roztočil, and David Dašek, as well as BSc/MSc-level students Petr Čech, Eva Bažantová, and Viachaslau Radzeuski. Their activities encompassed operating a supercritical loop, preparing samples, acquiring weight gain and electrochemical data, evaluating data, and descaling samples. To date, the group has successfully defended two MSc and three BSc theses, with three PhD and two MSc theses currently in progress. Notable research exchanges were conducted at Amalia Lab–JRC Petten.

Throughout the project´s duration, **CVR** involved several students and young researchers. They actively participated in various research activities, and some of them took part in ECC-SMART events, relevant conferences, and training courses, as described in detail below.

USFD contributed through Dr. Kenneth Chinembiri's DNS computer code development, with additional contributions from Dr. Steve Jackson (DNS code validation), PhD student Chenin Zhang (Sub-Channel CFD development), and Miss Zewen Zou (heat transfer modeling for supercritical fluids), all of whom actively participated in international conferences and site visits.

Lastly, **BME** contributed two young scientists, Zénó Bertesina and Péter Mészáros, further expanding the project's collaborative reach. These collective efforts highlight the project's ability to integrate diverse expertise across institutions, advancing its objectives in nuclear research and education.

The involvement of students and young researchers across ECC-SMART partner institutions highlights the project's commitment to fostering the next generation of experts in nuclear science and engineering. They contributed to various aspects of the project, from experimental work and advanced simulations to active participation in workshops and international conferences. Their diverse academic backgrounds and hands-on experiences have enriched the project while providing them with valuable opportunities for professional growth. These collective efforts underscore the collaborative and multidisciplinary achievements of the ECC-SMART initiative. Below, we delve into the specific contributions and activities of each student, showcasing their unique roles in advancing the ECC-SMART objectives.

2 Report on visits of PhD students/post-docs/ young scientists

2.1 Short-term Stays

This section provides an overview of student and young researcher participation in ECC-SMART events, as well as their involvement in their “short-term stay” visits through training courses and participation in conferences relevant to the project's objectives.

To begin, a general insight into ECC-SMART events and student contributions is presented, accompanied by a relevant image to illustrate their active involvement. The section then delves into individual cases based on the information students shared through a provided questionnaire and reporting, highlighting their unique experiences and contributions.

Figure 1: The Workshop on Materials organized in Madrid 2023.

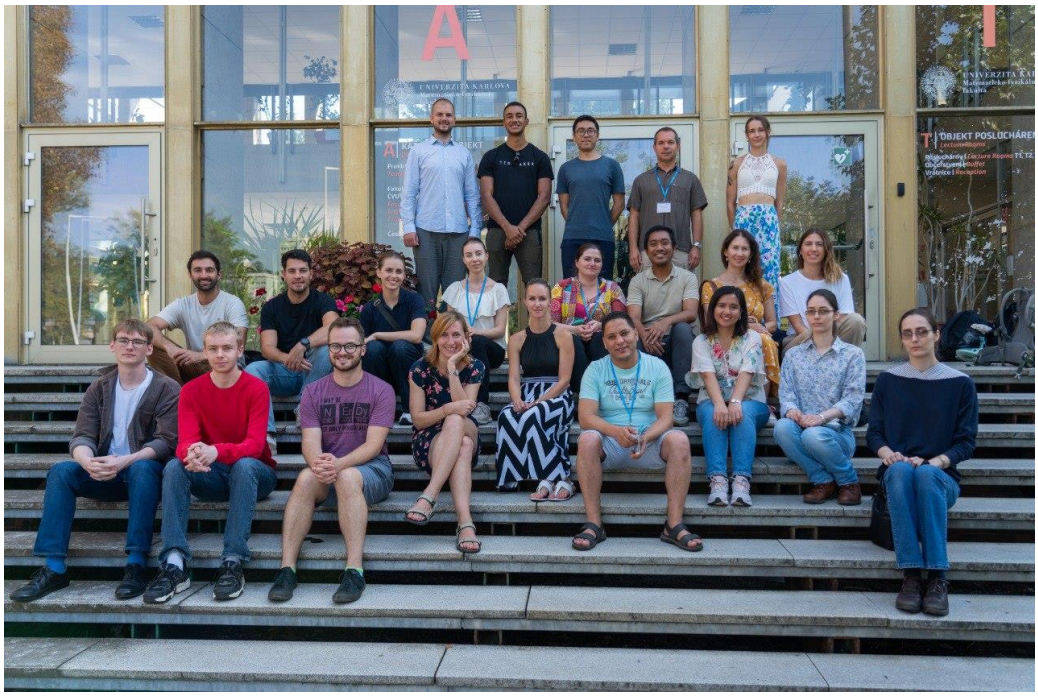


Figure 2: Group picture of the participants at the PIE Workshop

Figure 3: Picture of participants of the PIE Workshop over the reactor.

Oleksii Ishchenko, Zakhar Yaskovets, Kostiantyn Lukianenko (IPP)

Oleksii Ishchenko and Kostiantyn Lukianenko, both Mechanical Engineers at IPP-Centre and PhD students in Applied Mechanics at Igor Sikorsky Kyiv Polytechnic Institute in Ukraine, together with Zakhar Yaskovets, Head of the Department of Technical Diagnostics at IPP-Centre LLC, to participate in the Workshop on Structural Materials for GEN IV SMR Concepts. Their collective

expertise and active engagement contributed significantly to the discussions on advanced materials for next-generation reactors.

Sara Kassem (UNIPI)

Sara Kassem is a student at the University of Pisa, Italy, specializing in structural materials for advanced nuclear systems. She actively participated in the workshop on structural materials for Generation IV Small Modular Reactor (SMR) concepts, contributing as a young researcher to the advancement of this innovative field.

Fabian Wiltschko , Gürel Özesme (KIT)

Both, Fabian and Gürel, actively participated in the Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors, demonstrating their expertise and engaging in insightful discussions.

Gürel Özesme is an M.Sc. Nuclear Engineer and Ph.D. student at the Karlsruhe Institute of Technology (KIT), specializing in the analysis of turbulent conjugate heat transfer using computational fluid dynamics (CFD). During the Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors, Gürel engaged in valuable discussions and connected with professionals in the field, enhancing his knowledge and professional network.

Fabian Wiltschko is an M.Sc. Mechanical Engineer and Ph.D. student at KIT, focusing on the experimental investigation of heat transfer to fluids at supercritical pressure as part of the ECC-SMART project. Fabian participated in the Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors, contributing his expertise and furthering collaborative efforts within the research community.

David Dašek and Petr Roztočil (UCT Prague)

David Dašek participated in Workshop on the Safety of Small Modular, Advanced and Fusion Reactors, June 20-21, Celje, Slovenia Workshop on Structural Materials for GEN IV SMR Concepts, November 27-29, Madrid, Spain with the support of the ECC-Smart Project - All presentations are provided in Annex 1.

With ECC-Smart's support, Petr participated in the Workshop on Structural Materials for GEN IV SMR Concepts and the Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors, where he had the opportunity to share his findings and collaborate with other researchers in the field. His work contributes to a deeper understanding of material behavior in supercritical

water, providing essential data for the safe and efficient development of next-generation reactor designs.

Daniela Marušáková (CVR)

Daniela Marušáková is a dedicated researcher at the Research Center Rez, specializing in electron microscopy, supercritical water, corrosion, and power engineering. With extensive expertise in materials science, mechanical properties, and corrosion engineering, she aims to apply her knowledge to innovative research projects that advance materials and energy technology.

With the support of the ECC-Smart Project, Daniela Marušáková visited several laboratories, including Shanghai Jiao Tong University (SJTU) in Shanghai, and the University of Science and Technology Beijing (USTB) in China. She actively engaged in a series of professional development events and collaborations across multiple countries. She participated in the Materials Workshop at Ciemat in Madrid, Spain (November 27-30, 2023), the International Exchange Meeting in Shanghai, China (June 10-14, 2024), and a Summer School at the Research Center Rez (August 26-30, 2024).

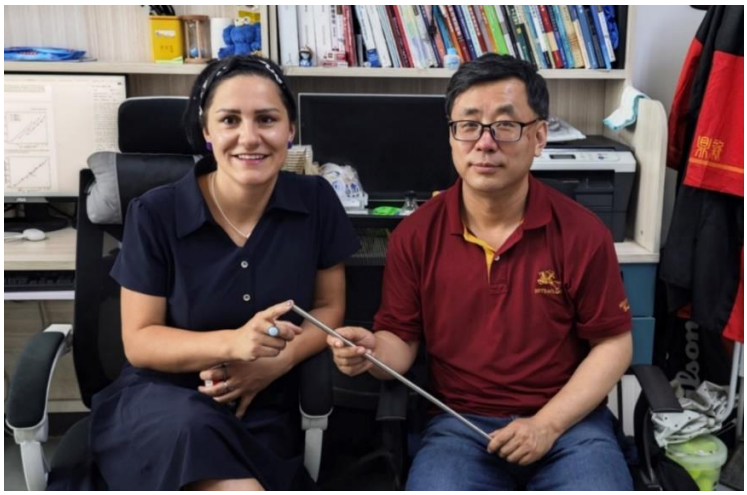


Figure 4: The International Exchange Meeting in Shanghai, China

Additionally, Daniela attended the NENE 2023 Conference in Slovenia and various Czech conferences, including the International Conference of Metallurgy and Materials - METAL 2024 and the 8th International Conference On Recent Trends In Structural Materials – COMAT 2024, as well as numerous Work Package 2 meetings. These events provided her with valuable opportunities to share her research, expand her professional network, and stay informed on the latest advancements in her field.

Figure 5: 1st Best Poster at COMAT 2024 Poster Contest

At NuMat 2024, in Singapore, ECC-SMART project was proudly represented by Daniela Marušáková (CVŘ) who presented her work on Corrosion and Stress Corrosion Cracking of 310S Under Supercritical Water at 500°C. Alongside her, Hygreeva N. (CNL) showcased a poster on Assessment of Irradiation-Induced Microstructure and Mechanical Properties of Alloy 800H and 310 Stainless Steel After 500 MeV Proton Irradiation. Full presentations and posters are provided in Annex 1.

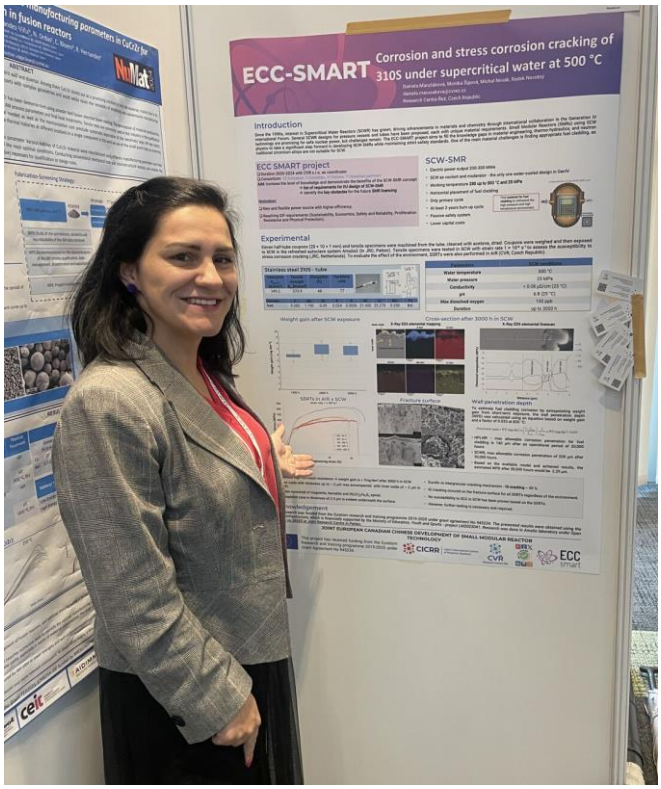


Figure 6: Daniela presenting her research results at NuMat 2024.

Tereza Válková (CVR)

Tereza Válková is a junior researcher at the Research Centre Řež, specializing in material testing for advanced energy engineering applications. She focuses on analyzing and testing materials for fourth-generation reactors, particularly those using helium, supercritical water, carbon dioxide, and, more recently, lead-cooled systems. Additionally, Tereza collaborates on a project investigating the use of supercritical carbon dioxide as a medium for heat exchangers in concentrated solar plants. Her primary responsibility involves the microscopic analysis of corrosion samples using light optical microscopy (LOM) and scanning electron microscopy (SEM).

Tereza is motivated to expand her expertise and skills to enhance her competitiveness in the nuclear field. She begins her doctoral studies in autumn at UCT Prague's Department of Power Engineering, aiming to contribute to the industry's goals with her acquired knowledge. Supported by the ECC-Smart Project, Tereza participated in several events, including: the Workshop on Structural Materials for Generation IV SMR Concepts (Madrid, November 2023), the EBSD User Meeting (Cracow, May 2024; Figure 7), and the Workshop on Post-Irradiation Examination (Prague, August 2024).

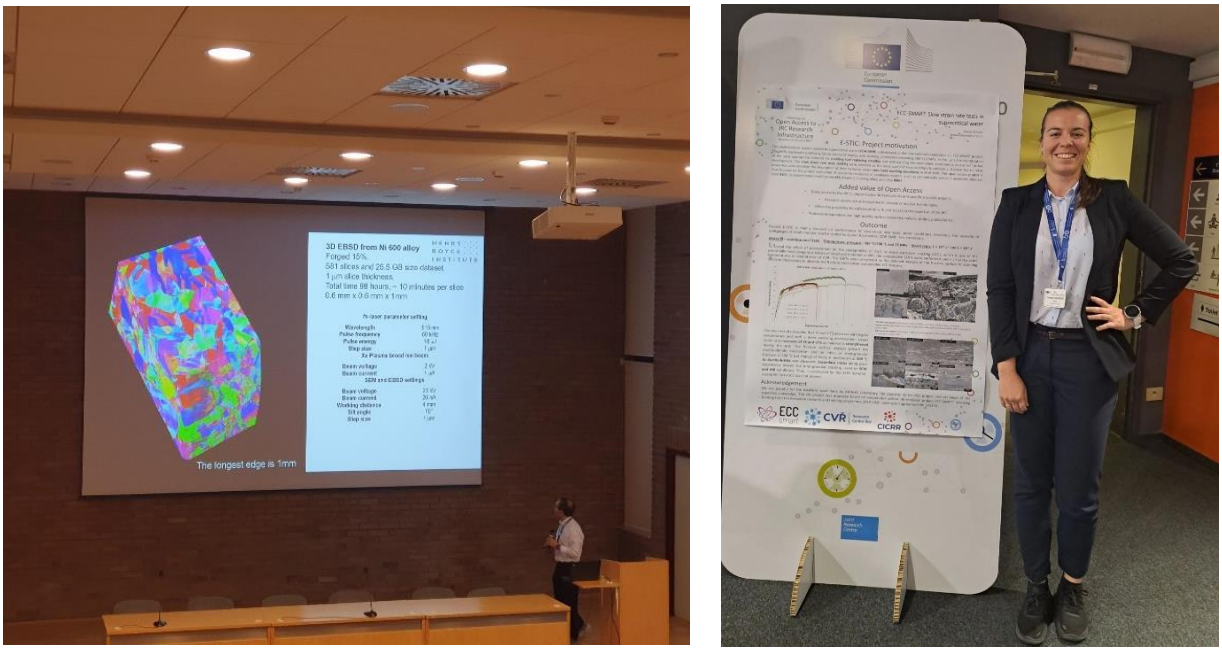


Figure 7: The EBSD User Meeting and Workshop in Brussel.

Kenneth Chinembiri (USFD)

Kenneth Chinembiri is a Postdoctoral Research Associate at the University of Sheffield, specializing in nuclear thermal hydraulics. He earned his PhD in Nuclear Thermal Hydraulics from

the University of Sheffield in late 2020. His current research focuses on the thermal hydraulic analysis and methodology development for SuperCritical Water-cooled Reactors (SCWR) and Advanced Gas-cooled Reactors (AGR).

Kenneth's research, titled *Direct Numerical Simulations of Supercritical Flow over Rough Surfaces*, explores innovative computational approaches to understanding supercritical flow behavior. As part of the ECC-Smart Project, Kenneth visited the Research Center Rez (CVR) and the Canadian Nuclear Laboratories (CNL). He participated in several key events and workshops, including:

- CHAPSim2 User Meeting (2022)
- UK Fluids Conference & Computational Insights UK (2022)
- Collaborative Computational Project - Nuclear Thermal Hydraulics Special Interest Group (2022, 2023, 2024)
- 11th International Symposium on Supercritical Water-Cooled Reactors (ISSCWR-11)

During these events, Kenneth actively presented his research findings, contributing to advancements in nuclear thermal hydraulics and SCWR technology.

Zewen Zou (USFD)

Zewen Zou is a final-year PhD student at the University of Sheffield, specializing in modeling heat transfer to supercritical fluids. Her research focuses on improving the understanding and prediction of mixed convection under strong heating.

Zewen has actively participated in international conferences, including the 17th International Heat Transfer Conference (IHTC) and the UK Fluids Conference. With the support of the ECC-Smart Project, she attended the CCP/SIG NTH Annual Technical Meeting.

Her work contributes to advancing thermal fluid dynamics, particularly in systems involving supercritical fluids, an area critical to improving reactor efficiency.

2.2 Long-term Stays

This section highlights the significant contributions and experience of ECC-SMART participants who engaged in extended research stays at prominent international laboratories and institutions. These long-term stays provided unique opportunities for in-depth experimentation, collaboration with global experts, and hands-on involvement in cutting-edge research.

The extended stays facilitated the development of advanced techniques and computational tools, fostering the participants' professional growth while directly contributing to the ECC-SMART Project's objectives. By immersing themselves in diverse research environments, these young scientists strengthened their expertise in reactor physics, materials science, and experimental methodologies, further advancing the field of SCW-SMR technology.

The exchange program for PhD students, post-docs, and young scientists, as outlined in the Grant Agreement, was envisioned as a cornerstone of the project, fostering hands-on collaboration, access to state-of-the-art facilities, and knowledge exchange among consortium members. However, the global COVID-19 pandemic introduced unprecedented challenges that significantly impacted the feasibility of such initiatives. Extended travel restrictions, health concerns, and institutional constraints severely limited mobility during critical periods of the project. Even after restrictions were lifted, residual uncertainties and hesitancy to travel persisted, further affecting participation and having a direct impact on the number of participants.

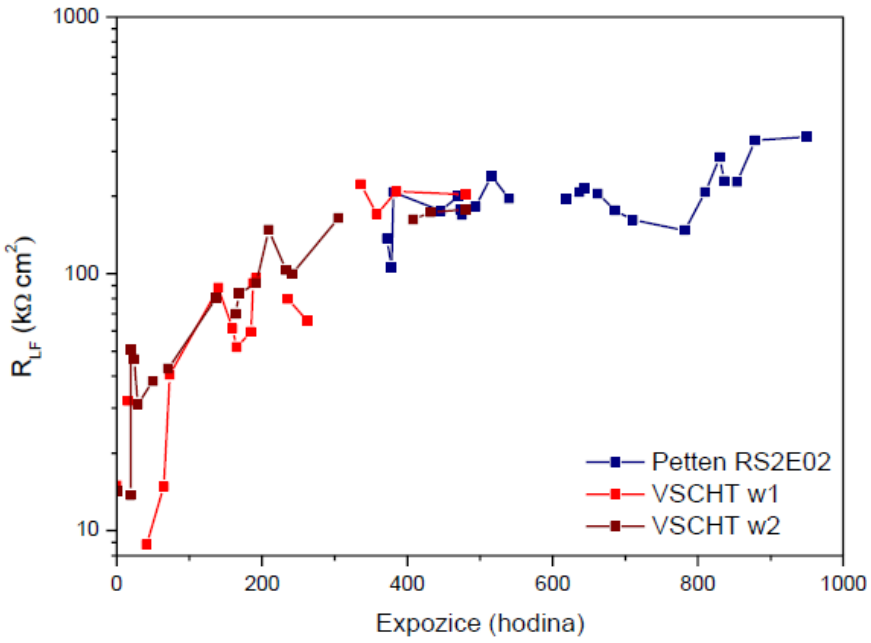
Recognizing these challenges, the consortium sought alternative approaches to ensure the project's educational and collaborative objectives are achieved. One major initiative was the transformation of the Workshop on Post-Irradiation Examination (PIE) into a summer school format. This adjustment allowed the inclusion of a larger cohort of students and young scientists in an intensive longer program. Participants were able to engage with leading experts, enhance their technical knowledge, and immerse themselves in discussions on advanced topics, while gaining some hands-on experience at the facilities, thereby contributing to their professional development.

In addition, virtual and hybrid formats were included to ensure continuity in collaboration and knowledge sharing. Online workshops, remote seminars, and digital networking platforms provided avenues for sustained engagement, allowing participants to benefit from the expertise within the consortium despite the limitations imposed by the pandemic. These adaptations underscore the consortium's commitment to supporting young researchers and achieving the project's objectives, even in the face of unforeseen challenges.

The section below highlight the young professionals who undertook long-term research stays, showcasing their dedication to advancing SCW-SMR technology. Each participant's experience is a testament to their commitment and ability to thrive in diverse and dynamic research environments. Their unique contributions, detailed individually, reflect not only their personal expertise but also the collective achievements of the ECC-SMART project, bolstered by extended access to key facilities and collaboration with international experts.

Petr Roztočil (UCT Prague)

Petr Roztočil is a third-year PhD student specializing in corrosion research at the University of Chemistry and Technology in Prague, within the Department of Power Engineering. Supported by the ECC-Smart Project, Petr conducted critical experiments at the Joint Research Centre in Petten, Netherlands, where he performed corrosion testing of steels in a supercritical water environment. This research, conducted from February 12 to March 16, 2022, aimed to evaluate the corrosion resistance of materials under extreme conditions relevant to advanced nuclear reactors. Picture of the experiment:



Obrázek 4.3: Graf závislosti nízkofrekvenčního faradického odporu na čase expozice.

Figure 8: Graph of dependence of low-frequency faradic resistance on exposure time.

David Dašek (UCT Prague)

David Dašek is a PhD student at the University of Chemistry and Technology (UCT) in Prague, specializing in the electrochemical corrosion of nuclear fuel cladding. His research focuses on studying the effect of surface modifications on the corrosion behavior of structural materials in subcritical and supercritical water environments. At UCT, David conducts in-situ electrochemical corrosion tests as part of his doctoral thesis. As part of his trainee mobility program, he took part in the ECC-SMART experiments performed at JRC. He commissioned devices and conducted tests for WP2.

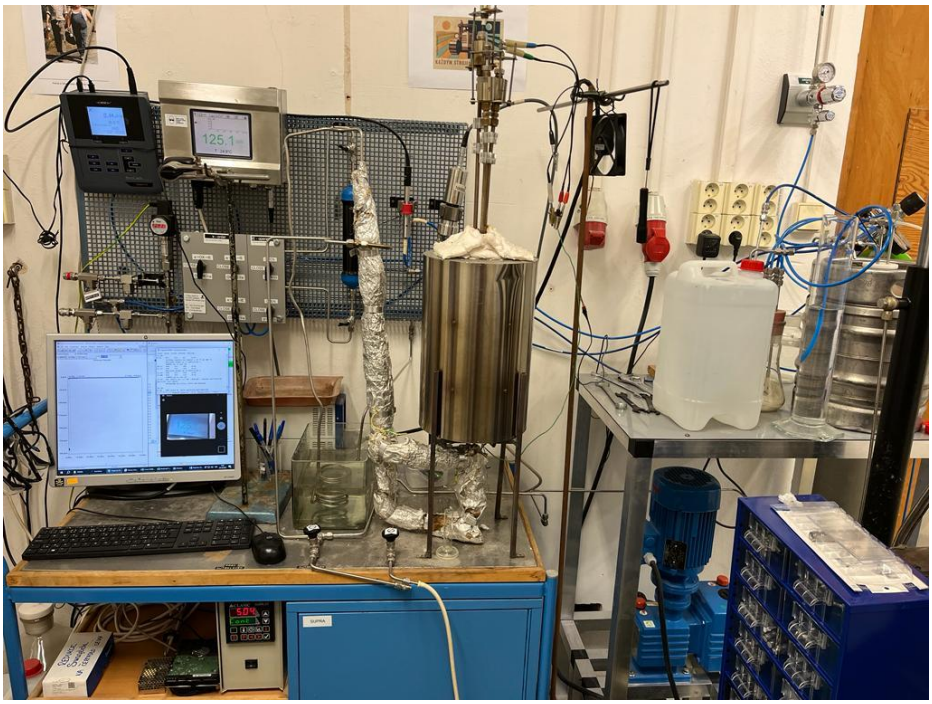


Figure 9: Experimental Laboratory Setup

Jaromir Valtr (UCT Prague)

Jaromir Valtr is a doctoral student at the Department of Power Engineering at UCT Prague, specializing in the corrosion study of Alloy 800H. With support from the ECC-Smart Project, Jaromir visited the Amalia Laboratory at JRC Petten, where he conducted electrochemical measurements. His research took place from March to June 2023.

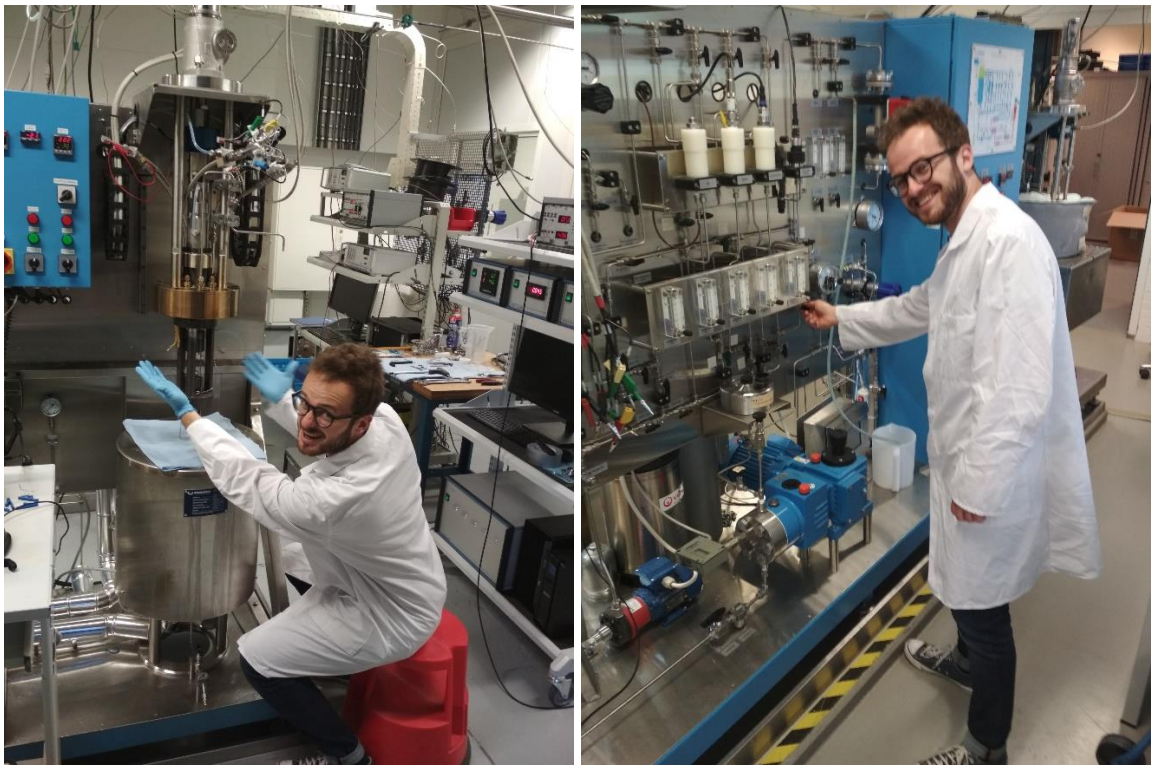


Figure 10: Jaromir Valtr performing his experiment at the laboratory.

Daniela Marušáková (CVR)

As part of the ECC-Smart Project, Daniela Marušáková visited several laboratories, including the Canadian Nuclear Laboratories (CNL) in Canada. At these facilities, she conducted exposure experiments in supercritical water environments, with the CNL experiments taking place from July to August 2024.

Figure 11: Lunch with colleagues of the Canadian Nuclear Laboratories

Péter Mészáros (BME)

Péter Mészáros is a reactor physicist at Paks Nuclear Power Plant and a former student of the Budapest University of Technology and Economics, where he earned degrees in energy engineering (bachelor's and master's with a nuclear specialization) and physics (master's with a focus on nuclear techniques).

As part of the ECC-Smart Project, Péter specialized in coupled thermal hydraulics and reactor physics calculations for the SCW-SMR reactor concept. In fall 2023, he spent six weeks at the University of Pisa under the supervision of Valerio Giusti, performing coupled thermal hydraulics and reactor physics calculations using tools like BERM-AN, Serpent, and RELAP5. His work aimed to develop a model and data transfer toolset to enhance productivity.

Péter's research, titled *Reactor Physics and Thermal Hydraulics Examination of the SCW-SMR Concept Using Serpent 2 and Apros Codes*, resulted in two theses and a detailed experiment report. He also participated in the *Joint ICTP-IAEA Workshop on Open-Source Nuclear Codes for Reactor Analysis* and the *Hungarian Nuclear Technique Symposium XX*, where he presented his findings (provided poster – Annex 1).

Bertesina Zéno (BME)

Bertesina Zéno is a physicist with a specialization in reactor physics. He graduated from Budapest University of Technology and Economics (BME) and currently works at Paks Nuclear Power Plant.

As part of the ECC-Smart Project, Bertesina spent three months (13 February – 14 May 2023) at the University of Pisa (UNIPI), working on a burnup module for BERM-AN, a reactor physics code developed at the university. Her research, titled *Coupled Reactor Physics and Thermal Hydraulics Computation, Burnup Calculations,* integrates advanced computational tools to enhance reactor performance modelling. Bertesina's work contributes to optimizing reactor safety and efficiency through innovative computational approaches.

2.3 Publications - Abstracts

This section provides a summary of key publications and presentations by researchers supported by ECC-Smart. Each abstract highlights specific findings in corrosion and materials science, particularly regarding supercritical water environments, a critical area in the development of Generation IV reactors. Full publications are provided in Annex 2.

Jivan Khatry (UoN)

1) Publication related to his research –In preparation.

"Development of coefficient-optimized Nusselt number equations for supercritical water in horizontal flow direction" - Hangxi Wang, Jivan Khatry, Ivan Otic, and Jie Zhu

Abstract

Supercritical flow is a phenomenon that is still not well understood, and the knowledge concerning thermal hydraulics in horizontal flow is far behind compared to that in vertical flow. Nine different correlations for the Nusselt number in the horizontal flow direction are selected in this paper and compared to experimental data in the literature for the wall temperature and heat transfer coefficient as per enthalpy. Based on the analyses, a MATLAB code is developed to optimise the coefficients, and two new correlation equations are proposed. It is found that the differences between the predictions from the new relations and the experimental data are less than 15%. Attempts are made to further improve the new relations by adding dimensionless quantities at last.

Keywords: Supercritical pressure, horizontal flow, Nusselt number, wall temperature, heat transfer coefficient

Publication status: Submitted for publication first time during February 2024; rejected and improvements are being made at this time as per reviewer comments.

Jaromir Valtr, Petr Roztočil and David Dašek (UCT Prague)

1) Publication related to his research - Published

Measurement system for in-situ estimation of instantaneous corrosion rate in supercritical water

Jaromír Valtr [a,*], Petr Roztočil [a], David Dašek [a], Radek Mušálek [b], František Lukáč [b], Jakub Klečka [b], Marek Janata [b], Mariana Arnoult-Růžičková [a], Eva Mištová [a], Luděk Jelínek [a], Petr Sajdl [a], Jan Macák [a]

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HIGHLIGHTS

- Experimental set-up for in-situ measurement of corrosion rate by electrochemical impedance spectroscopy is proposed.
- Careful set-up of impedance measurements provides reproducible data.
- The electrode response varies in different electrode set-ups.

GRAPHICAL ABSTRACT

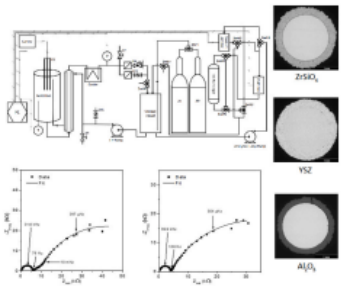

Figure 12: Publication - top of the 1st page

Abstract:

Current research of cladding and in-core materials for the supercritical water reactor concept is focused on Fe-Cr-Ni alloys (e.g. 800 H, 310 S). Along the standard measurements of general corrosion rate of materials by exposure testing in autoclaves, where poor reproducibility is an issue, especially when comparing results from different

experimental facilities, a good alternative may be the use of in-situ electrochemical measurements. The use of electrochemical methods is, however, more challenging due to complicated instrumentation as well as due to the supercritical water conditions. This paper is focused on the design of an experimental facility for in-situ electrochemical testing at supercritical water conditions, i.e. main circulating loop with autoclave, including the design of the electrode system, electrode leads and their surface insulation coating. Stability of electrochemical measurements has been tested using 2- and 3-electrode set-ups. Finally, surface insulation coating of the electrode leads with the best chemical and mechanical stability during experiment has been chosen for the presented application.

Keywords:

Electrochemical Impedance Spectroscopy - Nuclear industry - Nickel alloys - Plasmasprayed, insulation - High temperature corrosion - Supercritical water

Petr Roztočil (UCT Prague)

1) Publication related to his research - in preparation.

“Interaction of structural materials with supercritical water“

Abstract:

Candidate materials for the fuel cladding and internal structures of Generation IV Supercritical Water-cooled Reactor (SCWR) are in particular austenitic steels (e.g. 310S) or nickel alloys (e.g. 800H), as well as newly developed alloys, such as AFA (Alumina Forming Austenitic) steels. Testing of general corrosion resistance of these materials is most often performed by weight change measurements. This method is simple, but the results suffer from poor reproducibility and the errors in the measurements are significant. In contrast, the electrochemical impedance spectroscopy method allows a satisfactorily reproducible in-situ determination of the corrosion rate, even in supercritical water conditions, but at the cost of relatively complex measuring equipment. This paper focuses on the interaction of 310S stainless steel with supercritical water. The corrosion properties of the material were studied in four experiments, each 1000 hours long. In all experiments, the supercritical water pressure was maintained at 25 MPa. Experiments were carried out at two different temperatures: 380 °C close to the pseudocritical point, and at 500 °C, the steam outlet temperature of e.g. the European concept of the SCWR and SCWR-SMR. Furthermore, the effect of dissolved oxygen content was studied. Measurements were made over a wide range of oxygen concentrations from less than 5 ppb, at 150 ppb of oxygen (simulating the slightly oxidizing conditions in the reactor core due to radiolysis of water) and at concentration of oxygen of 6000 ppb.

The experiments confirmed parabolic corrosion kinetics. The corrosion processes were controlled by diffusion through the solid phase in addition to the charge transfer process, which was demonstrated using an appropriate equivalent circuit. The results obtained by electrochemical impedance spectroscopy were obtained with satisfactory precision and reproducibility.

Daniela Marušáková (CVR)

2) Publication related to her research - in preparation.

Corrosion Resistance of Alumina-Forming Austenitic Steels Under Simulated Accident Conditions for SCWR and SCW-SMR Applications

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Abstract. This study evaluates the potential of Alumina-Forming Austenitic (AFA) steels, containing 2–5% aluminum, derived from SS 310S, as high-temperature corrosion-resistant materials for Supercritical Water Reactors (SCWR) and Small Modular Reactors cooled by Supercritical Water (SCW-SMR) under simulated accident conditions. AFA steels exhibit high-temperature corrosion resistance through alumina (Al□O□) scale formation and enhanced mechanical strength via precipitation hardening, with key strengthening phases including NbC, Laves phase, and B2–NiAl. As part of the international ECC SMART project which aims to develop SCW-SMR, flat coupons were exposed to water at the reactor's inlet temperature of 380 °C and 25 MPa for 1000 hours, where water properties change drastically. The exposed samples were analyzed using SEM-EDS/EBSD to evaluate the bulk material microstructure and to determine the corrosion layer. Based on weight gain and the absence of significant layer formation, a very low corrosion rate was detected, with the calculated wall penetration depth after 30.000 hours of the fuel cycle indicating the alloy's long-term corrosion stability.

Keywords: Alumina-forming austenitic (AFA) steel, high-temperature corrosion, supercritical water reactors, microstructural analysis.

Figure 14: Publication - top of the 1st page

Zewen Zou (USFD)

1) Publication related to her research – Under review.

PREDICTION OF HEAT TRANSFER DETERIORATION DUE TO BUOYANCY

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ABSTRACT

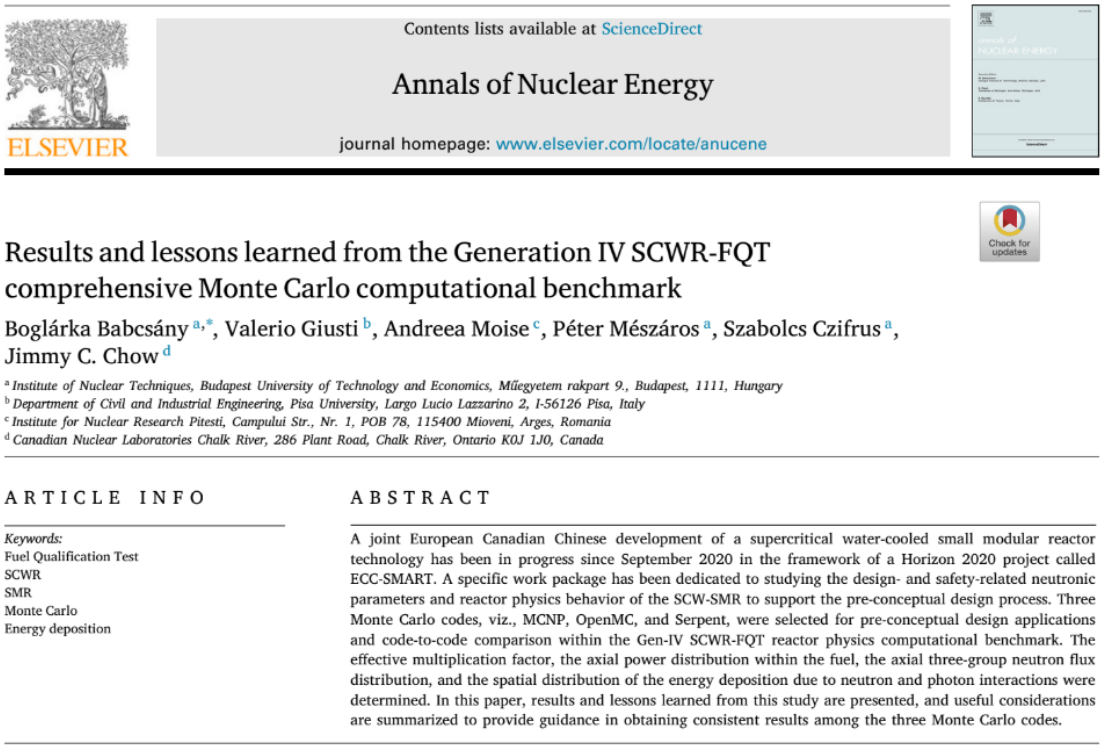
Recently a so-called apparent Reynolds number (ARN) approach has been proposed to explain the laminarisation of an isothermal turbulent flow caused by an idealised non-uniform body force (He, He and Seddighi, 2016). This concept was further applied to heated flows with a strong influence of buoyancy, for example, an upward pipe flow of air or supercritical CO2 (He, Tian, Jiang and He, 2021). In both cases, turbulent characteristics during the laminarisation process are well explained using the ARN approach. In the present study, this ARN approach, previously used to explain turbulence, is extended to describing the heat transfer deterioration. The prediction is based on the determination of the eddy viscosity of a simple reference flow defined by the apparent Reynolds number. The new method has been demonstrated to predict the heat transfer deterioration very well in comparison with DNS data. This ARN concept greatly simplifies the calculation of heat transfer in mixed convection flows and offers a better explanation of heat transfer deterioration mechanisms.

KEY WORDS: Mixed convection, heat transfer deterioration, laminarisation, apparent Reynolds number

Figure 16: Publication - top of the 1st page

Péter Mészáros (BME)

1) Publication related to his research – Published:



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Results and lessons learned from the Generation IV SCWR-FQT comprehensive Monte Carlo computational benchmark

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ABSTRACT

A joint European Canadian Chinese development of a supercritical water-cooled small modular reactor technology has been in progress since September 2020 in the framework of a Horizon 2020 project called ECC-SMART. A specific work package has been dedicated to studying the design- and safety-related neutronic parameters and reactor physics behavior of the SCW-SMR to support the pre-conceptual design process. Three Monte Carlo codes, viz., MCNP, OpenMC, and Serpent, were selected for pre-conceptual design applications and code-to-code comparison within the Gen-IV SCWR-FQT reactor physics computational benchmark. The effective multiplication factor, the axial power distribution within the fuel, the axial three-group neutron flux distribution, and the spatial distribution of the energy deposition due to neutron and photon interactions were determined. In this paper, results and lessons learned from this study are presented, and useful considerations are summarized to provide guidance in obtaining consistent results among the three Monte Carlo codes.

Figure 17: Publication - top of the 1st page

3 Conclusions

In conclusion, Deliverable 6.6 highlights the pivotal role of the ECC-SMART project in advancing nuclear research while nurturing the next generation of experts in the field. By facilitating impactful research activities, laboratory visits, and academic contributions, the project has empowered PhD students and early-career scientists to engage in cutting-edge investigations and collaborative endeavors. These researchers have significantly advanced the understanding of materials behavior in supercritical environments, providing critical insights for the safe and efficient design of Supercritical Water-cooled Small Modular Reactors (SCW-SMRs).

Beyond technical achievements, this deliverable emphasizes ECC-SMART's commitment to education, capacity-building, and knowledge dissemination. By enabling access to state-of-the-art laboratories, hosting specialized workshops, and fostering international collaboration, the project has not only enhanced technical expertise but also strengthened the skills and confidence of young researchers. Through mentorship and interdisciplinary engagement, ECC-SMART has cultivated innovation and sustainability within the nuclear sector, ensuring that this new generation of scientists are well-prepared to address the complex challenges of the future.

Ultimately, this deliverable reinforces ECC-SMART’s overarching objectives of advancing safety, fostering innovation, and enhancing industrial engagement, while showcasing the project’s dedication to scientific progress and collaboration on a global scale. The collective contributions of these researchers, documented here alongside their publications and presentations, underscore the project’s lasting impact on the development of sustainable nuclear technology.

4 Annexes

The annexes include full versions of presentations, posters, and publications by the participating researchers, offering a comprehensive view of their research contributions. Annexes can be accessed via provided links. **Annex 1** includes the presentations and posters and **Annex 2** includes the publications available at the moment.

Access the annexes through the following link: Annex - D.6.6