(Project Number: 945 041)

DELIVERABLE D5.5

Masters and PhD theses connected to the project – topics, assignment, and progress reports

Lead Beneficiary: CTU

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CO	Confidential, only for Beneficiaries of the SafeG project	

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Project information

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EXECUTIVE SUMMARY

The document highlights the collaborative efforts between students, academic institutions, and senior experts, emphasizing the significance of academic-industry partnerships in advancing nuclear energy research. It underscores the pivotal role of student participation in the project, not only for their academic and professional development but also for the generation of innovative solutions and successful project outcomes.

Within the SafeG project, master theses focus on various aspects related to the ALLEGRO gas-cooled reactor design, material studies, safety evaluations, and hydrogen production within the context of gas-cooled reactors. These theses demonstrate students' engagement in diverse fields and contribute to the advancement of knowledge and technologies in specific areas of nuclear energy.

The PhD theses within the SafeG project delve into specialized fields such as advanced safety analyses, thermal hydraulics, innovative fuel assemblies, and severe accident mitigation approaches (core catcher design) for gas-cooled reactors. The research conducted by PhD students significantly contributes to the progression of knowledge and technologies in these specific domains within the realm of nuclear energy and reactor design.

Furthermore, the document underlines the commitment of university members within the project consortium to provide students with meaningful and engaging topics aligned with their interests and goals. By offering valuable learning opportunities, the project aims to foster the growth and development of students in the nuclear field, preparing them for successful careers in the industry or further academic research.

CONTENT

1 OVERVIEW OF MASTER AND PHD THESES

Student participation in projects like SafeG is crucial for their academic and professional development. It provides them with practical, hands-on experience that complements their theoretical knowledge acquired in the classroom. By working alongside senior experts, students gain valuable mentorship and guidance, helping them to grow and succeed in their chosen field. Additionally, actively engaging students in projects can spark creativity, innovation, and fresh perspectives that can lead to successful outcomes and advancements in the project. Overall, student participation not only benefits the individual students but also contributes to the overall success and impact of the project.

The university members of the project consortium are committed to finding meaningful and engaging topics for students to work on in this project. Our aim is to provide them with valuable learning opportunities that align with their interests and goals, ultimately fostering their growth and development in the nuclear field. By identifying relevant and impactful topics, we aim to empower students to excel in their academic pursuits and contribute meaningfully to the project's success.

Each partner involved in the project brings a unique expertise and focus area that enriches the overall collaboration. By leveraging the diverse perspectives and strengths of each partner, we can ensure that a wide range of topics and perspectives are considered, leading to a more comprehensive and impactful project outcome. This diversity of focus areas allows for a holistic approach to problem-solving and innovation, ultimately benefiting both the project and the participating students.

Students participating in the project have the opportunity to engage in advanced research through Master's and PhD theses, diving deep into complex topics and making significant contributions to the field of nuclear science. These higher-level academic pursuits allow students to develop specialized knowledge and skills, preparing them for successful careers in the nuclear industry or further academic research. By supporting and guiding students through these thesis projects, we aim to cultivate the next generation of experts and innovators in the nuclear field.

The collaboration between the National University Corporation Kyoto University, Slovenska Technicka Univerzita v Bratislave (STU), Budapesti Muszaki Es Gazdasagtudomanyi Egyetem (BME), Ceske Vysoke Uceni Technicke v Praze (CTU), and The Chancellor Masters and Scholars of the University of Cambridge (UCAM) showcases the global network of prestigious academic institutions dedicated to advancing nuclear science research and education. These universities bring together diverse expertise, resources, and perspectives, creating a rich collaborative environment that fosters innovation and excellence in the field. By leveraging the strengths of each institution, this partnership serves as a hub for cutting-edge research, knowledge exchange, and talent development, shaping the future of nuclear science for the benefit of society.
The main focus of National University Corporation Kyoto University in the nuclear field lies in conducting advanced research and education spanning various aspects of nuclear science and engineering, including nuclear energy, radiation safety, and nuclear materials. The university is dedicated to addressing critical issues in the field, such as nuclear power plant safety, nuclear waste management, and the development of next-generation nuclear technologies. Through collaborative projects, partnerships, and academic programs, Kyoto University aims to drive innovation, foster talent, and contribute to the sustainable advancement of nuclear science for the benefit of society.

Slovak University of Technology in Bratislava (STU) is one of the most prestigious technical universities in Slovakia, offering a wide range of engineering, architecture, and IT programs. It is known for its strong focus on practical, hands-on learning, innovative research, and strong industry collaborations. STU is known for its focus on nuclear engineering and nuclear technology research. The university's nuclear program emphasizes reactor physics, nuclear safety, radiation protection, and nuclear materials. STU collaborates with industry partners and research institutions to advance knowledge in the field and develop practical solutions for nuclear energy challenges. Through cutting-edge research and academic programs, STU contributes to the global nuclear community and plays a crucial role in shaping the future of nuclear technology and innovation.

Budapest University of Technology and Economics (BME), has a strong emphasis on nuclear engineering and research within its Faculty of Electrical Engineering and Informatics. The university offers specialized courses in nuclear power plant design, nuclear safety, and nuclear reactor technology. BME collaborates with industry partners and research institutions to address challenges in the nuclear field, with a focus on developing innovative solutions and advancing nuclear science and technology. The university's contributions to the nuclear sector play a significant role in shaping the future of nuclear energy and promoting sustainable development in this crucial field.

The University of Cambridge (UCAM) is one of the oldest and most prestigious universities in the world. Cambridge has a long history of excellence in various disciplines, including nuclear research and technology. The university's Department of Engineering, Department of Physics, and other research centers have been actively involved in nuclear energy research, nuclear physics, nuclear engineering, and related fields for many years. Cambridge's contributions to nuclear science and technology have been significant and have had a lasting impact on the development of nuclear technologies globally.

In the area of direct student involvement in the project these universities contributed among other through specialized master and doctoral thesis topics. There have been 7 master thesis assigned of which 2 have been already successfully defended. In the doctoral degree level 3 doctoral students are working on the research and preparing their theses in the field of the GFR.

2 MASTER THESES

This section provides an overview of the master thesis topics and the current progress.

Slovak University of Technology in Bratislava (STU)

Student name: Bc. Marcela Hyksova

Thesis title: ALLEGRO – the gas cooled reactor

Degree which the thesis is part of: MSc

Supervisor's name: Dr. Stanislav Sojak

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: In frame of thesis on Bc. level the student was focused on special design of nuclear demonstrator ALLEGRO. In the next step selected materials foreseen for application in ALLEGRO design were studied in as received as well as in thermal treated state. Isochronal annealing was performed in vacuum. Defects in form of small vacancy clusters and screwed or edged dislocation was experimentally studied using positron annihilation lifetime spectroscopy which is available for student's thesis at Slovak University of Technology – Institute of Nuclear and Physical Engineering in Bratislava.

The diploma thesis includes the following points:

1) Theoretical search and analyses

2) Theoretical considerations and evaluation of expected materials defects in selected materials foreseen for ALLEGRO reactor

3) Experimental evaluation of selected specimens

4) Conclusions

Status: Defense planned 06/2024

Student name: Bc. Pavlina Pronska

Thesis title: Material for thermonuclear fusion and gas cooled fast reactors

Degree which the thesis is part of: MSc

Supervisor's name: Dr. Vladimir Krsjak

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: Material for thermonuclear fusion and gas cooled fast reactors were studied using nondestructive techniques with the aim to evaluate radiation resistivity and degradation of design materials. Neutron irradiation was replaced via ion irradiation, which was performed at selected specimens at Tandetron facility of STU. Such treatment (without spallation reaction) enables good manipulation with specimens which were treated by accelerated ions simulating neutron treatment. In experimental part non-destructive techniques as Doppler broadening as well as positron annihilation livetime spectroscopy were applied.

The diploma thesis includes the following points:

1) Theoretical analyses of expected material degradation due to expected operational treatment.

2) Evaluation of vacancy type defects via applied non-destructive techniques (DB, PALS)

3) Experimental evaluation of defects and their mobility in studied specimens

Status: Defense planned 06/2024

Student name: Bc. Matus Hupka

Thesis title: Analysis of lost power of the self-consumption from the external grid due to extreme wind

Degree which the thesis is part of: MSc

Supervisor's name: Dr. Jana Simeg Veternikova

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: The thesis will present the procedure for creating a site threat analysis for a new power plant. The impact of extreme wind on the reactor building is solved, which depends mainly on the sites' climatic conditions. The thesis also discusses the vulnerability assessment of external equipment of the nuclear unit's self-consumption, such as connection to the electric grid and transformers. The result of the thesis will evaluate the safety of the site for current reactors as well as GEN IV reactors.

The diploma thesis includes the following points:

1) Theory about the safety evaluation.

2) Analysis of the threat to the selected location of the new nuclear power plant due to extreme wind.

3) Analysis of the vulnerability of external self-consumption devices of the nuclear block to extreme wind.

Status: Defense planned 06/2024

Student name: Bc. Matus Huska

Thesis title: Perspectives in optimal use of hydrogen production in gas cooled reactors

Degree which the thesis is part of: MSc

Supervisor's name: Dr. Vladimir Krsjak

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: This thesis is focused on the perspectives in optimal use of hydrogen production in gas cooled reactors. Hydrogen seems to be critical element from the nuclear safety point of view mainly because its high diffusivity and possible detonation in concentration over 4% in air. In case of this thesis the student was focused on hydrogen diffusion and its accumulation in design materials – especially in alloys. Materials were studied using nondestructive techniques with the aim to evaluate radiation resistivity and degradation of design materials. Hydrogen treatment was performed via ion irradiation at selected specimens at Tandetron facility of STU. In experimental part non-destructive techniques as Doppler broadening as well as positron annihilation lifetime spectroscopy were applied.

The diploma thesis includes the following points:

1) Analyses of possibilities for hydrogen production in gas cooled reactors.
2) Theoretical studies of expected material degradation due to hydrogen diffusion or cumulation in selected alloys.
3) Evaluation of vacancy type defects via applied non-destructive techniques (DB, PALS)
4) Evaluation of defects and their mobility in studied specimens

Status: Defense planned 06/2024

Student name: Bc. Julia Bockayova

Thesis title: New materials for advanced reactors

Degree which the thesis is part of: MSc

Supervisor's name: Dr. Jana Simeg Veternikova

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: This thesis is a continuation of the bachelor thesis focused on the investigation of austenitic steels as prospective construction materials for components of gas cooled fast reactors. Materials were investigated using positron annihilation spectroscopy. The first part of the work was focused on small modular reactors and microreactors. The second part was devoted to steel as a perspective material, mechanical properties and usefulness of the material in the production of components. The third part was focused directly on the non-destructive method of examining material defects, positron annihilation lifetime spectroscopy. The third part was followed by an experimental part, which is dedicated to the practical application of positron annihilation lifetime spectroscopy on a sample of NF 709 austenitic steel material, which we examined in terms of microstructure changes - the presence of open vacancy defects after exposure to radiation and thermal stress. The results from the NF 709 measurements demonstrated the sensitivity of positron annihilation spectroscopy even to small changes, such as a low level of implantation.

Status: Defense planned 06/2024

National University Corporation Kyoto University (KU)

Student name: Baopu Wang

Thesis title: Effect of Ion Irradiation on Mechanical Properties of Silicon Carbide

Degree which the thesis is part of: MSc

Supervisor’s name: Tatsuya Hinoki

Academic institution awarding the degree: Kyoto University

Scope: Ion irradiation is a powerful tool to understand irradiation effect on a material in various irradiation conditions. The significant difference between neutron irradiation and ion irradiation is a range of irradiation region limited to near surface. Nano-indentation technique is used to evaluate mechanical properties of an ion irradiated material. The residual stress caused by non-irradiated region was evaluated. Effect of the residual stress on the mechanical properties by nano-indentation was evaluated. The mechanical properties of various SiC were evaluated considering the residual stress.

The diploma thesis includes the following points:

1) Ion irradiation of SiC

2) Evaluation of residual stress of ion-irradiated SiC

3) Evaluation of mechanical properties of ion-irradiated SiC

Status: Defended 03/2023

Czech Technical University in Prague (CTU)

Student name: Bc. Jan Komrska

Thesis title: Simulation of melt formation and propagation in severe accidents of nuclear reactors

Degree: MSc.

Supervisor's name: Dr. Pavel Zácha, Ph.D.

Academic institution awarding the degree: Czech Technical University in Prague

Consultant's name and institution: Ing. Petr Vácha, ÚJV Řež

Scope: Severe accidents associated with core melting are among the hypothetical cases that can occur in a nuclear power plant. However, their impact on the environment can be significant, which is why great attention is paid to them when designing new nuclear power plants. Sophisticated computational tools significantly help to design processes associated with reducing the consequences of such an accident. The aim of this diploma thesis is to simulate a selected scenario of a corium spill in the core catcher of the proposed ALLEGRO demonstration reactor using appropriate computational tools.

The diploma thesis includes the following points:

1) Research of severe accident scenarios with core melting

2) Overview of computer programs for the simulation of severe accidents associated with core melting

3) Model and calculation of the selected scenario in the MELCOR program

4) Model and calculation of the selected scenario in the ANSYS Fluent program

5) Processing and analysis of the achieved

Status: Defended 06/2022

3 DOCTORAL THESES

Slovak University of Technology in Bratislava (STU)

Student name: MSc. Slavomír Bebjak

Thesis title: Safety analyses of GenIV gas cooled reactors

Degree: PhD

Supervisor's Name: Prof. Vladimír Slugeň, DSc.

Academic institution awarding the degree: Slovak University of Technology in Bratislava (STU)

Scope: This thesis is focused on advanced safety analyses of gas cooled reactors, especially ALLEGRO design. This conceptual model is foreseen for application in V4 countries, which together with France will dominantly participate on its design development. PhD thesis will solve thermohydraulic problems using computing codes RELAP5 and CATHARE2. Experimental part will be performed at STU helium loop located in Trnava. These experiments will contribute to validation of the computing models.

The PhD thesis includes the following points:

1) Deep theoretical literature search about actual state of art and theories about the safety evaluation.

2) Development and validation of thermohydraulic based on computing codes RELAP5 and CATHARE2.

3) Experiments on STU helium loop focused on validation of theoretical models.

4) Conclusion and results application towards safety increasing of gas cooled reactors

Status: Defense planned 08/2024

Budapest University of Technology and Economics (BME)

Student name: Gergely Imre Orosz

Thesis title: Investigations of thermal hydraulics of ALLEGRO fuel assemblies

Degree: PhD

Supervisor's Name: Prof. Dr. Attila Aszódi

Academic institution awarding the degree: Budapest University of Technology and Economics, Institute of Nuclear Techniques

Scope: Gas-cooled Fast Reactor (GFR) is one of the generation IV reactor concepts. Fast neutron spectrum and high outlet temperature of the coolant make this reactor type a contributor to sustainability of nuclear technology. One of the main challenges of the concept is the development of innovative fuel assemblies, which can withstand the high temperature. Because of the high temperature, the thermal conditions in the core have to be known in detail to design and operate the reactor safely. The thesis deals with these issues and investigates the thermal hydraulics assemblies of the GFR demonstrator, ALLEGRO. In the past, models have been built for bare rod bundle regions to determine the inlet boundary conditions of the complex models. Based on these simulations models have been developed, which include active length ceramic rods with four spacer grids in the regions. These models describe heat convection in the active part of the rod bundles and heat conduction in the clads and assembly shroud. Using these models temperature fields in typical regions are determined and effects of the heat conduction in the clads and thermal radiation are also investigated. Considering the computational effort and accuracy, modelling of the rod cladding and shroud material is required, while modelling of the radiative heat transport is less important.

For the development of a new fuel bundle validation of codes is necessary. The thesis present a new measuring system developed at Budapest University of Technology and Economics (BME) Institute of Nuclear Techniques (NTI). The system is designed to investigate the emerging flow structures in GFR relevant 7 pin rod bundle geometry. The created rod bundle is a simplified and reduced version of the ALLEGRO GFR fuel assembly (P/D=1.208). BME test facility named PIROUETTE (PIv ROd bUndlE Test faciliTy at bmE) is capable of capturing 2D velocity flow fields inside the rod bundle. The fuel rods made of special polymer (FEP), which are practically transparent in water, therefore provide with the opportunity to investigate the effect of different spacer grids even inside the rod bundle. With high resolution 3D printing method different mixing vane spacer grid types (e.g. spacer grid without vane, and spacers with SPLIT and TWISTED type mixing vanes) were manufactured and tested. An uncertainty estimation related to the PIV methodology was also performed. CFD models have been developed for the flow domain, which includes the test section of the PIROUETTE facility and the rod bundle inside it. Separate CFD models were made to describe the different mixing vanes. Mesh independence study was created to provide suitable discretisation of the models. Steady-state RANS calculations were performed with different turbulence models. The measurement results were compared with the results of the CFD modelling. Transient calculations were created to achieve more accurate results.

Status: On going

Czech Technical University in Prague (CTU)

Student name: Jan Komrska

Thesis title: Advanced simulations of severe meltdown accidents of nuclear reactors

Degree: PhD

Supervisor's Name: Prof. Dr. Pavel Zácha

Academic institution awarding the degree: Czech Technical University in Prague (CTU)

Scope: The work deals with simulations of a severe accident with melting of the active zone of the ALLEGRO reactor. As part of the work, a system of capturing and removing heat from the melt of the active zone of the molten ALLEGRO reactor - the so-called Koria Trap - will be designed. An integral calculation of a severe accident starting with the nominal state of the reactor and ending with the cooling of the melt in the corium trap will be performed, which will also include numerically proving the correct functionality of the cooling system. The initial part of the severe accident (nominal state to TNR melting) is solved by the MELCOR system code, corium spillage and long-term heat dissipation is solved using CFD simulation with ANSYS Fluent software. Between these two phases, the calculation of the ablation of the trap sacrificial materials is inserted using the CORQUENCH code.

During the year 2023, all planned courses for 2023 have been completed, a lecture at the NURETH foreign conference has been completed, participation in classes in the subjects Nuclear Power and CFD for Thermal Engineering I.

Publications: Komrska, J., Zácha, P., Vácha, P. (2023). Mesh Sensitivity Analysis of the CFD Model of the Core Catcher of the ALLEGRO Reactor (pp. 3956-3969). 20th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-20). DOI: 10.13182/NURETH20-40672

Status: Ongoing

4 CONCLUSIONS

The document serves as a comprehensive overview of the progress and contributions made by students involved in the SafeG project, highlighting the importance of academic-industry collaboration in advancing nuclear energy research. The collaboration between students, academic institutions, and senior experts leads to innovative solutions, fresh perspectives, and successful project outcomes. Student participation in the project is crucial for their academic and professional development, providing practical experience that complements theoretical knowledge.

The master theses within the SafeG project are focused on specific fields related to the ALLEGRO gas-cooled reactor design, material issues and exploring special design features of this nuclear demonstrator. The master theses highlight the students' engagement in diverse fields such as reactor design, material studies, safety evaluations, and hydrogen production within the context of gas-cooled reactors. The research conducted by the students contributes to advancing knowledge and technologies in these specific areas of nuclear energy.

The PhD theses within the SafeG project are focused on specific fields related to advanced safety analyses, thermal hydraulics, innovative fuel assemblies and severe accident mitigation approaches (core catcher design) for gas-cooled reactors. The research conducted by the PhD students contributes significantly to advancing knowledge and technologies in these specialized fields within the realm of nuclear energy and reactor design.