SAFER2028 Year 2024 Annual Plans

Contents

1. SG1 – Overall Safety and Society

1.1 Hazards

1.1.1 FASAANI - Fire behaviour and safety of nuclear infrastructure, VTT, Aalto

Project name: FASAANI	
Project manager: Nikhil Verma	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd.
Partner organisations: Aalto University	
National collaboration: SAFER2028	**Foreign collaboration:** OECD/NEA FAIR
Objective of research: This research aims at providing new knowledge and validated simulation tools for the assessment of fire development and compartmentation layers in nuclear infrastructures.	
Expected results: **WP1 Smoke compartmentation in nuclear facilities** Based on the approach developed in 2023 to find ventilation model parameters using FDS software for a ventilation network found in nuclear power plant set-up, validation of FDS implementation of ventilation network model and its interaction with fire will be carried out using fire test data. Over-pressure in a compartment and flow anomalies (e.g., reverse flow) in such ventilation network will be computed using FDS software. **WP2 Aging of polymeric materials** DSC/TGA testing of cross-linked polyethylene sample, both virgin and aged, will be completed. The data will preliminarily indicate, if any, the changes in the thermal degradation of virgin and aged samples tentatively pointing towards change in the fire behaviour. DSC/TGA analysis is done both in N_2 and O_2 atmospheres to see the effect of oxidative reactions that happen at lower temperatures than the thermal degradation in N_2. **WP3 Fire barrier systems performance assessment and aging** 2024 results will include experimental characterization of high temperature/post-heating properties of polymeric materials used in fire barrier seals of cable and pipe penetrations.	
Expected publications and theses: A deliverable from WP1 will lead to the submission of a manuscript to Fire Technology journal in early 2025 (on the basis of work done in 2024). A deliverable from WP3 will lead to the submission of a manuscript to Fire Technology journal in early 2025 (on the basis of work done in 2024).	
Other dissemination: Participation in OECD/NEA FAIR project review and analytical working groups; Paper presentation in Nordic Fire & Safety Days Conference, and European Symposium on Fire Safety Science (2024); Submission of XLPE validation data to FDS open-source repository.	

1.1.2 MAWECLI - Marine and Weather Events in the Changing Climate as Potential External Hazards to Nuclear Safety, FMI

Project name: MArine and WEather events in the changing CLImate as potential external hazards to nuclear safety (MAWECLI)	
Project manager: Ulpu Leijala	**Project manager organisation:** Finnish Meteorological Institute (FMI)
Partner organisations: -	
National collaboration: Finnish Environment Institute on coastal flood risks and climate change scenarios Aalto University on coastal flood risks and impacts of heat waves University of Helsinki on convective storms	**Foreign collaboration:** Norwegian Meteorological Institute on sea level and wave research NorCP (Nordic Convection Permitting Climate) group on very high resolution climate modelling NORDLIS (Nordic Lightning Information System) group on lightning observations in the Nordic region
Objective of research: The main objective of the MAWECLI project is to increase preparedness towards single and compound marine and atmospheric extreme events in the changing climate that may pose external hazards at plant level. In addition, the project aims at enhancing methods on physical and statistical modelling, extreme value analysis and uncertainty quantification by joining expertise of scientists from various disciplines.	
Expected results: WP1 Single hazards. Expected results include: • First insights of the future short-term sea level variability based on CMIP6 scenarios, • Characteristics of derecho environments and climatology, • Comparison of wind speeds and wind gusts in atmospheric reanalysis and observational dataset, • Scenarios for the intensity and occurrence of sea-effect snowfall, and • Determination of annual probabilities of extreme air temperatures in the future climate. WP2 Multi hazards. Expected results include: • Estimation of impact of serial cyclone clustering on extremely high sea levels, • Simulated sea levels based on refined synthetic cyclones, • Characteristics of convective storm cells over the Finnish sea areas, and • First outcomes of simultaneously occurred high wind speed and intense snowfall events. WP3 Project management. Expected results include: • Active and fruitful interaction with stakeholders at various levels.	
Expected publications and theses: Expected journal article on: • Environments and climatology of derechos	

- Cyclones and cyclone clustering causing extreme sea levels in the Baltic Sea region

Expected doctoral theses on:

- Sea surface dynamics in the Baltic Sea region using modelling and measurements
- Wind applications to support forestry in Finland
- Severe convective storms in Finland

Other dissemination:

Dissemination activities of the project include:

- 1-2 Ad-hoc meetings

FMI Science news for general public and media

1.1.3 PRALINE - Probabilistic Risk Assessment Labour, Improvements aNd Extensions, VTT

Project name: Probabilistic Risk Assessment Labour, Improvements aNd Extensions (PRALINE)	
Project manager: Ilkka Karanta	**Project manager organisation:** VTT
Partner organisations: -	
National collaboration: -	**Foreign collaboration:** OECD/NEA WGRISK
Objective of research: To advance knowledge and develop methods in seismic human reliability analysis and PRA of systems including digital subsystems. To promote knowledge and understanding of PRA in Finland, to train new PRA experts, and foster international collaboration.	
Expected results: WP1 Seismic probabilistic risk analysis: a conference paper draft on quantification considerations of human performance in seismic situations. WP2 Digital I&C PRA: a PRA model for the reference case of the international DIGMORE project; comparison of the model with the models developed by the other participating organizations. A research report or a conference paper on VTT's DIGMORE model and complementary analyses (possibly e.g. comparison of PRA modelling approaches or comparison of CCF models).	
Expected publications and theses: A review paper on seismic HRA (written in 2023)	
Other dissemination:	

1.1.4 SERIOUS - Sensitivity and risk informed seismic hazard updates, VTT, RMCF, AFRY, HU

Project name: Sensitivity and risk informed seismic hazard up-dates (SERIOUS)	
Project manager: Ludovic Fülöp	**Project manager organisation:** VTT Technical Research Center of Finland
Partner organizations: Institute of Seismology, University of Helsinki[1] , AFRY Finland Oy[2], Rock Mechanics Consulting Finland Oy[3]	
National collaboration: SAFER2028 STAFLOW (Task 1.2 - underground fractures), PRALINE (Task 3.3 – interaction with fragility task)	**Foreign collaboration:** Academy of Finland SEISMIC RISK project: Seismic Risk | University of Helsinki Collaboration with the ESHM20 team (EFEHR | ESHM2020 Overview) SERIOUS is used as input for the international SIGMA3 project, with EDF, PG&E, CEA, SWISSNUCLEAR, CEZ and CRIEPI. VTT has formally joined SIGMA3 using SERIOUS as input, on behalf of the Nordic consortium with STUK, FORTUM and TVO. NKS project: Starting NKS project: "*Evaluating Seismic Hazard in the Nordic Countries in the Context of SMRs: Streamlining Approaches for Assessing Earthquake Sources and Activity Rates*" VTT, Uni. Of Helsinki, Uppsala & Bergen, GEUS
Objective of research: Probabilistic seismic hazard analysis (PSHA) is used in Finland to provide surface hazard for probabilistic risk assessment of NPPs and to estimate underground fracture movement hazard for the spent nuclear fuel repository. The YVL guide requires seismic hazard re-assessed ca. every ten years. In this project, we follow up findings of the earlier STUK investigation (SENSEI); generate synthetic earthquake data and ground motions for NPPs and fracture movement data for the repository; update PSHA methods in Finland in line with the European Seismic Hazard Model 2022 and develop 10-5…10-7/year hazard maps with the perspective of deploying SMRs and extending site-specific studies. The project promotes cross-cutting cooperation between research and industry, natural science and engineering and trains young researchers.	
Expected results: WP1: Synthetic seismicity data serving PSHA The continuity required in WP1 work tasks was to the reason to apply for a 3 year project, initially. In 2023 Task 1.1 did not succeed to attract the MSc student, but the Institute of Seismology managed to recruit a researcher for the task. The focus partly remains on the current stress field and seismicity represented by the available earthquake catalog (i.e. relevant for NPPs) and generating synthetic catalogues to increase the insights, in comparison with what actual earthquake data can provide, but maximum magnitude considerations are also included. T1.1 will produce a **research manuscript.** T1.2 concentrates on introducing the off-fault fractures in the simulation models (POSIVA) and run a benchmark simulation corresponding to real-world earthquake observations in order to simultaneously improve the fault-rupture validation of the FLAC3D/PFC3D approach. T1.2 will produce a **research report.** WP2: Near-site and in-structure effects In 2023 T2.1 collected the suitable earthquake events for national-scale kappa computations, and calculated the kappa for all the recordings. The year 2024 is dedicated to further interpretation and a neat writeup of the kappa work. T2.1 will produce a **research report.**	

~~T2.2~~ Task postponed to 2025 due to budget cuts.

WP3: Data curation & integration in PSHA model updates

T3.1 is not active in 2024.

T3.2, for evaluating the possibility of integration of the kappa factor to PSHA computations is the main activity in 2024. With the kappa values calculated in WP1, the path to implementation in ground motion prediction equations will be assessed. T3.2 will produce **slides and algorithms** for integration of kappa parameter to PSHA computations.

Expected publications and theses:

The main outputs of 2024 are:

- one manuscript from T1.1 (P. Mäntyniemi)
- a research report from T1.2, for off-fault fracture simulation models for POSIVA (O. Kaisko)
- a research report from T2.1, with the calculated regional kappa values (M. Malm, L. Fulop)

Other dissemination:

1.2 Human, organisation and society

1.2.1 SCALA – Safety Culture and Leadership in Sociotechnical Changes and Transitions, VTT, Liliko

<table>
<tr><td colspan="2">Project name:
Safety Culture and Leadership in Sociotechnical Changes and Transitions (SCALA)</td></tr>
<tr><td>Project manager:
Kaupo Viitanen</td><td>Project manager organisation:
VTT</td></tr>
<tr><td colspan="2">Partner organisations:
VTT[1], Lilikoi[2]</td></tr>
<tr><td>National collaboration:
SAFER2028 TONUS</td><td>Foreign collaboration:
NKS-R INSOLE (Internal nuclear safety oversight as part of organizational defence-in-depth – Lessons learned for the Nordic nuclear industry) project is linked to SAFER2028 SCALA WP2 to enable research, experiences exchange and networking in the Nordic.

Other planned collaboration includes data collection in foreign nuclear power companies, international webinars, information exchange with IRSN (France), participation in international nuclear industry peer group events, cooperation with OECD/NEA WGHOF, and cooperation with WANO INSO WG.</td></tr>
<tr><td colspan="2">Objective of research:
Wide-ranging sociotechnical changes potentially impact the ways in which nuclear organizations organize and lead their operations, and what organizational approaches are effective for each context from nuclear safety perspective, and what are the roles and tasks of leaders and safety culture experts. This project studies safety culture and leadership during sociotechnical changes and transitions. We examine the sociotechnical characteristics of major changes and identify ways of managing them. The main methods used in the project are case studies in Finnish NPPs, international data collection, participative development, comparative analysis, and modelling. In addition to case-specific results, the project develops a continuous improvement framework for resilient sociotechnical change for the Finnish nuclear industry. The framework contributes to leading, overseeing, and assessing nuclear safety aspects of sociotechnical changes and transitions.</td></tr>
<tr><td colspan="2">Expected results:
WP1 - Leading safe sociotechnical changes
Summary of organizational lessons learned in terms of assuring nuclear safety in selected case studies (OL3 commissioning and ELSA I&C modernization) (continues in 2025)
WP2 - Overseeing changes: internal oversight function as part of organizational defence-in-depth
Summaries of international and non-nuclear data collection
Normative framework for internal oversight function
Participative case studies on internal nuclear safety oversight in Nordic NPPs
Facilitating international and Nordic information exchange on independent internal oversight
WP3 - Continuous improvement framework for resilient sociotechnical change
Insights from international information exchange (continues in 2025)
WP4 - Annual seminar of Human and Organizational Factors
Annual seminar of Human and Organizational Factors arranged jointly with SAFER2028 TONUS (continues in 2025)</td></tr>
</table>

Expected publications and theses:

- Conference paper on nuclear power plant commissioning (D1.1.3)
- Scientific publication (conference paper or manuscript of journal article) on internal nuclear oversight (D2.1.1)
- NKS final report jointly with NKS-R INSOLE (D2.2.2)

Other dissemination:

- Results from case studies for power companies (slide sets and workshops) (D1.1.1 and D1.1.2)
- Nordic workshop on internal nuclear safety oversight (D2.1.2)
- International webinar on internal nuclear safety oversight (D2.1.3)
- Finnish oversight case study workshops (D2.2.1)
- Summary of information exchange session results (slide set) (D3.3.1)
- Dissemination of public research highlights in social media (posts or articles) (D3.3.2)
- Annual seminar of Human and Organizational Factors co-arranged with SAFER2028 TONUS (D4.1.1)

1.2.2 TONUS - Towards Nuclear Human Systems Integration, VTT, FIOH

Project name: Towards Nuclear Human Systems Integration (TONUS)	
Project manager: Jari Laarni	**Project manager organisation:** VTT Technical Research Centre of Finland
Partner organisations: Finnish Institute of Occupational Health (FIOH)[1]	
National collaboration: SAFER2028 SCALA, SEAMLES	**Foreign collaboration:** OECD/NEA WGHOF, IRSN, SSM, Idaho National Laboratory, Vattenfall, Chalmers University
Objective of research: The project will promote the integration of human, technical and organizational (HTO) factors in order to increase the stakeholders' (i.e., nuclear power plants, regulators and technical support organizations) resources for action in case of severe accidents and other fault situations.	
Expected results: *WP1 Development of Human Systems Integration (HSI) framework for nuclear domain:* Methods and tools are developed for the assessment of Human Factors Engineering (HFE) product and program impact and maturity as well as maturity of HFE organizations. Furthermore, a holistic, integrated and life-cycle-based framework for nuclear Human Systems Integration is created, and applicability of digital twin (created from design data and environment data) as a communication tool between stakeholders, especially between licensee and regulator, will be tested. *WP2 Supporting and evaluating resilience skills in a digital control room:* Simulator tests will be conducted in the OL3 training simulator with licensed operators in Autumn 2024. The scenarios of the simulator runs will be analysed (i.e., operating experience review, function and task analysis and treatment of human actions) by established techniques. Analyses are partly based on the WP2 results from 2023 (e.g., Systems Usability survey results). Initial simulator test results are presented in a slide set format. The analysis of the test results will continue in 2025. *WP3 New methods and tools for operator work and training of cognitive readiness skills:* The effectiveness of VR training will be studied to examine whether there are clear benefits of field operator training in a virtual simulator compared to reading task instructions from a manual. *WP4 Development of field personnel's work practices:* First, we will further study current practices for training and maintaining visual inspection skills in field personnel work and develop tools and recommendations for visual inspection skills training. Second, we will gain a better understanding of how field workers' needs should be described in terms of new mobile tools and of what mobile tools suit them best. Mobile tool concepts for promoting field workers' work practices will be developed. *WP5 Annual seminar on Human and Organizational Factors:* We will disseminate the project results to a larger group of stakeholders and integrate the knowledge and the project results jointly with the SCALA project.	
Expected publications and theses: Three conference articles will be published: one on HFE program and organization maturity, the second one on the evaluation of VR training effectiveness and transfer, and the third one on the visual inspection tool development and use.	
Other dissemination: An annual seminar on Human and Organizational Factors will be organized jointly with the SCALA project.	

1.3 System safety

1.3.1 SEAMLES - Systems Engineering approaches for managing the life cycle of I&C systems, VTT, Aalto

Project name: Systems Engineering approaches for managing the life cycle of I&C systems (SEAMLES)	
Project manager: Antti Pakonen	**Project manager organisation:** VTT
Partner organisations: VTT[1], Aalto University[2]	
National collaboration: SAFER2028 (TONUS, PRALINE), BF (FEMMa)	**Foreign collaboration:** Horizon Europe (A-IQ Ready), IAEA TWG-NPPIC, FBK, ZČU

Objective of research:

The objective of SEAMLES is to develop deterministic safety assessment methods to use in the design and licensing of nuclear instrumentation and control (I&C) systems. Given the current life-cycle phase of Finnish nuclear facilities, we are particularly interested in solving the challenges of upgrade and modernisation projects. We develop modelling and analysis techniques applicable to both early, functional design and late, detailed I&C design.

We promote Systems Engineering practices, by considering the entire life cycle of the plant, and developing techniques to support a multi-disciplinary approach to design assessment. Specifically, we apply Model-Based Systems Engineering (MBSE) practices to facilitate information exchange between engineering disciplines, ease the use of formal verification methods, and in general, improve precision in design.

One focus is on assessment methods that consider various factors (software, hardware, and human and organisational issues) in tandem. We are particularly interested in the Systems-Theoretic Process Analysis (STPA) method based on the Systems-Theoretic Accident Model and Processes (STAMP) causality model.

Another focus is on the broader application of formal verification methods. We will investigate new techniques and tools that expand our current practical capabilities based on model checking.

Expected results:

WP1 Multidisciplinary design assessment:

Our 2023 TVO case study on STPA proved the usefulness of the method in identifying unsafe control actions, but the results are not in a format that could directly applied in I&C engineering processes. Accordingly, we will next develop ways to better integrate STPA in the overall MBSE processes. We will also evaluate types of available tool support for what currently is “pen-and-paper” work, to promote accurate information exchange, traceability, and reuse.

WP2 Formal verification methods:

We will develop methods for considering human used actions in I&C logic model checking. After analysing the practical issues detected in industry projects (where such human actions have often played a significant role), we will identify techniques to, e.g., filter out irrelevant, unrealistic counterexamples, or model erroneous actions by operators.

In both WPs, we will use realistic case studies from TVO (Olkiluoto 1&2 NPPs) or Posiva (encapsulation facility).

Expected publications and theses:

Journal articles and scientific conference papers on STAMP/STPA and formal verification.

A Master’s thesis on practical tool support for STPA.

Other dissemination:

1.3.2 SINARP - The Safe Interaction of Nuclear with a Renewable Rich Power System

Project name: The **S**afe **I**nteraction of **N**uclear with a **R**enewable Rich **P**ower System (SINARP)	
Project manager: Janne Seppänen	**Project manager organisation:** Aalto University
Partner organisations: VTT[1], Fingrid[2], Energiforsk[3]	
National collaboration: SAFER2028, Fortum, TVO, Fingrid	**Foreign collaboration:** Energiforsk, Cigré?

Objective of research:

Energy balance and stability are becoming of great concern in the grid. This project will build on modelling done in the SAFIR/Cosi and SINARP2023 projects to investigate the impact of rapid swings in renewable generation and demand on the safe operation nuclear power plants (NPP), and also investigate the role of nuclear in providing stability. The themes initiated in SAFIR will be continued, using the COSI platform to investigate the impact on the NPP of faults in the power during N-1 contingencies and low inertia (high wind) scenarios. Power system oscillations between the grid and the NPP will also be investigated.

Expected results:

WP1 Scenarios and sub-system modelling:

Significant work was carried out in the latter part of the SAFIR2022-COSI project in terms of building up a working model of Finland's 400 kV grid, using open-source data, and this has been continued in SINARP. The SAFER2028-SINARP project will continue to develop, improve and maintain the open-source model. However, the most appropriate platform for further development will have to be established (continuation with Simulink is preferred, but the other likely candidate is DIgSILENT Power Factory) in which to further develop the model, confidentially if need be, to be fit for specific purpose in Finland by the SAFER partners. That is, the grid model will continue to be developed to aid the operation and safety of nuclear plants in a power system subject to increasing levels of stochastic generation and a consequent loss of inertia. Phenomena such as frequency and voltage collapse, a wide range of oscillations and the usual portfolio of faults in the grid will be both investigated, and will also form a useful benchmark for the grid model (i.e., does the grid model exhibit the same range of oscillations and fault responses as found in the actual grid?). To this end, we need to more accurately model the power flows at the 400 kV nodes. WP1 will continue throughout the project and will be handled by Aalto University. Subsystems for wind parks and HVDC connections will continue to be developed, as these have a great impact on the dynamic behaviour of the grid with respect to the NPPs.

WP2 Simulations and platforms:

The 400 kV transmission grid model will be constantly updated and refined with the output from WP1. The modelling of the synchronous machines in the model, including their inertia parameters and power system stabilizers must continue. If data is available, the grid model will also extend into Sweden and roughly model Sweden and Norway, as the lowering of inertia in Sweden will also be felt in Finland. It takes considerable time to complete these activities, as the model has to be checked after every major change, including adjusting shunt reactors to keep the voltage within prescribed values. The grid model also enables studying the behaviour of the NPP with respect to the other new phenomena of the future system, such as low short circuit power or dynamics related to converters.

Maintaining the CoSim platform to enable co-simulation by VTT, combining the transmission grid, the NPP local grid and the thermo-mechanical behaviour of the NPP will be the role of VTT in SINARP. VTT and the steering group will be relied on to interpret the results in terms of the safety impacts of events in the grid on the NPP under consideration.

Expected publications and theses:

There will be at least 1 conference publication per year and 2 journal publications during the project. There will be, depending on funding, at least 2 associated Master's theses under the supervision of Janne Seppänen or John Millar, and possibly 1 doctoral thesis. At least one seminar presentation per year can also be expected, along with the obligatory reports.

Other dissemination:: As lecturers at Aalto, Janne and John are in an ideal position to disseminate general results and conclusions to master's students

It is expected that the open-source SIMSCAPE version of the 400 kV grid model will be made available to all interested Finnish and Swedish parties at the end of the second year of the project, starting with other departments at Aalto and other units at VTT, depending on the robustness of the model…

2. SG2 Reactor Safety and Fuel

2.1 Thermal hydraulics and severe accidents

2.1.1 ALISA - Analytical and experimental investigation of severe accident phenomena, VTT

Project name: Analytical and experimental investigation of severe accident phenomena (ALISA)	
Project manager: Ari Silde	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd
Partner organisations: No	
National collaboration:	**Foreign collaboration:** OECD/NEA ESTER, OECD/NEA THEMIS, OECD/NEA FACE, USNRC CSARP, OECD/NEA FORESEEN, NKS TRIO (APRI 11), EU SEAKNOT, EU SASPAM-SA, EU MUSA, EU OFFERR EPSILON (IRSN as a partner in WP3), Chalmers University of Technology, SNETP/NUGENIA TA2 IPRESCA
Objective of research: ALISA project combines the experimental and analytical research on severe accident phenomena, which will be performed utilizing separate effect experimental facilities and MELCOR and ASTEC severe accident analysis codes, thus producing new information on the safety significance of SA phenomena. In this work, direct comparison and validation between experiments and simulations/codes will be established and the related uncertainties will be estimated. The results will enhance nuclear safety in Finland.	
Expected results: WP1 Modelling of PAR behavior: MELCOR will be used to reproduce the passive autocatalytic recombiners (PAR) behavior in different gas concentrations and pressures. Data collected during the THAI projects will be used as the input data for modelling. In addition, sensitivity and uncertainty analysis of the THAI experiments will be included in this work. Methods for severe accident sensitivity and uncertainty analyses will be applied in practice in the ALISA project. The combination of MELCOR modelling and uncertainty analysis will give more confidence in the severe accident simulation with respect to hydrogen and PAR behavior and overall improve the safety assessments. WP2 Formation of organics and reactions with Cs and I: The formation of volatile organic compounds from the representative Finnish NPP containment paint samples is being studied in a wide temperature range from 20 up to e.g. 500 °C (representing temperatures generated nearby operating PAR, used for hydrogen management). The volatile organic compounds (VOCs) released in different temperatures will be identified and the degradation of the paint analysed. An updated experimental facility allows the monitoring and identification of the VOCs online. Furthermore, the reactions of Cs and I with the formed volatile organics from paint surface at the same conditions reaching up to 500 °C will be investigated. WP3 Pool Scrubbing of fission products: The retention of fission products in the water pools of containment building will be investigated using the pool scrubbing experimental facility. The emphasis will be on the pool temperatures close to boiling pool and the high flow rates (jet regime) into the pool. The pool scrubbing models in the current SA codes are based on the data from the experiments at low pool temperatures and low flow rates (globule regime) into the pool. Therefore, there is a lack of knowledge on pool scrubbing at elevated conditions. The work will cover gaseous fission products I2, CH3I and particulate fission products CsI, Te, as well as boron representing a neutron absorber. WP3 will be strengthened in 2024 by an EU OFFERR collaboration with the IRSN. The project includes researcher visits in both directions. The experiments will be simulated using MELCOR or ASTEC code and thus validating the pool scrubbing models. The uncertainties in the simulations will be considered.	

WP4 Participation fees and licenses:

This work package is dedicated for the follow-up severe accident research programs. The international programs include OECD/NEA ESTER, OECD/NEA THEMIS and OECD/NEA FACE. These programs will cover fission product behaviour in various accident conditions as well as hydrogen management issues. The FACE program (Fukushima Daiichi Nuclear Power Station Accident Information Collection and Evaluation) is specifically focused on the Fukushima accident topic. In the USNRC CSARP program, the objective is the exchange of data and analyses on experimental and analytical research on severe accidents. The MELCOR license fee for the Finnish users (VTT, Fortum, TVO) is also paid via the CSARP program. As a result of participation in the follow-up meetings of these programs, travel reports summarizing the meeting content will be prepared and the shared documents will be made available for SAFER2028 participants.

Expected publications and theses:

In addition to the research reports and travel reports in 2024, conference papers and/or scientific publications will be prepared.

At least two PhD students are participating in the project in 2024.

Other dissemination:

Results of ALISA in 2023 will be presented at the European Review Meeting on Severe Accident Research Conference (ERMSAR2024). Scientific publications have been submitted to scientific journals and more are expected to be submitted during 2024. The experimental facilities and work will be connected to an “international network of source term experimental facilities” to be established in the EU SEAKNOT project starting in autumn 2022. The results of ALISA work will be also discussed in the meetings of various projects listed in “Foreign collaboration” and the expertise of the ALISA members will be utilized in these projects.

2.1.2 CeReSa - CFD for Reactor Safety, VTT

Project name: CFD for Reactor Safety (CeReSa)	
Project manager: Ville Hovi	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd
Partner organisations: Fortum Power and Heat Oy	
National collaboration:	**Foreign collaboration:** CEA DEBORA benchmark, CFD Direct Ltd, OpenFOAM Foundation, Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

Objective of research:

The overall objective of the project will be to improve the usability and reliability of Computational Fluid Dynamics (CFD) calculations in Nuclear Reactor Safety (NRS) assessment.

In **WP1**, open-source CFD methods will be developed and validated for the analysis of hydrogen transport in NPP containment. The methods will be compared with the models implemented in the commercial ANSYS Fluent code. This work package is a joint effort of VTT and Fortum.

In **WP2**, international CFD benchmarks are participated. In 2024, post-benchmark analysis of the boiling models of OpenFOAM will be analysed and improved.

Expected results:

WP1. CFD modelling of hydrogen transport in containment: Multiphase OpenFOAM model for the analysis of hydrogen transport in NPP containment will be developed and validated. Comparison with commercial ANSYS Fluent will be made in co-operation with Fortum. New scientists will be trained to replace already retired experts for containment analysis. The developed submodels and functionality will be integrated into the OpenFOAM Foundation's public distribution.

WP2. Participation in international CFD benchmarks: In SAFIR2022 programme, the DEBORA benchmark on boiling was participated with OpenFOAM. A fundamental issue was found in the formulation of turbulent dispersion when the method of classes is used in modelling bubble size distributions. This issue is expected to widely affect CFD results obtained with several CFD codes. In 2024, a correction to the transport of bubble size distributions will be finalized and the corrected model will be validated against suitable experimental data.

Expected publications and theses:

Journal or conference articles are expected later in the project, in 2025.

Other dissemination:

In both work packages of the CeReSa project, new models will be implemented in the open-source code OpenFOAM. The goal in the project is to integrate the validated models in the public version of OpenFOAM in co-operation with the main developers of OpenFOAM at CFD Direct. The public version of OpenFOAM is distributed by the OpenFOAM Foundation to world-wide CFD user community.

2.1.3 C-FLOW - Critical Flow Separate-Effect-Test Facility & Experiments, LUT

Project name: Critical Flow Separate-Effect-Test Facility & Experiments (C-FLOW)	
Project manager: Lauri Pyy	**Project manager organisation:** LUT University
Partner organisations: -	
National collaboration: SAFER2028 THEME&DEMAIN	**Foreign collaboration:** SILENCE Network
Objective of research: C-FLOW will contribute for reducing uncertainties in safety analysis done with SYS TH codes focusing on PRISE scenario with the new SET facility CRAFTY which is under commission. In 2024, the aim is to carry out larger test series where L/D ratio and upstream values can be varied. One general objective of C-FLOW is to deepen the co-operation between experimentalists and modellers, and education of experts and the future generation of researchers. This will manifest itself by a research visit by LUT research staff to VTT Apros presentation and tutorial work, and how critical flow is being modelled.	
Expected results: WP2 TPCF experiments with changing L/D ratio tubes: The facility will be operated after commission in 2024. There is a plan to conduct test series that will be planned in accordance with TAG2.1 ad-hoc meeting and with the funding secured from 2024 proposal round of SAFER2028. The co-operation with VTT's THEME project will manifest itself by pre and post-test calculations, and a journal article from the experiments will be written. All results from all experiments will be made available for funding partners of SAFER2028 through LUT EDS database with accompanying quick look report. In addition, results from simulations made within C-FLOW will be made into a conference article for NUTHOS-14. Also, NURETH-21 abstract will be written about the experiment results. WP4 Project management: In addition to all project management related work, in WP4 Bachelor's/Master's Theses will be supervised, SILENCE meeting will be participated when TPCF issues are discussed, and deepening understanding of modelling that will be manifested with a visit to VTT by LUT researchers.	
Expected publications and theses: A journal article about the final design of the facility and the characteristic tests A conference article about the simulations made within C-FLOW in 2023 An abstract about the experiments conducted in 2024 for NURETH-21 conference	
Other dissemination: SILENCE meetings can be participated depending on when TPCF related issues are discussed. NUTHOS-14 conference will be participated.	

2.1.4 ESPO - Analysis of Passive Safety Systems' Operations and Modelling, VTT

<table>
<tr><td colspan="2">Project name:
analysis of passivE Safety systems oPeratiOns and modelling (ESPO)</td></tr>
<tr><td>Project manager:
Fares Alblouwy</td><td>Project manager organisation:
VTT Technical Research Centre of Finland Ltd</td></tr>
<tr><td colspan="2">Partner organisations:</td></tr>
<tr><td>National collaboration:</td><td>Foreign collaboration:
OECD/NEA ETHARINUS
OECD/NEA PANDA
OECD/NEA WGAMA
French Institute for Radiation Protection Nuclear Safety (IRSN)</td></tr>
<tr><td colspan="2">Objective of research:
ESPO main objective is to enhance the knowledge and experience in the area of passive safety systems' operations and modelling. The project relies mainly on the interaction with the international nuclear society through participating indifferent OECD projects in addition to biliteral project with IRSN. The project aims to transfer the skills and experience from senior experts to junior researchers through direct supervision and interactions. In addition to that, the project allows fruitful opportunities for codes comparison and validation.</td></tr>
<tr><td colspan="2">Expected results:
WP1 - Thermal Hydraulic Analysis
The analysis work and pre-calculations activities of ESPO project is conducted under this WP. The expected results of this WP are:
• Analysis report that captures the phenomena and operations of the targeted passive safety systems.
• Developing safety analysis modelling capabilities to be able to capture and better understands the operation scenarios of passive safety systems during postulated DBA, BDBA and SA.
• Identifying the challenges of passive safety systems' operations and modelling.
• Accurate modelling development and code's validation through code-to-experiment validation and code-to-code comparison.
The analysis of each experiment's data will be concluded by different deliverables. Deliverables include created models and detailed technical analysis reports.
WP2 - Management and International Cooperation
Through ESPO project, the national representations in the PRG of OECD/NEA PANDA and WGAMA will continue, in addition to the participation support to the OECD/NEA ETHARINUS project. Expected results are to serve the Finnish nuclear and scientific communities by transferring the knowledge and best practices applied by the project's parties, in addition to providing a window for local capabilities to grow and expand. Annual participation reports will be generated and shared with the SAFER2028 community to maximize the benefits. In addition, Finland's representation in the U.S. NRC CAMP program will continue, and should be managed under this project.
WP3 - International Participation Fees
ESPO aims to cover the participation fee needed to continue Finland's participation in the OECD/NEA PANDA project, which is essential to access the valuable experimental data on passive safety systems, needed for WP1. As per the recommendation of SAFER2028 Management Group in 2023, Finland's membership fee in the U.S. NRC CAMP program will be covered by the ESPO project budget.</td></tr>
<tr><td colspan="2">Expected publications and theses:</td></tr>
</table>

The data analysis conducted under WP1 can be developed further to scientific articles, as it would create models, and raise any challenges in passive safety systems' operation. Master's degree thesis write up is among the tentative goals of ESPO 2024 (subjected to needs/budget), when the targeted experiments conducted by the OECD projects.
Other dissemination:

2.1.5 GRAF - Gravity driven flow experiments, LUT

Project name: Gravity driven flow experiments (GRAF)	
Project manager: Vesa Riikonen	**Project manager organisation:** LUT University
Partner organisations: -	
National collaboration: SAFER2028 THEME	**Foreign collaboration:** OECD/NEA ETHARINUS
Objective of research: Improves understanding and modelling capabilities of phenomena related to gravity-driven flows in various nuclear power plant systems like the PWR primary circuit and passive safety systems. Benefits the nuclear community in Finland and worldwide through studying various concepts and situations related to gravity-driven flows, not concentrating only on one specific situation or nuclear power plant type.	
Expected results: WP1 OECD/NEA projects: LUT University participates in the OECD/NEA ETHARINUS project. An expert meeting is organized to help refine the new OECD/NEA SYSTHER project proposal and to fit it better to the potential partners` needs. The technical and financial proposal, financial arrangements, and the project agreement of the new OECD/NEA SYSTHER project. WP2 PWR PACTEL tests: Completing the nitrogen effect test series and publishing the results in a suitable journal. WP3 PASI tests: Studying still existing issues concerningthe long-term operation of the open passive heat removal systems and publishing the results in a suitable journal to be used as a part of the forthcoming doctoral theses. WP5 Project management: To ensure that the project meets its objectives within the allocated budget and scheduled time limits.	
Expected publications and theses: A draft journal article of the nitrogen effect test series. A draft journal article of the experiment results of the open passive heat removal system tests.	
Other dissemination: The OECD/NEA ETHARINUS project.	

2.1.6 THEME - Computational Modeling of Thermal-Hydraulic Phenomena, VTT

Project name: Computational Modeling of Thermal-Hydraulic Phenomena (THEME)	
Project manager: Tatu Hovi	**Project manager organisation:** Technical Research Centre of Finland, VTT
Partner organisations: LUT University	
National collaboration: SAFER2028	**Foreign collaboration:** -
Objective of research: The Computational Modeling of Thermal-Hydraulic Phenomena (THEME) project focuses on investigating various thermal-hydraulic phenomena through computational modeling. The project is tightly linked with separate SAFER2028 projects in which thermal-hydraulic experiments are carried out at the LUT University, to establish a true cooperation effort that benefits both participating organizations and the SAFER2028 community in general.	
Expected results: WP1 Computational modeling of gravity driven flows: For the year 2024 a general support is provided for GRAF project experiments that include nitrogen effect tests, flow oscillation fade-out and long-term heat transfer capacity tests. In addition, a code-to-code comparison will be done for one of the chosen experiments up to three different system codes. Expected results include validated/calibrated existing models related to gravity driven flows, development of new computational models to accurately describe the phenomena taking place during gravity driven flow related occasions in a form that can be included in computational tools used for actual safety assessment of nuclear power plants. WP2 Computational modeling of critical flows: For the year 2024, simulation model of C-FLOW test facility, pre- and post-test simulations, a joint journal article on experimental results, final conference paper to NUTHOS-14 and abstract to NURETH-21 conference. WP3 Management and cooperation: Management includes reporting of the project progress, planning, preparation, budgeting, participation, and preparation in the SAFER2028 seminars.	
Expected publications and theses: WP 1: One research report on code-to-code comparisons. WP 2: One joint journal article on C-FLOW experimental results and two conference proceedings.	
Other dissemination: Participation to the NUTHOS-14 Conference	

2.1.7 REST: The reduction of large source term during severe nuclear accidents, UEF

Project name: The reduction of large source term during severe nuclear accidents (REST)	
Project manager: Anna Lähde	**Project manager organisation:** University of Eastern Finland
Partner organisations:	
National collaboration: Teollisuuden Voima Oyj	**Foreign collaboration:** CIEMAT Spain; Paul Scherrer Institute, Switzerland

Objective of research:

The overall objective of the project is to improve the safety of the existing and future nuclear power plants during severe accident scenarios by developing technologies to prevent the large-scale particle emissions during the severe reactor accidents. The focus is on the improvement of aerosol filtration, particularly cesium and iodine species, and hydrogen mitigation technologies utilizing electrostatic precipitators. The expected results of the project will provide understanding and new knowledge on the ESP filtration technologies and controlled combustion of hydrogen to improve the safety of nuclear power. In addition, the aim is to raise interest and educate a new generation of experts that will be able to guarantee the safety of nuclear energy also in the future.

Expected results:

The REST project consists of the PhD studies and research of the doctoral candidate, MSc Satish Basnet. During the four-year doctoral studies starting in 2023 and continuing until 2026, the candidate will gain thorough understanding on nuclear safety, which will enable the person to work closely in this field in the future. The research will result in at least three scientific articles, which will be included in the thesis to be defended at the end of the last project year. The research work is divided into three work packages (WPs), which are described below, including the expected results of each WP.

WP1 Aerosol filtration in severe accident conditions: The goal of this WP is to gain understanding of the performance and suitability of the electrostatic precipitators (ESPs) for the removal of aerosols, especially cesium and iodine species, at high flow rates and conditions relevant to the containment buildings. The focus is on the filtration technologies that will improve the safety of the nuclear power plants. The suitability and efficiency of the ESPs will be systematically studied using refence aerosols and compared to the existing filtration techniques currently in use in the containment buildings.

WP2 Controlled hydrogen mitigation: The conditions for the controlled ignition in the different gas and steam mixtures will be studied to reduce the risk of hydrogen explosions in the containment during severe accident scenarios. The analysis of the conditions in the reactor building including the hydrogen distribution, and gas and steam mixtures will be used when designing a controlled ignition and combustion system that can be combined with other passive hydrogen removal systems to reduce the risk of hydrogen explosions.

WP3 Simultaneous removal of iodine species from the gas streams and hydrogen mitigation using electrostatic precipitators: High efficiency filtration technology for iodine and cesium species combined with controlled hydrogen combustion will be developed. It will provide new and enhanced methods that will reduce the likelihood of the large source term during severe accidents. In addition, the knowledge related to the iodine chemistry obtained during all WPs will be combined to provide accurate data that can be used to improve the predictions of the evolution of iodine speciation during the severe accident scenarios.

Expected publications and theses:

The thesis work will consists of four scientific publications (Deliverables D2.1.2, D4.2.2, D5 2.1-2.2, D6.3.1 that will be written during the four-year doctoral studies between 2023 and 2026), and the thesis that will be finalized in 2026. In 2024, the first scientific publication (Deliverable 2.1.2 related to the high efficiency electrostatic precipitators for filtration of iodine species) will be written and submitted for publication. The paper will be published in the acknowledged open access, peer-reviewed journal, e.g., Annals of Nuclear Energy.

A conference abstracts/proceedings will be submitted to the selected conference and the results of the studies will be presented either as a poster or an oral presentation in the conferences. In 2024, the results are foreseen to be presented in 11th conference on Severe Accidents Research (ERMSAR 2024) in Stockholm and in the DENSE seminars.

Other dissemination:

The results and data obtained during the studies will be shared through the reliable, open data repositories (e.g., Zenodo) to promote the dissemination of the results. The common creative license (e.g., CC BY-NC-SA) will be used for the shared data. The results will also be presented in the relevant national and international seminars, e.g., arranged by the European Severe Accident Community. The results will also be discussed in face-to-face meetings with Teollisuuden Voima and other relevant stakeholders. The research and most interesting results will be presented to the students in the energy technology courses and open lab days. Social media pages of FINE laboratory and researchers (e.g., LinkedIn, Instagram, ResearchGate, etc.) will be used to communicate the results to the wider audience.

2.1.8 NCDGDENSE: The Measuring, modelling and development of non-condensable gas models for nuclear safety research, LUT

Project name: The measuring, modelling and development of non-condensable gas models for nuclear safety research (NCGDENSE)	
Project manager: Giteshkumar Patel	**Project manager organisation:** LUT University
Partner organisations: -	
National collaboration: SAFER2028 C-FLOW&DEMAIN	**Foreign collaboration:** -
Objective of research: The objective of NCGDENSE is study the release and dissolution of non-condensable gases through analytical, experimental, and numerical means. This objective will be reached by the means of PhD dissertation. In 2024, the process will start by recruiting a suitable candidate. The literary survey on the current state-of-the-art of measuring NCGs will be conducted with the emphasis of measuring non-condensable gas solubility online. Also, focus will be in the experiment work conducted in the field of solubility and release of non-condensable gases.	
Expected results: WP1 Work plan for 2024: After the recruitment of the candidate, the expected result is to compile a research report on the literary survey conducted in 2024 that will contribute to the state-of-the-art section of the dissertation and will work as a basis for possible measurement system planned for measuring non-condensable gas online. An abstract to NURETH-21 conference will be written. YJK21 course will be participated by the candidate in the case of the candidate coming out of nuclear field and being native Finnish speaking person. The doctoral studies needed for eligibility of the dissertation will be started.	
Expected publications and theses: A research report on the state-of-the-art of measuring non-condensable gases, abstract of NURET-21 conference.	
Other dissemination: -	

2.2 Fuel and reactor physics

2.1.9 DECAPOD: Deterministic safety analyses with Kraken, VTT

Project name: Deterministic safety analyses with Kraken (DECAPOD)	
Project manager: Ville Valtavirta	**Project manager organisation:** VTT
Partner organisations: -	
National collaboration: SAFER2028: NOTCO, MATFINE, CeReSa	**Foreign collaboration:** OECD/NEA Data Bank, RSICC, BWR Club, past AER community, international BWR control rod history benchmark

Objective of research:

The project develops and validates the Kraken framework for the safety analyses of the Finnish nuclear power plants in accordance with the SAFER2028 Framework plan. This is achieved through the modelling of suitable experimental or computational benchmarks.

Through this task, the project builds expertise on conducting such analyses, further develops the Kraken framework, especially the Ants nodal neutronics program, as needed by such analyses and develops tools and practices for evaluating the fulfilment of thermal margins in transient modelling with the Kraken framework.

Expected results:

WP1 Ants nodal neutronics program:

- Publication of the AFEN/FENM axial homogenization approach as implemented in Ants.
- Publication of the AFEN/FENM near critical node treatment as implemented in Ants.

WP2 Validation of Kraken:

- Evaluation of the suitability of Ants and its group constant model for BWR fuel cycle simulations using the BWR control blade history benchmark.

WP3 Kraken user community

- 2024 version of Kraken distributed to OECD/NEA data bank and RSICC.
- First Finnish Kraken workshop.
- Third international Kraken workshop (PHYSOR 2024)

Expected publications and theses:

- PhD Riku Tuominen, expected in 2024.
- Two journal articles from WP1.

Other dissemination:

- 2024 version of Kraken distributed to OECD/NEA data bank and RSICC.
- First Finnish Kraken workshop.
- Third international Kraken workshop (PHYSOR 2024)

2.1.10 MATFINE - Methods for current and accident tolerant fuels modelling, VTT

Project name: Methods for current and accident tolerant fuels modelling (MATFINE)	
Project manager: Asko Arkoma	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd.
Partner organisations: -	
National collaboration: SAFER2028 DECAPOD	**Foreign collaboration:** IRSN, OECD/NEA FIDES II HERA, OECD/NEA-CSNI and -NSC: Working Group on Fuel Safety, Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems, Expert Group on Reactor Fuel Performance, Working Party on Materials Science Issues in Nuclear Fuels and Structural Materials, Expert group on Fuel Materials

Objective of research:

The MATFINE project covers integral fuel behaviour modelling and cladding behaviour. Integral fuel behaviour modelling considers both steady-state and accident conditions, and both current and Accident Tolerant Fuel (ATF) cladding is considered. ATF cladding is analysed experimentally by performing creep testing to gain knowledge on ATF cladding behaviour in loss-of-coolant accidents. NEA burst fission gas release (FGR) benchmark is taken part in. Computational reactivity-initiated accident (RIA) analyses will be conducted. LOCA cladding ballooning model in FINIX will be further developed, verified and validated. Collaboration in research is done, e.g., within NEA working parties and groups, FIDES II HERA project, and bilaterally with IRSN.

Expected results:

WP1 SMR fuel, BEPU analyses and code validation:

In 2024, LOCA cladding ballooning model in FINIX will be validated against experimental data.

In 2024, in connection with the on-going burst FGR benchmark under the NEA Expert Group on Reactor Fuel Performance (EGRFP), AOO conditions will be analysed with the U.S.NRC's FAST code and benchmarked with several partners for regular type of fuel.

WP2 Accident Tolerant Fuel

In 2024, thermal creep tests with coated ATF cladding samples will be performed. The goal of these tests are: 1) methodology development of the plugging is in key role as creep testing has not yet been accomplished at VTT with zircaloy based cladding alloy without suffering from loss of test segment tightness during the test, 2) educate new experts to these kinds of tailored experiments, 3) explore the creep performance of the selected materials and the adherence of the coating. Currently, there are two creep tests planned to be done during 2024. For the first test, VTT has one 46 mm segment of Cr coated Opt. Zirlo cladding.

WP3 Design basis accidents

In 2024, VTT will suggest IRSN one of the following subjects to be made as a SCANAIR in-kind work, as per the SCANAIR license agreement: 1) post-test part of the RIA modelling benchmark in FIDES II HERA project, or 2) post-test analysis of CABRI CIP1-2B test and blind calculations of CIP3-3, or 3) adaptation of the SCANAIR code for ATFs.

In 2024, implementation of the LOCA ballooning model into FINIX will be finalized (in WP3), and the implementation will be validated in WP1.

WP4 Management and international collaboration

Reporting to SAFER2028 TAG. Current OECD/NEA forums with a VTT representative are situated under NEA's Committee on the Safety of Nuclear Installations (CSNI) and NEA's Nuclear Science Committee (NSC):

CSNI: Working Group on Fuel Safety (WGFS)
NSC: Working Party on Scientific Issues and Uncertainty Analysis of Reactor Systems (WPRS)
Expert Group on Reactor Fuel Performance (EGRFP), under WPRS
Working Party on Materials Science Issues in Nuclear Fuels and Structural Materials (WPFM)
Expert group on Fuel Materials (EGFM), under WPFM

Other international forums are the FRAPCON/FRAPTRAN/FAST Users' Group and the ENIGMA Users' Group. The progress of the CABRI International Project will be followed in MATFINE, and CABRI Technical Advisory Group meetings are participated. Halden Programme Group (HPG) meetings will be participated.
Expected publications and theses: One PhD thesis is expected to be published during the course of the project (3 years). In 2024, no theses are expected.
Other dissemination: A full-day Fuel Day will be organized related to international and national fuel related projects within VTT, utilities, universities and STUK. Invited organizations are STUK, Fortum, TVO, Posiva, LUT, Aalto University, Helsinki University

2.1.11 NOTCO- Neutronics for fuel outside the reactor core, VTT

Project name: Neutronics for fuel outside the reactor core (NOTCO)	
Project manager: Pauli Juutilainen	**Project manager organisation:** VTT Technical Research Centre of Finland
Partner organisations: N/A	
National collaboration: SAFER2028: SMRSiMa, DECAPOD, KDS-ROM, RAVEN-K	**Foreign collaboration:** OECD/NEA WPNCS
Objective of research: The project aims at developing tools and expertise in computational spent nuclear fuel (SNF) characterization including the uncertainty quantification of SNF nuclide inventories. For propagating the nuclear data uncertainties, new methods are implemented to Serpent and externally developed codes are utilized. As part of the Kraken development, capability for SNF characterization with 3D full-core calculation will be enabled, thus upgrading the traditionally used 2D assembly-level calculation capability. Practically, the required routines for automatic data transfer between the Monte Carlo code Serpent and nodal core neutronics solver Ants will be implemented to the KrakenTools python package. Additionally, validating the computing tools for criticality safety with burnup credit and decay heat evaluations is included in the project.	
Expected results: WP1 Uncertainties and applications with Serpent: new deterministic uncertainty propagation method will be implemented to Serpent. Preliminary results are expected in 2024, but it is a demanding task and will need to be continued in following years. The on-going and to-be-started benchmarks related to criticality safety and decay heat evaluation under NEA WPNCS are participated under WP1, providing code-to-code and possibly also code-to-experiment data relevant in validating Serpent for safety analyses in these fields. The results are published in the final report of each, with possible intermediate results published in relevant conferences. WP2 Serpent – Ants for spent fuel characterization: the main focus of the WP is to verify the micro-depletion method of Ants, utilizing a small core model. Preparative actions will be performed for further development of the Ants micro-depletion functionalities, consisting of a development roadmap and initial implementation of the selected method(s). WP3 Project management and international collaboration: the reporting duties of the project management and international meetings, i.e., NEA WPNCS, Serpent UGM and IAEA SFM conference are included in this WP.	
Expected publications and theses: Journal article on Ants full-core fuel depletion model verification, conference article on initial implementation of uncertainty propagation functionalities in Serpent (for a 2025 event)	
Other dissemination: Presentations in Serpent UGM, IAEA SFM24	

3. SG3 Nuclear Waste

3.1 Fuel and engineered barrier system

3.1.1 ABCRad - Alternative Buffer/Backfill Characterisation + Radionuclide Interactions, HU

Project name: Alternative Buffer/Backfill Characterisation + Radionuclide Interactions (ABCRad)	
Project manager: Gianni Vettese	**Project manager organisation:** The University of Helsinki
Partner organisations: The University of Helsinki	
National collaboration: SAFER2028 RACEMAT, SUREPhD	**Foreign collaboration:** The Helmholtz Zentrum Dresden Rossendorf (HZDR), Germany & the European Synchrotron Radiation Facility (ESRF), both facilitated via Prof. N. Huittinen (HZDR)

Objective of research:

ABCRad is a project continuation proposal for SAFER2028 from the University of Helsinki.

The current safety case for the disposal of spent nuclear fuel in Finland has detailed analysis on only 1 reference bentonite material, Wyoming-type high-grade sodium bentonite. For a more robust safety case, it must consider other alternative materials that could replace the reference material without compromising the integrity of the EBS. ABCRad aims to provide detailed thermal and chemical analyses on two alternative bentonite materials that could be used in spent nuclear fuel disposal in Finland.

Its objectives are: **(1)** to screen seven alternative bentonites and to select two leading candidates for further study; **(2)** study the physico-chemical evolution of the materials following heat treatment at 100 and 150 ºC; and **(3)** to provide a detailed quantitative, kinetic, and mechanistic understanding of how the selected bentonites react with key, risk-driving radionuclides. The experimental work mostly takes place in the radiochemistry unit (UH) but has collaborations with international partners at HZDR (Germany) and ESRF (France). The project also provides training, supervision, and funding for a Masters thesis in 2023 and another in 2024. The knowledge gained can be used to inform the safety case for spent nuclear fuel disposal in Finland and beyond. ABCRad also builds Vettese's expertise in the area, he will gain experience as a supervisor and he will develop international networks.

Expected results:

WP1: Selection and characterisation of the starting materials

In 2023, WP1 provided a desktop study of POSIVA's leading alternative bentonite materials which merit study. UH, in collaboration with end-users, will select the most promising two alternative bentonites. This work package is complete and was delivered on time.

WP2: Thermal treatment of the bentonites

WP2 assesses the long-term effects of heat load on the physico-chemical properties of the chosen alternative bentonites. These results serve as an excellent basis to predict changes in the buffer material structure and how they evolve with time.

WP3: Chemical interactions with the bentonites

WP3 supplies site-specific data that describes radionuclide mobility along potential transport pathways from the ONKALO repository to the surrounding biosphere. This will yield a quantitative, kinetic, and mechanistic understanding of radionuclide-buffer material chemistry under site-specific conditions, and serve an excellent basis for validating and improving predictive geochemical models

Expected publications and theses: ABCRad will deliver 1 Masters thesis per year. The current project student is on track. We also anticipate at least 2 other scientific papers to be published from the project, 1 based on thermal change of the alternative bentonites, and 1 based on radionuclide interactions with the alternative bentonites.
Other dissemination: GV is a member of the AIPEA (International Association for the Study of Clays) and will present his findings at the annual conference as well as other relevant conferences.

3.1.2 DEHYDSU - Defects, hydrogen and susceptibility of Cu-OFP to stress corrosion cracking in sulphide containing environment, VTT

Project name: Defects, hydrogen and susceptibility of Cu-OFP to stress corrosion cracking in sulphide containing environment (DEHYDSU)	
Project manager: Timo Saario	**Project manager organisation:** VTT
Partner organisations: University of Chemical Technology and Metallurgy (UCTM), Sofia, Bulgaria	
National collaboration:	**Foreign collaboration:** UCTM, Bulgaria

Objective of research:

The objective of the research is to find if Cu-OFP is susceptible to stress corrosion cracking in presence of sulphides in the water. In overall the project aims at providing answers to the following research questions:

1 - Does sulphide exposure induce surface defects (SCC micro-cracks) in Cu-OFP or are they formed due to pure mechanical loading only?

2 - Is the general corrosion rate of Cu-OFP in sulphide containing saline groundwater so high and the re-passivation rate so low that SCC becomes unlikely?

Expected results:

WP1 Nature of surface defects:

In 2023, SEM investigation of three SSRT samples from SKB batch tested in air revealed a large number of surface cracks, with most of them having a length between 1 and 6 µm. A comparison sample has been tested in water with 80 mg/l sulphide and is waiting for the SEM analyses. In 2024, two additional different batches of Cu-OFP (in addition to the SKB batch already studied in 2023) will be studied in a similar manner. **The expected result from this part of the work is whether the sulphide exposure has an effect on the number and size of the surface cracks.**

In another Task, the possible effect of sample thickness and surface finish on the number and size of the surface cracks will be investigated.

WP2 Effect of sulphide on hydrogen uptake in FSW Cu-OFP:

WP2 was cancelled because it was planned to be executed in close co-operation with Aalto University, who did not get funding for their part of the work.

WP3 Corrosion studies in saline groundwater:

The expected result from WP3 is an answer to the research question 2 presented above. All the planned experimental work has been performed during 2023, and a journal paper publication is being prepared. No further experimental work is seen necessary. **The expected result in 2024 is publication of the journal paper.**

WP4 Communication, cooperation and knowledge transfer:

Communication of the project results will be done within the SAFER2028 –programme, and internationally in the form of journal paper publications.

Two young generation researchers, DSc Sneha Goel and MSc Essi Jäppinen, will be introduced and further educated in the area of nuclear waste management and the related safety issues.

Expected publications and theses:

Journal paper based on experimental results from WP 3.

3.1.3 MOCRYCO - Model based on crystal plasticity for copper, VTT

Project name: Model based on crystal plasticity for copper (MOCRYCO)	
Project manager: Tom Andersson	**Project manager organisation:** VTT
Partner organisations:	
National collaboration:	**Foreign collaboration:** Participating ECCC meetings and discuss the possibility of collaboration with SKB Collaboration with Jean-Michel SCHERER assistant professor in Centre des Matériaux, MINES Paristech regarding developing a model for creep void formation
Objective of research: The project aims to gain more in-depth knowledge, with testing, characterizing and building micromechanical models, about the behaviour of oxygen-free phosphorus (OFP) copper and how the microstructure and the segregation of chemical elements at grain boundaries affects it.	
Expected results: WP1 Name of the Workpackage: Experimental research to support characterization and modelling • Gain insight of the effect of grain size to ductility and creep life time and relaxation behaviour • Characterize the stress-strain behaviour of OFP copper in relevant temperatures WP2 Advanced and AI assisted characterization • Characterize and produce input from the relevant material regions for the micromechanical modelling • Produce data for the training for ML based creep cavity analysis tool • Set up solid co-operation between materials scientists and AI experts and create suitable procedures for AI assisted creep cavitation detection for this specific material. WP3 Developing models to predict the time dependent behaviour of OFP copper • Continue developing macroscopic model's capability to mimic the effect of microstructural features to the long-term behaviour estimation • Continue the development and model parameter calibration to better capture creep void formation and based on the experimental work done in year 2023 continue the development of the models capability to capture the cyclic relaxation/creep behaviour. • Investigate the suitability of atomistic (MD/DFT) approach to investigate the damage mechanisms and effect of impurities and alloying elements. • Continue the work done with Taylor factor gradient for filtering the most interesting microstructures for a deeper analysis using a computationally expensive CPFE modelling.	
Expected publications and theses: Paper regarding PF-CP modelling of creep void formation in OFP copper.	
Other dissemination:	

3.1.4 SAGE - Sensitivity analysis guided disposal barrier experiments, VTT, JyU, GTK

Project name: Sensitivity analysis guided disposal barrier experiments (SAGE)	
Project manager: Veli-Matti Pulkkanen	**Project manager organisation:** VTT
Partner organisations: VTT, University of Jyväskylä, GTK	
National collaboration: SAFER2028: ABCRad, MIBARDI	**Foreign collaboration:** GRS, University of Lorraine, EURAD HITEC, EURAD-2 ANCHORS

Objective of research:

In Finland, the final disposal of spent nuclear fuel is moving to implementation phase, during which the disposal barriers' design, materials and processing techniques are optimised for feasibility. Simultaneously, the requirements for the safety and performance assessments evolve towards considering the whole disposal system behaviour during initial and long-term transient phases when the disposal conditions change. Covering the new barrier options in these varying conditions in safety and performance assessment simulations requires experimental data for model parametrisation in a large number of material-conditions-combinations. Scanning through the combinations with traditional experimental techniques is impractically slow as well as laborious, and the problem is magnified by conventional modelling schemes, where the number of material parameters is very high.

In this project, we tackle these issues by a sensitivity analysis for the whole disposal system with the objective to reveal the material parameters that are the most important for safety and performance in the varied conditions. During the first project phase (the first half of the SAFER2028 programme), the scope of the analysis is limited to 1) hydro-chemo-mechanical continuum models and 2) saturating or saturated clay barriers in varying chemical and mechanical conditions set by the surrounding host rock. To reduce the number of needed experiments, the sensitivity analysis is utilised to guide the experimental work, where the main goal is a coherent set of measurements that gives values for the critical parameters. Instead of conventional measurement techniques, we apply state-of-the-art methods such as 4D (3 spatial dimensions + time) X-ray tomography, fast triaxial mechanical tests and calibrated electrical resistivity tomography that allow testing a large number of samples and conditions in multiple length scales from laboratory to entire disposal system scale. In order to progress the scientific state-of-the-art, we will commission and validate new experimental techniques for physical and chemical characterization of the buffer materials. The main outcome of the project is 1) knowledge on the relative importance of the disposal components and their material properties for safety and performance, 2) means to optimize the barrier designs meaningfully, and 3) possibilities to evaluate safety even in cases where the barrier materials, configurations, and conditions change.

Expected results 2024:

WP1 Coordination and dissemination

1st SAGE Public seminar between researchers, authority, and waste management organisations

WP2 Design of experiments, uncertainty and sensitivity analysis:

Developed methods to transform the experimental results consistently to bentonite constitutive models and model parameters

WP3 Experiments

Project data bank updated with the results of tomography experiments performed during 2024.

Project data bank updated with the results of mechanical experiments performed during 2024.

Project data bank updated with the results of the electrical resistivity studies for small-scale bentonite samples.

Expected publications and theses 2024:

2 journal articles, progressing 2 doctoral thesis
Other dissemination: Public seminar between researchers, authority and waste management organisations Conference presentations

3.2 Low and intermediate level waste

3.2.1 GasOff - Termination phase of the LLW Gas Generation Experiment, Safram Oy, VTT

Project name: Termination phase of the LLW Gas Generation Experiment (GasOff)	
Project manager: Mikko Nykyri	**Project manager organisation:** Safram Oy
Partner organisations: Safram Oy[1], VTT Technical Research Centre of Finland[2]	
National collaboration: Teollisuuden Voima Oyj (TVO), Fortum Oyj	**Foreign collaboration:** The EURAD project ACED
Objective of research: The main objectives of GasOff are to gain understanding 1) on gas generation handled in the long-term safety cases of LILW final disposal facilities, where biodegradable waste will be disposed of, 2) on the corrosion of carbon steel, and 3) on the changes in concrete in the repository near-field. This includes justified information about the highest gas generation rates from low-level solid operational waste and understanding about the main mechanisms influencing on gas generation.	
Expected results: **WP1 Management** Documented follow-up of the developments in GasOff during 2023. Coordination between the research tasks and the decommissioning of the large scale experiment equipment (GGE). **WP2 Sampling of the experiment** The samplings in WP2 will be completed by the end of the year 2023. **WP3 Analytics and interpretations** Analysis results on the chemical and microbiological composition and the radioactivity of the water samples, and on the composition gas samples. Interpretations of the analytical results, including the hydrogeochemical modelling (PHREEQC). The samples to be analysed are 1) the waters in the experiment tank and the waste drums, 2) bottom sediment, 3) gases, 4) drum steel, 5) waste materials, 6) concrete of the concrete box, and 7) small sample capsules containing steel plates and simulated waste materials. **WP4 Synthesis and reporting** The final report of GasOff for SAFER2028.	
Expected publications and theses: An article to a scientific publication is under consideration.	
Other dissemination: GasOff activities can be posted in the social networking service X at the account SAFER2028GasOff, @SAFERGasOff.	

3.2.2 MICWEST - Influence of environment and microbes on corrosion behaviour of welded steels in the LILW repositories, VTT

Project name: Influence of environment and microbes on corrosion behaviour of welded steels in the LILW repositories (MICWEST)	
Project manager: Vilma Ratia-Hanby	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd.
Partner organisations: -	
National collaboration: SAFER2028 GasOff and DODGE, EU-ACED	**Foreign collaboration:** EUROMIC COST network, ICDP
Objective of research: The objective is to create new information on the durability of welded steel joints in LILW repository conditions throughout its evolution. This is done through defining how environment and microbial interactions affect the corrosion response of the welds. Also the roles of weld manufacturing and post-weld cleaning methods on corrosion are studied to get directly usable information on the suitability of the methods to be used in LILW repositories.	
Expected results: WP1 - Sample materials: • Preparing the specimens and waters for the corrosion experiments in WP4 WP2 – Microbial growth conditions: • Finalising the analysis defining microbial activity enabling conditions for the long-term experiments • Exploring repository site groundwater metagenomes from TERKOR project originating samples, estimate especially MIC related functional diversity and genetic potential of metagenome assembled genomes. Identifying potential corrosion related microbial groups from the repository groundwaters and steel surface metagenomes. • In addition, in parallel with a VTT in-house project: validating new databases covering genes related to microbially influenced corrosion WP3 - Corrosion of steels in groundwater / concrete environments: • Completing the Master of Science thesis on the corrosion of steel welds in LILW simulating conditions: Improving our knowledge of the influence of water chemistry on the behaviour of the welded joints in LILW repositories • Finalising the shorter-term comparisons of the corrosion resistance of different post-weld cleaning methods of welds under conditions relevant for LILW disposal • Finalising the shorter-term definitions of corrosion in dissimilar joints due to galvanic corrosion and by temperature effects WP4 – Weld durability • To prepare, construct and monitor the longer-term setups in order reveal how the performance (risk for corrosion) of the welds varies in different LILW conditions simulating its evolution during a longer exposure • To assess the progress of the start of the exposure for its electrochemical results and document the setup and the first results	

WP5 – Project management • Managing the WPs and organising the work across the WPs
Expected publications and theses: Conference abstract and presentation or poster Master's thesis on the short-term corrosion tests on various materials in various environments
Other dissemination: Social media posts

3.2.3 POLYDEC – POLYelectrolyte gels for DEContamination, HU

Project name: Full name (POLYDEC)	
Project manager: Susanna Salminen-Paatero	**Project manager organisation:** University of Helsinki
Partner organisations:	
National collaboration:	**Foreign collaboration:**

Objective of research:

Development work of polyelectrolyte gels, which have been observed to be fairly effective in radionuclide absorption, will be continued for eventually using the gels as decontamination agents in the nuclear industry. The produced gel will be peelable and either water soluble or releasing radionuclides easily with a simple chemical treatment. This will decrease aqueous and solid LILW formation and need for storing. Sorption experiments will be executed for two polyanion-polycation combinations with three radionuclides having different valence states. The effects of gel formation reaction conditions and selected polyanions on gel properties will be investigated for improving the radionuclide absorption and hydrophility of the gel. The proposed pilot project is an intermediate step between preliminary testing and preparing a final product. After completion of the project, we will have a prototype of a polyelectrolyte gel for decontamination. The prototype gel from the pilot project can be refined to a ready product for a large-scale use in nuclear industry in the next phase after 2024.

Expected results:

WP1 (Co)polymerisation of anion and cation: Two approaches will be tested for determining their effect on polymer structure and resulting radionuclide absorption. First, polyanion and polycation will be mixed to form a gel, and secondly, cation and anion monomers will be polymerised and then gel formation takes place. Water solubility and hydrophility of the gel should be increased in the second approach, as the polymer chains will be more open due to structural changes during copolymerisation. Two polyanions will be compared in this WP. We will determine absorption efficiency of radionuclides for differently polymerised gels to select the most productive (giving highest absorption percentages) polymerisation strategy.

WP2 Effect of reaction conditions on radionuclide absorption: Two reaction rates, fast and slow, will be used in the gel preparation. Kinetics of gel formation reaction has a major impact on the structure of the forming polyelectrolyte gel and further to its absorption properties. We will determine absorption efficiency of the gels prepared by two reaction rates to select the most productive (giving highest absorption percentages) gel formation rate.

Expected publications and theses:

A research report and a Master thesis.

Other dissemination:

3.2.4 SurePhD - Increasing surety in the performance of present and future VLLW disposal, HU

Project name: Increasing surety in the performance of present and future VLLW disposal (SUREPhD)	
Project manager: Prof. Gareth Law	**Project manager organisation:** University of Helsinki
Partner organisations: VTT	
National collaboration: SAFER2028: LIIMA, RACEMAT, ABC-Rad	**Foreign collaboration:** Helmholtz Zentrum Dresden Rossendorf (HZDR) University of Manchester (RWM-RSO) EURAD2 Sudoku

Objective of research:

The PhD project's objective is to support the safe surface-level disposal of VLLW in Finland. In this project, we: **(i)** contribute to the safety of current Finnish VLLW disposal, by documenting the behaviour of risk-driving radionuclide ^{14}C in the current Finnish VLLW disposal concept; **(ii)** assess the viability of including Finnish nuclear power plant decommissioning waste (namely, concrete) in the current Finnish VLLW surface disposal concept, and seek to understand its impact on the chemical evolution of the repository; and **(iii)** investigate whether the future Finnish VLLW disposal could be improved through use of alternative packaging materials (e.g., novel geopolymers or low pH cement).

Expected results:

SUREPhD has proceeded to plan in its first year. The student (Taavi Vierinen, MSc.) was successfully recruited and began working on his project in April 2023. We anticipate that all year 1 project milestones and deliverables (as outlined in the initial project plan) will be met. Below we describe work and expected results for **year 2** of the PhD (April 2024–2025), as requested in the 2024 call documents. **We note that the PhD project has not deviated from the original project plan.**

In **WP2,** mesocosm experiments will start in late 2023 and they will continue to run under controlled conditions with regular solution and headspace gas sampling for 12 months. Solution samples will be analysed for ^{14}C speciation (e.g., dissolved inorganic ^{14}C vs. dissolved organic ^{14}C) and headspace samples will be analysed for gas production and composition (e.g., $^{14}CO_2$ vs. $^{14}CH_4$ etc.). When the experiments end, the metallic and soft wastes included in the mesocosms will be collected for analysis. There, the wastes will be separated and undergo extraction to understand changes in ^{14}C distribution and speciation in the solids. Replicate mesocosms also be setup in 2023, will be used in 2024 to establish WP2 seawater intrusion experiments.

In **WP3**, column flow through experiments that will start in late 2023 will run well into 2024. During the experiments, the column's effluents will be monitored with time for their ^{14}C content, ^{14}C speciation, and other geochemical markers. After 12 months of water pumping, we anticipate sufficient ^{14}C will have been removed to the column solids to permit quantification of solid phase ^{14}C interactions (e.g., sorption reactions, carbonate precipitation, organic matter uptake). Accordingly, in late 2024, select columns will be removed from the rig for sectioning and solid phase analysis. Here, ^{14}C partitioning will be assessed through use of sequential chemical extractions. ***Data from the column experiments will provide baseline information on ^{14}C partitioning and***

reactivity after its transport away from VLLW packages and as it moves through the surface repository's barrier / backfill. Combined with outputs from WP2, the expected result is a holistic understanding of ^{14}C dynamics in the VLLW disposal concept. Finally, in **WP3**, un-sectioned ^{14}C labelled columns will be transitioned to non-radiolabelled seawater influent after 1 year. The columns will be pumped with seawater and the effluent chemistry will be monitored throughout to understand changes in solution geochemistry and potential for ^{14}C remobilisation from the barrier / backfill materials. That work will continue into 2025. ***When combined with the seawater intrusion work from WP2, the expected result is a detailed understanding of how seawater intrusion impacts ^{14}C behavior in the VLLW surface disposal concept.***

WP4 and 5 experiments will also begin in mid 2024. In **WP4,** concrete from the decommissioning of the VTT FIR-1 research reactor bio-shield will be used as a mock NPP decommissioning waste. In the first WP4 experiment, FIR-1 concrete chips will be added to mesocosms (as per the WP2 methodology) containing mock ^{14}C labelled VLLW waste-forms (metallic and soft waste packages). The mesocosms will then be reacted for 12 months (i.e., into year 3 of the project), with solution samples taken after 1 year to monitor for changes in overall leachate composition and gas production / composition. Solid samples will also be retrieved for post-mortem analysis. The radionuclide concentrations originally present in the concrete may allow us to track radionuclide remobilsation from the concrete chips into solution. Any data gained will be very useful for assessing potential radionuclide release from NPP concretes, if managed via surface or intermediate depth disposal (i.e., the data will also be relevant to Finnish L-ILW disposal). The other purpose of the experiments is to track how the wastes (concrete, metallic, and soft) co-evolve under the expected alkaline conditions that result from concrete corrosion. Data from the PhD experiment can then be compared to results from non-concrete amended mesocosm systems. ***The expected result is assessment of how the inclusion of concrete impacts the VLLW surface disposal concept.*** In the second WP4 experiment, the concrete chips will be added into the column rig (as per WP3 methodology) along with barrier and backfill materials. Non-radiolabeled leachates will be pumped through the columns to track evolution of the waste / barrier / backfill system over 1 year from mid-2024. Effluent will be monitored to track loss of (detectable) radionuclides from the concrete. After 1 year of reaction, the columns will be removed from the rig for sectioning and solid phase analysis. ***Particular attention will be paid to chemical extraction of the barrier / backfill materials, with an expected result of understanding if they act as preferential sites for uptake of radionuclides released from corroding concrete.***

In **WP5** work, a selection of inorganic binder materials that have previously been validated for reducing radionuclide transport (specifically low-pH cement and geopolymers), will be fabricated as mock barrier materials for VLLW wastes as defined in WP1. Small amounts of the mock wastes will be bound in the materials, which will be cured and then reacted in mesocosm studies mirroring work described for WP2. This work then continues well into 2025/26 and ***the expected result is evaluation of optimization pathways for future VLLW disposal in Finland (and internationally).***

Expected publications and theses:

None. Experimental work starts in year 1 of the PhD and continues alongside sample analysis throughout years 2 and 3. We anticipate the first of three to four PhD publications will appear towards the mid- to end-point of year 3, given the long-term nature of the project's experiments. The publications and target journals are detailed in the original proposal.

Other dissemination:

Vierinen expects to attend 1 international conference in year 2 of his PhD and will present his up-to-date research as a poster. Travel funds will be requested from the DENSE network. He already presented his work at the 2023 DENSE seminar and will do the same in 2024. He will also present at the University of Helsinki 2024 CHEMS summer seminar.

3.2.5 MOXSEAL - Metal Oxides for Group Separation of Actinides and Lantanides, HU

Project name: Metal oxides for group separation of actinides and lanthanides (MOXSEAL)	
Project manager: Risto Koivula	**Project manager organisation:** University of Helsinki
Partner organisations:	
National collaboration:	**Foreign collaboration:** PSI, ANKA, DESY, ALBA
Objective of research: Train expert of the area of advanced fuel cycles Fabricate a material capable for actinide-lanthanide group separation • first year's targets are: 1. Understanding how to use different templates to produce targeted tunnel-sized metal oxides 2. understanding the relation of tunnel size and ion exchange selectivity 3. gather up-to-date information on the latest research/achievements on advanced fuel cycle and generate idea where the research is going	
Expected results: WP1 and 2: Series of materials with different pore structure with different pKa i.e. controlling uptake preference for Eu and Am uptake. • material with suitable physical form and uptake preference for f-group elements i.e. actinides and lanthanides and functions in acidic media, distribution coefficients >> 1 000 ml/g •	
Expected publications and theses: Conference paper on selective Ac/Ln uptake from acidic media	
Other dissemination: Poster presentation in DENSE and CHEMS doctoral school seminar and that extended in int. conference preferably for f-elements	

3.3 Rock, Site and Biosphere

3.3.1 ECOLAB - Laboratory-based studies for radioecological modelling of 14C, HU, FMI, UI, UEF, EnviroCase

Project name: Laboratory-based studies for radioecological modelling of ^{14}C (ECOLAB)	
Project manager: Soroush Majlesi	**Project manager organisation:** Organisation University of Helsinki
Partner organisations: University of Eastern Finland, Finnish Meteorological Institute, EnviroCase Ltd., University of Innsbruck (Austria) and PIANOFORTE	
National collaboration: SAFER2028, University of Eastern Finland, Finnish Meteorological Institute, EnviroCase Ltd., CORES	**Foreign collaboration:** University of Innsbruck (Austria), BIOPROTA Forum, IAEA MEREIA, Horia Hulubei Institute (Romania), NKS-BIORAD, NKS-BIOAPP projects, RadoNORM project (funded by EU) and PIANOFORTE (funded by Euratom)
Objective of research: The objective of this research project is to use a novel approach to understand the distribution and uptake of ^{14}C in the biosphere and food web transfer from below-ground sources (soil/sediment) as implications for possible release of ^{14}C from geological disposal of radioactive wastes as well as for discharges from nuclear power plants. **Such coordinated datasets are not available in many species and their relevant food webs**. The project will develop radioecological models on ^{14}C radiological assessments based on quantitative data on this radionuclide. Such upgraded research is important for proactive maintenance and enhancement of scientific credibility and societal acceptability of new and continued operation of nuclear power and waste repositories, with likely increasing attention with general achievements in carbon cycle and climate change research and policies.	
Expected results: WP1) Transfer of sedimentary ^{14}C in aquatic plants: The results of this study will reveal valuable information on contribution of sedimentary C to different aquatic plants species. Such coherent quantitative data on transfer of ^{14}C in aquatic plants is still lacking internationally. WP2) Transfer of sedimentary ^{14}C into freshwater animals: The results of this work would be useful to investigate the transfer of ^{14}C in freshwater animals by experimentally simulating aquatic food web, using benthic organisms and the crucian carp as one of the common fishes in Finland. The data will help to understand the distribution of ^{14}C in aquatic systems from lower (benthic animals) to upper trophic chains (fish) and corroborate existing relatively poor international data basis. WP3) Transfer of soil-derived ^{14}C into terrestrial animals: This work will reveal the distribution and transfer of ^{14}C into earthworms at the bottom of terrestrial food chain to its uptake by ground beetles as their predators under different environmental conditions in the laboratory, by using different amounts of old C vs. recently fixed C. The findings would be helpful for transfer of ^{14}C in terrestrial food webs as such data is limited.	
Expected publications and theses: The results of the project will be published in 3 peer-review articles and 3 master's degree theses.	
Other dissemination: The results of this project will also be shared within the national and international collaborators, and with the public through reporting in common seminars, international meetings, and research reports.	

3.3.2 FLOP - Flow pathways within faults and associated fracture systems in crystalline bedrock, UTU, GTK, JyU, Åbo Academi

Project name: FLOw Pathways within faults and associated fracture systems in crystalline bedrock (FLOP)	
Project manager: Prof. Esa Heilimo	**Project manager organisation:** University of Turku
Partner organisations: University of Turku[1], Geological Survey of Finland[2], University of Jyväskylä[3], Åbo Akademi[4]	
National collaboration: SAFER2028: Projects MIRKA, SERIOUS; Posiva	**Foreign collaboration:** NGU (Norway), GRS/SIRUB (Germany), University of Stuttgart, EURAD, University of Bergen

Objective of research:

This project addresses the fluid flow properties of the bedrock, which, together with the seismic stability, is among the most important engineering-geological features of the bedrock in the Fennoscandian Shield area. Fluid flow within the bedrock is controlled by the networks of mechanical discontinuities, particularly faults and fault-related fractures, and these are the focus of this project. With respect to fluid flow, we will provide realistic models about the hydrogeological behaviour of geological structures. Here we place particular focus on testing the concept of channelized flow, using structurally controlled samples in micro-scale flow modelling experiments (micro-CT) and new DFN-tools. As the main outcome of our project, we will deliver new openly available and usable data, tools and workflows to i) obtain accurate scientific knowledge about the 3D-networking of bedrock discontinuities, ii) understand the effective fluid flow pathways generated by these fracture networks, and iii) provide means to improve the long-term safety of confine-ment of harmful nuclear substances. Ultimately, outcomes of the present project will provide the industry and regulatory agencies updated knowledge and parameters for assessing the risks and creating solutions for the safe underground storage of nuclear waste which - key to achieving our global decarbonisation goals while minimising environmental impacts.

Expected results:

WP1 – "Fluid flow in fault-related fracture systems" will result in the following in 2024:

- Complementing the digital outcrop models delivered during the 1st project year with selected targets
- Fault-scalability analyses of 2D-outcrop datasets; development of this dataset into a scientific paper (see below)
- Update of the fracture network geometry & property Atlas, to be further updated in 2025
- Acquisition of all samples and their basic petrographic and alteration characterization completed
- CT-imaging of all the large elongate samples completed
- Report on available open-source software for fracture network and flow modelling
- The first flow visualization experiment done
- First experiments in simulating laboratory flow experiments done

Expected publications and theses:

Submission of scientific publication for peer review (Task 1.1): ""Quantifying the heterogeneity of fracture networking (or topology) properties associated with meso-scale faults in crystalline rocks; implications for fracture scalability analyses"

Other dissemination:

Presentation of the project results in the Nordic geological Winter Meeting (Jan 2024 in Gothenburg and at EGU, Vienna, in April 2024.) We will publish social media postings through already established channels such as Geohouse Turku X (former twitter) account.

3.3.3 MIRKA - Scale-effect in fractured rock mass, Aalto

Project name: Scale-effect in fractured rock mass (MIRKA) Mittakaavavaikutus rakoilleessa kalliomassassa (MIRKA)	
Project manager: Prof. Mikael Rinne (responsible manager) DSc. Lauri Uotinen (project manager)	**Project manager organisation:** Aalto University
Partner organisations: Organisation[1], Organisation[2]	
National collaboration: SAFER2028 STAFLO (GTK and UTU), CORF (Aalto)	**Foreign collaboration:** KTH (Sweden), LTU (Sweden), NB&A (Norway)
Objective of research: MIRKA research project aims to improve the safety of nuclear waste disposal by improving the confidence in upscaling of values obtained from laboratory sized samples to site scale sizes for rock joint shear strength or hydraulic conductivity.	
Expected results: WP2, Task 1: Planning and acquisitions for the transverse fluid flow tests 10 samples of 1 m x 1 m (top) and 1.5 m long x 1.0 m wide (bottom) of Kuru gray slab pairs with a horizontal artifically induced tensile crack are obtained. A detailed research plan is produced to conduct the experiments so that the shearing can be halted to conduct transverse fluid flow testing at variable shear displacement intervals. WP2, Task 2: Conducting the transverse fluid flow testing series A rock slab shear test series will be conducted where each shearing is halted at multiple shear displacement intervals to allow for photogrammetric recording of the slab positions and/or numerical modelling of fluid flow in the transverse direction to loading and/or to perform validative fluid flow testing at one or more normal loads.	
Expected publications and theses: BSc thesis: A literature study on scale effect for rock joint shear tests (tentative) MSc thesis: Transverse fluid flow test for displaced rock joints of crystalline hard rock DSc thesis: Characterization of hydromechanical properties of rock fractures (tentative) Conference paper: Rock mechanical investigation of the negative scale effect in peak shear strength of rock joints Journal paper: Transverse fluid flow test for displaced rock joints of crystalline hard rock	
Other dissemination: Participation to SAFER2028 seminars, STAFLO seminars, international and national conferences, dissemination on Aalto University website and partner websites and social media, open access publication of all deliverables including journal papers, conference papers, doctoral dissertations, master's thesis, and bachelor's thesis.	

3.3.4 SMRSiMa - SMR Siting and Waste Management, VTT, GTK, LUT

Project name: SMR Waste Management and Siting (SMRSiMa)	
Project manager: Sami Naumer (coordinator of the joint project, project manager at VTT) Jaakko Hietava (project manager at GTK) Matti Kojo (project manager at LUT)	**Project manager organisation:** VTT (coordinator)
Partner organisations: VTT[1], GTK[2] and LUT[3]	
National collaboration: SAFER2028 RESPECT, SAFER 2028 Fuel Outside Reactor	**Foreign collaboration:** University of Regina, Canada Universitat Pompeu Fabra, Barcelona, Spain CO-SUSTAIN Project (H2020) Presentations/papers/abstracts at: IAEA meeting "International Conference on the Management of Spent Fuel form Nuclear Power Reactors" to be held at 10-14 June 2024 in Vienna. OECD NEA Working Group on Human and Organizational Factors (WGHOF)
Objective of research: SMR Waste Management and Siting continues the work started in 2021 in KYT2022 with the aim to build further knowledge in the areas of SMR waste management, SMR plant siting, societal engagement and organisational managment and leadership factors. WP1 continues the full-core neutronic calculations to get a better understanding on the spent fuel characterisitcs and disposability. WP2 focuses on generic organisational models for organising the waste management in Finland. WP3 is aimed at studying SMR plant siting and the safety distance to the nearest capable fault, as well as summarises the current state-of-the-art of the SMR specific EPS studies. WP4 focuses on stakeholders' views on SMR siting and asks how safety regulation and trust are perceived as part of social license to operate (SLO) of a SMR project by the local civil society stakeholders. The project is conducted in cooperation between VTT (coordinator.), GTK and LUT.	
Expected results: **WP1** (VTT) provides preliminary information on spent fuel inventories in a LWR SMR with full core Serpent – Ants calculations **WP2** (VTT) provides generic organisational models that are suggested for SMR waste management in Finland. **WP3** (GTK & VTT): Objective is to create initial boundary conditions for SMR plant siting processes concerning capable faults (GTK) **WP4** (LUT) The Task supports context specific design of social license to operate (SLO) in a possible SMR project.	
Expected publications and theses: • D1.1.1: Spent fuel characterisation calculations, reported as part of a SMRSiMa VTT research report • D2.1.1 Identification of generic organisation models for waste management in Finland. Chaper in SMRSiMa VTT research report • D2.3.1. Chapter in SMRSiMA VTT research report: Summary of pre-study on regulatory oversight of organisational, management and leadership aspects in SMRs • D2.3.2. Presentation at OECD NEA Working Group on Human and Organizational Factors (WGHOF), special interest group on SMRs	

- D3.1.1 A GTK research report on the large-scale geological lineaments, faults and fracture zones in the Uusimaa region and implications on the site selection processes of a SMR power plant
- D.4.1.1 An article manuscript on social license to operate: SMR case studies in Finland and Canada
- D4.1.2 A conference paper on residents' opinions on the options for managing nuclear waste from SMRs, IAEA Conference 10-14 June 2024, Vienna (an abstract proposal submitted on 29 September 2023).

Other dissemination:

WP2: Presentation at IAEA meeting “International Conference on the Management of Spent Fuel form Nuclear Power Reactors” to be held at 10-14 June 2024 in Vienna.

WP2: Presentation at OECD NEA Working Group on Human and Organizational Factors (WGHOF)

WP4: Two conference presentations (ESA 2024, Porto, Portugal; IAEA 2024, Vienna, Austria).

3.3.5 DODGE - Dark oxygen in the deep geobiosphere of the geological repository, HU

Project name: Dark oxygen in the deep geobiosphere of the geological repository (DODGE)	
Project manager: Riikka Kietäväinen	**Project manager organisation:** University of Helsinki, Dep. of Geosciences and Geography
Partner organisations: VTT Technical Research Centre of Finland	
National collaboration: Posiva, Geological Survey of Finland (GTK), Research Council of Finland (RCF) project DAFNE22 (Drilling active faults in northern Europe: Deep life, hydrogeology and geothermics in the ICDP-DAFNE scientific drilling project)	**Foreign collaboration:** Andalucian Earth Sciences Institute (IACT), Institut de Physique du Globe de Paris (IPGP), International Continental Scientific Drilling Program (ICDP)
Objective of research: The main objectives of the DODGE project are to 1) evaluate the possibility of the production of dark oxygen in-situ, 2) identify the source of the microbially produced oxygen and hydrogen in microcosms studies using substrates with labelled oxygen and/or hydrogen, and 3) study the microbial processes affected by or affecting the production and consumption of dark oxygen and hydrogen and related cycles of redox sensitive nutrients in the deep geobiosphere.	
Expected results: <u>WP1 Oxygen and hydrogen in natural groundwater</u> First year result: Free oxygen (O_2) and hydrogen (H_2) are detected in the groundwater of Olkiluoto and Kopparnäs and their origin (dark microbial and radiolytic) investigated by isotope, isotopologue, and molecular biological methods. Overall result: Facultatively aerobic microorganisms and aerobic microbial processes are found to actively proceed in the anoxic environment. <u>WP2 Laboratory experiment</u> First year result: Pressure reactor with natural groundwater spiked with labelled substrates for the identification of the source of microbially produced oxygen and hydrogen is up and running. Overall result: The source of the microbially produced oxygen and hydrogen is identified in microcosms studies. <u>WP3 Redox sensitive nutrients</u> First year result: Already existing isotope data on redox sensitive nutrients (S, C, N) and metabolic pathways collected during previous KYT2022 projects (BIKES, MIMOSA) together with new data from Olkiluoto and Kopparnäs is combined and evaluated. Overall result: Re-evaluation of biogeochemical cycles and microbial metabolic potential in the presence of microoxic niches in the deep geological repository environment. <u>WP4 Management</u> Overall result: The project is progressing as planned in a well-coordinated way.	
Expected publications and theses: Scientific paper on the pressure reactor experiment results (second year) Scientific paper on sulfur speciation, concentration, isotopes, and microbiological evidence on sulfur cycling in the bedrock biosphere (second year) MSc Thesis on detection of dark microbial oxygen in natural groundwater (first year)	

MSc Thesis on biogeochemical processes in the presence of microoxic niches (second year)
Other dissemination: Communication in social media under #DODGESAFER2028 and #SAFER2028.

3.4 Concrete

3.4.1 FN-CAMP - Finnish Nuclear Concrete Ageing Management Project, VTT

Project name: Finnish Nuclear Concrete Ageing Management Project (FN-CAMP)	
Project manager: Until 08/23 Miguel Ferreira From 08/23 Pirkko Kekäläinen	**Project manager organisation:** VTT
Partner organisations: -	
National collaboration: SAFER2028 INSER project, STUK, TVO, FORTUM	**Foreign collaboration:** OECD/NEA WGIAGE, IAEA IGALL WG3, H2020 ACES, H2020 EURAD-ACED, IRSN ODOBA Project, EPRI, ZAG, and Lund University

Objective of research:

Specifically, the FN-CAMP project will focus on developing:

• WP2: Improved understanding of internal swelling reactions through development of an assessment tool for ASR expansion of concrete (thermo-chemo-cracking model) taking into account the effect of the exposure environment on ASR expansion, i.e., relative humidity (RH), temperature, and confining stresses.

• WP2: Develop an assessment tool to evaluate the deterioration of concrete exposed to an aggressive aqueous environment (found in NPPs and RWSs), and to evaluate the degradation depth of concrete and the deterioration rate for different exposure durations (e.g.: for pure water, Na_2SO_4, seawater, and groundwater).

• WP3: Critical review the existing knowledge on the degradation of containment and pool liners, including review of the potential state-of-health monitoring methods.

• WP3: Root-cause analysis of the degraded pool liners from Finnish NPPs.

• WP3: Define the safe operation conditions of pool liners in order to exclude the possibility of liner degradation under specific conditions (experimental) and summarize existing ageing management practices (ageing mechanisms and state-of-health monitoring capabilities).

• WP4: A methodology for the interpretation of monitoring data from a pre-stressed containment building by a comparison to simulation results using inverse problem formulation. The proposed methodology is benchmarked for two data-streams collected in NPP containments. From the practical point of view, data from the VerCoRs OECD benchmark and data from OL3 will be considered.

Expected results:

WP2 – Alkali-silica reaction (ASR) and aggressive aqueous attack (AAA) on structural performance: VTT Research Report: Assessment of ASR and AAA in concrete 2023

WP3 – Assessing the performance of containment and pool liners: VTT Research Report: Literature review on the mechanisms and detection of corrosion in NPP containment and pool liners.

WP4 – Value extraction & data analysis from the results of containment monitoring system: VTT Research Report: Data analysis from the results of optical monitoring system and measurement precision validation

Expected publications and theses:

Two conference publications, one journal publication (submitted).

Other dissemination:

• EU H2020 ACES - Towards improved Assessment of Safety Performance for LTO of nuclear Civil Engineering Structures: information/data and scientific experience exchange (EU) with ACES WP2 - Corrosion assessment of embedded liners in concrete (ZAG, Slovenia), and ACES WP3 - Characterization, prediction and monitoring of internal swelling reactions in concrete (IRSN, France).

• ODOBA Project - Observatory of the lifetime of reinforced concrete structures (France): information/data and scientific experience exchange with IRSN, especially regarding experimental results of ASR and DEF of concrete structures.

• EPRI – Electric Power Research Institute (USA) collaboration discussions ongoing with interest in FN-CAMP WP1, WP2 and WP3.

• Lund University (Sweden) in the field of modulated non-linear ultra-sonic NDT.

3.4.2 PERCO2 - Long-term Performance Modelling of Concrete in Final Repositories of LILW Nuclear Waste , Aalto

Project name: Long-term Performance Modelling of Concrete in Final Repositories of LILW Nuclear Waste (PERCO2)	
Project manager: Jouni Punkki Fahim Al-Neshawy	**Project manager organisation:** Aalto University School of Engineering
Partner organisations: -	
National collaboration: SAFER2028, TVO, FORTUM.	**Foreign collaboration:** OECD/NEA, *WGIAGE Group*.

Objective of research:

PERCO2 research project addresses the research needs that focus on specific deterioration mechanism of reinforced concrete that have a significant contribution and influence on the long-term durability performance and to service-life estimations of reinforced concrete structures in low- and intermediate-level radioactive waste (LILW) repositories. The length of the service life of concrete at the final disposal, which can extend for hundreds of years, should be considered in the analysis as it could influence the performance of reinforced concrete during the post-closure period.

The main objectives of the research project are:

1) To continue the investigation of the long-term durability tests for concrete specimens (Fortum and TVO started in 1998) which have been 25 years immersed in various chemical water solutions resembling the ground water and still going on.
2) To design new durable and ecologically compatible concretes mixes for the low- and intermediate level nuclear waste repositories in Olkiluoto and Loviisa considering the enlargement of these repositories for radioactive waste generated from the decommissioning of the NPP.
3) To study modelling approaches for the deterioration of concrete structures, and to predict the useful engineered service lifetime.

The methods of the research include: (i) long-term assessment of the durability of concrete specimens stored in condition similar to the LILW repositories, (ii) investigate the potential of using the ecologically compatible concretes in LILW repositories and (iii) mathematically modelling of the deterioration of concrete structures, and to predict their useful engineered service lifetime.

Expected results:

WP1 – Durability testing of cementitious materials

WP2 – Testing of new durable concretes for the LILW repositories

WP3 – Durability, service life prediction, and modelling for the LILW reinforced concrete structures

The expected results for all Work packages are (i) to evaluate the long-term durability performance of the existing LILW concrete structures, (ii) to design and assess the durability of new concrete mixtures using the recent cement types for the use in the extension of the LILW repositories and (iii) to predict the service life of the LILW reinforced concrete structures using mathematical models.

As a result of the research project, it is expected that changes will be suggested to the current design procedure to consider a performance-based approach to design of new plans of reinforced concrete structures for extending the LILW repositories. NPP utilities will benefit from increased service life of their infrastructure. This is quite significant because the results are directly linked to the sustainability of the sector; reduction in the consumption of natural resources; reduction in the production of construction; reduction in the production of CO2 as a result of the previously mentioned factors. The research project will also educate one doctoral researcher and one master student as a new expert for the Finnish NPPs and industry.

Expected publications and theses:

The PERCO2 project is an important instrument in the education of new and high-level experts with focus on nuclear applications and creating international networks for cooperation for young engineers. The following doctoral thesis and M.Sc. thesis topics are planned to be produced in the PERCO2 project:

- **Doctoral thesis** – Automated Expert System for the design and assessment of concrete in Nuclear Waste Repositories using advanced AI techniques. Abobaker Ba Ragaa who made his M.Sc. thesis at the KYT 2022/ConLoT project is a suitable candidate for the doctoral study.
- **M.Sc. thesis 02/2024** – Potential use of ecological concretes for low level nuclear waste (LLW) storage. Niklas Sundström started his master thesis at the end of 2023 and expected to finalize his thesis during the 1st quarter of 2024.

During the year 2024, three research reports, two scientific articles and master thesis will be published:

1) **Report 1**: Measuring of concrete porosity and aggressive ion concentration profile - Part II.
2) **Report 2**: Laboratory investigation plan for accelerated leaching and thaumasite attack of cementitious materials
3) **Report 3**: Initial characteristic properties of LILW concretes.
4) **Article 1**: Long-Term Durability Assessment of Concrete in Low and Intermediate Level Waste Repositories, 27th International Conference on Structural Mechanics in Reactor Technology - SMiRT 27, March 3-8, 2024, in Yokohama, Japan.
5) **Article 2**: Machine learning model for estimating concrete ageing in LILW repositories.
6) **Master thesis**: Potential use of ecological concretes for low level nuclear waste (LLW) storage, Niklas Sundström.

The test results and data analysis of the research project will be published in Aalto research report and as scientific conference or journal articles for the field of nuclear waste management, final disposal and decommissioning of the low- and intermediate nuclear waste.

Other dissemination:

During the PERCO2 project, the research methodology and results of the year 2024 will be presented at the master's degree courses "CIV-E 2020: Concrete Technology" and "CIV-E2030: Experimental Methods in Building Materials" arranged by Aalto university School of Engineering, Department of civil engineering as a "research-based learning" teaching method. The PERCO2 research project will introduce the undergraduate students to the field of nuclear energy as doctoral/master's thesis work or as field researchers.

3.4.3 RACEMAT - Radionuclide transport in cementitious materials, HU, GTK

Project name: Radionuclides' transport in cementitious materials (RACEMAT)	
Project manager: Juuso Sammaljärvi.	**Project manager organisation:** University of Helsinki
Partner organisations: Geological Survey of Finland	
National collaboration: SAFER2028 (PERCO2), Aalto University, VTT	**Foreign collaboration:** EURAD2/RAMPEC, EURAD2/SUDOKU, ANDRA, BRGM, IRSN, University of Poitiers (France), NAGRA,
Objective of research: This study investigates the radionuclide's transport in cementitious materials. Cementitious materials are commonly used to immobilise LILW waste and act as part of engineered barrier systems in Low- and Intermediate Level Waste (LILW) repositories. Highest uncertainties in the safety case of LILW are mostly related to behaviour of radionuclides with small or poorly known retention. Therefore we aim to study the transport and retention properties of these safety case-important radionuclides. Diffusion coefficients and distribution coefficients of HTO, C-14, Cl-36 and Ni-63 will be measured via through-diffusion experiments and autoradiography. We will also characterise the in situ concrete-based waste material in terms of 3D microstructure, distribution of activity and chemical speciation of radionuclides. This study will produce safety case-relevant information on the transport properties of LILW radionuclides in cementitious materials commonly encountered in LILW repositories. New experts on radioactive waste management are planned to be trained during the course of this study and the skills of senior experts are kept up to date.	
Expected results: WP1 Diffusion experiments: Results on diffusion coefficients and distribution coefficients of studied radionuclides in concrete samples. Bulk porosity values and spatial distributions of porosity in concrete samples.3D structure of concrete samples characterised. Construction of 3D-model of the concrete material taking into account pore structure and mineral heterogeneity. Incorporating deep learning methods into the constructed model. WP2: In situ material characterisation 3D microstructure of solidified concrete waste characterised with X-ray microtomography. Autoradiography results of distributions of activity in solidified concrete waste. Microstructural analyses, chemical mapping and speciation analysis of solidified concrete waste. Construction of 3D-model of the waste material incorporating deep learning methods.	
Expected publications and theses: Article draft on radionuclides' behaviour in cementitious materials Master thesis of N.N	
Other dissemination:	

4. SG4 – Mechanical and Structural Safety

4.1 Welds, fatigue and inspection

4.1.1 AI4NDE - Advanced and Intelligent Nondestructive Evaluation, VTT, Aalto

Project name: Advanced and Intelligent Nondestructive Evaluation (AI4NDE)	
Project manager: Mohammed Siddig	**Project manager organisation:** VTT Technical Research Centre of Finland
Partner organisations: VTT Technical Research Centre of Finland [1], Aalto University[2]	
National collaboration:	**Foreign collaboration:** Via the Program for Investigation of Non-Destructive Examination by International Collaboration - Phase 2 (PIONIC 2), with USA, Republic of Korea, Switzerland, Sweden, and Germany

Objective of research:

The Nondestructive Evaluation (NDE) methods have been proven inevitable in the safety diagnosis of Nuclear Power Plants (NPPs) from the construction phase to Plant Life Extension (PLE) strategies.

This project seeks to support the maturity of the NDE innovations introduced in the previous projects and provide significant improvement in sizing reliability with the combined use of Artificial Intelligence (AI), new imaging modes and betters reliability models.

The project's specific objectives are:

- Raising the level of AI solutions for NDE from flaw detection to much more challenging crack characterization.

  Training data for second-tier models will be developed based on the first-tier model data that was acquired in 2023 using the advanced Plane Wave Imaging (PWI) mode with Total Focusing Method (TFM) and Synthetic Aperture Total Focusing Method (SATFM) reconstruction, and then use the data to train the modern transformer neural networks architecture. The final task is to complete a thorough model evaluation and prepare a scientific paper on the new model architecture.

- Assessing the efficacy of the emerging Ultrasonic Testing method, Phase Coherence Imaging, with a focus on enhancing crack characterisation and sizing reliability. The study involves simulations and experiments to reconstruct phase coherence images from data acquired through Full Matrix Capture (FMC) and PWI techniques. Additionally, comparative analyses will be conducted with other advanced reconstruction methods, such as TFM. The results of the performance evaluation and the comparison studies will be disseminated in a research report.

Expected results:

WP1 Artificial Intelligence (AI):

Machine Learning model for flaw sizing and characterisation in Ultrasonic Testing of a Reactor Pressure Vessel mock-up.

WP3 Emerging methods:

Comprehensive evaluation of the Phase Coherence Imaging in selected applications.

Expected publications and theses:

- Scientific publication on ML flaw characterisation
- Report on Phase Coherence Imaging

4.1.2 LOAD - Long-term Operation on Aging and environmental Degradation of nuclear reactor materials, VTT

Project name: Long-term Operation on Aging and environmental Degradation of nuclear reactor materials (LOAD)	
Project manager: Zaiqing Que	**Project manager organisation:** VTT Technical Research Centre of Finland
Partner organisations: No	
National collaboration: SAFER MINERVA, BRIGHT, TOFFEE	**Foreign collaboration:** EU-DELISA, EU-INCEFA-SCALE and NKS-FEMMA
Objective of research: The overreaching objective of LOAD project is to gain understanding on environmental degradation mechanisms in NPP component materials – including environmental assisted cracking (EAC) and long-term thermal embrittlement, etc. The LOAD project aims to: • Increase the knowledge on SCC of cold worked stainless steels (welds) and the potential influencing factors. • Fill the knowledge gap of thermal aging and EAC concerning 22K steel used in VVER design.	
Expected results: This work is separated into four work packages (WP): • WP1, SCC of cold worked stainless steel. Through the activities in WP1, the national knowledge on SCC of cold worked stainless steels (welds) and the potential influencing factors can be increased. An international collaboration platform with French, Swedish, Japanese, UK and USA partners on this topic under the framework of ICG-EAC is being set up. Knowledge on both potential mitigation and failure analysis on this topic can be obtained. • WP2, thermal aging study and EAC of 22K steel. The understanding of aging and degradation issues concerning LAS used in VVER design can be increased. • WP4, international collaboration. This WP ensures (i) the participation of researchers in international scientific conferences and meetings where project results will be presented, (ii) the publication of results in high quality scientific journals and conference proceedings and (iii) dissemination of Horizon2020 projects EU-DELISA and EU-INCEFA-SCALE, and the closely linked Nordic NKS-FEMMA project.	
Expected publications and theses: One ongoing PhD thesis as well as a MSc thesis. 5-6 peer reviewed journal papers and conference proceedings.	
Other dissemination: The international seminar organized through the WP1 of LOAD project within the ICG-EAC framework built up the continuous global collaboration platform. The WP2 will be in close link with EU-DELISA and NKS-FEMMA projects. Through the participation of international conferences and meetings and the publication of peer reviewed papers, the results of LOAD can be disseminated.	

4.1.3 TOFFEE - Total fatigue life in plant environment, VTT, Aalto

Project name: Total Fatigue Life in Plant Environment (TOFFEE)	
Project manager: Juha Kuutti	**Project manager organisation:** VTT Technical Research Centre of Finland
Partner organisations: VTT Technical Research Centre of Finland, Aalto University	
National collaboration: SAFER2028 LOAD	**Foreign collaboration:** EPRI EAF collaboration group, ASME III/XI working
Objective of research: The topic of the project is the evaluation of the safe operation life of primary piping in plant environment. Environmental degradation, thermomechanical fatigue and subsequent cracking remains one the ageing mechanisms that limit the lifetime of nuclear piping. The aim of the project is to provide experimentally verified means to determine the total safe lifetime of primary piping with respect to fatigue and crack growth in coolant water environment and subjected to relevant stressors.	
Expected results: WP1 Experimental environmental fatigue: WP1 will focus on the fatigue endurance of the PWR primary piping material. Material characterizations and both air and environmental fatigue testing will be performed to determine the true fatigue endurance of the material. Such baseline and environmental fatigue curves without considerable uncertainty have not been available previously for a relevant material from an actual piping segment. WP2 Implementation of EAF model: WP2 will focus on the development of environmental and total fatigue life models. The WP will provide the developments needed to transfer the laboratory results of WP1 and WP3 into models utilizable by the NPPs. WP3 Thermally induced stress corrosion cracking: WP3 will focus on thermally induced SCC through an experimental campaign. The WP will clarify the role of thermal loads in increasing susceptibility of stainless steels to SCC and help to understand the root causes of recent SCC findings of components not thought to be susceptible to SCC.	
Expected publications and theses: ASME PVP 2024 presentation on commissioning of new environmental fatigue apparatus ASME PVP 2025 paper manuscript on first environmental fatigue tests with PWR piping material ASME PVP 2025 paper manuscript on VTT environmental fatigue model Doctoral dissertation on environmental fatigue of nuclear stainless steels (2025)	
Other dissemination: Along the SAFER community, the progress of the research and main results will be disseminated through main international conferences. An integral part of the project is the collaboration in the EPRI and ASME international workgroups on fatigue and environmental degradation, where the project results will be subjected to international visibility and examination.	

4.2 Material and material testing

4.2.1 AMANE - Additively Manufactured Materials in Nuclear Environments, VTT

Project name: Additively Manufactured Materials in Nuclear Environments (AMANE)	
Project manager: Tuomas Riipinen	**Project manager organisation:** Teknologian Tutkimuskeskus VTT Oy
Partner organisations: Teknologian Tutkimuskeskus VTT Oy	
National collaboration: N/A	**Foreign collaboration:** EURATOM NUCOBAM
Objective of research: To increase the understanding on the material behaviour of Additively manufactured materials under conditions typically found in Nuclear Power Plants. This knowledge is essential for utilities and regulators to ensure safe operation of components built with this novel manufacturing method.	
Expected results: WP1: Novel fatigue test method for AM: In this work package a test rig for a miniaturized fatigue testing method will be designed, built and validated to be able to perform cyclic loading of specimens with the objective of having a better understanding of the fatigue life of AM materials, which in many cases, due to geometrical factors, cannot be properly tested in real condition using standard fatigue testing methods. The developed test method will be validated by comparing the results of the miniature specimen geometries to standard size methodology. After validation the fatigue properties of AM specimens with different surface conditions will be tested and evaluated.	
Expected publications and theses: Journal paper: Design and validation of a fatigue test method for AM 316L using miniature specimen geometry	
Other dissemination: The project team will be monitoring relevant events during 2024 and participate sharing results from AMANE whenever possible and relevant.	

4.2.2 BRIGHT - Barsebäck RPV investigation through thickness, VTT

Project name: Barsebäck RPV Investigation Through Thickness (BRIGHT)	
Project manager: Noora Hytönen	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd.
Partner organisations:	
National collaboration: SAFER2028 CHAOS	**Foreign collaboration:** OECD/NEA SMILE, NKS, Energiforsk, Ringhals, KTH, Chalmers

Objective of research:

The safe operation and durability of the reactor pressure vessel (RPV) is one of the most important tasks for nuclear power plants. The most pronounced ageing mechanism of the RPV and especially of the beltline region is radiation-induced embrittlement, which cause an increase in the ductile to brittle transition temperature. There is a known attenuation effect meaning on the RPV wall through thickness where the inner surface of the RPV wall is exposed to higher radiation than the middle/outer surface causing possibly higher radiation damage and more significant embrittlement. A unique opportunity to determine the mechanical behaviour and microstructural features of material removed from a decommissioned Barsebäck RPV Unit 2 was made available within BREDA project. The objective is to determine the representativeness of the surveillance programme compared to the true material embrittlement, and the focus is on the base material. In BRIGHT project the focus is on toughness variation through wall thickness and the effect of attenuation as well as improving the fractographic examination by advanced microscopy methods. The BRIGHT project includes VTT's participation in the SMILE consortium (including Studsvik, OKG, Ringhals and SSM of Sweden, EPRI and NRC of the USA, SCK, UJV, GRS, MPA Univ. Stuttgart in Europe, CRIEPI and NRA of Japan, and six different Chinese nuclear organizations) with an in-kind contribution and the dissemination of the SMILE project results to Finnish stakeholders.

Expected results:

WP1 Fracture mechanical testing

Cutting and testing of the reactor pressure vessel base material at various thickness locations close to the inner surface. Fracture mechanical testing includes tensile testing, instrumented impact toughness testing and fracture toughness testing. The expected results show ductile to brittle transition curve and effect of attenuation in toughness properties. First year of the project focused more on sample preparation and cutting, therefore in 2024 the emphasis is more on the fracture mechanical testing.

WP2 Microstructural characterisation

Fractography is performed on all brittle fracture specimens tested in WP1. The primary initiation site is located and analysed the microstructure at the initiation site. Advanced microscopy techniques such as focused ion beam (FIB) is used for lift-out of lamellas for transmission electron microscopy (TEM) to analyse the primary initiation sites and second-phase particles. The capability of using FIB technique on fracture surfaces is developed and new TEM experts are trained. The first year results on FIB and TEM have created a solid basis for methodology development on the second year.

WP3 Stakeholders forum and SMILE dissemination

The WP3 includes reporting progress to the advisory group and Finnish stakeholder group, fostering technical discussions with stakeholders, knowledge transfer, networking and international co-operation. The BRIGHT project results are disseminated in international conferences and meetings. The SMILE (Studsvik Material Integrity Life Extension Project) is an OECD NEA consortium project initiated by Swedish nuclear power plant operators Ringhals, OKG and Forsmark in collaboration with Studsvik and SSM, in which materials harvested from Swedish decommissioned power plants are characterised. The SMILE dissemination includes the reporting of BRIGHT project results to the SMILE consortium, enable VTT's active participation in SMILE meetings on behalf of Finnish stakeholders, and most importantly, disseminate the SMILE project results to the Finnish stakeholders.

Expected publications and theses:

Scientific article on toughness properties obtained in BRIGHT project Scientific article on brittle fracture initiation using advanced microscopy techniques One doctoral thesis estimated to finish in 2025
Other dissemination: - IGRDM (the International Group on Radiation Embrittlement Mechanisms), - ICG-EAC (the International Co-operation Group on Environmentally-assisted Cracking), - SMILE project meetings

4.2.3 CHAOS - Characterization of NPP structural integrity, VTT

Project name: Characterization of NPP structural integrity (CHAOS)	
Project manager: Laura Sirkiä	**Project manager organisation:** VTT
Partner organisations: -	
National collaboration: **SAFER BRIGHT**	**Foreign collaboration:** KTH, Kiwa inspecta (Sweden), ASME, ASTM, ESIS
Objective of research: In the SAFER2028 level, the objective of CHAOS project is to develop state-of -the-art fracture mechanical assessment methods for use in NPP applications and improve safety by developing more **accurate structural integrity assessment methods to account for transferability of fracture toughness to real components** (= the constraint-effect), and at the same, **offer a solution for diminishing volume of RPV surveillance material caused by extending lifetimes of NPPs**. The latter goal is focused on optimizing the miniature C(T) specimen size for surveillance programs and developing a miniaturization technique to assess crack arrest toughness.	
Expected results: Related to WP1, in 2024, the goal is to carry-out the mechanical testing related to the SET and CC(T) specimens, and method development of elliptical surface cracks. A suitable temperature range will be selected based on the work done in 2023. Numerical simulations are required to assess the fracture toughness, which are done in task 3. The results are compared to existing results on high constraint specimens. This work is reported together with contributions from digital image correlation (DIC) task 2 and numerical modelling task 3. A scientific article, a combination of numerical, experimental and analytical methods to develop a procedure which can be applied to assess the ATLAS+ full-scale pipe test that failed by the brittle mechanism after 3 mm of ductile tearing will be written. The numerical methods were developed in 2023 and the experimental work was carried out in ATLAS+ project. The analytical assessment of brittle fracture and Master Curve transferability for the pipe component is described in the work. Related to WP2, in 2024, series of 4 mm and 3 mm thick miniature C(T) specimens are tested in order to investigate the fracture mechanism variation with specimen thickness, and studies of mitigation of the dimensional tolerances of miniature C(T) specimens without risking reliability of the results will continue. Numerical modelling as well as microstructural characterization will be used to support fracture mechanical research. In all probability, a PhD thesis should be completed in 2024. Related to WP3, in 2024, prior results are utilised to determine the material's crack arrest toughness from miniature impact specimens. This is then investigated in conjunction with fracture toughness of the same material to establish a correlation between the two, and demonstrate the applicability of crack arrest toughness, measured from miniature impact specimens, as a measure of minimum fracture toughness. Both the standard-sized impact specimens and fracture toughness specimens are tested in SAFER BRIGHT project. A research report will be prepared on the subject.	
Expected publications and theses: In WP1: Scientific article, research report In WP2: PhD thesis In WP3: Research report	
Other dissemination: ASME Pressure vessel & piping conference, International/European conference on fracture, ASTM seminars and conferences	

4.2.4 MINERVA - Mitigation of corrosion and novel water chemistries in light water reactors, VTT

Project name: Mitigation of corrosion and novel water chemistries in light water reactors (MINERVA)	
Project manager: Konsta Sipilä	**Project manager organisation:** VTT
Partner organisations:	
National collaboration: Loviisa NPPs, Olkiluoto NPPs	**Foreign collaboration:** UCTM

Objective of research:

The MINERVA project aims to provide solutions for chemistry and corrosion related issues that the currently operating plants in Finland have. The following objectives for 2024 has been defined:

- Determination the effect of alternative oxygen scavenger chemicals DEHA and carbohydrazide on long term corrosion behaviour of 22K, 08X18H10T and A690. Evaluate the effect of these chemicals on FAC of 22K.
- Verify the use of zeta potential measurements for magnetite in simulated PWR conditions and assess magnetite agglomeration in simulated secondary side conditions
- Evaluate the Co source terms in primary circuits
- Improve the method for evaluating hide-out-return kinetics in simulating steam generator conditions
- Assess the applicability of turbidity measurements in nuclear power plants

Expected results:

WP1 Project management:

The project has progressed as planned.

WP2 Advanced water chemistry:

How DEHA and carbohydrazide affect the corrosion of structural materials and how the effects compare to those of hydrazine.

WP3 Improved safety assessment of steam generators:

How the agglomeration of magnetite in steam generators can be inhibited.

WP4 Impurity & corrosion product transport and enrichment:

More detailed data on the source term of Co and hide-out-return of chlorides in simulated PWR conditions.

WP5 Chemistry monitoring in NPPs:

Can turbidity measurements be used in nuclear power plants and could turbidity monitoring produce meaningful data for chemistry monitoring.

WP6 International cooperation and dissemination:

Interaction in the ECG-COMON group activities. Presentation on chloride hide-out-return studies in EUROCORR conference.

Expected publications and theses:

Master thesis on application of streaming potential technique in zeta potential measurements and verification of the test setup and results on magnetite agglomeration in simulated PWR secondary side chemistry.

Conference paper summarizing on the hide-out-return studies performed in simulated secondary side conditions in EUROCORR.

Other dissemination:

Participation to the ECG-COMON activities.

4.2.5 PRANCS - Practical solutions for sealant performance issues in nuclear power plants, VTT

Project name: Practical solutions for sealant performance issues in nuclear power plants (PRANCS)	
Project manager: Konsta Sipilä	**Project manager organisation:** VTT
Partner organisations: -	
National collaboration: Fortum, TVO	**Foreign collaboration:** -

Objective of research:

The PRANCS project aims to provide solutions for sealant related issues that the currently operating plants in Finland have. The following objectives for 2024 has been defined:

- Develop hardness measurement to monitor joint sealant condition on site
- Study the effect of compression to sealant ageing
- Study the effect of nitrogen atmosphere on ageing of sealants
- Evaluate how much impurities can leak from sealants into reactor coolant
- Assess the performance of graphite sealants under compression and high temperature

The project aims to provide practical solutions to the identified sealant issues.

Expected results:

WP1 Project management:

The project has progressed as planned.

WP2 Condition monitoring of joint sealants:

Verified hardness measurement ready to be used in condition monitoring of joint sealant material.

WP3 Ageing of sealants in nuclear power plants:

Estimation how much compression affects the ageing of sealants, estimation how much difference is between when sealant is aged in nitrogen and air atmospheres and the impurity amounts that can be released from different types of sealants in high temperature water is presented.

WP4 Performance of graphite sealants in nuclear power plants:

Provide proper graphite sealant qualities for high temperature and compressive environments.

Expected publications and theses:

Five VTT research reports are published during the project.

Other dissemination:

The use of joint sealant condition monitoring method is demonstrated.

5. DENSE

5.1.1 DENSECO - DENSE coordination project, Aalto, LUT, HU

Project name: Coordination Project for DENSE Network (DENSECO)	
Project manager: Jarmo Ala-Heikkilä	**Project manager organisation:** Aalto University
Partner organisations: SAFER2028 organizations obtaining DENSE funding or involving doctoral students in projects	
National collaboration: SAFER2028 projects involving doctoral students	**Foreign collaboration:**
Objective of research: This project covers the coordination activities and networking operations of the Doctoral Education Network DENSE. Our objective is to support networking of doctoral students implementing their DENSE projects, both within DENSE network, domestically, and internationally. Additionally, all other doctoral students working in SAFER2028 projects have been invited to DENSE network activities. We have established an annual seminar for doctoral students in the DENSE network of which the first was held in August 2023 and was given very positive feedback. We will also continue to financially support doctoral students in their participation fees of conferences, workshops, and summer schools, as well as their national and international mobility and costs related with publications, equipment, and materials. We will organize two funding calls during 2024 and expect to receive an increasing number of applications that deserve funding. This expectation is motivated by the growth of the DENSE network as well as an increasing knowledge of this funding instrument within SAFER2028.	
Expected results: WP1 Funding of DENSE operations - Planning and organization of DENSE annual seminar - Running the practical implementation of funding for participation in conferences, workshops, and summer schools, as well as for international mobility (two calls annually) - Running the practical implementation of funding for costs related with publications, use of infrastructure, equipment, and materials (two calls annually)	
Expected publications and theses: None. Publications and theses will be produced in DENSE research projects that this project supports.	
Other dissemination: Annual seminar of DENSE network, publication of its presentations on SAFER2028 web pages.	

6. Infrastructure

6.1.1 DEMAIN - Development and maintenance of LUT thermal hydraulic infrastructure, LUT

Project name: Development and maintenance of LUT thermal hydraulic infrastructure (DEMAIN)	
Project manager: Joonas Telkkä	**Project manager organisation:** LUT University
Partner organisations:	
National collaboration: SAFER2028: C-FLOW, GRAF, NCGDENSE	**Foreign collaboration:** SILENCE (Significant Light and Heavy Water Reactor Thermal Hydraulic Experiments Network for the Consistent Exploitation of the Data)
Objective of research: The objective of the project is to develop and maintain the experimental thermal hydraulic infrastructure at LUT University nuclear safety research laboratory in Lappeenranta. The project includes maintenance of the thermal hydraulic test facilities and development and upgrade of the facilities, instrumentation and data acquisition and analysis capabilities. Knowledge management is also a part of the project, comprising the full implementation of the new data storage systems of the laboratory. The project also includes significant international co-operation with other top-level universities and research institutes conducting experimental nuclear thermal hydraulic research worldwide within the frame of the SILENCE network.	
Expected results: **WP1 Development of thermal hydraulic instrumentation:** Conference paper on the optic fiber measurement results. Implementation of the gamma densitometer system to the critical flow test facility. Procurement and testing of a measurement system for measuring of non-condensable gases. **WP2 Laboratory maintenance:** Maintaining the facilities operable for the use in other research projects. Yearly calibrations of instruments. Pressure vessel inspections according to the schedule. **WP3 Knowledge management:** Archiving of the large data sets from the PIV, WMS, optic fiber, and high-speed camera measurements to the new FairData cloud service data storage. Investigation of the high-speed camera data for the possible future use. **WP4 Project management and international co-operation:** Successful management of the project. Participation in the SILENCE network activities. Participation to the SWINTH-2024 workshop.	
Expected publications and theses: Master's or bachelor's theses may result from testing of novel thermal hydraulic measurement techniques. At least one thesis is expected for 2024 from the testing of the gamma densitometer system.	
Other dissemination: Results of the optic fiber measurements will be presented in the SWINTH (Specialist Workshop on Advanced Instrumentation and Measurement Techniques for Experiments Related to Nuclear Reactor Thermal Hydraulics and Severe Accidents) workshop in June 2024.	

6.1.2 JHR2028 - Participation in the Jules Horowitz Reactor project, VTT

Project name: Participation in the Jules Horowitz Reactor project (JHR2028)	
Project manager: Jussi Peltonen	**Project manager organisation:** VTT
Partner organisations:	
National collaboration:	**Foreign collaboration:** Jules Horowitz Reactor-project, OECD/NEA FIDES, JHOP2040, Halden Reactor Project
Objective of research: The primary objective of the JHR2028 project will be to continue in the international collaborations and programmes related to JHR, representing Finnish interests in the operational planning and contributing to the development of the largest European MTR project. A prototype of MeLoDIE II will be built and tested VTT's facilities in the conditions of the in-core of the LWR-15 test reactor, after which it will be dismantled and transferred to the reactor in the Czech Republic for experimental use. PhD students participate in the WG activities by contributing research in the form of a secondment period, experimental materials studies and applying VTT's reactor analysis software for computational simulations.	
Expected results: WP1 JHR Working Groups: Participation in the JHR WG activities twice in 2024 (spring and fall) WP2 Materials Investigations: Progress in dismantling and transporting of MeLoDIE II from VTT's facilities to Rez, Czech Republic as form of FIDES-INCA in-kind contribution and continuation of secondment research in the form of JAM project at VTT's facilities. WP3 Nuclear Fuel: No expected results, WP3 starts in 2025. WP4 Project Management: Project management and communication of the project to SAFER.	
Expected publications and theses:	
Other dissemination: JHR Technical Seminar 2024	

6.1.3 RADCNS - Radiological laboratory facility costs of the Centre for Nuclear Safety 2023, VTT

Project name: Radiological laboratory facility costs of the Centre for Nuclear Safety (RADCNS)	
Project manager: Wade Karlsen	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd
Partner organisations: N/A	
National collaboration: N/A	**Foreign collaboration:** N/A
Objective of research: This project is specifically for the 2nd part of the call, the facility cost of the laboratory part of the Centre for Nuclear Safety directed only to the VTT Technical Research Centre of Finland Ltd, as described in Nuclear Energy Act Amendment (676/2015), YEL § 53 a	
Expected results: The results are manifested through the many VYR-funded projects that include direct activities and other connections to the new laboratory facility.	
Expected publications and theses: None expected in this project.	
Other dissemination: The VTT Centre for Nuclear Safety is still a popular place for guests to visit, and the facility has already received international attention.	