SAFER2028

National Nuclear Safety and Waste Management Research Programme 2023-2028 – updated for 2026

Suvi Karvonen

Contents

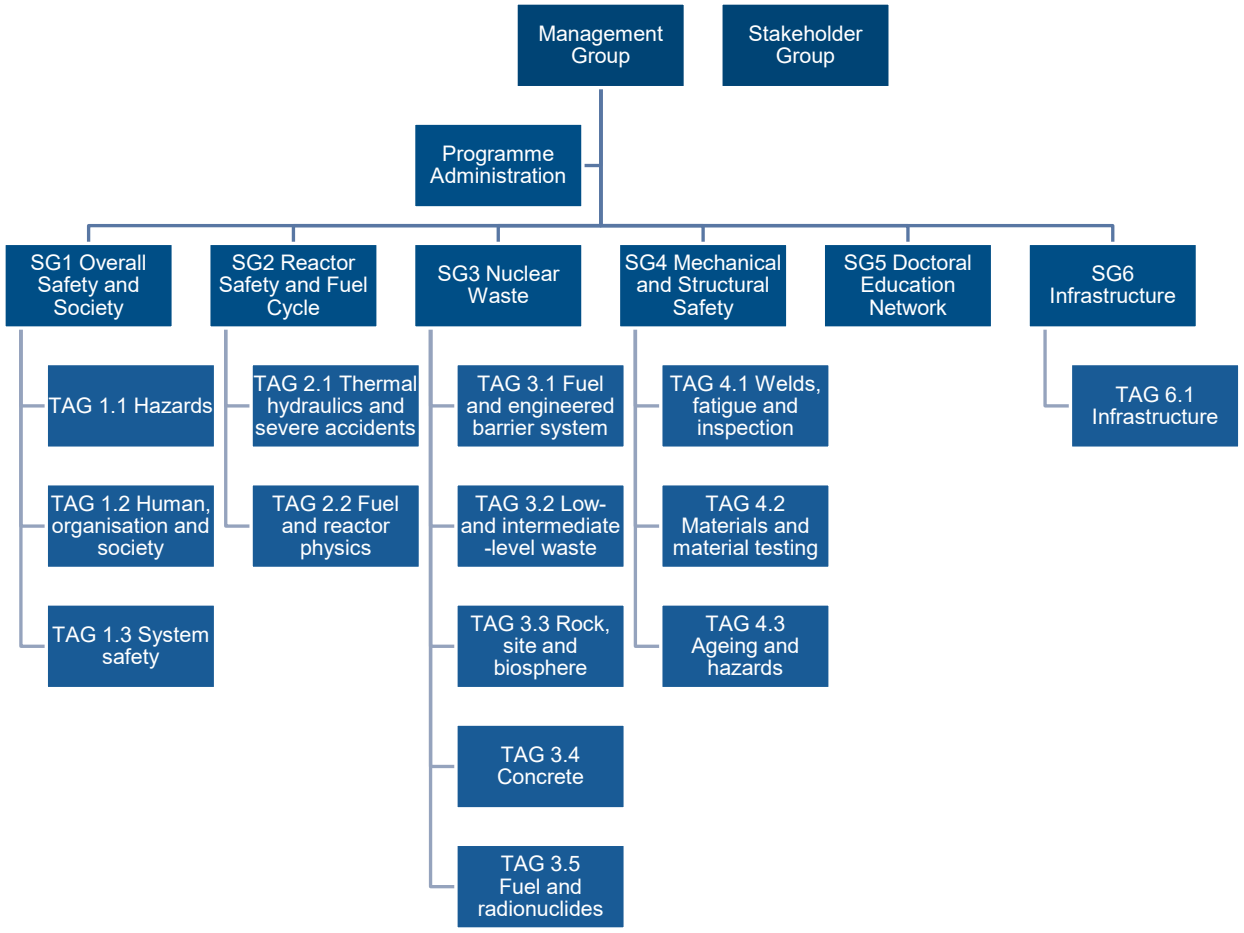
- Introduction to SAFER2028
- Doctoral Education Network - DENSE
- SAFER2028 Project portfolio
- SAFER2028 Project abstracts

Introduction to SAFER2028

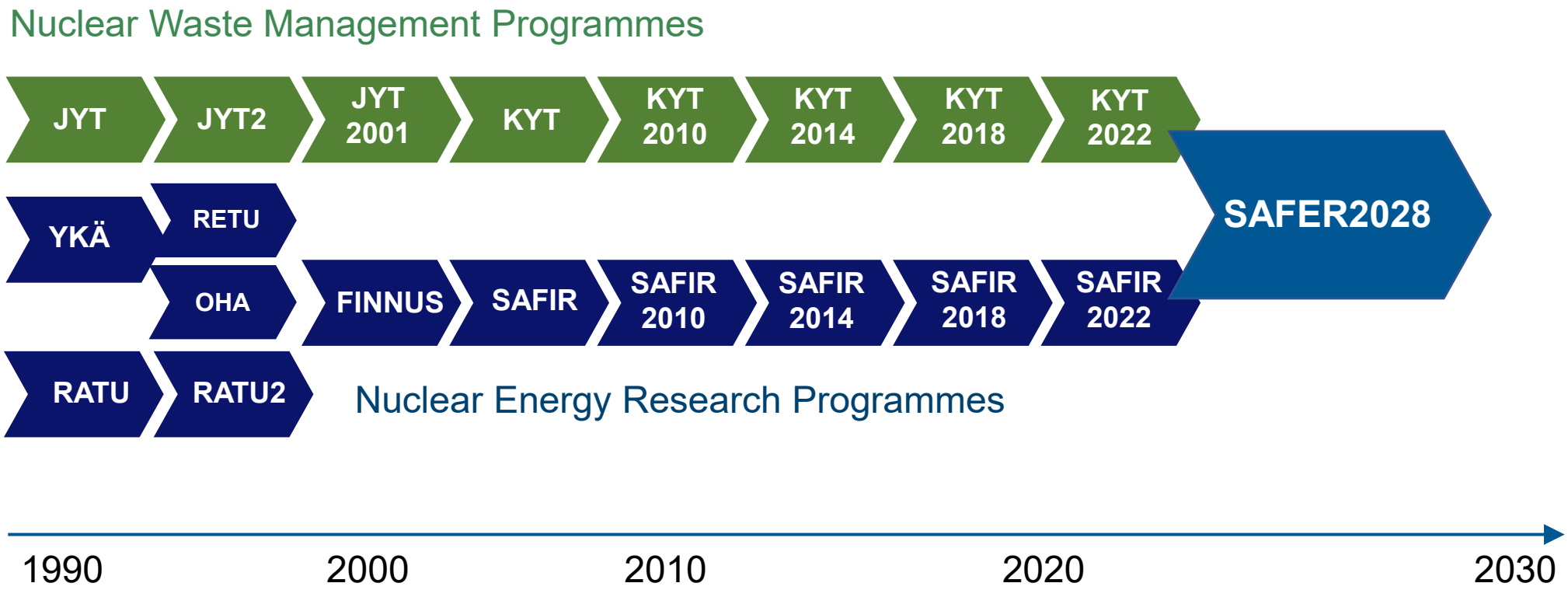
Public research programmes in Finland from 1990's

Research topics

Organisation



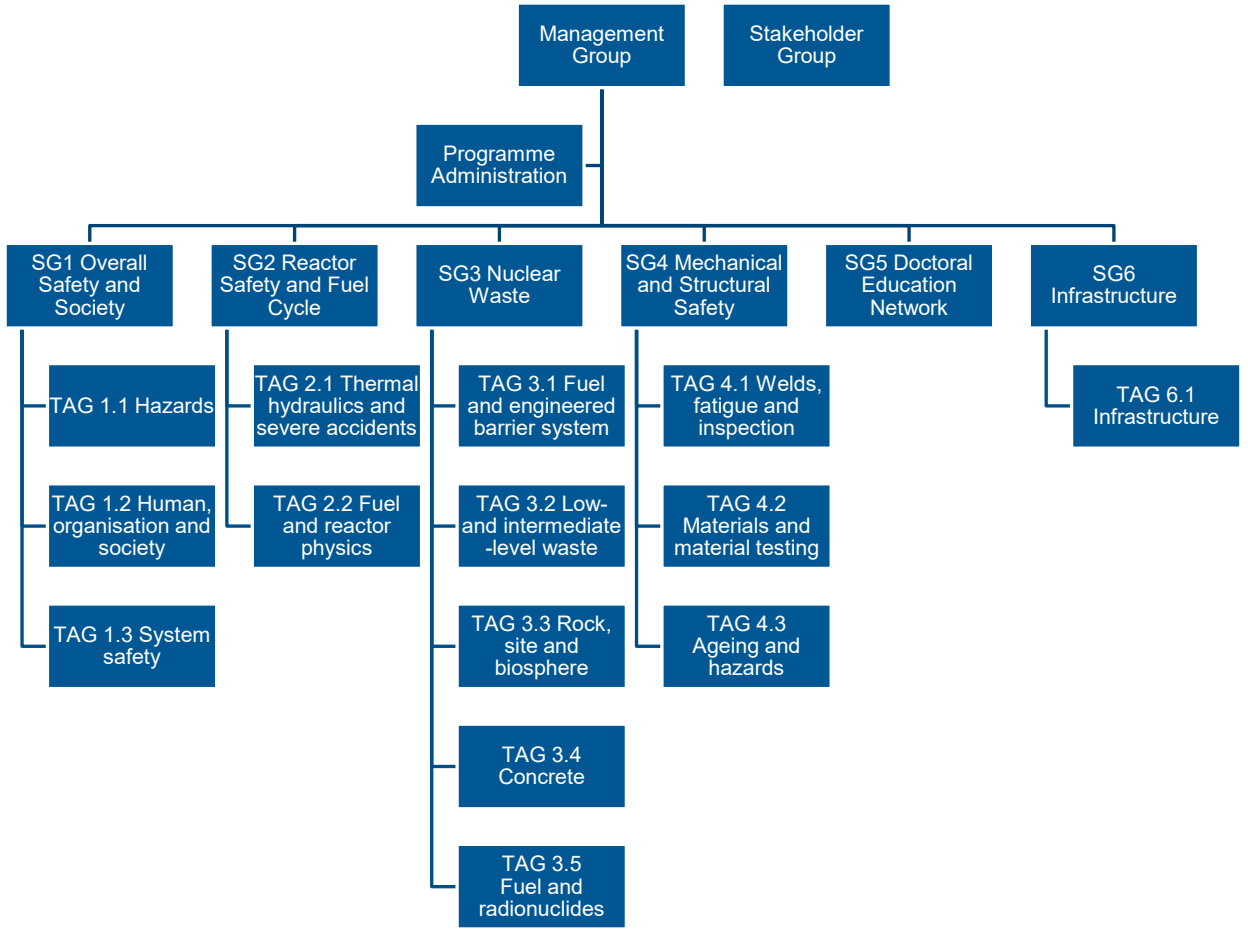
SAFER2028 - National Nuclear Safety and Waste Management Research Programme 2023-2028



SAFER2028 – Research topics

- Framework Plan with four main research areas
  - Overall Safety and Society
  - Reactor Safety and Fuel
  - Decommissioning, Treatment and Long-term Safety of Nuclear Waste
  - Mechanical and Structural Safety of Nuclear Power Plants
- Cross-cutting topics: SMR's, International Collaboration, Infrastructure
- ~9,3 M€ funding per year, distributed through annual calls
- https://safer2028.fi/framework-plan/

Programme organisation



Project types

- Project types
  - Research projects (”standard project”) – 1-3 years
  - Excellence projects – 2-3 years
  - Doctoral Education Network (DENSE) projects (new) – 1-4 years
  - Infrastructure projects – 1-3 years
- Maximum 70 % funding from VYR
  - Certain exceptions apply for e.g. international membership fees
- International participants are welcome (with own funding)

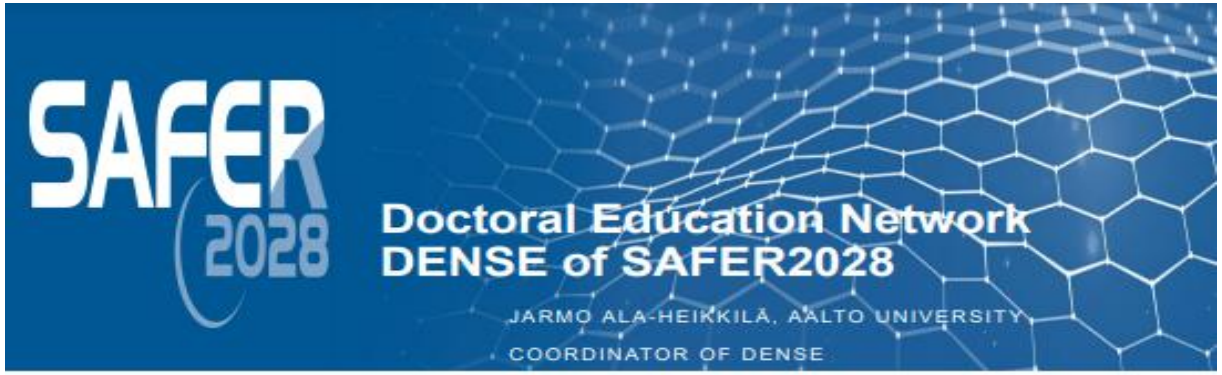
Evaluation Criteria for Research and Excellence Projects

- Projects's ability to develop exertise
- Significance to nuclear safety
- Usability for end users
- Scientific level of the proposal
- Novelty of the methods and new approaches
- Use of experimental facilities
- National and international collaboration and networking

Participating organizations

- VTT Technical Research Centre of Finland (VTT)
- Lappeenranta-Lahti University of Technology (LUT)
- Aalto University (Aalto)
- University of Helsinki (HU)
- University of Turku (UTU)
- University of Jyväskylä (JyU)
- Geological Survey of Finland (GTK)
- University of Oulu (OU)
- University of Eastern Finland (UEF)
- Rock Mechanics Consulting Finland Oy (RMCF)
- AFRY Ab (AFRY)
- Finnish Meteorological Institute (FMI)
- Safram Oy (Safram)
- Åbo Akademi (Åbo A)
- Finnish Institute of Occupational Health (FIOH)
- Lilikoi Consulting (trade name Teemu Reiman) (Lilikoi)

Doctoral Education Network - DENSE



What is DENSE?

1. New doctoral student salary funding instrument in SAFER2028
2. Operational funding for scientific activities and mobility

Purpose: networking of doctoral students – among themselves, between universities and with industry

DENSE Salary Funding

DENSE salary funding for doctoral students:
- Full-time doctoral students at universities (4 years)
- Thesis finalization (4–6 months) of part-time doctoral students
- Model: excellence projects with multiyear funding
- Full cost model, typical funding level 70%
- Evaluation by SG-DENSE (SG5)
- Funding decisions by SAFER MG

Footnote:
General project funding like in KYT and SAFIR still available:
- Mainly applicable for part-time doctoral students

Selection Process for Salary Funding

- Stronger weight on scientific level as a quality criterion
  - The mindset of the SAFIR/KYT programmes has been a challenge for universities: emphasis on practical applicability, not fundamental research
- Relevance for SAFER programme also requested
- Diversity of topics and disciplines within DENSE is an evaluation criterion
- SG-DENSE has members from universities and research organizations in addition to stakeholders
  - Outside experts may be consulted
  - Multidisciplinary SG supports multidisciplinary projects (if proposed)

DENSE Operations and Networking

Activities of **all DENSE network members** to be funded through coordination project:
1. Networking events, such as **annual seminars** where students and members of the professional community meet and present
2. Research exchanges and visits (mobility) of both short (1–2 weeks) and long duration (up to 6 months), including infrastructure use-related costs
3. Participation in conferences, workshops and summer schools
4. Research publication-related costs

Application procedures and selection criteria to be defined by DENSE Steering Group in early 2023
- Probably 2-4 calls per year
- Announced to DENSE mailing list (to sign up, contact jarmo.ala-heikkila@aalto.fi)

DENSE Steering Group 2023

STUK	Jarkko Kyllönen
Posiva	Antti Poteri
TVO	Nina Paaso
Fortum	Jyrki Kohopää (vice chair)
UEF	Jarkko Akkanen
HU	Gareth Law (chair)
LUT	Juhani Hyvärinen
VTT	Jaakko Leppänen
VTT	Elina Huttunen-Saarivirta
Aalto	Andrea Sand
UTU	Pietari Skyttä

Interested? Contact jarmo.ala-heikkila@aalto.fi and sign up to DENSE mailing list!

https://safer2028.fi/dense/

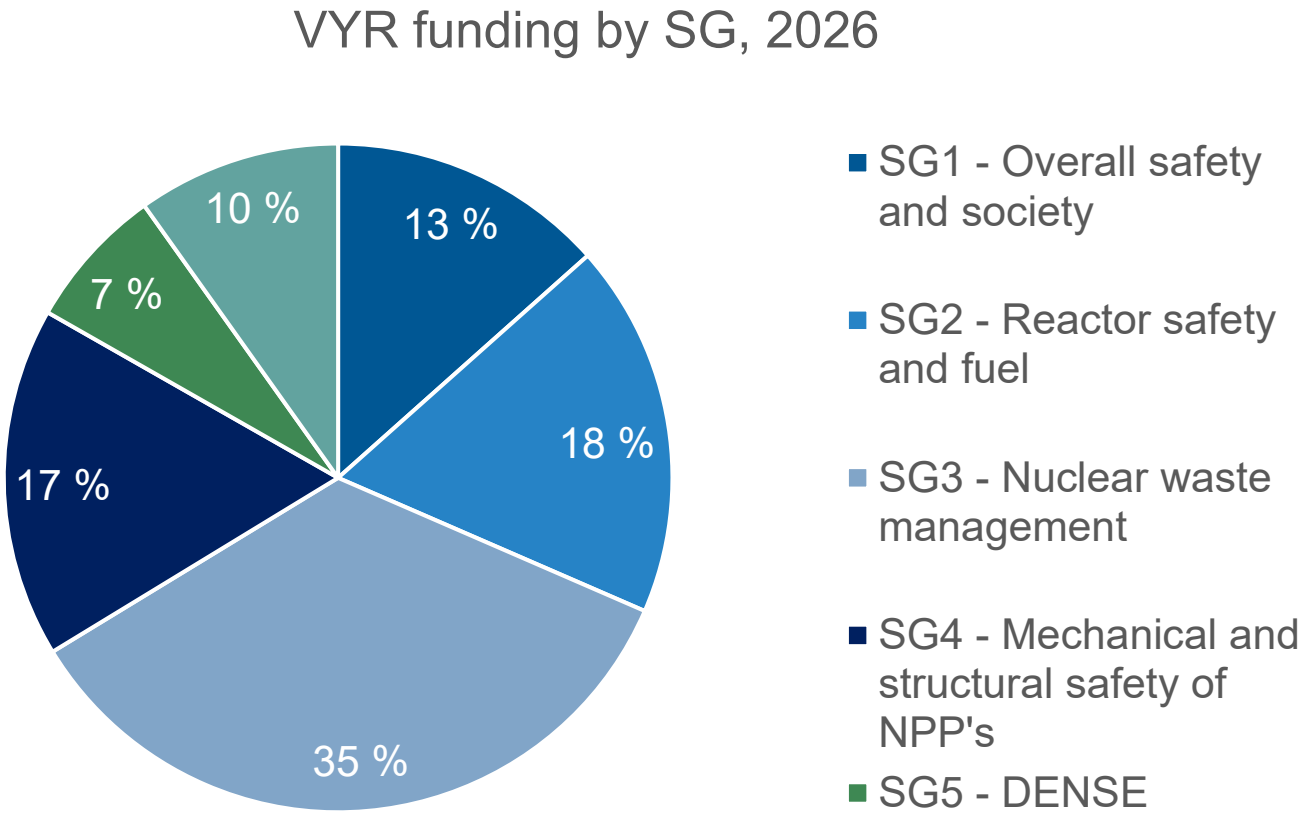
To be announced: DENSE Annual Seminar!

Doctoral Education Network - DENSE

- Bringing together all PhD students in Finland working on nuclear energy and waste management related topics
- Funding for PhD research
- Two annual calls for mobility and other funding to support the students
- Annual seminar
- https://safer2028.fi/dense/

Project portfolio in 2026

- 59 projects
  - 10 excellence projects
  - 7 DENSE projects
- 6,6 M€ of VYR funding
  - 32 % growth from previous year
- 100 k€ for MG Small Projects



SG1 Technical Advisory Groups

Overall Safety and Society

1.1 - Hazards

- **POMOPRA** - Practice-oriented solutions for modern challenges in probabilistic risk assessment, VTT
- **MAWECL2** - Marine and Weather Events in the Changing Climate as potential external hazards to nuclear safety 2, FMI
- **PLUMO** - Dispersion of Airborne Contaminants from SMR Accidents in Built Environments - Novel Approaches/Developments to Practical Near Source Plume Dispersion Modeling, FMI, VTT
- **REASSURE** - Refining Analysis of Seismic Uncertainty and Risk Estimates, VTT, HU, AFRY, RMCF

1.2 - Human, organisation and society

- **AIDA** - AI enhanced Dialogue for Atomic Energy Future, OU, VTT
- **LANOS** - Leadership and Safety Culture for Assuring Nuclear Safety in Changing Environments, VTT, Lilikoi
- **EASILY** - Intelligent human system integration throughout the nuclear plant lifecycle, VTT, FIOH

1.3 – System safety

- No projects in 2026

SG2 Technical Advisory Groups

Reactor safety and fuel

2.1 Thermal hydraulics and severe accidents

- **C-FLOW** - Two-phase critical flow experiments, LUT
- **SYSTHER** - SYStem THERmal hydraulics, LUT
- **ALISA 2** - Analytical and experimental investigation of severe accident phenomena, VTT
- **CFD4LWR** - CFD for Light-Water Reactors, VTT
- **SOPIS** - Study on nuclear power plant behaviour in various scenarios, VTT

DENSE-projects:

- ***REST*** *- The reduction of large source term during severe nuclear accidents, UEF*
- ***NCGDENSE*** *- The measuring, modelling and development of non-condensable gas models for nuclear safety research, LUT*
- ***CONTEST*** *- Fundamental study of counter-current flow limitations, LUT*

2.2 Fuel and reactor physics

- **FORMA** - Fuel performance modelling and cladding experimental assessments, VTT
- **RECODOS** - Reactor Computational Dosimetry, VTT
- **VIBRA** - Flow-induced fuel vibrations and neutronic feedback effects, LUT
- **SYSI** - Future of Core Simulations, VTT

SG3 Technical Advisory Groups

Nuclear Waste Management

3.1 - Fuel and engineered barrier system

- **MORO** - Spatial Stability and Integrity of Montmorillonite for Robust Assessment of Long-term Climate Driven Scenarios, GTK"
- **ABCRad 2** - Alternative Buffer/Backfill Characterisation + Radionuclide Interactions 2, HU"
- **CULFIX** - Surface micro-cracks in Cu-OFP exposed to sulfide water at elevated temperatures, VTT"
- **HAGEN** - Hefty up-scAling of Granular bENtonites, VTT, GTK, JyU
- **UNDEADCOP** - Understanding of the Deformation and Damage Mechanisms in Copper, VTT

3.2 - Materials and material testing

- **HERA** - High-Efficiency Radionuclide Adsorption, VTT
- **AVOCADO** - Advanced Oxidation Processes with Cavitation for Decontamination Processes, HU
- **COWMATE** - Corrosion Behaviour of Welded Steels in the LILW Repositories - Effect of Materials and Environment, VTT

DENSE projects:

- ***SurePhD*** *- Increasing surety in the performance of present and future VLLW disposal - HU*
- ***MOXSEAL*** *- Metal Oxides for Group Separation of Actinides and Lantanides, HU*

SG3 Technical Advisory Groups

Nuclear Waste Management

3.3 – Rock, site and biosphere

- **FLOP2** - Understanding Reactive Flow in Fractured Crystalline Bedrock for Safe Nuclear Waste, UTU, GTK, JyU, ÅA,
- **AQUA_14C** - 14C biosphere assessment in aquatic ecosystems: green and brown food web dynamics, HU
- **MIRKAII** - Fluid flow in fractured rock mass, Aalto
- **DARKO2** - Deep dark oxygen production and consumption and its impact on biogeochemical processes, VTT, HU

3.4 - Concrete

- **RAD-DAC** - Radionuclide behavior and transport in degraded and aged cementitious materials, HU, GTK
- **FN CAMP II** - Finnish Nuclear Concrete Ageing Management Project Part II, VTT, Aalto
- **PERCO3** - Durability Assessment of Concrete in Low and Intermediate Waste Repository Environment, Aalto, VTT
- **EMCEM** - Emerging supplementary cementitious materials for nuclear safety sector, OU

SG3 Technical Advisory Groups

Nuclear Waste Management

3.5 Fuel and radionuclides

- **RENOIR** - Radionuclide Emission and Source Term Investigation through Modelling and Experimental Research, VTT
- **VOLA II** - Characterisation of long-lived Chlorine-36, VTT
- **MEDERA** - Method development for DTM radionuclides towards service measurements, HU
- **POLYDEC** - POLYelectrolyte gels for DEContamination, HU

SG4 Technical Advisory Groups

Mechanical and structural safety of NPP'S

4.1 - Welds, fatigue and inspection

- **DEEP-NDE** - Deep Non-Destructive Evaluation, VTT, Aalto
- **CONI** - Constraint, irradiation embrittlement and RPV safety, VTT
- **HIFI** -Thermal fluctuations and fatigue modelling by high-fidelity simulations, VTT
- **NIEMI** - Improving Nuclear Integrity by Studying Environmental-assisted Degradation and Fatigue, VTT

4.2 - Materials and material testing

- **IAEXIT** - IASCC Experimental testing knowledge transfer, VTT
- **MAILIS** - Modeling and analysis of fracture from inclusions in RPV welds, VTT
- **SADENA** - Safe use of directed energy deposition components in nuclear applications, VTT
- **WAMOS** - Water chemistry and material degradation study supporting lifetime management in nuclear power plants, VTT

SG4 Technical Advisory Groups

Mechanical and structural safety of NPP'S

4.3 – Ageing and hazards

- **FSPOLY** - Fire-stop Polymers, Aalto
- **TOPAZ** - Total plant fragility in ageing and external hazards, VTT
- **PACMAN** - Polymer ageing and condition monitoring at nuclear power plants, VTT

SG6 Technical Advisory Groups

Infrastructure

6.1 - Infrastructure

- **JULES** - Jules Horowitz Reactor Participation and Instrumentation Development, VTT, JyU
- **MADEIN** - Maintenance and development of LUT thermalhydraulic infrastructure, LUT
- **TREFFI** - Thermal-hydraulic research environment for fuel investigations, LUT
- **UHINFRA** - Infrastructure enhancement at the University of Helsinki – better enabling high throughput radiometric measurements relevant to nuclear safety, plant operation, and waste disposal, HU

SAFER2028 Project abstracts

2026

- SG1 Overall Safety and Society
- SG2 Reactor Safety and Fuel
- SG3 Nuclear Waste Management
- SG4 Mechanical and Structural Stability
- SG5 Doctoral Education Network
- SG6 Infrastructure

POMOPRA - Practice-oriented solutions for modern challenges in probabilistic risk assessment, VTT

POMOPRA will develop practice-oriented solutions for the probabilistic risk assessment (PRA) of digital instrumentation and control systems, passive systems and human failures, and demonstrate those solutions in case studies. Due to lack of data for PRA modelling, expert judgments must be utilized extensively. Procedures and good practices for performing expert judgments in different areas of PRA will be developed. Procedures for comprehensive and efficient verification and validation of PRA will be studied and developed as well. International co-operation will be utilized in this work as much as possible.

MAWECLI2 - Marine and Weather Events in the Changing Climate as potential external hazards to nuclear safety 2, FMI

The objective of MAWECLI2 is to improve preparedness against exceptional marine and weather events that may challenge safety functions of the Finnish NPPs. We utilize reanalysis and model datasets, extreme value and machine learning tools, and physical and statistical modeling to assess probabilities of the events in the changing climate. The results include estimates for unprecedented wintertime windstorms, jointly occurring strong wind gusts and heavy snowfall, severe thunderstorms, tornadoes, extreme sea levels and high seawater temperatures.

PLUMO - Dispersion of Airborne Contaminants from SMR Accidents in Built Environments – Novel Approaches / Developments to Practical Near Source Plume Dispersion Modeling, FMI, VTT

This study focuses on near-source dispersion of airborne radioactive releases from Small Modular Reactor (SMR) accident scenarios in various built environments considered realistic sites for SMR power plants. The overarching objective is to develop Large-Eddy Simulation (LES) based parameterisations of dispersion processes, aiming to eliminate the need for costly site-specific LES modelling while significantly improving the accuracy and reliability of low-cost dispersion models in arbitrary built environments. The project advances the state-of-the-art by integrating high-resolution LES data into the development of enhanced, uncertainty-aware low-cost dispersion modles, thereby enabling more accurate, reliable and context-sensitive safety assessments for SMR's in built environments.

REASSURE - Refining Analysis of Seismic Uncertainty and Risk Estimates, VTT, HU, AFRY, RMCF

We aim to refine seismic hazard modelling methods used in Finland, improving uncertainty evaluation. Earlier projects developed harmonizes seismic inputs, reaching a baseline level by classic data analysis means; this project is focused on advanced methods. We update to internationally recognized scientific standards by utilizing direct access to the SIGMA3 framework, which has been integrated already into SAFER. Theis ensure alignment with leading advances in NPP hazard assessment worldwide. Such approach is critical, as deploying SMRs in various locations will require rapid evolution of hazard, which is only possible with good quality datasets in public domain and qualified personnel.

AIDA - AI enhanced Dialogue for Atomic Energy Future, OU, VTT

The AIDA project investigates the potential of generative artificial intelligence (GenAI) to enhance stakeholder engagement and risk communication in new nuclear projects. It aims to develop and empirically test a GenAI-based simulation tool that facilitates transparent, inclusive, and dialogic communication, thereby supporting the social license to operate (SLO). Through theoretical integration of SLO and human–AI interaction frameworks, controlled stakeholder workshops in new nuclear communities, and ethical guideline development, the project addresses a critical research gap. Expected outcomes include a prototype tool, empirical insights into AI-mediated dialogue, and contributions to the science of digital engagement in nuclear contexts.

LANOS - Leadership and Safety Culture for Assuring Nuclear Safety in Changing Environments, VTT, Lilikoi

Finnish nuclear power ecosystem faces wide-ranging sociotechnical changes, such as lifecycle transitions, regulatory updates, new technologies, and new business and organizational models. LANOS applies organizational theory and sociotechnical approach to study leadership, management, and culture for nuclear safety in topical contexts including organizational integration of old and new plants, outsourcing, leadership development, regulatory renewal, and corporate governance. The project aims to further develop nuclear leadership and safety culture models and practices to better match the changing nuclear power industry environment and its demands, and to be more actionable and effective for nuclear safety assurance.

EASILY - Intelligent human system integration throughout the nuclear plant lifecycle, VTT, FIOH

The project will promote the integration of human, technical and organizational factors to increase nuclear facilities' resources for action in case of accidents. To achieve this goal, methods, tools and guidance are developed in a multidisciplinary research group applying both engineering and behavioural science methods. To promote more efficient Human Factors Engineering, an analysis method will be developed and applied in case studies; tools and best practices for resilient process control are developed, and recommendations and guidance will be devised to promote skills development. The results will enhance safety by improving personnel's ability to anticipate and respond to threats.

C-FLOW - Two-phase critical flow experiments, LUT

C-FLOW is heavily focused on experiment work, with some focus on modelling considering two-phase critical flow (TPCF). One focus of C-FLOW is to also develop both the facility and processing of the data. Young experts are being introduced to TPCF and nuclear safety in via BSc and MSc Theses and recruiting interns to be involved in C-FLOW project. International co-operation has been and will be conducted with both FONESYS and especially SILENCE networks. Publishing experiment data will reach the whole international scientific community. This is enforced by joining major conferences in the field of nuclear safety.

SYSTHER - SYStem THERmal hydraulics, LUT

LUT participates in the NEA SYSTHER project. Half of the operating agents´ funding in the NEA pro-jects should come as a national financing. Another half comes from the participation fees of the pro-ject. The SAFER2028 SYSTHER project application covers the national funding for 2026-2028.
The PWR PACTEL, PASI, and MOTEL facilities will be used in the project. The project develops and maintains a comprehensive understanding of matters relevant for the safe operation of nuclear facili-ties, maintains and extends the research expertise, maintains thermal-hydraulic system testing re-search infrastructure, and produces data for the validation of computational tools.

ALISA 2 - Analytical and experimental investigation of severe accident phenomena, VTT

The ALISA-2 project focuses on phenomena occurring during severe nuclear reactor accidents. The project combines expertise in both experimental and modeling work and aims to strengthen competencies in these areas. ALISA is divided into three work packages, which cover:1) Formation of organics and fission product behavior, 2) Performance of autocatalytic passive recombiners under specific conditions, and 3) Participation in international collaborations, including OECD/NEA programs and the USNRC CSARP (payment of the MELCOR license fee on behalf of Finnish users) This work will also establish a direct comparison between experiments and simulations/codes, which increases the confidence in the results. The outcomes of the project will enhance nuclear safety in Finland.

CFD4LWR - CFD for Light-Water Reactors, VTT

Two-phase flows in light-water reactors (LWRs) are studied using computational fluid dynamics (CFD) with special emphasis on counter-current flow limitation (CCFL) in nuclear safety critical applications. 3D CFD methods are applied to model CCFL conditions in two configurations: countercurrent flow through a VVER-440 fuel bundle tie-plate and a pressurized-water reactor primary circuit hot leg. Novel morphology-adaptive Euler-Euler methods will be assessed and adapted for the needs of CCFL modelling and nuclear safety research. In addition, the project aims at disseminating the research results of the SAFER2028 programme as journal articles.

SOPIS - Study on nuclear power plant behaviour in various scenarios, VTT

Though system-scale analysis codes have been developed and validated throughout the years, especially novel designs and new purposes require further assessment of the tools due the complexity of the calculated problems. SOPIS tackles this problem with existing system codes by using them for sets of analyses for thermal-hydraulic integral effect test facilities. SOPIS also co-operates with LUT's C-FLOW project.

FORMA - Fuel performance modelling and cladding experimental assessments, VTT

Computational fuel performance modelling, model development and experimental cladding studies are conducted in the FORMA project. Ring compression tests on unirradiated, coated accident tolerant fuel claddings, combined with finite element modelling, are done in order to get insight on material behaviour and to use the produced data in fuel performance codes. In fuel modelling, following are covered: pellet-cladding mechanical interaction, fission gas release in chromium additive ATF fuel, further development of in-house fuel module and design basis accident analyses. The project continues and expands the work started in SAFER2028 MATFINE project.

RECODOS - Reactor Computational Dosimetry, VTT

The RECODOS project seeks to develop and provide a robust, validated calculation chain methodology for reactor computational dosimetry. The methodology incorporates real measurement data. This approach showcases the strategy and highlights the project's impact on the nuclear industry. The project is involved in the next development phase of the Kraken framework, providing quantitative data on the impact of using advanced multi-physics/multi-scale and delivering industry-grade fluence and dosimetry estimates for RPV, core internals, and out-of-vessel structures up to TRL6. It will offer factual arguments about the biases and uncertainties of the methodology, more accurate margins, and estimates.

VIBRA - Flow-induced fuel vibrations and neutronic feedback effects, LUT

VIBRA investigates flow-induced vibrations in nuclear fuel rods and assemblies, and their impact on neutronic feedback. Combining experiments and simulations, the project aims to develop validated multi-physics models and experimental data to understand and mitigate vibration-related safety issues in reactors. The work begins with developing neutronic simulation capabilities that account for fuel vibrations, proceeds with incorporating fluid–structure interaction (FSI) simulation capabilities coupled with neutronics, and concludes with conducting flow-induced vibration experiments to validate the FSI approach. Overall, the research objective is to provide insight into the core-scale interplay between flow, fuel structures, and neutronics.

SYSI - Future of Core Simulations, VTT

Kraken is the modern, domestic, reactor analysis framework providing the Finnish nuclear field with a flexible and adaptable alternative to foreign commercial codes. The SYSI project covers developments that will allow Kraken to be easily used also for VVER-440 and boiling water reactors very quickly after the relevant implementations have been made. Furthermore, SYSI manages the distribution of Kraken updates to the international data banks as well as the organisation of Kraken workshops for acquisition of new users, training of new and existing users and building of the Kraken community.

MORO - Spatial Stability and Integrity of Montmorillonite for Robust Assessment of Long-term Climate Driven Scenarios, GTK

This project investigates spatial occurrence and long-term stability of smectite clays, particularly montmorillonite, within bedrock fault architecture, mineralogy and groundwater systems. The geochronological constraints of the mineralisation will be assessed. This will allow assessing montmorillonite longevity during the past climate events and related scenarios in more robust manner (e.g. groundwater dilution and buffer erosion). The study aims to improve understanding of engineered barrier systems and groundwater interactions. By mapping smectite occurrences across Finland, assessing their age, depth-related variation, and exchangeable cation composition, the project explores regional versus local controls on late-stage alteration – findings that will support buffer stability assessments.

ABCRad 2 - Alternative Buffer/Backfill Characterisation + Radionuclide Interactions 2, HU

The project focuses on Georgian bentonite, now a candidate buffer/backfill material for ONKALO®. Objectives are to: (1) determine how groundwater salinity (1–70 g/L) influences uranium and cesium retention; (2) identify sorption/precipitation products and mechanisms using spectroscopies; and (3) build surface complexation models incorporating ionic strength effects.
The project involves international collaborations, trains one MSc student annually, and delivers datasets supporting POSIVA and STUK in safety case development. The outcomes will inform Finland's safety case and strengthen expertise and networks in radionuclide geochemistry.

CULFIX - Surface micro-cracks in Cu-OFP exposed to sulfide water at elevated temperatures, VTT

The aim of the project is to determine sulfide induced SCC susceptibility of Cu-OFP in initial period of vault disposal temperatures of 60°C and 90°C via experimental and modelling methods.

This project aims to address these research questions:
- How elevated temperature affects the microcrack size and appearance in Cu-OFP under mechanical loading and does sulfide have a role to play in their formation.
- If void formation in CU-OFP due to deformation from mechanical loading in a sulfide environment play a role in causing surface defects and susceptibility to sulfide SCC.
- How does grain-level plastic deformation contribute to void and void string formation, and how do surface crack affect further deformation and SCC-related damage in Cu-OFP

HAGEN - Hefty up-scAling of Granular bENtonites, VTT, GTK, JyU

The HAGEN project focuses on quantifying the hydromechanical behaviour of new bentonite materials (granular bentonites and bentonites from various sources) by advanced experimental methods, such as quantitative X-ray computed tomography (XCT) and mechanical testing, and upscaling the results from laboratory scale towards the repository scale by modelling and by a novel combination of XCT and electrical resistivity tomography (ERT). The implementer needs the information to ensure the performance and the safety of the new materials, and the regulator to evaluate their safety.

UNDEADCOP - Understanding of the Deformation and Damage Mechanisms in Copper, VTT

The project aims to gain more in-depth knowledge about the behaviour of OFP copper used in end disposal canister and how the microstructure and segregation of chemical elements at grain boundaries affects it. The information is used to further develop a micromechanical modelling workflow for relevant copper overpack material for describing the material behaviour under mechanical stresses. Micromechanical model is used to formulate engineering model that can be used for component level analysis. Advanced characterization methods are applied and further developed.

HERA - High-Efficiency Radionuclide Adsorption, VTT

HERA (High-Efficiency Radionuclide Adsorption) develops advanced metal–organic frameworks (MOFs) for efficient capture of radionuclides in nuclear safety applications. The project targets two priority challenges identified with Finnish nuclear operators: iodine capture in air systems and actinide removal from aqueous wastes. Emphasis is placed on adsorption performance, chemical, hydrothermal, radiation, and mechanical stability, and integration into existing Finnish waste management concepts. Jointly with the DENSE MOSAIC project, HERA will cover synthesis, functionalisation, adsorption testing, and stability studies. The project trains a PhD researcher, ensuring competence renewal and providing nuclear-relevant knowledge to enable safe, efficient radionuclide capture and reduced secondary waste.

AVOCADO - Advanced Oxidation Processes with Cavitation for Decontamination Processes, HU

The integration of cavitation within AOPs presents a promising avenue for improving wastewater treatment in the nuclear industry. By systematically evaluating radical production and the synergistic effects of different AOP techniques, focusing on ultrasound and hydrodynamic cavitation, this research aims to contribute to the development of more effective and environmentally friendly decontamination strategies. The ultimate goal is to enhance the safety and sustainability of nuclear power operations and their decontamination efforts while minimizing the generation of secondary waste.

COWMATE - Corrosion Behaviour of Welded Steels in the LILW Repositories - Effect of Materials and Environment, VTT

COWMATE will study how envinronmental changes over time affect steel weld corrosion in LILW repositories. The project's significance is based on the limited data currently available regarding the corrosion of welded steels under these conditions. Long-term laboratory tests will be analyzed and in-situ corrosion testing will be planned and executed to validate the long-term test results. Material characterization, mass loss calculations and electrochemical testing are employed to evaluate corrosion rate and types present in the studied environment. A corrosion model will be developed and validated to provide a new tool for assessing corrosion in LILW repository conditions.

FLOP2 - Understanding Reactive Flow in Fractured Crystalline Bedrock for Safe Nuclear Waste, UTU, GTK, JyU, ÅA,

Ensuring the long-term safety of subsurface radioactive waste disposal requires a comprehensive understanding of fractured crystalline bedrock, where mineral alterations affect porosity, permeability, and mechanical stability. The FLOP 2 project builds on FLOP 1 by integrating three complementary approaches: (i) isotopic dating of alteration phases to constrain temporal evolution, (ii) laboratory experiments on reactive rock–fluid interactions, and (iii) open-source discrete fracture network (DFN) and coupled thermal–hydraulic–mechanical–chemical (THMC) modeling to foster a community of practice for reproducible, transparent workflows. This integrated strategy strengthens Finland’s research capacity and confidence in repository performance.

AQUA_14C - 14C biosphere assessment in aquatic ecosystems: green and brown food web dynamics, HU

Radiocarbon (^{14}C) is a key radionuclide in operating waste, spent fuel, and decommissioning waste, yet its environmental speciation and chemical forms remain poorly constrained. This project will quantify ^{14}C uptake and transfer in aquatic green and brown food webs, focusing on dissolved inorganic (DIC), dissolved organic (DOC), and particulate organic carbon (POC). Special emphasis is on microorganisms, particularly methane-oxidizing bacteria, as mediators of ^{14}C movement. We will also pioneer investigations of green and brown food chains, where data are lacking. Using natural abundance and isotopic mixing models, we will reduce uncertainties in biosphere modelling and inform nuclear safety assessments.

MIRKAII - Fluid flow in fractured rock mass, Aalto

MIRKA II (2026–2028) builds on MIRKA I to improve safety assessments for nuclear waste repositories by focusing on fluid flow and channelization in fractured crystalline rock. The project combines laboratory testing of rock cores, photogrammetric characterization, 3D-printed replicas, and numerical DFN/CNM modelling to generate benchmark datasets. By quantifying how channelization evolves under stress and varies with rock type, MIRKA II reduces epistemic uncertainty in radionuclide transport modelling. Results will be openly published, providing validated inputs for regulators and industry. The project also trains doctoral and MSc students, strengthening Finland's long-term competence in geological disposal and repository safety.

DARKO2 - Deep dark oxygen production and consumption and its impact on biogeochemical processes, VTT, HU

In situ produced oxygen has recently been reported in presumed anoxic deep subsurface environments. This oxygen appears to be produced in situ and may origin from both abiotic (e.g. water radiolysis) or biotic (dismutation of nitric oxide, superoxide, hydrogen peroxide, chlorite) processes and may affect the stability and safety of the deep geological repository for spent nuclear fuel. Our research has identified in situ produced “dark” oxygen in Kopparnäs groundwater. The objective of the DARKO2 project is to obtain a detailed picture of the biotic and abiotic oxygen-releasing processes in repository relevant environments and assess the biological oxygen production potential.

RAD-DAC - Radionuclide behavior and transport in degraded and aged cementitious materials, HU, GTK

This research project investigates the diffusion and retention of key radionuclides (HTO, C-14, Cl-36, and Ni-63) in aged and degraded cementitious materials used in Finnish low- and intermediate-level radioactive waste (LILW) repositories. Building on prior studies, it aims to quantify radionuclide transport under long-term disposal conditions and assess the evolving containment performance of engineered barrier systems. Results will support safety case evaluations, inform repository design, and reduce uncertainty in long-term performance predictions. The project also contributes to expert training in nuclear waste management and aligns with SAFER2028 goals for improving final disposal safety and understanding concrete aging phenomena.

FN CAMP II - Finnish Nuclear Concrete Ageing Management Project Part II, VTT, Aalto

The FN CAMP II project continues to focus on relevant degradation mechanisms that correspond to recognized knowledge gaps of high importance for both Finnish Nuclear Power Plants and Radioactive Waste Storage facilities. The concrete performance studies addressed in the project are related to 1) embedded liner in concrete and spent fuel pool liner corrosion, 2) monitoring of structures for predictive maintenance, 3) structural damage due to internal expansive reaction in concrete resulting from alkali-silica reactions or delayed ettringite reaction, 4) the vulnerability of concrete structures to climate change and predicting their future performance, and 5) the long-term safety of cement grout-ed rock bolts and anchors.

PERCO3 - Durability Assessment of Concrete in Low and Intermediate Waste Repository Environment, Aalto, VTT

The obectives of the PERCO3 project are to : (i) investigate the long-term durability of concrete, (ii) conduct accelerated durability testing, and (iii) design and implement Artificial Intelligence (AI) –driven models to enable accurate predictions of the service life of concrete structures. The relevance of the objectives for NPP's utilities and regulators is linked to the correct understanding of deterioration mechanisms of concrete in LILW repositories, their nature and consequences. The project is an important instrument in the education of high-level experts with focus on nuclear applications.

EMCEM - Emerging supplementary cementitious materials for nuclear safety sector, OU

Concrete is vital in the nuclear sector for both structural integrity and radioactive waste immobilization. In Finland, blast furnace slag has been the primary supplementary cementitious material (SCM), but its production will end in 2030. The EMCEM project investigates alternative SCMs for nuclear sector relevant concretes, focusing on solidifying radionuclide-containing ion-exchange resins. The project investigates end-user relevant aspects of emerging SCMs using advanced materials science methods.

RENOIR - Radionuclide Emission and Source Term Investigation through Modelling and Experimental Research, VTT

The RENOIR project investigates radionuclide release from spent nuclear fuel (SNF) under deep geological disposal conditions, integrating experiments, modeling, and international collaboration. Building on EURAD-2 SAREC, it focuses on instant release fractions, grain boundary contributions, and radionuclide solubility limits, with particular emphasis on iodine and cesium. Using advanced experiments for UO_2 and repository-relevant test environments, RENOIR refines predictive models and improves confidence in source term assessments. Results support Finnish stakeholders and the European waste management community by reducing uncertainties, strengthening safety cases, and enhancing training of experts, contributing directly to the SAFER2028 programme objectives.

VOLA II - Characterisation of long-lived Chlorine-36, VTT

SAFER VOLA II project proposal is a continuation project for SAFER VOLA, in which characterisation method development was carried out for stable Chlorine-35. In VOLA II, the focus is turned to the long-lived beta emitter Chlorine-36 (half-life 3 $\times 10_5$ years) and its quantitative detection using triple quadrupole inductively coupled plasma mass spectroscopy (QQQ-ICP-MS). Quantitative analyses of Chlorine-35 and Chlorine-36 in different reactor materials are needed in radioactive waste management as Chlorine-35 is a precursor for Chlorine-36 in neutron activation. Chlorine analyses are also important because it is very soluble and readily migrates in geosphere. As the concentrations of Chlorine-35 and Chlorine-36 may be at trace level, there is a need for their accurate and sensitive analysis.

MEDERA - Method development for DTM radionuclides towards service measurements, HU

The MEDERA project (Method Development for DTM Radionuclides) aims to establish Finland's first dedicated radioanalytical service laboratory while advancing methods for difficult-to-measure (DTM) radionuclides such as 14C, 36Cl, 55Fe, 59Ni, 63Ni, 93Mo, 99Tc, 129I, and 135Cs. By developing validated separation and detection techniques for challenging matrices (resins, sludges), MEDERA will enhance nuclear waste characterization, support emergency preparedness, and strengthen regulatory oversight. Running during 2026–2028, the project integrates cutting-edge radiochemistry, ICPMS / MS, and AMS with expert training, providing long-term benefits for nuclear safety, waste management, and national resilience.

POLYDEC - POLYelectrolyte gels for DEContamination, HU

The project aims to advance the development of a polyelectrolyte gel as a decontamination agent for the nuclear industry. Polyelectrolyte gels can be developed into quantitative absorbants of radionuclides and refined into a large-scale product. Radionuclide absorption on the polyelectrolyte gels was tested in 2024. Gel properties were modified for increasing peelability in 2025, with preliminary characterization of the gel molecular structure. Next steps in POLYDEC are detailed molecular structure exploration and fine-tuning of mechanical properties. The produced gels have applications for decontamination of nuclear facilities for several materials. They have also applications in cleanup of environmental and urban contamination.

DEEP-NDE - Deep Non-Destructive Evaluation, VTT, Aalto

The project is consisted of three Work Packages (WPs). In WP1, Artificial Intelligence (AI) is applied to Ultrasonic Testing (UT) to reduce inspection time and radiation dose by advancing UT methods, enhancing mechanisation, and implementing AI-based data quality monitoring for faster acquisition and evaluation. WP2 extends UT beyond flaw detection to material condition assessment by developing methods to measure hardness, residual stress, and elasticity in nuclear-grade materials through wave velocity, attenuation, and frequency analysis. WP3 develops multi-frequency UT datasets of real flaws to train and validate AI models, improving reliability and strengthening flaw characterisation in nuclear inspections.

CONI - Constraint, irradiation embrittlement and RPV safety, VTT

The CONI project aims to develop and validate a methodology for low constraint fracture toughness testing of irradiated reactor pressure vessel steels, using miniature specimens. The project combines literature review, numerical modeling, and experimental testing with unirradiated and irradiated materials. The goal is to reduce conservatism in safety assessments, support regulatory compliance, and extend the operational life of nuclear reactors. The expected result is a ready-to-use, validated testing method that can be applied immediately in safety evaluations and shared with both Finnish and international stakeholders through workshops and publications.

HIFI -Thermal fluctuations and fatigue modelling by high-fidelity simulations, VTT

The overall objective is to develop structural integrity assessment and fluid-structure interaction methods for the reliable prediction of high-cycle thermal fatigue due to flow mixing. The motivation is the continuing importance of the damage mechanism in critical components, e.g. internals of boiling water reactors. Methods for ASME compliant fatigue analyses are developed especially for welds.
Uncertainties in the assessments due to various correction factors and fatigue curves are reduced. The latest advancements in computational fluid dynamics modelling of the thermal mixing loads are taken into use and validated. Efficient methods for performing fatigue analyses in practice are developed.

NIEMI - Improving Nuclear Integrity by Studying Environmental-assisted Degradation and Fatigue, VTT

Repair welding and high constraint have been identified as key contributors to stress corrosion cracking (SCC) with significant depths observed in French NPPs. A worst-case full-scale 316L weld (simulating the SCC-failed elbows at Penly-1 and Penly-2) with OL3 stainless steel material was prepared. SAFER NIEMI aims to study SCC and environmentally assisted fatigue (EAF) in these representative repair welds. ASNR, INSS and Ringhals/KTH and PSI have agreed in joining NIEMI with in-kind experimental contributions. The NIEMI project will advance knowledge on LTO and degradation, train young researchers, and reinforce international cooperation under the ICG-EAC framework.

IAEXIT - IASCC Experimental testing knowledge transfer, VTT

There will be IASCC (SSRT) tests of LPBF AM316L and similarly irradiated reference material, cold worked 316L, in BWR environment, supported with microstructural characterization (TEM&SEM) of both the pre-exposure irradiation damage and post-test characterization of IASCC specimens. The goal is to see the effect of manufacturing method to the IASCC resistivity of the material, i.e. to study environmental degradation and aging of additively manufactured materials in primary circuit environment. During the project, younger scientists are educated in the area of IASCC testing and operating of active material experimental corrosion testing facilities. Materials have already been irradiated (300°C, neutrons (2-3 dpa)).

MAILIS - Modeling and analysis of fracture from inclusions in RPV welds, VTT

MAILIS aims to advance the understanding of fracture initiation from inclusions in reactor pressure vessel (RPV) welds, a key factor in nuclear plant safety and longevity. The project integrates ad-vanced experimental characterization and computational modeling to identify microstructural features, especially non-metallic inclusions, that act as brittle fracture initiators. Objectives include developing robust models for predicting failure onset, clarifying the role of multi-phase inclusions, and supporting safer, longer-lasting RPVs through improved assessment tools and international collaboration.

SADENA - Safe use of directed energy deposition components in nuclear applications, VTT

The SADENA project aims to advance the safe use of Directed Energy Deposition (DED) additive manufactured components in nuclear applications. DED enables remanufacturing of parts for which moulds no longer exist (spare part availability), repair of high-value equipment without the need for lengthy factory returns and manufacturing completely new designs, minimising downtime during critical outages. The 2026 project focuses on qualification and standardization landscape analysis, DED roadmap development and process and material qualification methodology development together with identifying the key process variables to understand material-process-property relationships and developed a robust qualification methodolody.

WAMOS - Water chemistry and material degradation study supporting lifetime management in nuclear power plants, VTT

Water chemistry is an essential part of the safe and long-term operation of nuclear power plants. Proper optimisation of water chemistry can reduce the number of unexpected breakdowns of structural components and other disturbances as well as decrease the radiation doses of personnel during annual maintenances. In the WAMOS project several water chemistry-related topics have been recognised and will be studied to improve the overall nuclear safety:

- Primary circuit water chemistry during transients
- Alternative oxygen scavenging chemicals for hydrazide
- Corrosion product deposition and impurity enrichment in steam generators
- Water chemistry monitoring to measure colloidal corrosion products from the coolant

FSPOLY - Fire-stop Polymers, Aalto

This project aims at generating understanding of the performance of polymeric fire-stop materials and products (fire barrier systems) and providing numerical models for the engineering assessment of compartmentation function. The research was started during the FASAANI –project 2024-2025, producing thermo-chemical assessment of five selected polymers. Years 2026-2028 will focus on intermediate scale performance assessment of fresh and aged samples, as well as model development and validation. We will address the topic of polymer aging through accelerated ageing.

TOPAZ - Total plant fragility in ageing and external hazards, VTT

The general theme of the project is evaluation of risks caused to plant safety due to failure of structural elements under the combined effect of ageing and external hazards. The general work plan of the TOPAZ project consists of three work packages, each of which aims at solving a particular problem raised by the Finnish plant operators, which is relevant form the point of view of probabilistic risk assessment.

1. Fragility assessment of slender cantilever structures under combined action of material ageing and exceptional wind loads (WP1)
2. Probabilistic assessment of floor response spectra in aged concrete structures under seismic loads (WP2)
3. Seismic analysis of spent fuel pool, movement of fuel racks, damage to pool liner and emptying of the pool (WP3)

PACMAN - Polymer ageing and condition monitoring at nuclear power plants, VTT

Polymers are found in various types of applications inside nuclear power plants, such as sealants and cables. They are subjected to elevated temperature, radiation and moisture, which all accelerate their ageing. Their proper function needs to be ensured throughout the whole lifetime of the plants to guar-antee proper and safe function of the systems they are part of. In the PACMAN project the following safety-related topics are studied:

- Condition monitoring of joint sealants
- On-site trial measurements of cables
- Development of an AI model to predict the condition of polymeric components

The results contribute to improved condition monitoring of polymeric components.

DENSECO - DENSE coordination project, Aalto, LUT, HU

DENSECO-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.

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

The overall objective of the doctoral project titled “The reduction of large source term during severe nuclear accidents” is to improve the safety of the existing and future nuclear power plants by developing technologies to prevent the large-scale particle emissions during the hypothetical severe nuclear accidents and educating new experts in the field. The expected results of the project will improve understanding and generate new knowledge that will be in the development of new filtration technologies for aerosols, especially cesium and iodine species, by applying high efficiency electrostatic precipitators. In addition, the applicability of the electrostatic precipitators for controlled hydrogen mitigation will be investigated. The project will be carried out in collaboration with the international and national network providing an excellent framework for the studies. The project will also closely interact and share knowledge with national and international stakeholders through various communication channels.

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

SURE-PhD supports efforts towards safe surface level disposal of VLLW in Finland. We will (1) document 14C behaviour in the current Finnish VLLW disposal concept; (2) assess if contaminated materials sourced from future Finnish NPP decommissioning could be safely disposed in current existing Finnish VLLW surface disposal concept, an therein understand the evolving chemistry of the disposal system; and (3) investigate whether other waste packaging materials (namely low pH cement and novel geopolymers) could improve the overall safety of future VLLW surface disposal by lessening radionuclide release from the wastes (e.g., for VLLW management from Olkiluoto 3, future Finnish NPPs, SMRs etc.).

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

The project aims to investigate group separation materials for actinides and lantanides from porous metal oxides. The porosity will create an ion sieve effect and together variation on pore diameter selectivity toward Ac – Ln will be adjusted.

NCGDENSE- The measuring, modelling and development of non-condensable gas models for nuclear safety research, LUT

Comprehending the dynamics and potential effects of non-condensable gases (NCGs) on the reactor coolant system is crucial. NCGs in the reactor coolant system can have various adverse effects and lead to accidents and transients. Thus, studying NCG release and dissolution is vital. The NCGDENSE project aims to investigate the release and dissolution of NCGs through analytical, experimental, and numerical means. Theoretical modelling of NCG dissolution and release phenomena will be performed. A SET facility will be constructed to perform NCG release and dissolve tests using novel instrumentation and measurement techniques and the test section will be upgraded to optically transparent ones. Pattern recognition algorithms will be developed and implemented to extract fundamental details of NCG experiments. This algorithm will generate data for model validations. The NCGDENSE project aims to improve the modelling of NCG release and dissolution of SYS-TH codes. The release and dissolution models for NCG will be implemented in the SYS-TH codes. The results of this project will be published in high-level journals and conferences.

PART-IN - Hot Particle Inhalation – Bio-weathering and Long-Term Health Impacts, HU

Inhalation of fine particulate matter poses serious health risks in the lungs and beyond (via transloca tion). While non-radioactive particles like vehicle emissions are well studied, little is known about in haled radioactive “hot” particles sourced from nuclear discharges and accidents and their impacts. Such particles can present combined radiotoxic and chemical hazards, but information on the behaviour and impact post inhalation is lacking. The HOP-IN DENSE project addresses these knowledge gaps by investigating size-sorted cesium-rich microparticles sourced from severe nuclear accidents, applying dissolution studies, in vitro methods, advanced spectroscopic analysis, and microdosimetry, to better understand health impacts

CONTEST - Fundamental study of counter-current flow limitations, LUT

Understanding counter-current flow limitation (CCFL) dynamics is crucial for maintaining thermal-hydraulic stability and protecting the core in accident scenarios. Current interfacial friction models for CCFL are rudimentary and often fail in complex flow situations and intricate geometries. This project aims to study the CCFL phenomenon. In 2026-27, theoretical modeling of CCFL will take place. The CCFL tests will be done using advanced measurement techniques. During 2028-29, the developed CCFL model will be implemented in SYS-TH and CFD codes. The project will enhance the analytical capabilities of computer codes used for the safety assessment of reactor coolant systems. This project will facilitate international collaborations with MIT-USA and POLIMI-Italy, resulting in publications in scientific journals and conferences.

JULES - Jules Horowitz Reactor Participation and Instrumentation Development, VTT, JyU

The JULES project supports Finland’s participation in the Jules Horowitz Reactor (JHR), a major European materials testing reactor under construction in France. The project aims to develop irradiation facilities for Finnish nuclear safety use and foster international collaboration. Objectives include rep-resenting Finnish interests in JHR planning. The project also contributes to international programs like FIDES-II and Halden, ensuring Finland’s active role in nuclear safety research and technology development.

MADEIN - Maintenance and development of LUT thermal hydraulic infrastructure, LUT

The purpose of the MADEIN project is to maintain and development the experimental thermal hydraulic infrastructure at LUT University nuclear safety research laboratory. The project includes maintenance of the thermal hydraulic test facilities and development and upgrade of the facilities, instrumentation and data acquisition and analysis capabilities. The project includes important international co-operation with other top-level universities and research institutes conducting experimental nu-clear thermal hydraulic research worldwide in the form of the SILENCE network. The project offers good possibilities for summer trainees and bachelor's thesis workers.

TREFFI - Thermal-hydraulic research environment for fuel investigations, LUT

TREFFI project establishes an advanced thermal-hydraulic test facility focused on nuclear fuel and reactor core safety research. Featuring a modular water loop with transparent test sections and stateof- the-art instrumentation, the facility enables high-resolution visualization and measurement of complex flow phenomena at full scale. It supports realistic investigations of fuel assembly behavior under normal and accident conditions. Designed for flexibility and expandability, the infrastructure will enhance LUT's experimental capabilities, foster academic and industry collaboration, and strengthen Finland's competence in nuclear safety research.

UHINFRA - Infrastructure enhancement at the University of Helsinki – better enabling high throughput radiometric measurements relevant to nuclear safety, plant operation, and waste disposal, HU

This project will modernise Finland's radiometric capabilities by enhancing the University of Helsinki's infrastructure with a modern multi-point pyrolyzer and ultra-low level liquid scintillation counter (ULL LSC). The proposal is submitted in two stages, the first targets the multi-point pyrolyzer. The additions strengthen UH's role as a low-cost, point-of-access platform for researchers, supporting high-sensitivity radionuclide analysis across environmental, geological, and nuclear industry studies. The infrastructure will also enable UH to better provide commercial analytical services for utilities, Posiva, and STUK, ensuring accurate radionuclide inventories for waste disposal, decommissioning, and safety. Critically, it also enhances national emergency preparedness capabilities.

SAFER2028 Administration Contact Information

Twitter: @SAFER2028

Website: https://safer2028.fi/

Email: safer2028@vtt.fi

Programme director
Suvi Karvonen

suvi.karvonen@vtt.fi
040 356 2536

Project experts Anna Korpinen & Essi Immonen