SAFER2028 Year 2023 Annual Plans

Contents

1. **SG1 – Overall Safety and Society** ... 3
   1.1 **Hazards** ... 3
      1.1.1 FASAANI (Fire behaviour and safety of nuclear infrastructure), VTT, Aalto ... 3
      1.1.2 MAWECLI - Marine and Weather Events in the Changing Climate as Potential External Hazards to Nuclear Safety, FMI ... 4
      1.1.3 PRALINE - Probabilistic Risk Assessment Labour, Improvements aNd Extensions, VTT ... 5
      1.1.4 SERIOUS - Sensitivity and risk informed seismic hazard updates, VTT, RMCF, AFRY, HU ... 6
   1.2 **Human, organisation and society** ... 7
      1.2.1 RESPECT - Residents' Gendered Safety and Risk Expectations - The Case of SMRs in the urban area, LUT ... 7
      1.2.2 SCALA – Safety Culture and Leadership in Sociotechnical Changes and Transitions, VTT, Liliko ... 8
      1.2.3 TONUS - Towards Nuclear Human Systems Integration, VTT, FIOH ... 10
   1.3 **System safety** ... 11
      1.3.1 SEAMLES - Systems Engineering approaches for managing the life cycle of I&C systems, VTT, Aalto 11
      1.3.2 SINARP - The Safe Interaction of Nuclear with a Renewable Rich Power System ... 12
2. **SG2 Reactor Safety and Fuel** ... 13
   2.1 **Thermal hydraulics and severe accidents** ... 13
      2.1.1 ALISA - Analytical and experimental investigation of severe accident phenomena, VTT ... 13
      2.1.2 CeReSa - CFD for Reactor Safety, VTT ... 15
      2.1.3 C-FLOW - Critical Flow Separate-Effect-Test Facility & Experiments, LUT ... 16
      2.1.4 ESPO - Analysis of Passive Safety Systems' Operations and Modelling, VTT ... 17
      2.1.5 GRAF - Gravity driven flow experiments, LUT ... 19
      2.1.6 THEME - Computational Modeling of Thermal-Hydraulic Phenomena, VTT ... 20
   2.2 **Fuel and reactor physics** ... 21
      2.2.1 DECAPOD: Deterministic safety analyses with Kraken, VTT ... 21
      2.2.2 MATFINE - Methods for current and accident tolerant fuels modelling, VTT ... 22
      2.2.3 NOTCO- Neutronics for fuel outside the reactor core, VTT ... 24
3. **SG3 Nuclear Waste** ... 25
   3.1 **Fuel and engineered barrier system** ... 25
      3.1.1 ABCRad - Alternative Buffer/Backfill Characterisation + Radionuclide Interactions, HU ... 25
      3.1.2 DEHYDSU - Defects, hydrogen and susceptibility of Cu-OFP to stress corrosion cracking in sulphide containing environment, VTT ... 27
      3.1.3 MOCRYCO - Model based on crystal plasticity for copper, VTT ... 28
      3.1.4 SAGE - Sensitivity analysis guided disposal barrier experiments, VTT, JyU, GTK ... 29
   3.2 **Low and intermediate level waste** ... 30
      3.2.1 MICWEST - Influence of environment and microbes on corrosion behaviour of welded steels in the LILW repositories, VTT ... 30
      3.2.2 GasOff - Termination phase of the LLW Gas Generation Experiment, Safram Oy, VTT ... 32

3.3 Rock, Site and Biosphere 33
3.3.1 ECOLAB - Laboratory-based studies for radioecological modelling of 14C, HU, FMI, UI, UEF, EnviroCase 33
3.3.2 FLOP - Flow pathways within faults and associated fracture systems in crystalline bedrock, UTU, GTK, JyU, Åbo Academi 34
3.3.3 MIRKA - Scale-effect in fractured rock mass, Aalto 36
3.3.4 SMRSiMa - SMR Siting and Waste Management, VTT, GTK, LUT 37
3.4 Concrete 38
3.4.1 FN-CAMP - Finnish Nuclear Concrete Ageing Management Project, VTT 38
3.4.2 PERCO2 - Long-term Performance Modelling of Concrete in Final Repositories of LILW Nuclear Waste , Aalto 40
3.4.3 RACEMAT - Radionuclide transport in cementitious materials, HU, GTK 42
4. **SG4 – Mechanical and Structural Safety** 43
4.1 **Welds, fatigue and inspection** 43
4.1.1 AI4NDE - Advanced and Intelligent Nondestructive Evaluation, VTT, Aalto 43
4.1.2 LOAD - Long-term Operation on Aging and environmental Degradation of nuclear reactor materials, VTT 44
4.1.3 ReQu - Repair welding and performance quality of welded pipe joints, LUT 45
4.1.4 TOFFEE - Total fatigue life in plant environment, VTT, Aalto 46
4.2 Material and material testing 47
4.2.1 AMANE - Additively Manufactured Materials in Nuclear Environments, VTT 47
4.2.2 BRIGHT - Barsebäck RPV investigation through thickness, VTT 48
4.2.3 CHAOS - Characterization of NPP structural integrity, VTT 50
4.2.4 MINERVA - Mitigation of corrosion and novel water chemistries in light water reactors, VTT 52
5. **DENSE** 54
5.1.1 CORF - Characterization of hydromechanical properties of rock fractures, Aalto 54
5.1.2 DENSECO - DENSE coordination project, Aalto, LUT, HU 56
5.1.3 REST - The reduction of large source term during severe nuclear accidents, UEF 57
5.1.4 SurePhD - Increasing surety in the performance of present and future VLLW disposal – HU 58
6. **Infrastructure** 59
6.1.1 DEMAIN - Development and maintenance of LUT thermal hydraulic infrastructure, LUT 59
6.1.2 JHR2028 - Participation in the Jules Horowitz Reactor project, VTT 60
6.1.3 RADCNS - Radiological laboratory facility costs of the Centre for Nuclear Safety 2023, VTT 61

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** Development of a robust method for finding unknown parameters for ventilation network model of complex ventilation systems in Nuclear Power Plants. Models with different complexities are built and the missing parameters are estimated using optimization techniques. The result of the task is a report documenting best practices and optimization methods for obtaining robust sets of ventilation model parameters so that its interaction with fire is properly captured. **WP2 Aging of polymeric materials** Setting up aging experiment plan for XLPE material for providing validation data for aging models. Development of degradation kinetics model for XLPE in air. FDS modelling of non-aged XLPE. **WP3 Fire barrier systems performance assessment and aging** A validated, simulation-based capacity for expert assessments of the fire performance and compartmentation reliability of fire stops and other fire barrier systems that have no standard fire resistance rating. In addition, we will quantify the aging effects on fire stops.	
Expected publications and theses: All topics are new research and will require more than one year for journal publication. Conference articles and presentations based on the work is expected to start in 2024.	
Other dissemination: Participation in OECD/NEA FAIR project review and benchmarking groups; Palotutkimuksen päivät -conference for the Finnish fire community; 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)
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: • Enhanced return period estimates for sea level extremes on the Finnish coast based on non-stationary GEV modelling, • Determination of derecho environments in the current climate, • Frequency estimates of high 10-meter wind speeds and wind gusts, • Refined sea-effect snowfall detection algorithm with a very high resolution climate model data, and • Estimates for the occurrence of extreme air temperatures in the past climate. WP2 Multi hazards. Expected results include: • Definition of cyclones and cyclone clustering causing extreme sea levels in Finland, and • Identifying characteristics of sea-area thunderstorms in Finland. WP3 Project management. Expected results include: • Active and fruitful interaction with stakeholders at various levels.	
Expected publications and theses: Expected journal article on: • Non-stationary GEV modeling on extreme sea levels on the Finnish coast Expected doctoral theses on: • Sea surface dynamics in the Baltic Sea region using modelling and measurements • Wind applications to support forestry in Finland • Sea-effect snow in Finland • Severe convective storms in Finland	
Other dissemination: Dissemination activities of the project include: • Workshop on extreme value analysis (a follow-up for a similar workshop on 12.10.2022 at FMI) • 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: literature survey of seismic human reliability analysis and the effects of seismic events on human performance. WP2 Digital I&C PRA: a tentative model for the international DIGMORE project reference case; tentative comparison of the model with the models of other DIGMORE participants; a literature survey on PRA of instrumentation and control architecture.	
Expected publications and theses: A scientific paper on DIGMAP results (predecessor of the DIGMORE project).	
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 – PSHA interacts with fragility task)	**Foreign collaboration:** Academy of Finland SEISMIC RISK project: Seismic Risk | University of Helsinki Collaboration with the ESHM20 team (EFEHR | ESHM2020 Overview)
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 is the reason to apply for a 3 year excellence project. In 2023 T1.1 will focus on the MSc study, on the current stress field and seismicity represented by the available earthquake catalog and generating synthetic catalogues to increase the insights, in comparison with what actual earthquake data can provide. 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. WP2: Near-site and in-structure effects The active tasks in WP2 in 2023 are T2.1 and T2.3. In T2.1 the suitable earthquake events for national-scale kappa computations will be collected, and the analysis carried out. The new kappa values will be available by the end of 2023 (*but a neat writeup of the work only in Q1 of 2024*). In T2.3 the work focuses on finalizing and submitting of a manuscript focused on floor vibrations and preparation of the PhD summary of Vilho Jussila. The work is in collaboration with Prof. Jari Puttonen's research group at Aalto University. WP3: Data curation & integration in PSHA model updates WP3 is only starting with T3.1. T3.1 is the first update to the hazard models, in the sensei of re-evaluation for the Gutenberg-Richter parameters (a_{GR} and b_{GR}) with the maximum likelihood estimation method (MLE). At this stage the current earthquake catalogs are used (no input from WP1).	
Expected publications and theses: The main outputs of 2023 are: - one MSc thesis at ISUH (P. Mäntyniemi): focuses on the current stress field and seismicity represented by the available earthquake catalog. Synthetic catalogs created to explore the validity of common assumptions of earthquake occurrence. - one journal paper submitted to e.g. Nuclear Engineering and Design from Task 2.3 (V. Jussila) - one PhD thesis submitted to Aalto University (V. Jussila). PhD work started in SAFIR/SESA project. Public defense planned for early 2024.	
Other dissemination:	

1.2 Human, organisation and society

1.2.1 RESPECT - Residents' Gendered Safety and Risk Expectations - The Case of SMRs in the urban area, LUT

Project name: Residents' Gendered Safety and Risk Expectations – The case of SMRs in the urban area (RESPECT)	
Project manager: Associate Professor Matti Kojo	**Project manager organisation:** LUT University
Partner organisations: University of Jyväskylä [1], Universitat Pompeu Fabra [2]	
National collaboration: University of Jyväskylä, the Promises project funded by the Academy of Finland	**Foreign collaboration:** Dr M. Lehtonen / Universitat Pompeu Fabra, the Promises project funded by the KONE Foundation
Objective of research: The RESPECT project analyses residents' views and expectations on the safety and risks of small modular reactors (SMRs) in the Helsinki metropolitan area and in the city of Tampere, with special attention to the gender perspective, given that women's and men's views on nuclear technologies are known to significantly differ from each other.	
Expected results: WP1 "Residents' gendered safety and risk expectations": Bringing together the gender perspective and theories and concepts related to a gender gap in risk perceptions, the project brings novel insights into the perceptions of nuclear energy in Finland. By reviewing the gender perspective and theories from earlier research on nuclear energy attitudes and risk perceptions, the project provides valuable information on the possible specificities of SMRs. The results will show the most typical expectations of respondent groups related to safety. The results can assist energy-sector practitioners to better plan their communication and engagement activities, notably in the process of site selection for a possible SMR project.	
Expected publications and theses: 1) Professional journal article on the most typical residents' concerns related to a possible SMR project 2) Article in a peer-reviewed science journal on gendered expectations on SMR safety and risks	
Other dissemination: 1) Press release, LUT University 2) Presentations at the SRA-E Conference and the SRMSiMa Stakeholder Workshop 3) Researcher visits	

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

Project name: Safety Culture and Leadership in Sociotechnical Changes and Transitions (SCALA)	
Project manager: Kaupo Viitanen	**Project manager organisation:** VTT
Partner organisations: VTT[1], Lilikoi[2]	
National collaboration: SAFER2028 TONUS	**Foreign collaboration:** NKS-R INSOLE 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 and cooperation with OECD/NEA WGHOF.

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.

Expected results:

WP1 - Leading safe sociotechnical changes

- Summary of organizational lessons learned in terms of assuring nuclear safety in selected case studies (OL3 and ELSA I&C modernization) (continues in 2024-2025)
- Guidance and insights concerning safety culture work and leadership in different sociotechnical contexts (continues in 2024-2025)

WP2 - Overseeing changes: internal oversight function as part of organizational defence-in-depth

- Summaries of international and non-nuclear data collection (continues in 2024)
- Normative framework for internal oversight function (continues in 2024)

WP3 - Continuous improvement framework for resilient sociotechnical change

- Insights from international information exchange (continues in 2024-2025)

WP4 - Annual seminar of Human and Organizational Factors

- Annual seminar of Human and Organizational Factors arranged jointly with SAFER2028 TONUS (continues in 2024-2025)

Expected publications and theses:

- Conference paper on leadership for resilience (D1.3.1)
- Conference paper on resilience and safety culture (D1.3.2)
- NKS intermediate report (D.2.1.1) (jointly with NKS-R INSOLE)

Other dissemination:

- Results from case studies (slide set and one workshop) (D1.1.1)

- Summary results from international oversight study (slide set + joint Nordic workshop) (D2.1.2)
- International information exchange sessions (D3.3.1)
- Annual seminar of Human and Organizational Factors co-arranged with SAFER2028 TONUS (D4.1.1)

1.2.3 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, IFE, SSM, Idaho National Laboratory, Vattenfall
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:* Guidance is created for operator practices in a digital control room based on the results of a Systems Usability survey and cognitive walkthrough of Olkiluoto 3 main control room. Furthermore, a Finnish methodology for human performance modelling and Systems Usability Case -based approach for synthetisation of operating experiences are developed. *WP3 New methods and tools for operator work and training of cognitive readiness skills:* We will gain a better understanding of 1) prospects and limitations of part-scope simulator training in process control and in cognitive readiness skills development, and 2) participatory design of VR training environments. Guidelines will be developed for part-scope simulator training and cognitive readiness training as well as for participatory design of VR training environments. *WP4 Development of field personnel's work practices:* We will gain a better understanding of the current practices for training and maintaining visual inspection skills in field personnel work and develop tools and recommendations for visual inspection skills training. *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, one on the initial operating experiences in Olkiluoto 3 digital control room, the second one on part-scope simulator training, and the third one on visual inspection skills in field personnel's work. A doctoral dissertation on user-centred design of safety-critical systems will be completed.	
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	**Foreign collaboration:** CPESCIAR (Horizon Europe), IAEA TWG-NPPIC

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:

We will investigate the opportunities of integrating STAMP and STPA in the Systems Engineering process, considering the recent updates to STPA. We will then investigate how the understanding of systems element interaction gained using STPA can then be applied in the (re)design of I&C.

WP2 Formal verification methods:

We will experiment with compositional verification. A tool called OCRA enables contract-based design, which in practice means that logics that are otherwise too large and complex for model checking can be verified in parts, resulting in proof of properties about the whole model.

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

Expected publications and theses:

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

A Master's thesis on STAMP/STPA

Doctoral thesis on user-friendly analysis of I&C design issues.

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]	
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 project 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. The SAFER2028-SINARP project will maintain the open-source model, making it available for wider dissemination in Simulink. 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.

WP2 Simulations and platforms:

The 400 kV transmission grid model will be constantly updated and refined with the output from WP1. We also need to refine the modelling of the synchronous machines in the model, including their inertia parameters and power system stabilizers. 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 first year of the project, starting with other departments at Aalto and other units at VTT.

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: Teemu Kärkelä	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd
Partner organisations:-	
National collaboration:	**Foreign collaboration:** OECD/NEA ESTER, OECD/NEA THEMIS, OECD/NEA FACE, USNRC CSARP, NKS TRIO (APRI 11), EU SEAKNOT, EU SASPAM-SA, EU MUSA, IRSN, Chalmers University of Technology

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 Steel oxidation during core melting:

The MELCOR model of steel oxidation in steam will be reviewed. A literature search will be performed, in order to find if the 1966 correlation is still state-of-the-art, or if better correlations are available. If experiments on steel oxidation in steam are found in the literature, the MELCOR oxidation model will be tested by simulating some of the experiments, examining the effect of modifying the correlation.

WP2 Formation of organics and reactions with Cs and I:

The formation of volatile organic compounds from the representative Finnish NPP containment paint samples will be studied with experiments in a wide temperature range from 20 up to e.g. 500 °C (representing temperatures generated nearby operating PAR, used for hydrogen management). In a next step, 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 with experiments. The existence of these possible volatile species also at lower temperatures will be verified.

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. 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 workpackage 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. In total, the participation fees and MELCOR license fee comprise a significant part of the ALISA project budget.

Expected publications and theses:

In addition to the research reports and travel reports in 2023, a conference article will be possibly prepared in WP2. A scientific publication will be possibly prepared in WP3.

A PhD student is participating in the project in 2023.

Other dissemination:

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 this work will be also discussed in the meetings of various projects listed in “Foreign collaboration” (see above).

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: SAFER2028 DECAPOD	**Foreign collaboration:** 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 **WP 1**, 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 **WP 3**, international CFD benchmarks are participated. In 2023, post-benchmark analysis of the boiling models of OpenFOAM and other CFD codes 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.

VTT's submodels implemented years ago in ANSYS Fluent by already retired scientists will be transferred to OpenFOAM. In addition, use of multiphase solver makes possible improved modelling of wall and bulk condensation, transport of mist, liquid films on walls and floors and heat capacities of water pools.

WP3. 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 2023, post-analysis of the DEBORA benchmark and improvement of the method of classes will be performed in co-operation with HZDR and CFD Direct and other international partners.

Expected publications and theses:

Journal and conference articles are expected later in the project in 2024—2025.

Other dissemination:

In all three 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: At first C-FLOW will offer a new platform for conducting critical flow experiments thus strengthening Finnish nuclear research infrastructure. In the following stages C-FLOW will contribute for reducing uncertainties in safety analysis done with SYS TH codes focusing on PRISE scenario. Finally, C-FLOW will produce data for critical flow model development by means of HS-imaging coupled with pattern-recognition and other non-intrusive methods. The main interest will be in imaging details of flashing in high speed flows with rapid depressurization. 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.	
Expected results: WP1 Detailed design and commissioning of the facility In WP1 the goal is to design and build a separate-effect-test facility capable of critical flow experiments. The facility is modifiable in the later phases of the project. WP4 Project management In WP4 are included all the work needed for preparation and participation to technical advisory groups, attending SILENCE meetings when two-phase critical flow topic is discussed, and supervision of possible Bachelor's and Master's theses.	
Expected publications and theses: C-FLOW will offer many multiple topics for Bachelor's and Master's Theses during its lifetime including the planning phase and applying advanced measurement systems in novel ways to supply data with non-intrusive ways. The facility can be used as a platform for SYS TH focused theses.	
Other dissemination: -	

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

Project name: analysis of passivE Safety systems oPeratiOns and modelling (ESPO)	
Project manager: Fares Alblouwy	**Project manager organisation:** VTT Technical Research Centre of Finland Ltd
Partner organisations:-	
National collaboration: --	**Foreign collaboration:** **OECD/NEA ETHARINUS** **OECD/NEA PANDA** Institute for Radiation Protection Nuclear Safety (**IRSN**)

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 in different 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.

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. As per the recommendation of SAFER2028 Management Group, 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, Finland's membership fee in the U.S. NRC CAMP program will be covered by the ESPO project budget.

Expected publications and theses:

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 goals of ESPO 2024, 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 ETHARINUS project participation: LUT University will participate in the analytical work of the experiments in the joined OECD/NEA ATLAS & ETHARINUS workshop. WP3 PASI tests: LUT University has some excellent yet unpublished experiment results from commissioned research to be published in a suitable journal. WP4 SMR related tests: With the MOTEL experiments the range of stable operating conditions of the helical coil steam generator can be defined. 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 unpublished experiment results of PASI 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: Thermal-hydraulic phenomena investigation related to gravity driven flows through computational modeling. Experiments for the year 2023 include helical coil steam generator experiments. 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. WP3 Computational modeling of critical flows: For the year 2023, participation in the designing of C-FLOW test facility, attendance in technical meetings, creation of simplified C-FLOW test facility simulation model and preliminary experiment planning with pre-test simulations. WP4 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: Research reports (1) or/and journal/seminar articles (0-1), total 1-2 WP 3: Research reports (0-1) or/and journal/seminar articles (0), total 0-1 WP 4: Reseach reports (0) or/and journal/seminar articles (0), total 0 In total, 1-3 publications are expected from THEME project for the year 2023.	
Other dissemination: None	

2.2 Fuel and reactor physics

2.2.1 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:** BWR Club, AER community, OECD/NEA Data Bank, international BWR control rod history benchmark

Objective of research:

The project advances the validation of the Kraken framework for the safety analyses of the Finnish nuclear power plants in accordance with the SAFER2028 Framework plan through the modelling of suitable transients that either took place at one of the plants or are deemed to be representative computational transients with reference solutions. 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 fulfillment of thermal margins and the associated uncertainties in transient modelling with the Kraken framework.

Expected results:

WP1 Ants nodal neutronics program:

- Implementation of axial homogenization approach to address control rod cusping and other issues.
- Evaluation of the suitability of Ants group constant models (with plutonium history) for BWR and VVER-440 safety analyses.
- Identification of a reasonable approach for alleviating the convergence issues from near critical nodes in AFEN/FENM nodal neutronics solutions.

WP2 Thermal margins with uncertainties:

- Revision of three conference papers for which extended abstracts were written in 2022.

WP3 Transient validation of Kraken:

- Revision of two journal articles on Kraken validation, which were submitted in 2022.

Expected publications and theses:

- PhD Riku Tuominen (work conducted in previous projects, topics continuing in DECAPOD).
- Bachelor's thesis / special assignment, N.N., evaluating Ants group constant models for safety analyses of VVER-440s and BWRs.

Other dissemination:

- Distribution of the 2023 Kraken update to OECD/NEA data bank.
- Organizing the 2023 international Kraken workshop.
- Presentation on CBH benchmark participation using the plutonium history group constant model (Kraken workshop).

2.2.2 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:** OECD/NEA FIDES, IAEA CRP ATF TS, IRSN, Studsvik Nuclear

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 (creep, high temperature oxidation) within the IAEA Coordinated Research Program (CRP) "Testing and Simulation for Advanced Technology and Accident Tolerant Fuels" (ATF TS) to gain knowledge on ATF cladding behaviour in loss-of-coolant accidents. In addition, cladding hydrogen/hydride experimental studies could be conducted. These studies will benefit the cladding integrity analysis in backend. A review on district heating SMR operating conditions on fuel rod integrity will be done. Computational reactivity-initiated accident (RIA) analyses will be conducted. VTT's FINIX fuel module will be extended for ATFs. LOCA cladding ballooning model in FINIX will be further developed, verified and validated.

Expected results:

WP1 SMR fuel, BEPU analyses and code validation:

In 2023, the effects of unconventional operating conditions in district heating SMR will be analysed by conducting a literature survey accompanied by preliminary analysis with a fuel performance code.

WP2 Accident Tolerant Fuel

In 2023, thermal creep tests with Cr/Al coated and Zr based ATF cladding samples will be performed to explore the creep performance of the selected materials as well as the adherence of the coating.

In 2023, steam oxidation tests with Cr base coated cladding samples will be done as part of IAEA CRP ATF TS.

WP3 Design basis accidents

In 2023, VTT will participate to a literature review on Cr coated cladding behaviour in RIA situations (possibly also for LOCA). This will serve as SCANAIR in-kind work for 2023, as per the SCANAIR license agreement with IRSN.

WP4 Backend

Due to the feedback from the SAFER2028 Management Group *("WP4 is of less importance and should be cut due to limited SAFER2028 resources"*), this work has been cut from the work plan at least concerning the year 2023.

WP5 Management and international collaboration

Reporting to SAFER2028 TAG. Current international forums within MATFINE are OECD/NEA Working Group on Fuel Safety (WGFS) and FRAPCON/FRAPTRAN/FAST Users' Group. Halden Programme Group is planned to convene for the last time in 2023 and in 2024. The progress of the CABRI International Project will be followed, and CABRI TAG meetings are participated if those are organized. The annual VTT Review of International Fuel Research Projects is organized as a half-day seminar in 2023. IAEA CRP ATF TS meetings will be participated, and finished research results are presented in a relevant international conference.

Expected publications and theses:

One PhD thesis is expected to be published during the course of the project (3 years). In 2023, no theses are expected.
Other dissemination: -

2.2.3 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,	**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, codes developed externally will be used. 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: options for perturbating and processing nuclear data for uncertainty propagation through burnup calculation with Serpent are mapped through a literature review, in addition to which feasibility tests are performed for the applicable codes. The literature review is published as a research report and a conference paper is planned to present the calculation results, but it would be for an event in 2024, e.g. PHYSOR. 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 WP2 Serpent – Ants for spent fuel characterization: the main focus of the WP is to extend the spent fuel characterization capabilities from 2D to 3D level by implementing required data transfer scripts to couple Serpent and Ants in the Kraken framework. The work is documented with results of demonstration calculations in a journal article. WP3 Project management and international collaboration: the reporting duties of the project management and meetings of the NEA WPNCS are included in this WP.	
Expected publications and theses: A journal article describing Serpent – Ants sequence for SNF characterization; conference article on nuclear data uncertainty propagation to be presented in a 2024 event	
Other dissemination: Applicable results to be presented in Serpent user group meeting	

3. SG3 Nuclear Waste

3.1 Fuel and engineered barrier system

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

<table>
<tr><td colspan="2">Project name:
Alternative Buffer/Backfill Characterisation + Radionuclide Interactions (ABCRad)</td></tr>
<tr><td>Project manager:
Gianni Vettese</td><td>Project manager organisation:
University of Helsinki</td></tr>
<tr><td colspan="2">Partner organisations: University of Helsinki</td></tr>
<tr><td>National collaboration:
SAFER2028 RadXAS.</td><td>Foreign collaboration:
The Helmholtz Zentrum Dresden Rossendorf (HZDR), Germany & the European Synchrotron Radiation Facility (ESRF), both facilitated via Dr. N. Huittinen (HZDR)</td></tr>
<tr><td colspan="2">Objective of research:
ABCRad is a new project 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 multiple (>9) 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 will mostly take place in the radiochemistry unit (UH) but has collaborations with international partners at HZDR (Germany) and ESRF (France). The project also provides supervision and funding for a Masters thesis. The knowledge gained can be used to inform the safety case for spent nuclear fuel disposal in Finland and beyond. ABCRad will also build GV's expertise in the laboratory, he will gain experience as a supervisor and he will develop international networks.</td></tr>
<tr><td colspan="2">Expected results:
WP1: Selection and characterisation of the starting materials

In 2023, WP1 will provide 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. Once they have been chosen UH will compliment POSIVAs pre-characterisation with our own state-of-the-art methods.

WP2: Thermal treatment of the bentonites

In 2023, 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

In 2023, 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.</td></tr>
<tr><td colspan="2">Expected publications and theses:</td></tr>
</table>

ABCRad is expected to deliver 1 Masters thesis in 2023, and one per year afterwards. We also anticipate at least 2 other scientific papers to be published (in 2024), 1 based on thermal interactions with the bentonites. 1 based on U and Cs chemical interactions with the 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.

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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:

Aalto University[1], University of Chemical Technology and Metallurgy (UCTM), Sofia, Bulgaria[2]

National collaboration:	**Foreign collaboration:**
SAFER2028 MOCRYCO-project	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:

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

• *Does hydrogen enter FSW Cu-OFP to a sufficient degree during exposure to sulphide containing environment and induce SCC?*

• *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, at least three different batches of Cu-OFP will be identified and the material secured for experimental purposes. It is expected that as a minimum, SSRT-experiments in air and in sulphide (100 mg/l) containing water with samples from one of the batches will be conducted and the results analyzed in 2023.

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

Friction stir welded (FSW) specimens (both coupons and creep) will be produced by Aalto University and exposed at VTT to sulphide containing environment. The exposure will be made in an autoclave allowing for creep testing (a coupon control specimen, without straining, will be exposed in the autoclave as well, to effectively identify the effect of straining on H uptake). Two exposures at 80 mg/l [HS^-] are planned for 2023.

WP3 Corrosion studies in saline groundwater:

Coupon samples of Cu-OFP will be exposed to sulphide (100 mg/l) containing groundwater (saline near-field reference water with 14500 mg/l Cl^-). The general corrosion rate and re-passivation rate will be determined using electrochemical techniques already established in previous work. The effect of sulphide addition on pH in the un-buffered groundwater will be determined.

WP4 Communication, cooperation and knowledge transfer:

Communication of the project results will be done mainly within the SAFER2028 –programme, especially with the MOCRYCO project led by Tom Andersson.

Cooperation with Aalto University (with regard to FSW Cu-OFP) and UCTM (with regard to corrosion studies of Cu-OFP) will be deepened.

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: No expected journal articles or theses during 2023.

Other dissemination:

No planned dissemination activities outside SAFER2028 administration in 2023.

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
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 • Gather data and do literature survey of the existing (macroscopic engineering) creep models • Continue the calibration of creep void formation and continue the development of the models relaxation/creep behaviour and also start to build the phase field based crystal plasticity modelling approach with already existing experimental data. • Investigate the suitability of atomistic (MD/DFT) approach to investigate the damage mechanisms and effect of impurities and alloying elements.	
Expected publications and theses: ECCC conference paper	
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

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 2023:

WP1 Coordination and dissemination

Project data bank format and embargo periods definitions

WP2 Design of experiments, uncertainty and sensitivity analysis:

Reported plan for condition-material combinations in experiments from the data gap statistical analysis

WP3 Experiments Describe the expected results shortly for all Workpackages.

Project data bank updated with the results of tomography experiments performed during 2023.

Project data bank updated with the results of mechanical experiments performed during 2023.

Expected publications and theses 2023:

2 journal articles (based on experimental results from previous projects), 1 MSc thesis, progressing 2 doctoral thesis

Other dissemination:

Public seminars between researchers, authority and waste management organisations: one in 2024 and one in 2025

3.2 Low and intermediate level waste

3.2.1 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	**Foreign collaboration:** EURAD-ACED, ICDP, EURO-MIC COST network
Objective of research: The objective of the project is to create new knowledge on the durability of welded steel joints in the LILW repository conditions throughout its evolution. This is achieved by defining how the environment and microbial interactions affect the corrosion behaviour of the welds. The roles of welding methods and post-weld treatment on the corrosion resistance of the welded steels are studied to provide directly usable information on the suitability of the manufacturing methods to be used in the LILW repositories.	
Expected results: WP1 - Sample materials: During 2023, the expected results for WP1 are the definitions of materials, and their manufacturing, post-treatment and preparation methods for the samples to be tested in other WPs, as well as the preparation of the samples. Moreover, the selection of the test solutions to be used in the other WPs is to be done in WP1. WP2 – Microbial growth conditions: During 2023, we will conduct microbiological testing for anaerobic growth conditions and microbial enrichment cultures originating from the Hästholmen (Loviisa) groundwater in a series of water solutions. As a result, we will define the conditions that represent aged, evolved repository conditions already enabling more microbial activity for the long-term experiments in WP4. WP3 - Corrosion of steels in groundwater / concrete environments During 2023 in WP3, we will conduct corrosion tests on samples from WP1 with several materials and test solutions relevant for LILW disposal. We will get information on the influence of water chemistry on the corrosion of welded joints, find out the differences in performance between the welding and post-treatment methods for those conditions, and define how dissimilar joints and temperatures affect the materials' corrosion behaviour. The task will continue to 2024; most of the results are obtained in 2023. As the final result, we will identify the most relevant solution compositions and material preparation methods for long-term testing in WP4 in 2024. The M.Sc. thesis of the project is done within WP3 during 2023-2023. WP4 – Weld durability There are no planned activities in WP4 for year 2023. Long-term exposure tests are planned to be started in 2024, after obtaining results from WPs 1, 2 and 3. WP5 – Project management	

In 2023, the WPs will be organised to play together smoothly, as information is used efficiently across the WPs.
Expected publications and theses: Conference abstract to, e.g., EUROCORR 2024 Starting of M.Sc. thesis on the short-term corrosion tests welded carbon and stainless steels in concrete / groundwater environments typical for Finnish LILW repository sites Preparation of a manuscript for an open-access journal
Other dissemination: Social media posts, e.g. Twitter under #MICWEST and #SAFER2028

3.2.2 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, Dr. Joe Small (UK)
Objective of research: The main objective of the entire project time is to obtain gas generation rates for the long-term safety cases of LILW final disposal facilities, where biodegradable waste will be disposed of. More specifically, the aim is to produce justified information about the highest gas generation rates from low-level solid operational waste and to improve understanding about the main mechanisms influencing on gas generation. Secondary objectives are to gain understanding 1) on the corrosion of carbon steel, and 2) on the degradation of concrete in the repository near-field.	
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** Samples from tank water, gas, drum steel, water and waste materials inside the drums and concrete of the concrete box. In addition, small sample capsules containing steel plates and simulated waste materials are removed from the tank. **WP3 Analytics and interpretations** The first results on the chemical and microbiological composition of tank water. The first composition gas sample analysed. Early interpretations of the analytical results. **WP4 Synthesis and reporting** The first progress report for SAFER2028.	
Expected publications and theses: No other reporting than progress reporting for SAFER2028 in 2023.	
Other dissemination: GasOff activities will be posted in the social networking service Twitter, through the account @SAFERGasOff and using hashtags #SAFERGasOff and possibly #SAFER2028.	

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 zebrafish. 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. Pietari Skyttä	**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 2023:

- Delivery of test samples for method testing and development of the micro-scale 3D-charcaterization
- Preparation of suited holders for different sizes of samples for the purposes of micro-scale 3D-imaging
- Imaging protocol yielding suitable image data
- Completion of digital geological models from up to 5 representative fault-outcrops
- Initial version of a public fracture network geometry & property Atlas, to be filled during 2024-2025
- Initial version of a journal article manuscript about extraction of fracture networks from CT images
- Selection of most suited agents and protocols for fluid flow experiments
- An updated review of the fluid flow concepts; this forms the theoretical premise of a scientific article to be written in 2024

- Initial review of available software packages, scripts, libraries, to be finalized in 2024

Expected publications and theses:

No complete publications or theses are expected during the first year of the project. In 2023 we expect to write an initial version of a journal article manuscript about extraction of fracture networks from CT images (WP1)

Other dissemination:

We will disseminate the ongoing research through press announcements at the onset of the project. We will open a twitter-account for the project and publish tweets about the activities and outcomes of all the participating partners.

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:	
National collaboration: SAFER2028 STAFLO (GTK and UTU)	**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: WP1, Task 1: Planning of the shear strength scale effect laboratory experiments 14 samples at sizes 2x 2 m x 1 m, 4x 1 m x 1 m, 8x 0.5 m x 1 m of Kuru gray slab pairs with a horizontal artifically induced tensile crack are obtained. A detailed research plan is produced to conduct the slace experiments so that the shear load is evenly distributed along the fracture surface. WP1, Task 2: Contructing a distributed shear loading rig The KARMO push-shear loading rig is modified to distribute the shear load evenly across the fracture surface between the bottom and top slab. This is obtained using multiple load cells and horizontal beams attached to the top sample. Rotation is prevented using roller plates at the sides to induce more realistic boundary conditions. The same rig can accept different widhts of samples: 2 m wide, 1 m wide or 0,5 m wide. The length along the shearing direction must remain constant at 1 m. WP1, Task 3: Distributed shear scale effect laboratory experiments The 14 slab pair samples are tested for peak shear and residual shear (50 mm, 5 % of sample length) are measured. The uplift and rotation is tracked with LVDT sensors. The results of the scale series may determine if the consensus of negative scale effect (peak shear strength is lower for longer rock joints) can be explained with the mismatch of the top and bottom fracture surfaces. For well mated (well matched top and bottom surfaces), the peak shear strength should remain constant regardless of sample size.	
Expected publications and theses: BSc thesis: A literature study on scale effect for rock joint shear tests (tentative) MSc thesis: Distributed shear test for crystalline hard rock DSc thesis: Characterization of hydromechanical properties of rock fractures Conference paper: Influence of loading arrangement and distribution of shear load in large-scale rock joint shear testing	
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 Siting and Waste Management (SMRSiMa)	
Project manager: Timothy Schatz	**Project manager organisation:** VTT
Partner organisations: GTK, LUT, JYU	
National collaboration: SAFER2028 XXX, …	**Foreign collaboration:** OECD/NEA XXX, NKS XXX, …
Objective of research: In WP1 the objective is to facilitate the Serpent – Ants computing sequence and demonstrate its capability to produce best-estimate spent fuel compositions based on a full-core calculation with a simplified reactor model over the first core. Furthermore, demonstration towards equilibrium cycle modelling is expected. In WP2 waste managements strategies and regulatory considerations regarding SMRs are studied further. The focus on them is on centralised waste management. In WP3 SMR plant and waste storage facility siting are studied. Alternative disposal methods such as borehole disposal are also studied. Finally, in WP4 the aim is to study societal engagement on SMRs and SMR waste management. This includes strategies and adaptation of current methods.	
Expected results: WP1 SMR Spent Fuel Characteristics: A demonstration on a full-core Serpent-Ants calculation is performed and fuel compositions for one SMR concept are obtained. The fuel compositions include waste management parameters such as decay heat and post-irradiation criticality. WP2 In WP2 a technology selection is performed by having discussions with Finnish end-users. As a result, an updated selection of relevant SMR vendors is obtained. Furthermore, feasible waste management strategies are outlined and regulatory concerns to SMR deployment identified. In work done on waste management issues and strategies data and information plan on how to demonstrate the safety of a KBS3-type and a LILW repository is identified. Furthermore, impacts of new fuel types on barriers are assessed. WP3 As a result of WP3 requirements criteria for SMR and SMR radioactive storage siting are assessed Furthermore a review and a general plan for deep borehole field investigation program is presented. WP4 In WP4 a roadmap for addressing societal engagement issues related to SMR technology adaptation in district heating from municipalities perspective is created. Additionally, data from a 2021 survey for Helsinki metropolitan residents on waste management strategies is analysed and compared to analysed data from a similar study in 2022. Furthermore, a stakeholder workshop will be held on the topics.	
Expected publications and theses: A journal article on the survey results will be published	
Other dissemination: Stakeholder workshop on addressing societal engagement issues related to SMR technology Stakeholder workshop/seminar on the survey results	

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: Miguel Ferreira	**Project manager organisation:** VTT Technical Research Centre of Finland
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:

• WP1: Critical review of the current state-of-the-art of ageing processes of reinforced concrete SSCs in the framework of transition from AM to LTO and identify key relevant knowledge gaps of relevance for Finnish Nuclear Power Plants (NPPs) and Radioactive Waste Storage solutions (RWSs).

• 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, Na2SO4, 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:

FN-CAMP will have a significant impact on the safety of operating NPPs and RWSs by demonstrating and revealing inherent safety margins being introduced by the conservative approaches used during design and being dictated by codes and standards. The project is expected to have an outstanding impact on national and international research activities concerning the use of advanced tools for structural integrity assessments, and through collaboration and dissemination activities.

The FN-CAMP project further contributes with the following impacts:

• Identification of key relevant knowledge gaps for ageing processes of reinforced concrete SSCs in the frame-work of transition from AM to LTO of relevance for Finnish NPPs and RWSs (WP1). Development of an assessment tool for ASR expansion in concrete will contribute to predicting the behaviour of concrete under various exposure conditions (e.g., relative humidity, temperatures, and confining stresses), and thus improve our understanding of the mechanism of ASR expansion (WP2).

• Development of an assessment tool to predict the deterioration of concrete exposed to an aggressive aqueous environment will contribute to evaluating the deterioration degree of concrete and comparing the deterioration rate at given exposure durations (WP2).

• Increased understanding of the corrosion mechanism enables greater precision in term of location of corrosion locations, reducing the costs of inspections (WP3).

• Results will contribute to improved modelling capabilities which will enable better maintenance and ageing management practices of containment and pool liners (WP3).

• Increased understanding of the structural behaviour of the pre-stressed containment building during short-term events, such as pressure tests, and long-term behaviour, such as leak-tightness in aged concrete structures. (WP4) • Contribution to development of an overall strategy within the EU for the safe life long-term prediction of rein-forced concrete SSC's for NPPS and RWSs;

• Dissemination of best practice guidelines for performance assessment related to key ageing and deterioration mechanism and lifetime management of reinforced concrete;

• Contribution to improvements in cost-effectiveness and safety of both existing and future NPPs and RWSs;

Expected publications and theses:

-

Other dissemination:

e.g. IRSN ODOBA Project dissemination, conferences (e.g. SMiRT series), .

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: Jari Puttonen Fahim Al-Neshawy	**Project manager organisation:** Aalto University School of Engineering
Partner organisations: -	
National collaboration: SAFER2028, TVO, FORTUM	**Foreign collaboration:** OECD/NEA

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 in low- and intermediate-level radioactive waste (LILW) repositories. The length of the service life of concrete at the final disposal, which can extend up to 500 years, should be considered in the analyses 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 1997) 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, 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 existing concrete specimens

WP2 – Design new durable concretes for the LILW repositories

WP3 – Mathematical models for estimating concrete ageing in LILW repositories

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 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 new experts 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** (initiation) – Modelling of the long-term durability of concrete barriers in the low- and intermediate level nuclear waste repositories. 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 01** – The influence of the concrete mixes on the durability of concrete barriers in the low- and inter-mediate level nuclear waste repositories

The test results and data analysis of the research project will be published in Aalto research report and/or as scientific conference or journal article 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 2023 will be presented at the master's degree course "CIV-E 2020 Concrete Technology" arranged by Aalto university, 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, Aalto University, VTT	**Foreign collaboration:** EURAD/CORI, EURAD/MAGIC, ANDRA, BRGM, IRSN, University of Poitiers (France), NAGRA, University of Texas at Arlington (USA)
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: Preliminary 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. WP2: In situ material characterisation 3D microstructure of solidified concrete waste characterised with X-ray microtomography. Preliminary autoradiography results of distributions of activity in solidified concrete waste. Microstructural analyses, chemical mapping and speciation analysis of solidified concrete waste.	
Expected publications and theses: Article draft on radionuclides' behaviour in cementitious materials Master thesis of N.N	
Other dissemination: Presentation or poster at NUWCEM 2023 conference Presentation or poster at Migration 2023 conference, Nantes	

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: SAFER2028, Aalto University	**Foreign collaboration:** Via PIONIC (USA, Japan, 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 the reliability of flaws characterisation and sizing.

The project's specific objectives are:

- Raising the level of AI solutions for NDE from flaw detection to much more challenging crack characterization
- Assessing the reliability of sizing with Ultrasonic Testing.

Update: *The 2023 task of WP3 is postponed*

Expected results:

WP1 Artificial Intelligence (AI):

- Data acquisition (T1.1): High-quality raw data from the test mock-ups.
- AI training (T1.2): Successful extraction of regions of interest in multi-channel data.
- Model evaluation and reporting (T1.3): Completion and evaluation of first tier model training and preparatory work for further model training.

WP2 Sizing reliability:

- Data exploration and BBN construction (T2.1): Construction of Bayesian Belief Networks for assessing sizing reliability.

Expected publications and theses:

- Manuscript for conference proceedings

Other dissemination:

- Report on first tier AI model training

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 long term thermal embrittlement and environmental assisted cracking (EAC), etc.

The LOAD project aims to:

• Increase the knowledge on SCC of cold worked stainless steels and the potential influencing factors.

• Improve the understanding of the role of thermal aging on hardness increase and EAC behavior of Alloy 690.

• Fill the knowledge gap of thermal aging 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 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 will be set up. Knowledge on both potential mitigation and failure analysis on this topic can be obtained.

• WP2, thermal aging and EAC study of A690. The microstructural features linked to an observed hardness increase due to thermal aging in Alloy 690 can be identified, thus improving the understanding of possible short- and long-range ordering and diffusion-induced grain boundary migration and their influences on EAC behavior. An international collaboration with strategic partners from USA and UK on this topic has been agreed.

• WP3, thermal aging study 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 and one new PhD thesis as well as a MSc thesis. 5-6 peer reviewed journal papers and conference proceedings.

Other dissemination:

An international seminar and a Finnish brainstorming workshop will be organized through the WP1 of LOAD project within the ICG-EAC framework. An international collaboration with strategic partners from USA and UK on WP2 has been agreed. The WP3 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 ReQu - Repair welding and performance quality of welded pipe joints, LUT

Project name: ReQu Full name: Repair welding and performance quality of welded pipe joints	
Project manager: Timo Björk	**Project manager organisation:** LUT University
Partner organisations: None	
National collaboration: SAFER2028, VTT, TVO, University of Oulu	**Foreign collaboration:**

Objective of research:

- Establish the state-of-art knowledge (limitations, current guidelines) on the main characteristics, including welding metallurgy and effects on the process parameters on the quality, of repair welded and post-weld-treated stainless steels (e.g., 316L)
- Understand the main characteristics (limitations, current guidelines) related to the repair welding and post-weld treatments of stainless steel structures in NPP environment
- Acquire knowledge on the residual stress characteristics of welded stainless steel joints and understand the key aspects related to the performance and lifetime of repair weldments

Expected results:

WP1 Task 1: Weld repair parameters and post-weld treatments for stainless steel (T1.1):

- Repair welding process parameter windows for stainless steel materials (especially 316L)
- Knowledge on the applicable PWT methods for stainless steel weldments based on literature review

WP1 Task 2: Residual stress and mechanical performance of repair-welded components (T1.2):

- Fundamentals of residual stresses in welded stainless steel materials and structures
- Effects of residual stresses on the mechanical performance of stainless steels weldments (e.g., fatigue test database for stainless steel materials and welded joints)

Expected publications and theses:

Conference paper on the residual stresses of welded stainless steels (aimed to be presented in ASME-PVP conference in 2024)

Other dissemination:

Participation in the *SAFER2028* annual seminar (if organized)

Participation in the *TVO* trainings (held by A. Kallio), discussion and dissemination of ReQu activities Participation in the *Nordic Nuclear Safety Research* activities (Finland 2023)

4.1.4 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
Partner organisations: VTT Technical Research Centre of Finland, Aalto University	
National collaboration: SAFER2028 LOAD, SAFER2028 PROVELTO	**Foreign collaboration:** EPRI EAF collaboration group, ASME III/XI working groups, EU INCEFA-SCALE
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 2023 presentation on HT fatigue tests with PWR piping material ASME PVP 2024 paper manuscript on first environmental fatigue tests with PWR piping material Master's thesis on fatigue crack initiation (2023) 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: Alejandro Revuelta	**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: WP2: Stress corrosion cracking: This workpackage will focus on the assessment of the stress corrosion cracking properties of 316L AM components. Previous research has shown the susceptibility of the material to different surface conditions. During 2023 it will be analysed the effect of different heat and surface treatments on the final properties in conditions found in boiling water reactors.	
Expected publications and theses: Journal paper: effect of surface treatment on SCC properties of AM 316L	
Other dissemination: The project team will be monitoring relevant events during 2023 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:	**Foreign collaboration:** OECD/NEA, NKS, Energiforsk, Ringhals, KTH

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 SMILE consortium (consisting of Vattenfall, EPRI, NRC, SCK, CRIEPI Japan) 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.

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.

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 and synthesis to BRUTE project.

Scientific article on brittle fracture initiation using advanced microscopy techniques. Conference proceedings of base material studies. One doctoral thesis estimated to finish in 2024.
Other dissemination: - IGRDM (the International Group on Radiation Embrittlement Mechanisms), - ICG-EAC (the International Co-operation Group on Environmentally-assisted Cracking), - SMILE project meetings, - ASME PVP (Pressure Vessel and Piping Conference).

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: **-**	**Foreign collaboration:** KTH, Kiwa inspecta (Sweden), ASME, ASTM, ESIS

Objective of research:

In this project, the objective 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 the following results are expected:

- A validated Master Curve constraint approach updated based on data for elliptical surface cracks and improved method for evaluating the load sensitivity in the ductile-to-brittle transition region to assess realistic loading conditions. This will enable long-term operation assessment of critical safety components (RPV, DMWs, Pipes).
- Experimental test results on low-constrained elliptical surface cracks and SE(T) and CC(T) low-constrained specimens in different temperatures relative to the reference temperature T_0.
- Numerical results to support the experimental work, validation of the 3D constraint interpretation of constraint. Development of load-constraint dependencies.
- Guidance development related to advanced fracture mechanical assessment for industrial use. This will be enabled by 1) writing two ASME PVP papers to give technical justification for the industry, which is also supported by scientific publications, 2) initiating discussion related to development of ASME code enabling constraint assessment of fracture toughness, 3) presenting that ASTM E2899 “Standard Test Method for Measurement of Initiation Toughness in Surface Cracks Under Tension and Bending” is updated with a constraint assessment method to connect with ASTM E1921. These actions will enable international acceptance of the proposed method.

Related to WP2 the following results are expected:

A proof-of-concept for miniature C(T) specimen with thickness of 3 mm, enabling reduction in surveillance material consumption; miniature C(T) specimens with 3 mm of thickness are offering a 50% increase to the amount of currently used 4 mm of thickness miniature test specimens getting out of one surveillance Charpy-V specimen; from 8 to 12 pieces. The results of WP2 will be proposed to be adopted in the ASTM standards to establish the protocol of miniature C(T) specimen.

Related to WP3 the following results are expected:

New method to assess crack arrest toughness from miniature impact toughness specimens. Arrest toughness can be applied in a safety assessment for the reactor pressure vessel as a conservative lower bound or understand the crack growth behaviour during a loss-of-coolant accident.

Expected publications and theses:

In WP1: 1 PhD thesis, 3 scientific articles, 2 conference proceedings

In WP2: 1 PhD thesis, 2-3 scientific articles, 1-2 conference proceedings

In WP3: 1 scientific article, 1 conference proceeding

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, CEA

Objective of research:

The MINERVA project aims to provide solutions for chemistry and corrosion related issues that the currently operating plants in Finland have, as well as the potential SMR designs in future will face. The following objectives for 2023 has been defined:

- Determination the effect of alternative oxygen scavenger chemicals to FAC, pitting corrosion and general corrosion
- Summarize all the scientific and technical aspects affecting the decision on whether or not KOH chemistry can be applied in PWRs
- Verify the applicability of molecular dynamics simulations to study interacting forces in magnetite deposition
- Verify the use of zeta potential measurements for magnetite in simulated PWR conditions
- Build a test setup for studying magnetite hardening in simulated steam generator conditions
- Evaluate the Co source terms in primary circuits
- Improve the method for evaluating hide-out-return kinetics in simulating steam generator conditions
- Summarize the state-of-the-art of action levels applied on impurities and their scientific background
- Launch the development of online particle measurement technique

Expected results:

WP1 Project management:

The project has progressed as planned.

WP2 Advanced water chemistry:

Definition whether the alternative oxygen scavenging chemicals have significant effect to FAC, general or pitting corrosion compared to hydrazine. Determination of the main obstacles on the way exchanging the LiOH chemistry to KOH chemistry in PWRs.

WP3 Improved safety assessment of steam generators:

Use of molecular dynamics simulations and streaming potential zeta potential measurements in magnetite deposition studies verified. Suitable test setup for the magnetite hardening experiments constructed.

WP4 Impurity & corrosion product transport and enrichment:

More detailed data on the source term of Co and impurity transportation in simulated PWR conditions.

WP5 Chemistry monitoring in NPPs:

Explanation why impurity action levels may vary between different countries. Development online particle measurement setup started.

WP6 International cooperation and dissemination: Interaction in the ECG-COMON group activities. Presentation on hydrazine replacement studies performed at VTT in the International Conference on Nuclear Plant Chemistry (NPC 2023).
Expected publications and theses: Scientific journal article draft on alternative chemicals and their effect on the corrosion of structural materials. Conference paper summarizing on the hydrazine replacement studies performed at VTT since 2016.
Other dissemination: Participation to the ECG-COMON activities. Giving a presentation on project results at the national nuclear power plant water chemistry day arranged by STUK.

5. DENSE

5.1.1 CORF - Characterization of hydromechanical properties of rock fractures, Aalto

Project name: Characterization of hydromechanical properties of rock fractures (CORF) (Dissertation finalization)	
Project manager (Supervising): Mikael Rinne	**Project manager organisation:** Aalto University
Applicant (Doctoral candidate): Masoud Torkan	**Department of Civil Engineering**
Partner organisations: N/A	
National collaboration: N/A	**Foreign collaboration:** N/A
Objective of research: Rock mass is a complex material consisting of intact rock and discontinuities characterized by its geometrical, physical, and mechanical properties. The discontinuities can be fractures, joints, bedding planes, or any other type of plane that separates the rock into distinct blocks. Discontinuities control the behavior of the rock mass in many ways, such as hydraulic conductivity, strength, and deformation behavior. In civil engineering, repositories for hazardous waste disposal or CO_2 sequestration are located in deep underground excavations, where the rock mass acts as a barrier to prevent leakage. To assess the long-term performance of these repositories, it is crucial to understand the intact rock and fracture properties. Geometrical properties of discontinuities include physical aperture, roughness, orientation, spacing, persistence, size, and shape. Measuring these properties accurately is essential for understanding fracture behavior in different conditions for example, redistribution of normal stress and water ground levels. The motivation for the CORF project is to create high-precision data for numerical analysis to characterize the hydromechanical properties of rock fractures. The main research objective of the doctoral dissertation is to evaluate the scale effect and the effect of normal stress on the permeability of rock fractures. The doctoral study plan consists of three stages: i) measuring roughness and ii) physical aperture by a photogrammetric method, and iii) characterization of hydromechanical properties of fractures in different sizes. For this purpose, a photogrammetric method is utilized to reconstruct 3D models of samples as initial data for the numerical modelling, and a laboratory setup was designed to validate the numerical modelling results. The obtained knowledge can be used to simulate large fracture networks and the fluid flow behavior in a large-scale field. Large simulations can be used to validate safety of nuclear waste repositories. This project has been started since 2019 and will cease by the end of 2022. The main funding source of this study was supported by the RAKKA project (2019-2022). To finalize Masoud Torkan's doctoral dissertation, this proposal is submitted for five months from July to the end of November 2023 for 70% of the salary funded by VYR and 30% of the salary funded by Aalto University.	
Expected results: The results can be used for the large-scale simulation as the initial data of fracture network. Also, it revealed that the scale could influence photogrammetric data acquisition. Moreover, the scale could impact fluid flow behavior through a fracture. These ideas are investigated in the CORF project. The first obtained data from water flow tests and numerical modellings of the small samples showed the importance of physical aperture and roughness. It seems crucial to obtain more reliable and accurate data on physical aperture and roughness. A photogrammetric method was used with a rotary table and different devices such as commercial, low-cost cameras, and smartphones to determine physical aperture and roughness of a rough fracture. This method was used to do numerical modellings. The numerical results showed good agreement with laboratory tests for low confinement pressures. This method can be used to estimate the initial physical aperture and roughness of rock fractures for the simulation of the large field. Also, this method could help to investigate fluid flow behavior and the effect of aperture distribution and roughness with high-precision data (20 micrometers). Other researchers could use the approach of this study with simple and low-cost cameras such as smartphones to	

reconstruct 3D models of a fracture. This study can help to design more safe nuclear waste repositories and improve safety of nuclear waste management.
Expected publications and theses: The doctoral thesis entitled “Characterization of hydromechanical properties of rock fractures” will be submitted by 31.11.2023 for pre-examination.
Other dissemination: Participating in 15th International ISRM Congress 2023 & 72nd Geomechanics Colloquium, Salzburg Austria

5.1.2 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 will be invited to DENSE network activities. We expect to establish an annual seminar for doctoral students in the DENSE network. We also expect to financially support doctoral students in participation fees of conferences, workshops, and summer schools, as well as their national and international mobility and costs related with publications, equipment, and materials.	
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 - Running the practical implementation of funding for costs related with publications, use of infrastructure, equipment, and materials	
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.	

5.1.3 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: Summarize the objective of the project with a few sentences.	
Expected results: The suitability and efficiency of the electrostatic precipitators (ESPs) will be systematically studied using refence aero-sols and compared to the existing filtration techniques currently in use in the containment buildings. The expected results during year 2023 include the knowledge related to the performance and suitability of the ESPs for the removal of aerosols at high flow rates and conditions relevant to the containment buildings and provide data on the new filtration technologies that will improve the safety of the nuclear power plants.	
Expected publications and theses: A report of the experimental facility and its validation will be written and disseminated to the relevant stakeholder groups.	
Other dissemination: The results obtained by the end of year 2023 have been presented in the workshops/conferences relevant to the field. The collaboration with Prof. Herranz, CIEMAT, Spain will enable the dissemination to the European Severe Accident Community.	

5.1.4 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: Gareth Law	**Project manager organisation:** University of Helsinki
Partner organisations: VTT	
National collaboration: SAFER2028: LIIMA, RACEMAT, RaDXAS	**Foreign collaboration:** Helmholtz Zentrum Dresden Rossendorf (HZDR) NKS NORDIC NANO consortium University of Manchester (RWM-RSO) French Institute for Radiation Protection and Nuclear Safety IRSN
Objective of research: SURERAD and SUREPhD are aligned follow up projects for the KYT2022 project SURFACE (Near Surface Disposal in Finland). SURERAD is a coordinated project between VTT and the University of Helsinki (VTT leads). SUREPhD is a DENSE PhD project (UH leads). The objective of SAFER2028 work in SURERAD is to study the evolution and safety of the repository, covering (1) engineered barrier performance and optimisation, (2) waste form evolution and radionuclide behaviour and migration, (3) hydrological modelling of the site and its surroundings, and (4) monitoring and development of a monitoring strategy. The working methods include a pilot test in Olkiluoto, laboratory studies, and numerical modelling. The DENSE PhD, titled "Increasing surety in the performance of present and future VLLW disposal," includes research on use of near surface disposal facilities for future decommissioning waste, the impact on C-14 evolution from the waste on system safety, and scoping experiments on future optimisation of the disposal system.	
Expected results: WP1: Information concerning existing VLLW materials at TVO will be collated. This information will be used to define 'average' representative material and radiological compositions for the metallic and soft waste packages destined for surface disposal at Olkiluoto. The procedures used by TVO for VLLW conditioning and final packaging will also be clearly defined. This information will be used to create representative mock, non-active metallic and soft wastes, and an additional set of ^{14}C labelled (i.e., active) mock wastes for use in later PhD work. WP2 and WP3 Set up starting experimentation. WP4 and WP5: • Collect, process, and characterise contaminated concrete for use in WP4. • Prepare low-pH concrete and geopolymer samples for use in WP5.	
Expected publications and theses: None	
Other dissemination: None	

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	**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 in the frame of the SILENCE network.	
Expected results: **WP1 Development of thermal hydraulic instrumentation:** More complete information of the measuring capability of the strain-compensated optic fibers for different measurement configurations. Possibly procurement of a high-speed single point radiographic density measurement system. **WP2 Laboratory maintenance:** Maintaining the facilities operable to be used in other research projects. Successful yearly calibrations of instruments. Definition of the specifications for the high-pressure vessel to be purchased in 2024-2025. **WP3 Knowledge management:** The large data sets from the PIV, WMS, and high-speed camera measurements will be mapped. **WP4 Project management and international co-operation:** Successful management of the project and participation in the SILENCE network activities.	
Expected publications and theses: Master's or bachelor's theses may result from testing of novel thermal hydraulic measurement techniques.	
Other dissemination: Results of the instrumentation development may 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 2023 or 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 continuation work to previous JHR analyses performed with VTT's software.	
Expected results: WP1 JHR Working Groups: Participation in the JHR WG activities twice in 2023 (spring and fall) WP2 Materials Investigations: Progress in building and testing of MeLoDIE II at VTT's facilities as form of FIDES-INCA in-kind contribution and completion of the secondment period at CEA Saclay-Paris as a part of PhD research. WP3 Nuclear Fuel: No expected results, WP3 starts in 2024. WP4 Project Management: Project management and communication of the project to SAFER.	
Expected publications and theses:	
Other dissemination: JHR Technical Seminar 2023, M&C2023 Conference	

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.	