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SAFIR2022 Program, KYT2022 Program and SAFER2028 Draft Framework External Evaluation Report

Ministry of Economic Affairs
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International evaluation team: Olivier Dubois, Åsa Ek, Olivier Leupin, Jürgen Sievers, Heli Talja, Peter Yarsky

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Abstract

At the request of the Ministry of Economic Affairs and Employment of Finland, an international evaluation team conducted an external review of the SAFIR2022 and KYT2022 research programs. Furthermore, feedback on the proposed framework plan of SAFER2028, a new research program that combines the previous SAFIR and KYT programs, was requested.

The team found that, in general, the research programs produce a remarkable level of scientific output for a modest stream of funding. The primary, perceived value added by the research programs is that they provide a pipeline of new talent and expertise necessary for the successful regulation of nuclear power and waste management activities in Finland.

The research products had, generally, a high technical quality. In some instances, however, the research aimed towards well-established, or mature fields of study where the value added in terms of increased knowledge or improved safety might be considered marginal or incremental. However, the benefit of these activities vis-à-vis the educational benefit in training new experts in relevant fields could be seen. There are opportunities for key improvements in some of the novel elements of the SAFER2028 framework plan, in particular the doctoral education network.

Keywords	energy, nuclear energy, nuclear safety, nuclear waste management, research		
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Kuvailulehti

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Arviointiraportti SAFIR2022- ja KYT2022-tutkimusohjelmista sekä uudesta SAFER2028-tutkimusohjelman suunnitelmasta

Työ- ja elinkeinoministeriön julkaisuja 2022:36		**Teema**	Energia
Julkaisija	Työ- ja elinkeinoministeriö		
Tekijä/t	Olivier Dubois, Åsa Ek, Olivier Leupin, Jürgen Sievers, Heli Talja, Peter Yarsky		
Kieli	englanti	**Sivumäärä**	69

Tiivistelmä

Työ- ja elinkeinoministeriö pyysi kansainvälistä ulkopuolista arviointia käynnissä olevista ydinvoimalaitosten ja ydinjätehuollon turvallisuustutkimuksen ohjelmista SAFIR2022 ja KYT2022. Lisäksi arviointia pyydettiin edellä mainitut tutkimusohjelmat yhdistävän SAFER2028-tutkimusohjelman alustavasta suunnitelmasta.

Arviointiryhmä havaitsi, että käynnissä olevat tutkimusohjelmat tuottavat huomattavaa ja korkealaatuista tieteellistä tietoa verrattain vaatimattomalla rahoituksella. Tutkimusohjelmien tärkein arvo on kehittää uutta osaamista, mitä tarvitaan ydinvoimalaitosten ja ydinjätehuollon oikeasuhtaisessa sääntelyssä. Joissakin tapauksissa tutkimus kohdistui jo paljon tutkittuihin aiheisiin, joiden tutkimisen hyödyllisyyttä tiedon tai turvallisuuden lisääntymisen kannalta voidaan pitää vähäisenä. Nämä tutkimusaiheet voidaan kuitenkin nähdä hyödyllisiksi uusien osaajien kouluttamisen kannalta.

SAFER2028-tutkimusohjelmaan suunniteltuja uusia toimintoja, erityisesti tohtorikoulutusverkostoa, nähtiin mahdolliseksi kehittää merkittävällä tavalla arvioinnin tulosten avulla.

Asiasanat	energia, ydinenergia, ydinturvallisuus, ydinjätehuolto, tutkimus		
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Extern utvärderingsrapport för programmen SAFIR2022 och KYT2022 samt utkastet till ramprogram SAFER2028

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Språk	engelska	**Sidantal**	69

Referat

På det finska Arbets- och näringsministeriets begäran har en internationell utvärderingsgrupp genomfört en extern granskning av forskningsprogrammen SAFIR2022 och KYT2022. Därutöver begärdes återkoppling om det föreslagna ramprogrammet för SAFER2028, ett nytt forskningsprogram som är en kombination av de tidigare SAFIR- och KYT-programmen.

Gruppen kom fram till att forskningsprogrammen i allmänhet, med förhållandevis begränsade medel, åstadkommer anmärkningsvärda nivåer av vetenskapliga resultat. Det mervärde som forskningsprogrammen primärt förefaller ge är att de ständigt producerar nya förmågor och tillhandahåller den expertis som krävs för en framgångsrik reglering av kärnkraft och kärnavfallshantering i Finland.

Forskningsprodukterna har generellt en hög teknisk kvalitet. I vissa fall berör forskningen dock väletablerade eller grundligt studerade ämnesområden för vilka mervärdet i form av utökade kunskaper eller förbättrad säkerhet får anses marginellt eller inkrementellt. Det fanns dock tecken på att dessa aktiviteter är mer fördelaktiga än att utbilda nya experter i de berörda ämnena. Det finns utrymme för viktiga förbättringar i vissa av de nya elementen i ramprogrammet SAFER2028, närmare bestämt inom nätverket för doktorandutbildning.

Nyckelord	energi, kärnenergi, kärnsäkerhet, kärnavfallshantering, forskning		
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EXECUTIVE SUMMARY

At the request of the Finnish Ministry of Economic Affairs and Employment, we gathered to conduct an external review of the SAFIR2022 and KYT2022 research programs. Our charge was to evaluate the relevance and efficiency of the research conducted under these programs, to examine the effectiveness of these programs in training new experts in key technical fields, and assess the quality and international impact of the research. Further, we were requested to provide feedback on the proposed SAFER2028 framework plan, which serves as a new research program that combines the previous SAFIR and KYT programs.

We had the opportunity to visit Finland and conduct interviews with research program stakeholders, attend technical presentations given by the researchers, and meet with government officials responsible for planning and administering the research programs. In addition to these meetings, we also had the benefit of receiving written responses to our questions that could not be answered during these meetings. Following these interviews, presentations and the review of the responses, we have compiled a list of key observations regarding the programs and noted some recommendations for improvements where we saw a potential shortcoming. This report provides those detailed observations and recommendations.

More generally, we observed that the primary, perceived value added by the research programs in the eyes of the stakeholders, or end-users, is that these programs provide a pipeline of new talent and expertise necessary for the successful regulation of nuclear power and waste management activities in Finland. As this is a key goal of the research programs, we believe it is important to note that the stakeholders find these programs to be beneficial in exactly this manner.

In our review, we looked at the research products and found them, generally, to be of a high technical quality. This is further evidenced by the body of peer-reviewed publications generated by the research programs. We found that the research, largely, had a clear nexus to supporting resolution of important safety significant technical questions – although, in some instances, we found the research aimed towards well-established, or mature fields of study where the value added in terms of increased knowledge or improved safety might be considered marginal or incremental. In any case, though, we could see the benefit of these activities vis-à-vis the educational benefit in training new experts in relevant fields.

We had the opportunity to review the expenditures of the funding relative to the various research projects and their output. We found that, in general, the research programs produce a remarkable level of scientific output for a modest stream of funding. In some instances, we have noted that projects with a smaller scope tend to be a less efficient use of the funding due to an outsized proportion of these project resources being dedicated to administrative tasks as opposed to technical ones.

Having observed the strengths and weaknesses of the SAFIR2022 and KYT2022 programs, we were well equipped to provide feedback on the new SAFER2028 framework plan, which we have done. Our feedback focuses heavily on some of the novel elements of the framework, in particular the doctoral education network. In this area we feel there are opportunities for key improvements that could make this element more effective, and we have assembled those recommendations in this report.

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Definition
CASL	Consortium for the Advanced Simulation of Light Water Reactors
CFD	Computational Fluid Dynamics
DENSE	Doctoral Education Network under SAFER2028
EJP	European Joint Programming
EPR	Evolutionary Power Reactor
EURATOM	European Atomic Energy Community
FiR 1	Finnish Research Reactor
HOF	Human and Organizational Factors
I&C	Instrumentation and Control
KYT	Finnish Research Program on Nuclear Waste Management
LTO	Long-term Operation
LUT	Lappeenranta University of Technology
MB	Management Board
MEAE	Ministry of Economic Affairs and Employment
MG	Management Group
NKS	Nordic Nuclear Safety Research Board
NORM	Naturally Occurring Radioactive Materials
NPP	Nuclear Power Plant
NWM	Nuclear Waste Management
PRA	Probabilistic Risk Assessment
PWR	Pressurized Water Reactor
RG	Reference Group
SAFER	Finnish Joint Nuclear Power Plant and Nuclear Waste Management Safety Research Program
SAFIR	Safety of Nuclear Power Plants – Finnish National Research Program
SG	Steering Group
SG-DENSE	Doctoral Education Network Steering Group
SITEX	Sustainable Network for Independent Technical Expertise for Radioactive Waste Disposal
SMR	Small Modular Reactor
SR	Follow-up Group

STUK	Finnish Radiation and Nuclear Safety Authority
TAG	Technical Advisory Group
TRIGA	Training, Research, Isotopes General Atomics
TSO	Technical Support Organization
TVO	Teollisuuden Voima
VTT	Technical Research Center of Finland
VVER	Water-Water Energetic Reactor
VYR	State Nuclear Waste Management Fund
WMO	Waste Management Organization

1 Introduction

At the request of the Finnish Ministry of Economic Affairs and Employment (MEAE), a small evaluation team made up of various experts from the international community was initiated and gathered to conduct an external review of the SAFIR2022 (Ref. 1) and KYT2022 (Ref. 2) research programs. Our charge was to evaluate the relevance and efficiency of the research conducted under these programs, to examine the effectiveness of these programs in training new experts in key technical fields, and assess the quality and international impact of the research. Further, we were requested to provide feedback on the proposed SAFER2028 framework plan (Ref. 3), which serves as a new research program that combines the previous SAFIR and KYT programs.

The scope of these research programs covers most important technical and non-technological aspects of safety for both nuclear energy generation and waste disposal. This scope must also be considered given the current regulatory environment in Finland. We note that the current Finnish regulatory environment comprises nuclear reactors in all phases of life from design (e.g., Fennovoima, VVER1200) to decommissioning (e.g., FiR 1; TRIGA Mark II). Olkiluoto 3 (EPR) is about to start electricity production alongside the existing Olkiluoto 1 and 2 units. Fortum is pursuing license extension to operate its two VVER440s. Posiva has submitted an application for operation of its long-term waste repository. A principal goal of the Finnish research programs is to provide a pipeline of new experts in relevant fields for the regulator, STUK. The need for regulatory expertise covers a wide range of licensing activities in Finland today and may need to expand to also cover small modular reactors in the future.

1.1 Objective

Our evaluation objective was multi-faceted. MEAE requested that we evaluate the SAFIR2022 and KYT2022 programs to determine:

- Whether the SAFIR2022 and KYT2022 programs achieved results commensurate with their respective levels of funding, if these results are used in practice, and if the results reach an international audience.

- The degree to which the SAFIR2022 and KYT2022 programs have covered relevant topics, how well these topics are balanced, and if the programs are effective in training and educating new experts in these topics.

In addition, we were requested to review the draft SAFER2028 framework plan and determine:

- The degree to which the new SAFER2028 framework plan covers relevant topics in the fields of nuclear reactor and waste management safety.
- Any recommendations for perceived challenges in the SAFER2028 framework plan.

1.2 Evaluation Team Composition

Our evaluation team is comprised by six members with different areas of technical expertise. We are a diverse, international team with members hailing from Finland, France, Germany, Sweden, Switzerland and the United States. Combined we have over 150 years of professional experience with expertise in the following areas:

- Fracture mechanics
- Fuel thermal-mechanical behavior
- Geochemistry
- Human and organizational factors
- Integrity assessment
- Large scale testing
- Leadership
- Multi-physics simulation methods
- Radioactive waste disposal
- Reactor physics
- Reactor systems and safety analysis
- Risk assessment
- Severe accidents
- Structural safety and structural mechanics
- Thermal-hydraulics

Due to travel restrictions related to the ongoing coronavirus pandemic, it was not feasible for every member of the evaluation team to attend the meetings in person. Therefore, we relied on a hybrid system where four of our members were in Finland while two other members participated remotely. Our hosts used Microsoft Teams to facilitate the participation of our remote members.

1.3 Methodology

We approached the evaluation systematically. First, we had the opportunity to interview the program end-users (i.e., STUK and the licensees); which included representatives from the reactor and waste repository licensees as well as the regulator. To prepare for these interviews, we generated a list of questions that we would pose to each end-user. We developed these questions to probe how stakeholders perceive the value added, efficiency and effectiveness of the program. These questions are:

- Given the quality of the research products, do you find there has been an acceptable return on investment?
- Is the form of the research products generally useful? For example, if a research effort produces an academic paper this might not be as useful as a publicly available databank with the data in a digital format.
- What is your level of satisfaction with your participation in the decision-making process?
- Do you find the distribution of funding to the various research areas to be balanced and fair?
- Do you find that there is an adequate consideration of risk significance or safety significance in decision-making?
- In your experience, have important research topics been overlooked? Is there a risk of important research topics being overlooked in the draft framework?
- What are your prime expectations regarding international collaborations (sharing the costs of research programs with partners, benefit from international infrastructures, ensure the worldwide recognition of research activities carried out in Finland...)? Are you satisfied with the way international collaborations are handled?

By asking this consistent set of questions we were also able to gauge where there was stakeholder consensus and where there were differences in perception. We found the answers to these questions sparked many interesting and insightful discussions during our interviews.

Second, after these end-user interviews, we attended tracks of technical presentations for each of the research programs. Similar to the end-user interviews, we posed a common set of questions to the technical presenters of each project. Given the short time allotted for each presentation, we asked the technical presenters to prepare written responses to this common set of questions. We crafted this series of questions to better assess the merit of the research products in terms of the safety significance, value added in terms of the increase in knowledge in the field, efficiency in the return on investment of the funding, and ultimate usefulness of the research in practice. The questions are:

- What is the safety significance of your research?
- How mature is your research?
- How many people were working on this project and how many person months were spent?
- What is the quality of your communications and working relationship with the end-users?
- Is there a plan to implement the outcome of your research?
- Do you see a possible future nexus with the doctoral education network as a research topic?

In retrospect the final question regarding the doctoral education network could have been better phrased as we learned few of the project participants had been briefed on the inclusion of such a network in the draft SAFER2028 framework plan.

This list of questions is not exhaustive – on a case-by-case basis the evaluation team members attending different technical presentations asked project-specific questions that fed into our ultimate findings. As before, we were able to review the responses to the common, listed questions and any additional question responses to gain insights about the various research projects and reach conclusions about the effectiveness of the SAFIR2022 and KYT2022 programs.

2 Evaluation of SAFIR2022

Our evaluation addresses: (1) implementation of recommendations made by the previous evaluators, (2) the quality, relevance and impact of the research itself, (3) the effectiveness of the program to manage the research projects, and (4) the effectiveness of the program to educate and train new experts in key technical fields. Our review benefited from technical presentations (see Attachments E and G), written responses to questions (see Attachment I) and other materials related to the program administration (see Attachments L and M).

2.1 Follow-up on Items from Previous Evaluation

One element of our evaluation was to examine the work of our predecessors and determine if the current SAFIR2022 program addressed the various recommendations made by the last external evaluation team. The previous evaluators provided their recommendations in Section 5 of their report (Ref. 4). For each suggestion, we followed up to evaluate their implementation in the current program and moving forward. We had the benefit of prepared written responses for most of the recommendations (see Attachment C).

- A. Sample SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats)

The SAFIR2022 program managers did not perform a SWOT analysis of the SAFIR2022 program. When we asked why this had not been done, the program representatives stated that this was the role of the external evaluation team. We concur with this position. While we have not adopted the SWOT analysis approach in our own evaluation, the exercise of seeking feedback from our independent, external evaluation team serves the purpose of identifying the strengths, weaknesses, opportunities and threats of the programs. We have made several observations regarding both the SAFIR2022 and KYT2022 programs and provided recommendations to address any potential shortcomings moving forward to the SAFER2028 program.

- B. Develop a Roadmap/Evaluate Capabilities Against Needs

In the SAFIR 2018 Evaluation report it has been recommended to formulate a roadmap to help to set priorities and determine needs regarding what has to be available within Finland in contrast to areas of expertise that can be found worldwide as needed.
An important aspect to nuclear safety is expertise and organizational competence. The needs thereof vary with time and roadmaps help ensure needed resources are identified and the organizational infrastructure is in place to support the activity.

Based on the presentations given we are not aware that this recommendation was implemented. A roadmap would have helped inform this evaluation by tracking research progress and would have helped evaluate future needs and resource requirements.

This roadmap recommendation has been taken up again in SAFER2028 (Chapter 2.3 of Ref. 3) where the overarching research topics and their milestones for 2025 and 2028 are reported.

- C. Consider Flexible Funding to Support More New Initiatives

The content of our exchanges with project managers during the evaluation are consistent with the response of the Ministry (see Attachment C). The feedback about the "Excellence" project system is favorable. Under the "Excellence" project system, a research proposal may be granted a guarantee of funding over several years without the need to reapply each year for renewal. The guarantee of funding gives researchers a positive sense of security and enables long-term planning. Reducing the annual reapplication requirement alleviates the administrative burden for project managers of Excellent projects. Excellence projects represent about 30% of the total VYR funding, which means most projects require annual reapplication for continued funding. However, most of these projects, even though not considered as Excellence projects, are still funded each year. Therefore, we believe the ratio of one third of funding for Excellence project could be raised.

On the contrary, there were few proposals for innovative 1 or 2 year-long projects made by research organizations. The effort required to prepare such proposals and the low chances of success are obstacles. We developed some recommendations to address these perceived barriers.

- D. Consider More Flexible Organizing to Build a Vibrant Research Community

The SAFIR2018 report made a recommendation on building a more interactive research community through a more flexible organization of the program (Ref. 4). Some efforts have been made in addressing this recommendation by the program. Ad-hoc meetings and small workshops have been organized, and a joint SAFIR2022/KYT2022 interim seminar was also held encouraging cooperation between research projects in the two

programs. In a few cases the program management board has merged projects. These mergers have increased interactions between stakeholders, for example by leading to data and equipment sharing.

We believe there are further opportunities that would increase research interaction and discussions in the SAFER2028 program going forward. Considerable time in the SG and RG formal meetings seems to be devoted to project monitoring. Diverting more time to research conversations, especially in the RG meetings, would be promising. The SAFER2028 program organization with TAGs replacing RGs, encourages ad hoc meetings at this level. One of our findings is that informal meetings between researchers and end-users more successfully facilitate research discussions and these interactions would be beneficial to the program and means to facilitate them is encouraged. The doctoral education network envisioned by the SAFER2028 creates unique opportunities for facilitating cross-topic research discussions and development of new ideas, possibly with interaction with end-users as well.

- E. Develop Ways to Assess Impact

The previous evaluation team observed that it is not obvious how to assess whether the results of SAFIR programs are succeeding in the long-term, although it is possible to assess short-term results by examining papers published, reports issued, conferences attended, and degrees conferred.

Within the current evaluation process of SAFIR2022 we observed that eight safety goals have been defined and the expenses of each project have been assessed, which results in a distribution of the VYR budget. The results from 2019-2020 show that about 50% of the budget is spent to the two goals: (1) ageing phenomena and integrity of barriers as well as (2) validated tools for reactor and nuclear power plant analysis. In total the budget distribution seems reasonable according to the corresponding safety issues. We recommend assessing the budget distribution against the safety goals periodically, because it seems that these evaluation results may indicate the necessity to change research priorities. Furthermore, the program's safety goals should be assessed periodically to determine whether they reflect the current issues important to nuclear safety.

We examined numerical indicators collected by the SAFIR2022 program managers (see Attachment M). In 2019-2020, reviewer assessed the quality of the research projects the SAFIR2022 program and in more than 90% of the cases, ranked the quality as excellent or good. The quality of the reports improved slightly from 2019 to 2020. The number of projects with an indication of international networking increased from 21 in 2019 to 32 in 2020. The number of doctoral theses was increased from 4 in 2019 to 7 in 2020. The survey

of competence shows that the area on thermal hydraulics had the biggest workload in 2019-2020 with about 18 person years, followed by material engineering with about 11 and reactor physics with about 6 person years. While we do not recommend making formalized, numerical objectives related to these indicators, we have found them to be useful as a tool for assessing the program.

Further we observed that an interim online seminar was organized on the status of SAFIR2022 and KYT2022 projects with about 450 participants from Finland and many other countries. This demonstrates that the Finish research work is visible to the international community.

- F. Think of Organizational Change as a Collaborative Opportunity

We found several means have been introduced to promote content related interaction between projects and with end-users. Ad-hoc meetings and small workshops have been organized to discuss multidisciplinary projects. A common interim seminar was organized together with KYT2022 program. This is an area that requires continued attention in the SAFER2028 program. We believe that the doctoral education network provides a unique opportunity to be innovative in this area.

2.2 Quality, Relevance, and Impact of Research Products

The research projects under the SAFIR2022 program are organized into eight reference groups. The assignment of the projects to the RGs, as well as brief project descriptions are given in Table 1.

Table 1. SAFIR2022 Listing of Reference Groups and Project Names

Project	Description
RG1	**Overall Safety and Organization**
BORS	Building operational readiness of control room crews: preparing for the unexpected
EPIC	Effective improvement of leadership and safety culture
OSAFE	Development of framework for justification of overall safety
PARSA	Participative development for supporting human factors in safety
RG2	**Plant Level Analysis**
COSI	Co-simulation model for safety and reliability of electric systems in flexible environment of NPP
NAPRA	New developments and applications of PRA
PREDICT	Predicting extreme weather, sea level and atmospheric dispersion for nuclear power plant safety
SEARCH	Safety and security assessment of overall I&C architectures
URAN	Uncertainty management in fire risk analyses
RG3	**Reactor and Fuel**
CATS	Coupled analysis of transient scenarios
EMBER	Enhanced multi physics calculation capabilities for fuel behaviour and reactor analyses
INFLAME	Interdisciplinary fuels and materials
LONKERO	Developing the working arms of Kraken, the next generation computational framework for reactor design and licensing analyses
PORA	Fuel microstructure and radium solubility
RACSA	Radiation shielding and criticality safety analyses
RG4	**Thermal Hydraulics**
CFD4RSA	CFD methods for reactor safety assessment
CONTSA	Containment safety research
PAHE	Passive heat exchanger experiments

Project	Description
PATE	PWR PACTEL tests
SCARP	Sub Channel Analysis of Reflooding Phenomena
SPASET	Sparger separate effect tests
THACO	Safety through thermal hydraulic analyses and cooperation
RG5	**Mechanical Integrity**
AMOS	Advanced materials characterization for structural integrity assessment
ELIAS	Effect of long-term operation on ageing and environmentally assisted cracking of nuclear power plant component materials
ELMO	Extended lifetime of structural materials through improved water chemistry
FATIMA	Fatigue Management for LTO
FENIX	Reactor Pressure Vessel Repair Welding Collaboration
FEVAS	Fatigue and evolving assessment of integrity
NOCO+	Cobalt free hardfacings
RACOON	Nondestructive examination of NPP primary circuit components, machine learning and reliability of inspection
RG6	**Structures and Materials**
AM-NPP	Additive manufacturing in nuclear power plants
CONAGE	Critical studies in support of the ageing management of NPP concrete infrastructure
CONFIT	Modelling of aged reinforced concrete structures for design extension conditions
SAMPO	Safety criteria and improved ageing management research for polymer components exposed to thermal radiative environments
RG7	**Severe Accidents**
ANSA	Analytical severe accident research
MANTRA	Mitigation and analysis of fission products transport
RG8	**Research Infrastructure**
BRUTE	Barsebäck RPV material used for true evaluation of embrittlement
IDEAL	Infrastructure development at LUT safety research laboratory
JHR2022	Participation in Jules Horowitz Reactor project towards first criticality in 2022
LABWAST	Preemptive reduction of radiological laboratory legacy waste

We have documented our review for each of the RGs in the following sections of this report.

2.2.1 RG1 Overall Safety and Organization

A subset of the evaluation team attended presentations on research projects under RG1, which focuses on the area of overall safety and human and organizational factors (HOF). The OSAFE project creates a framework for assessing overall safety for a nuclear facility as tested via case studies such as those conducted for SMRs and non-baseload operations. The BORS project focuses on building operational readiness of control room crews and field operators and to deepen our understanding of resilience skills, operators' work practices, and cognitive processes by using e.g., immersive virtual reality technology. The EPIC project develops knowledge and frameworks for effective approaches to safety culture improvement, as well as safety leadership best practices. The PARSA project focuses on organizational learning and verbalization of tacit knowledge in nuclear maintenance through participatory methods such as video-based reflection and collaborative work process analysis.

As the SAFIR2022 program has a strong focus on technical safety, we were glad to see the existence of research in non-technical safety areas, although there are few projects. The research is important in developing methods that can identify latent risk conditions, such as weaknesses in work processes, workplace learning, or safety culture. However, we believe that the funding of the projects in the HOF area is critically low. To uphold the inflow of competence and research on HOF in the nuclear safety context appropriate and long-term funding is needed. We acknowledge that the SAFER2028 framework plan highlights continued research on the HOF topic. However, the plans must be implemented through actual allocation of funds to HOF projects by the management group.

The RG1 projects have a strong end-user focus and give useful and practical research output back to operators, managers in nuclear power companies, the Finnish regulator and technical support organizations (TSOs). We were impressed by the large number of high-quality scientific publications and project reports produced, and in our opinion, the project researchers have achieved remarkable levels of output for relatively small levels of funding.

We also believe that the small projects in RG1 highlight the importance of avoiding administrative loads that can be disproportionately high in projects in this area and have made some recommendations to address this concern.

2.2.2 RG2 Plant Level Analysis

A subset of the evaluation team attended talks on the research projects under RG2, which focuses on plant level analysis. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to have

a clear relationship to questions important to nuclear safety and we found that several projects in this area include promising multidisciplinary approaches. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators and have heard positive feedback from NPP representatives and from STUK. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. Several projects have organized ad hoc meetings with end-users to discuss needs, prioritize tasks and receive feedback. An important finding from this evaluation is that these kinds of ad hoc exchanges have a high added value.

The COSI project (and the corresponding platform) promotes a multidisciplinary approach combining multi-physical models of a NPP with electrical grid simulation models. Contributing to the development of systemic safety analysis tools, this innovative approach induces a sustained interest from STUK, from the nuclear operators and from the grid operators, which led to the organization of a specific COSI Steering Group. This kind of specific group is a good example of an organization able to provide relevant steering and feedback from key stakeholders. For a relatively small level of funding, the COSI project developed a state-of-the-art platform. Considering the different possible nuclear energy scenarios mentioned in the draft SAFER2028 framework program and the possible evolutions of the Finnish electrical grid, we consider the COSI project to be an example of project that brings added value to end-users, provided that the efforts to validate the platform are continued and provided that pertinent validation data are made widely available. We reiterate the need to express overarching topics and specific goals for the SAFER2028 program and recommend that relationships with topics tackled by the COSI project should also be considered.

The NAPRA project contains the new developments and the applications of PRA (probabilistic risk assessment). PRA is an important tool in the safety assessment of NPPs and, despite the high level of maturity of tools and methods in this field, the NAPRA project tackles still open issues and develops innovative methods to help create relevant PRA models with reasonable efforts. No international collaborations were mentioned during the presentation of the project. If such absence is confirmed, international collaborations in this field would probably be fruitful as the issues tackled by the project are often of common interest in the nuclear safety community.

The PREDICT project, aiming at predicting extreme weather and sea level for NPP safety, under this RG stood out as an example of where ad hoc meetings, organized with STUK and utilities representatives, directly benefited the product. In 2019 a PREDICT workshop on probabilistic forecasting was organized with invited speakers from STUK, Fortum and TVO. In February 2022, a small meeting with end-users led to guidance development for

project tasks. A recommendation of the evaluation team is that the program encourages this type of informal meetings and provides means to facilitate them.

The SEARCH project under this RG, which focuses on the safety and security of instrumentation and control (I&C) architectures, has been granted the "Excellence" project status. It is an example of a project having produced many journal articles, conference papers and maintaining a high level of international collaboration. The feedback of project managers about the "Excellence project" status is usually positive, as with this status comes some security for the funding of the project. However, project managers underline that this status does not impart more flexibility to the administrative management of the project (i.e., planning, reporting, etc).

The URAN project under this RG, which focuses on uncertainties in fire simulations, is also an "Excellence" project. The outcomes of this project are state-of-the-art multi-scale methods and research articles. The URAN project benefits from well-established international collaborations such as the PRISME projects. Even though computational tools are routinely used for fire hazard analyses, quantifying uncertainties in these simulations remains a challenge studied by this project. In addition to the RG meetings organized three times a year, this project could benefit from more focused, technical and informal exchanges with end-users (e.g., STUK and NPP operators). Therefore, we made a recommendation regarding these kinds of meetings.

2.2.3 RG3 Reactor and Fuel

A subset of the evaluation team attended talks on the research projects under RG3 which focuses on reactor physics, radiation transport and reactor fuels. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current reactor regulatory environment in Finland with a clear relationship to questions important to nuclear safety, particularly in the areas of operational safety and safety analysis methods. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects, which were also presented to us.

The CATS project under this RG stood out to the evaluation team as an example of a project where the research focus was on a well understood technical area (i.e., coupled transient analysis). However, the practical use of the research products by the regulator

– as they could use the CATS developed methods for safety analysis purposes – was clear to us.

The EMBER project under this RG stood out to the evaluation team as a small project (3 to 7 person months of effort each year) with potential for high value-added implementations of the research products if sufficient funding is granted to the project to reach the production application stage.

The LONKERO project under this RG stood out to the evaluation team as an example of a project with a high degree of engagement with external stakeholders. We found the researchers here took actions to increase the visibility and engagement with potential users of their codes and methods. The workshops orchestrated by the researchers have helped to engage the Serpent user community in the Kraken multi-physics analysis framework, and we find these efforts laudable from a long-term knowledge management and knowledge transfer perspective. We heard feedback from STUK as well about how there is a consensus on the methods development strategy and believe that the Kraken development effort will continue to benefit from engagement with end-users such as STUK.

2.2.4 RG4 Thermal Hydraulics

A subset of the evaluation team attended talks on the research projects under RG4, which focuses on reactor thermal-hydraulics. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current reactor regulatory environment in Finland with a clear relationship to questions important to nuclear safety, particularly in the area of safety analysis methods. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects, which were also presented to us.

The PATE project under this RG stood out to the evaluation team as an example of a project that benefited from a high degree of engagement with industry partners. It was clear from the presentations that the engagement from TVO was valuable in defining the project and how the results of the experiments would, therefore, be directly applicable to reactor safety.

The THACO project under this RG stood out to the evaluation team as an example of a project that would benefit from enhanced knowledge management practices. Under this project the researchers have developed many thermal-hydraulics model decks for the purpose of code validation against various integral experiments. These decks and calculation notes include valuable information about modeling practices that should be preserved for future research efforts and, perhaps, disseminated to the thermal-hydraulic code users' community. We have noted the importance of knowledge management in the SAFER2028 framework plan and, therefore, made some recommendations in this area in light of our findings in this project.

The SCARP project under this RG stood out to the evaluation team as an example of a project that received only a small amount of funding. We observed that the administrative burden in terms of attending meetings and reporting is approximately 2-4 person weeks per year, regardless of the project size. Therefore, small projects such as SCARP will have a larger proportion of the funding spent on administrative effort compared to research. Therefore, we have made a recommendation for small projects to address situations where the administrative load may become an outsized proportion of the total effort.

2.2.5 RG5 Mechanical Integrity

A subset of the evaluation team attended talks on the research projects under RG5, which focused on mechanical integrity. The research projects were found to be relevant to the current reactor safety regulatory environment in Finland, especially to support life-time extension of older operating plants and building of new plants including SMRs. We found a clear relationship to questions important to nuclear safety, particularly in the area of advanced materials characterization for structural integrity assessment, extended lifetime of components due to improved water chemistry, fatigue management for long-term operation (LTO), development of repair welding techniques for LTO, removing cobalt containing alloys in hardfacings and investigations on the reliability of non-destructive testing techniques.

In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects. Several projects have frequent communication with end-users and key experts. Some also have strong international collaborations.

The AMOS project under this RG stood out to the evaluation team as an example of a research area where it would have been beneficial to pay more attention to a smooth transfer of knowledge from senior colleagues to juniors.

The FATIMA project under this RG stood out to the evaluation team as an example of a project that is relevant for fatigue analysis of components under LTO. The results are compared with international state-of-the-art programs to investigate the influence on codes and standards as well as regulations. It was clear from the presentation that the Finnish utilities and STUK are the primary beneficiaries of the project results.

The RACOON project under this RG stood out to the evaluation team as an example of a project that would benefit from machine learning techniques. In this context the effectiveness and reliability of in-service inspections will be improved which is relevant for Finnish utilities and STUK.

We have noted the importance of tacit knowledge management and, therefore, made some recommendations in this area in light of our findings in the projects (see Section 5.6 of this report)

2.2.6 RG6 Structures and Materials

A subset of the evaluation team attended talks on the research projects under R6 related to structures and materials. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current reactor regulatory environment in Finland with a clear relationship to questions important to nuclear safety or novel manufacturing methods relevant for maintenance of ageing plants (e.g., AM-NPP). We could understand the pragmatic value of the research products to the end-users, including the regulators.

Two of the projects, CONAGE and CONFIT, deal with ageing concrete structures. CONAGE examines material questions and non-destructive testing while CONFIT focuses on developing sophisticated damage analysis models for numerical analysis of reinforced concrete structures under design extension conditions. The CONAGE and CONFIT projects stood out to the evaluation team as an example of fruitful mutual collaboration between projects dealing with questions using different approaches. CONAGE is also an example of good collaboration between VTT and Aalto University.

The SAMPO project studies safety criteria and improved ageing management research for polymer components exposed to thermal radiative environments. The project stood out to the evaluation team as an example of the benefits of international collaboration. SAMPO is

being executed together with the Swedish research institute RISE, which performs its part with Swedish funding. The tasks in the various work packages of the project are divided between the partners, and the project's advisory group comprises both Finnish and Swedish end-users.

We requested each project manager provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment.

One of our observations is that the sum of the researchers' applications for funds tend to considerably exceed the availability of VYR funding. However, as most of the project proposals have been considered important and worth of funding, the typical solution has been to initiate as many projects as possible and cut the budgets, sometimes drastically. This inhibits achieving the timely, desired results and raises a question whether alternative funding strategies could be considered in some cases.

Further, we have noted the importance of collaboration between interrelated projects as well as both domestic and international research institutes in the SAFER2028 framework plan and, therefore, made some recommendations in this area.

2.2.7 RG7 Severe Accidents

A subset of the evaluation team attended talks on the two research projects under RG7 related to Severe Accidents. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to have a clear relationship to questions important to nuclear safety. We could understand the pragmatic value of the research products to the end-users. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. We were especially impressed by the level and number of scientific publications and the effort to educate doctoral students in the field of severe accidents. The RG7 group is a small group, with only two projects, focused on one topic, severe accidents. Therefore, the RG7 group meetings enable efficient exchange on needs from end-users and relevant feedback.

As an "umbrella" project, the ANSA project covers five different topics in the field of severe accidents physics. Each topic clearly corresponds to a need expressed either by STUK or by utilities, having been discussed during RG7 meetings. Recently, the funding for ANSA project has been of 12 person months per year, which means that the funding per topic is

very modest. In addition, as typically 5 or 6 people work on the project yearly, the average time spent per person on the project is quite low.

The MANTRA project under this RG aims at investigating the transport, chemistry and mitigation of gaseous and particulate fission products in severe accident conditions, an area where many phenomena are still not well understood. As ANSA, this project covers many topics with a modest level of funding. The project is inserted in a large international network of collaborations, which enables the project to benefit from efforts conducted by other organizations in this field where sharing the knowledge is important.

Both projects in the RG7 group cover a wide range of activities with a modest level of funding. As a result, it is not clear to us how a sufficient level of competencies can be maintained in this field long-term. As mentioned by the managers of the two projects, the severe accidents area is an area where multidisciplinary doctoral projects can be defined and carried out. For the next SAFER2028 program, the evaluation team made a recommendation about the definition of multidisciplinary challenge problems. The evaluation team considers defining such challenges and educating a sufficient number of doctoral students in this field would help maintain an adequate level of competency in severe accidents long-term.

2.2.8 RG8 Research Infrastructure

A subset of the evaluation team attended talks on the research projects under RG8 "Infrastructure". The projects under this reference groups are conducted in the new VTT facilities at the Center for Nuclear Safety (CNS) and at Lappeenranta University of Technology (LUT), using national infrastructures partly developed and maintained with VYR funding.

The BRUTE project investigates actual RPV material extracted from Barsebäck 2 NPP using the CNS facilities. This project clearly offers additional value to the Nordic nuclear community and produced important outcomes regarding the relevance of the RPV surveillance program of NPPs.

The IDEAL project goals are to develop the thermal hydraulic infrastructure at LUT University, to secure the operability of the existing facilities and build new facilities. We noted that the large thermal hydraulic test facilities at LUT University are unique to Finland and, perhaps, to Europe, which confers them a particular importance. The existing facilities and institutional expertise of the research teams result from a long history of development of such facilities. IDEAL is therefore an example of project for which knowledge

management and international collaborations are of particular importance, two areas in which the evaluation team made some observations and recommendations.

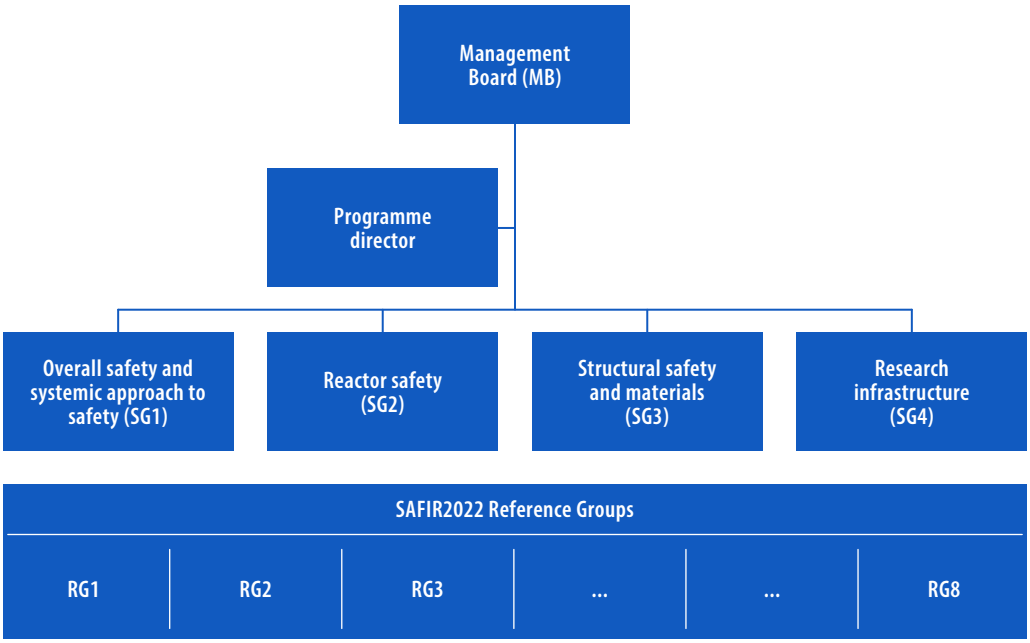
Finland, not having its own irradiation capacity, participates in the international Jules Horowitz Reactor Project (JHR). The JHR2022 project is the umbrella project for Finland's contribution to the international project. The evaluation team noted that the JHR2022 project has been able to develop a device which is part of Finland's in-kind contribution to JHR. This in-kind project defines methods for periodic inspections of irradiations devices of the JHR and develops a model of the JHR reactor with VTT tools. The contribution is rather impressive with respect to the level of funding for the JHR2022 project.

Some members of the evaluation team have been able to visit the VTT Center for Nuclear Safety (RADINFRA and RADCNS projects). We were impressed by the Class 1 hot cells and the existing experimental facilities (e.g., transmission electron microscope, scanning electron microscope, autoclave laboratory, etc.). A number of projects are underway in the facilities, which are unique to Finland. With respect to the future use of VYR-funded infrastructures, in general, we made recommendations for the MEAE to consider the classification of such facilities as "user-facilities," which would ensure their availability to other researchers.

2.3 Effectiveness of Program Management

The SAFIR2022 program framework is organized according to steering groups (SGs) and reference groups (RGs) who report to a management board (MB) as shown in Figure 1. This structure largely mimics that of the SAFIR2018 program except: (1) SG1 appears to have a broader focus, having changed from "plant safety and systems engineering" to "overall safety and systemic approach to safety" and (2) research infrastructure is recognized as having its own SG (i.e., SG4) which it did not have in the previous program.

Figure 1. Structure of the SAFIR2022 Program



In our interviews with the project managers and end-users we have found that the RGs are largely responsible for providing the technical direction for the awarded proposal projects, the SGs are more involved in the funding decision making once the project has been awarded, and the MB is responsible for making top-down decisions and determining program priorities. The program director is responsible for facilitating the administration of the program.

The SAFIR2022 program appears to have adopted this approach based on its demonstrated success in the previous iteration (i.e., SAFIR2018). We have evaluated similar performance metrics of the program, such as the number of advanced degrees conferred and number of peer-reviewed scientific publications produced. We found that the

program achieved a remarkable degree of success in terms of these indicators, especially when considering the modest resources of the program.

We have noted, however, that the participation of research organizations in the decision-making groups of this structure produces, if not a conflict of interest, then certainly the appearance of a conflict of interest. We observe that such participation contributes to the perception that large TSOs such as VTT have a competitive edge when seeking proposal awards under this structure.

We do, however, note that the SAFER2028 incorporates a major revision to this approach whereby the researchers no longer participate in the MB and we believe this is a prudent and warranted change.

The structure of the program also ensures stakeholder participation because the licensees are required to participate in the SGs and RGs. While the legislative requirements ensure participation, it is our finding that the nature and quality of that participation can vary significantly for different projects. In some instances, we found industry participants in the SGs and RGs to be heavily engaged with the researchers. In these instances, we believe that the high degree of engagement has helped to improve project focus, leading to improved outcomes for those projects.

2.4 Effectiveness in Training and Educating the Next Generation of Experts

We had the opportunity during our review to examine internal metrics, or indicators, of the SAFIR2022 program. The program indicators were available for 2019 and 2020 but had not yet been compiled for 2021. These indicators track the number of publications, degrees conferred, and the effort spent on the various projects. The indicators also provide a listing of key areas of expertise and how many new degrees are awarded in each field. We found these tracking data to be incredibly helpful in assessing the performance of the program. We found that the program was successful in educating experts in key competencies.

When we interviewed the end-users, we found that there is a consensus that the primary benefit realized from the research projects is the training of new talent, which then filters into the industry and regulatory agency. To this end, the end-users perceive the program as being effective. We tend to agree with this assessment. However, we have found that there is still room for improvement.

We found that the annual funding decisions for certain non-excellence projects can lead to uncertainty for doctoral students and can create a challenge for one of the program's major objectives. While the excellence funding model in many ways alleviates this concern for certain projects, we believe some additional considerations can be given for projects with doctoral student participants where the project outcomes are directly tied to the student's dissertation. We believe that such considerations were a motivating factor behind the Doctoral Education Network Steering Group (SG-DENSE) envisioned in the SAFER2028 framework.

We believe that such a programmatic tool can be helpful in addressing concerns with continuity of funding for doctoral research. Therefore, while we have recommendations it appears that the SAFER2028 framework planners have anticipated the need for some improvements and embodied these in the draft framework plan. Therefore, it is more appropriate for us to address our recommendations in the area of doctoral education support in Sections 4 and 5.4 of this report.

3 Evaluation of KYT2022

Our evaluation addresses: (1) implementation of recommendations made by the previous evaluators, (2) the quality, relevance and impact of the research itself, (3) the effectiveness of the program to manage the research projects, and to educate and train new experts in key technical fields. Our review benefited from technical presentations (see Attachments D and F), written responses to questions (see Attachment H) and proposal evaluation criteria (see Attachment K).

3.1 Follow-up on Items from Previous Evaluation

One element of our evaluation was to examine the work of our predecessors and determine if the current KYT2022 program addressed the various recommendations made by the last external evaluation team. The previous evaluators highlighted perceived challenges and made suggestions throughout the body of their report (Ref. 5). For each challenge and suggestion, we followed up to evaluate the implementation in the current program and moving forward. We had the benefit of a prepared written response to each of the following items (see Attachment B).

- Suggestion S1. As a reminder, the opportunity to enlarge the research projects to post accidental waste, NORM [naturally occurring radioactive materials] and operational safety of geological disposal would still be worth reassessing and, where appropriate, the non-relevance or low priority of these research areas made explicit.

This suggestion was not implemented, projects on post-accident waste were not presented in the frame of KYT2022. The KYT2022 program enables suggested research topics but has, in practice, focused on nuclear waste and long-term safety. However, NORM is not mentioned in the draft of SAFER2028 framework plan and appears to be left out.

- Suggestion S2. In planning of future reviews, the safety issues and associated technical/scientific needs should be introduced in more detail by the stakeholders of the KYT2018 program.

The stakeholders in the current review had been instructed to include this point of view. In general, the stakeholders were quite well prepared to discuss these themes in the meeting. This practice should be continued in SAFER2028.

- Suggestion S3. The Authority should provide clear guidance to the applicants regarding the need for depicting the technical context of the proposal (state-of-the-art, remaining issues, …) and the added value of the expected/ obtained outcomes for safety case reviews.

We found that this suggestion has been implemented through increased focus on technical areas of safety significance. This is reflected in the KYT2022 program, but also in the SAFER2028 framework plan.

- Suggestion S4. The Authority should display the last annual progress reports in English, as well as the slides ahead of the visit in case a deeper review of the relevance of the projects and of their scientific outputs is required.

The working language for the KYT2022 program was Finnish, so this suggestion had not been implemented. However, we note that the working language for the new SAFER2028 program will be English. Therefore, this suggestion will be implemented in the new combined program.

- Suggestion S5. A more secured budget should be preserved for the KYT multiyear projects.

The KYT2022 program management have followed-up on this suggestion by introducing "Excellence" projects. Excellence projects do not need to apply for funding for each year and are above all, funded according to the approved budget plan so long as no material changes are made to the research plan. Excellence projects will also be used in the SAFER2028 program and we agree with this approach. We also see the excellence project model as being useful, especially, for the doctoral education network so that the program can secure funding for the duration of a student's doctoral studies.

- Suggestion S6. The motivation why the project supports the safety case should always have a prime emphasis in the project planning and goal setting. Besides, innovations and research that would challenge the WMO [Waste Management Organization] safety case should be encouraged.

This suggestion has been partially followed but we have identified some KYT2022 projects with few or no direct links with the safety case. We noted that the draft SAFER2028 framework program clearly identifies four "central topics within the research area of

nuclear waste management" (see Section 5.3.2 of Ref. 3). We believe that it will be possible to improve the relevance of the projects to the safety case provided that the projects funded in SAFER2028 program are relevant to one of these four central topics. That will be up to the management group and Nuclear Waste steering group (SG3) of SAFER2028 to make sure corresponding projects are funded.

- Suggestion S7. Links with nuclear operators should be strengthened to anticipate potential further issues that would need R&D [Research and Development] and competence building regarding nuclear waste management.

We found that several means for promoting such links are in use. Nuclear operators are involved in the steering and reference groups. KYT2022 framework program was written in a planning group named by MEAE and all nuclear facility operators were represented. The draft of SAFER2028 framework program was similarly written. A competence mapping is planned for the current year in KYT. However, in many cases it was obvious that end-users, especially Posiva and the utilities, could be more proactive in guiding the projects.

- Suggestion S8. International collaboration should be further enhanced and in this work Finnish contributions could involve all national participants together (including all stakeholders in the Finnish team: KYT2018, Posiva, STUK, utilities, etc.).

We found that the international collaboration in the KYT2022 program varies a great deal from project to project. However, we find that there are links to EURATOM and NKS projects, but few, if any, direct international research partners. Finland as a forerunner in the waste management research area, and, therefore, should be able to attract international research exchange and collaboration. We acknowledge the goals set in the SAFER2028 draft framework program for widened European and international collaboration, as well as the identification of possible partners. Therefore, we believe there will be greater encouragement of international collaboration moving forward.

- Suggestion S9. The opportunity/benefits for KYT to enter the SITEX [Sustainable Network for Independent Technical Expertise for Radioactive Waste Disposal] network and the EJP [European Joint Programming] in case they take place should be evaluated.

We found that the suggestion had not been implemented in KYT2022 because there is no direct involvement in these, however, there are links on project level (e.g., KÄRÄHDE). Moving forward, we observed that the SAFER2028 framework plan aims to enhance useful joint programming with European projects; international collaboration is recommended

in the frame of SAFER 2028 (see Chapter 4 of Ref. 3). The evaluation team therefore agrees that the recommendations are taken seriously and have found their way in the SAFER2028 framework.

- Suggestion S10. Access to CNS for KYT funded teams should be favored where requested.

The previous evaluation team suggested that the access to CNS for KYT funded teams should be favored where requested. In this context we give the general recommendation that VYR-funded infrastructure should be available for use by researchers from other organizations (see Section 5.5 of this report). We had a discussion on that point during the exit meeting on February 18, 2022 (see Attachment A) and a CNS representative stated that CNS staff would like to facilitate sharing the resources but that the details for such collaborations are under development.

- Challenge C1. Synergies should be developed with international organizations dealing with NWM [Nuclear Waste Management] to further disseminate and exchange research results of KYT via various means.

Some KYT2022 projects have links to EURATOM and NKS projects, but few, if any, have direct foreign research partners. International collaboration was discussed widely in the SAFER2028 planning group, and collaboration goals and possible partners were introduced in the draft of SAFER2028 framework program. This is an area that should be further enhanced in SAFER2028, and this appears to be a goal of the current framework.

- Challenge C2. Ensure a good balance in the development of the national know-how in the NWM [Nuclear Waste Management] field which secures the needed level of independent expertise to support the authorities.

Securing independent expertise is difficult, especially in a field such as nuclear waste management, which requires a long lead time for a person to become an expert. These difficulties can be compounded for a smaller country, such as Finland. Therefore, we agree with the previous evaluators that this is a challenge. According to a survey from 2017 (see Section 1.3 of Ref. 3) the demand for master's degree holders was not met. The issue is being acknowledged in SAFER 2028 framework plan. Funds are being dedicated in SAFER2028 towards meeting this challenge.

- Challenge C3. The steering group must have an important role to increase the visibility of the programme [sic] and quality of the KYT2018 projects

We agree that this challenge has been partly met. Indeed, high level scientific publications have contributed to increase visibility, and researchers are quite engaged in international collaborations. Yet the public and international recognition of KYT2022 outcomes is probably not at an equivalent level to the SAFIR2022 program. In SAFER2028, SAFIR and KYT programs will be merged in a single program and there could be competition for funding between SG3 (Nuclear Waste) and other SGs. We understand the role of the MG in the SAFER2028 framework to balance the distribution of the funding according to several considerations. Just a few of these considerations include: (1) the relevance of the proposals to stated research priorities, (2) how effective a project would be in maintaining and developing important technical expertise, and (3) how funding distributions achieve an equitable distribution of funds between reactor and waste management projects. It will remain the role of the MG to balance the fundings properly. It will be the role of the TAGs in the new framework to ensure the quality of the SG3 research; the TAGs are modeled on the SAFIR2022 RGs, which we have found to be effective (see Section 2.3 of this report).

- Challenge C4. CNS is a very important research asset for the whole country and it is necessary that it will be fully exploited as a part of common R&D infrastructure of the country with enhanced national and international collaborations.

We recommend that VYR-funded infrastructure should be available for use by researchers from other organizations (see Section 5.5 of this report). We had a discussion on that point during the exit meeting on February 18, 2022 (see Attachment A) and a CNS representative stated that CNS staff would like to facilitate sharing the resources but that the details for such collaborations are under development.

3.2 Quality, Relevance, and Impact of Research Products

The research projects under the KYT2022 program are organized into several follow-up groups (SRs). The assignment of the projects to the SRs, as well as brief project descriptions are given in Table 2.

Table 2. KYT2022 Listing of Follow-up Groups and Project Names

Project	Description
SR1	**Bentonite-Rock Interaction**
BROCTIO	Bentonite-Rock Interaction
SR2	**Canister**
BECOLT	Behavior of Copper Under Load Transients
CRYCO	Validated advanced modelling and prediction of long-term deformation and damage of copper
KAPSELI	Canister Performance Assessment
MECAN	Mechanical Strength of the Copper Canister and its Cast Iron Interior
OXCOR	The effect of oxide layer on copper corrosion in repository conditions
SUCCESS	Sulphide induced stress corrosion in copper
SR3	**Multi-barrier Interaction/Microbiology**
BIKES	Biogeochemical scenarios
KaMu	Effect of existing conditions to gas formation in low level waste repositories
KUKO	Interactions of the release barriers and their impact on copper canister corrosion
MiBe	Microbial impacts on bentonite
MIMOSA	Diverse metabolic pathways of microbial communities in deep pressurized bedrock
MoToPro	Multibarrier System Performance - Microbiological and Chemical Processes
VaVu	Interactions of the release barriers
SR4	**Host Rock**
CROCK-2	Factors affecting the Chemical form and Retention of Radiocarbon in the Bedrock
KARIKKO	Bedrock Fractures
MIRA-3D	3D Modeling of microstructures
RAKKA	Water Conductivity of Fractured Rock

Project	Description
SR5/SR7	**Fuel and Biosphere / Alternative Technologies**
ALES	Actinide-Lanthanide Separation
KÄRÄHDE	Spent Fuel Characterization and Source Term
NATLAB-14C	Using volcanic-geothermal fields to investigate transfer of deep geological C sources into terrestrial food webs
PORA	Fuel microstructure and radium solubility
RABIO	Better Radioecology for Biosphere Modeling
RASK	In-situ Experiments - Radionuclide Transport on Cement and Rock Interface
SR6	**Low and Intermediate Level Waste**
DEMONI	Decommissioning Material characterization and final disposal studies
SURFACE	Near Surface Repositories
TERKOR	Corrosion of low and intermediate level steel waste under in-situ repository conditions
SR8	**Other Studies / Social License**
CLOMAP	Examining Closure-Related Issues in Finnish Radioactive Waste Repository Programs
SMRWaMa	SMR Waste Management in Finland
SOLID	Acquiring Social License for Disposal: trust and acceptance
YLYMU	Final disposal of spent nuclear fuel and societal memory

We have documented our review for each of the SRs in the following sections of this report.

3.2.1 SR1 Bentonite-Rock Interaction

The BROTICO project under SR1 was presented to a subset of the evaluation team. An overall introduction helped us to better frame and assess the work being done under this SR. The hydromechanical and hydrochemical interactions of bentonite is acknowledged to be a topic with few residual and safety relevant uncertainties. The BROTICO project has been running under different names since KYT 2014 (BOA) and 2018 (THEBES). The project involves participation by the University of Jyväskylä and the Finnish geological survey.

At the University of Jyväskylä a microtomography method is being developed to understand how water wets bentonite. At the Finnish geological survey rock samples are being characterized.

The project under SR1 is linked to running European EURAD (HiTec) and H2020 (BEACON) projects and as such may help to maintain expertise on Bentonite in Finland. The evaluation team is however convinced that a tighter collaboration with the end-users could result in more meaningful results that could improve Posiva's safety case.

3.2.2 SR2 Canister

A subset of the evaluation team attended talks on the research projects under SR2, which focuses on assessment of the canister evolution under repository conditions, i.e., KAPSELI. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current waste management regulatory environment in Finland with a clear relationship to questions important to nuclear safety. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects, which were also presented to us. Collaboration with the Swedish research program seems in this context very valuable. The evaluation team however considers the Finnish waste management program already well advanced, and we are uncertain about the practical value of asking research questions related to the canister material choice given the current schedule for the anticipated repository regulatory approval.

The BECOLT project under this SR investigates how creep of copper canister and weld material under repository conditions impacts the safety related properties of the canister. This project stood out to the evaluation team as an example of a project where national and international stakeholders can be involved to produce results that impact safety.

The MECAN project investigates different processes and phenomena related to the canister and cast-iron insert that affect the mechanical stability. It is not directly linked to any specific safety related issue but aims at further reducing uncertainties in the long-term performance assessment of this barrier.

The CRYCO projects investigates the formation and evolution of cavities as a result from creep processes with a combination of scanning and transmission electron microscopy. These mechanisms are then implemented in a crystal plasticity model to evaluate the material performance during the period under consideration by safety.

The OXCOR projects aims at answering the question whether an initial oxide film on the copper canister can increase the copper corrosion rate under relevant conditions. The results show that the impact of the initial oxide film has no measurable impact. These insights help to reduce uncertainties related to the performance of the canister for the period of consideration.

The SUCCESS project aims at answering the questions that arose from a Japanese publication in 2008 regarding the role of sulfide species in stress corrosion cracking. This project stood out to the evaluation team for its close collaboration between end-user and scientists and thus for well-target research.

3.2.3 SR3 Multi-barrier Interaction/Microbiology

A subset of the evaluation team attended talks on the research projects under SR3, which focuses processes and phenomena that are microbially induced, i.e., MoToPro. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be somewhat relevant to the current waste management regulatory environment in Finland with a relationship to some questions important to nuclear safety. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. A clear link to European projects such as MIND is encouraged as it promotes the scientific exchange and opportunities for networking.

The VaVu project under this SR coordinates the different sub-projects KuKo, BIKES, MiBe and MIMOSA. The overall goal of MoToPro is to understand the effect of microorganisms in the release of nuclides. We observed that in different cases the relevance of the results was flawed by choosing non-representative boundary conditions e.g., bentonite as a slurry, or the amendment of nutrients to speed up possible reactions.

The KUKO project under this SR stood out to the evaluation team as an example of a project that addresses a safety relevant question and educates future experts in an interdisciplinary field (corrosion science and microbiology).

We found the results presented in the frame of the MIMOSA and the BIKES projects did not convincingly show much significance to the safety case. Unfortunately, the MiBe experiments are done under conditions such that the obtained result can hardly be used for the safety case.

Dedicated to low level waste management, the large scale GGE experiment is ran in the frame of the KaMu project. This experiment has in the past allowed researcher to formulate a model of the different processes resulting from the degradation of the waste. This experiment is now being perturbed by adding sulfate and changing pH to understand how the system reacts. This experiment delivers valuable information on the system behavior under changing boundary conditions. Thanks to regular meetings with utilities (especially TVO, but also Fennovoima, Fortum and Safram), this project received a lot of useful feedback from end-users.

A more dedicated involvement by the end-user would be beneficial to some of the sub-projects in the frame of MoToPro by formulating relevant questions and defining representative boundary conditions so this project can produce meaningful results.

3.2.4 SR4 Host Rock

A subset of the evaluation team attended talks on the research projects under SR4, which focuses on host rock studies for radioactive waste repositories. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current waste management regulatory environment in Finland with a clear relationship to questions important to nuclear safety, primarily relating to fluid flow in fracture networks. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects, which were also presented to us.

The MIRA-3D project under this SR stood out to the evaluation team as an example of a project where the end-user (STUK in this case) was interested in the research products but was not actively engaged during the project. The MIRA-3D, KARIKKO and RAKKA projects all deal with fluid flow in fracture networks, and therefore, all have a similar nexus with the safety basis of the repository. This connection was made clear by STUK staff in attendance at the meeting, however, the evaluation team observed that the STUK engagement with the researchers could be enhanced. Along these lines, the KARIKKO researchers suggested they will host an upcoming workshop to interact with stakeholders and perhaps their international collaborators at Bergen. We would encourage such interactions as we have observed them to benefit other projects.

The C-ROCK2 project under this SR stood out to the evaluation team because of the unique nature of the research and other rather unique aspects of the context of this project. First, we found the topic of the research to be relevant to better understanding the possible radionuclide pathways for possible release. The effect of microorganisms on factors such as chemical form and fractionation are likely important, but it is not clear if the research here is being considered by the end-users in establishing the safety basis. Further, it appears that the project researchers have emigrated from Finland, and continued support of the research would be contra to the objectives of the program to develop and maintain expertise within Finland.

3.2.5 SR5 Fuel and Biosphere /SR7 Alternative Technologies

A subset of the evaluation team attended talks on the research projects under SR5 on fuel and biosphere and SR7 on alternative technologies. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area relevant to the current waste management regulatory environment in Finland with a relationship to questions important to nuclear safety and in education of the next generation of experts. In general, we could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment. The quality is further evidenced by the number of peer-reviewed scientific publications produced by the various projects, which were also presented to us. Several projects have frequent communication with end-users and key experts. Some also have international collaborations.

The RABIO project aims at refining radioecological transfer parameters of elements in boreal aquatic food chains for improved biosphere modeling. Whereas the NATLAB-14C project is focusing on the transfer of carbon-14 (^{14}C) from deep geological sources to the biosphere. Neither project is directly related to repository safety, rather both aim to decrease the uncertainties related to the postulated dose when nuclides are released. A link to the international collaborative research forum BIOPROTA was mentioned during the presentation.

The RASK project aims at characterizing the retention and diffusion behavior of radionuclides with low sorption capacity. This project stood out to us as a topic with a long history of research and a correspondingly small uncertainty that could be relevant for safety. We understand the key importance of expertise in the field of nuclide mobility because of the clear relevance of this expertise to safely licensing radioactive waste

disposal. The low potential for novelty driven research in this area seems to be somewhat compensated by international collaboration.

The ALES project stood out to the evaluation team as an example of a project where recommendations from the external review of the KYT2018 program have been implemented. Actinide-lanthanide separation is not a research topic that tries to answer urgent issues in the field of waste management. The motivation for this project appears to be purely the education of tomorrow's experts in waste management technologies.

The PORA project aims at understanding the mobility of radium in the nearfield under relevant conditions. Experimental work (using barium as proxy for radium) is being complemented with analysis using molecular dynamics. The connection to the safety case was not obvious to the evaluation team as radium is not a dose relevant nuclide nor are Zeolites used in Posiva's repository design. In this context it seems that coordination with the end-user could be improved. It appears that the main added value of this project is to educate the needed experts for the Finnish waste management program.

The KÄRÄHDE project dealt with the identification of relevant uncertainty components in computational spent fuel characterization. The KÄRÄHDE and RASK projects stood out to the evaluation team as examples of projects highlighting the importance of arranging informal meetings and seminars that facilitate research discussions with end-users, in this case Posiva and power companies. By going beyond the formal meetings of the program, the projects have benefited from increased engagement with industry partners.

3.2.6 SR6 Low and Intermediate Level Waste

A subset of the evaluation team attended talks on the research projects under SR6, which focuses on low and intermediate level waste. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current waste management regulatory environment in Finland with a clear relationship to questions important to nuclear safety primarily relating to release of nuclides as a result of corrosion processes. We could understand the pragmatic value of the research products to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment.

TERKOR and DEMONI projects stood out to the evaluation team as examples of interrelated projects that clearly benefit from extensive collaboration with the implementing organizations. The results are being implemented for the planning phase

for decommissioning. They deal with real nuclear power plant materials under both real site ground water and simulant water conditions.

TERKOR is conducted at VTT, and it deals with corrosion of low and intermediate level steel waste under in-situ repository conditions to better understand the nuclide release. DEMONI is a coordinated project between VTT and University of Helsinki. It is supported by NKS and the European Union which, besides providing additional resources, allows regular validation of the results by Nordic and international intercomparison.

The projects are characterized by open and active dialogue with end-users, including operators of present repositories, planned repositories and regulatory authorities. End-users have provided access to existing repository sites and access to ground water and provided additional information about relevant material samples and operational conditions. This kind of dialogue is important in directing the research on practically relevant questions and ensures that the results will be adopted by the end-users.

The SURFACE project stood out to the evaluation team based on its relevance. SURFACE focusses on the realization of near surface disposal of very low level radioactive waste. The project is being led by TVO. We found it difficult to assess how this project conforms to the overarching funding goals of KYT2022.

We have noted some imbalance between the available VYR funding and the extensive range of topics covered by the research program. We have made some recommendations in this area in light of our findings in these projects. We found that the DEMONI research team has managed to get additional funding through international collaboration, and the benefits are obvious in terms of the research output. We also saw that the well-functioning working relationship with the end-users helps to better frame the work and leads to a more efficient use of the available resources.

3.2.7 SR8 Other Studies/Social License

A subset of the evaluation team attended talks on the research projects under SR8 "Other studies," which is an umbrella area consisting of three projects CLOMAP, YLUMU and SMRWaMa. These are diverse, new topics that had not previously been studied within KYT2022 or its predecessors. The projects have been conducted in the latter half of the program period, with themes related to closure and post-closure issues, societal memory and special questions of waste management of SMRs. The researchers gave short presentations on their projects and addressed our questions. We found the research projects under this area to be relevant to the current waste management regulatory environment in Finland with a clear relationship to questions important to nuclear

safety. In general, we could understand the pragmatic value of the research themes to the end-users, including the regulators. We requested each project manager to provide information about the resources spent on the various research products and found that an impressive body of high-quality research was conducted for a modest investment.

The non-technological projects CLOMAP and YLUMU under this SR stood out to the evaluation team as examples where pioneering researchers have initiated studies with vital safety significance in novel, but still yet unresearched areas. At the time of the interviews, both projects had been going on roughly for a year only. Thus, they can be considered as preliminary studies. The results have not yet been published in scientific journals. However, they have been able to identify important and relevant research questions and point out directions of further research. Correspondingly, during its first year the SMRWaMa project has been able to identify critical questions for further studies.

KYT2022 also included a project on societal acceptance of nuclear waste management in the 2019-2020 timeframe. The quality of the project is evidenced by the two peer-reviewed scientific publications produced by the project. Analysis of risk and safety perceptions, opinions, and rhetoric (and their impact on acceptance and trust in technology and decision-making) can be vital for the understanding of changes in acceptability and attitudes in society. The evaluators acknowledge that the SAFER2028 framework plan highlights continued research on the social license topic. However, the plans must also be implemented through actual allocation of funds to such projects.

As a general conclusion we strongly recommend more interaction between the researchers and end-users throughout the project life-span, starting from formulation of the research questions motivating the projects. We recommend that MEAE and STUK play an active role in that process, but the utilities and Posiva could also be engaged.

3.3 Effectiveness of Program Management

The KYT2022 framework is simpler and flatter compared to the SAFIR2022 framework. The research is organized into follow-up groups (seurantaryhmä, or SRs). The flatter organization structure lends itself to more flexibility and could be considered appropriate for a smaller program (in terms of funding). We observed that over the course of the program the research had been restructured with a reassignment of the SR numbering. This led to some confusion for our evaluation team because the numbering of the SRs we received during the kick-off meeting did not match the numbering of the SRs in the final program of presentations.

In the new SAFER2028 framework, the framework more closer mimics the SAFIR2022 structure, with more clearly defined roles for the SGs and the TAGs (which replace the RGs or SRs). We believe this more regimented structure will help to prevent any future instances of confusion for the external evaluators.

While we did not have the benefit of tabulated indicators in terms of program achievements, such as theses written or papers published, we got the sense from the technical presenters that the program produced research of a high scientific quality, as evidenced by the number of peer-reviewed publications listed by the presenters, and by the technical content of the presentations themselves.

We observed during the meetings that Posiva appeared to be disengaged from the research evaluation process entirely. Further, it seemed that STUK staff perceived their role in the KYT2022 SRs as primarily a deliverable evaluator. We recommend exploring mechanisms to enhance the quality and quantity of end-user interactions with the researchers. The new structure of the SAFER2028 framework will likely facilitate such interactions by more clearly defining the role of the TAGs as a group for providing technical direction while other matters of project management (such as budgeting) are left for the SGs. The clear definition of four "central topics" in the SG3 research area of the SAFER2028 framework (see Section 5.3.2 of Ref. 3) will also facilitate engagement of end-users, provided these objectives are shared and the future selected projects are focused on these objectives.

3.4 Effectiveness in Training and Educating the Next Generation of Experts

The feedback we received from some of the end-users, most notably STUK, was that the research was meaningful insofar as it was yielding expertise in key competency areas important to the regulator. This might be contrasted with the relatively smaller value added in terms of the knowledge added or safety significance that we observed in some areas. For example, we found research on bentonite to yield incremental gains in fundamental understanding where many of the most safety significant technical issues have largely been resolved – or are at least well understood.

We, therefore, have found that the structure might lend itself to sponsoring research of modest safety significance, but, in recognition of one of the program's primary objectives, we conclude that the program has been effective in producing new experts in the technical fields relevant to the regulation of nuclear waste. Given that we have found the program to be effective, we do believe that there are opportunities for improvement

where the research could be better directed to produce more meaningful (i.e., safety relevant) results. This could be achieved through improved engagement between the researchers and the end-users, most notably STUK and Posiva. At the current stage of the Finnish disposal program, a reorientation of the SAFER2028 activities towards operational optimization and post-closure related topics should be considered. A careful assessment of the needed resources and expertise is being recommended to this end. In addition, the funding balance between research projects related to the final disposal of spent fuel and research projects related to low and intermediate level waste repository may have to be reconsidered in the future.

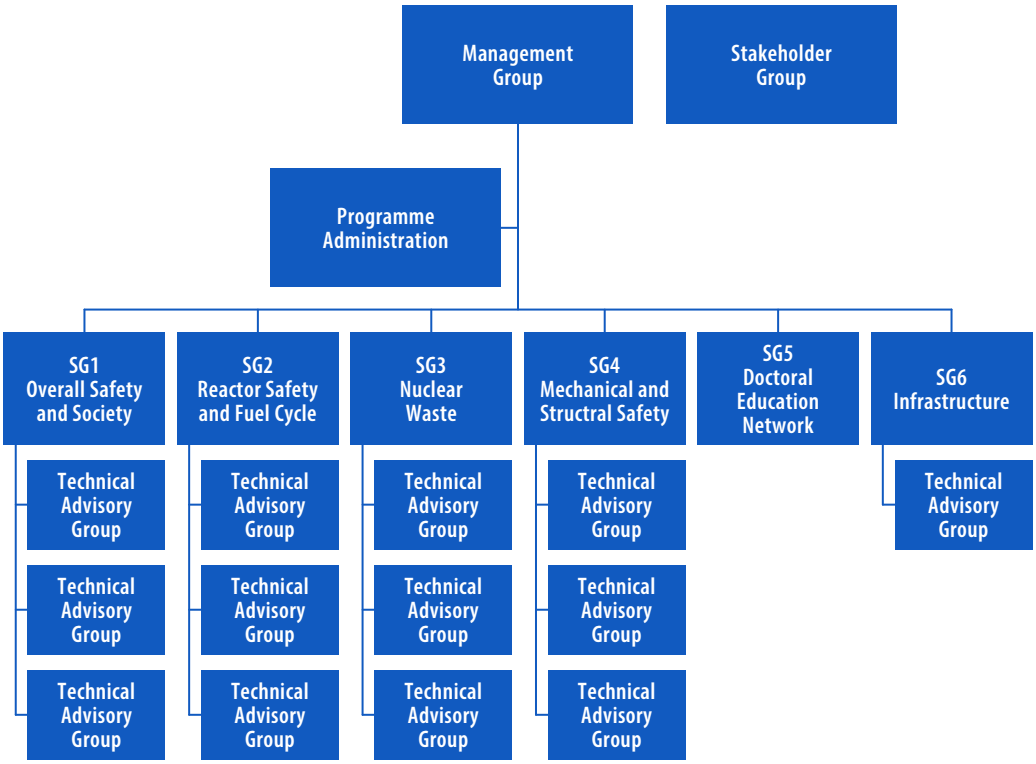
4 Review of the SAFER2028 Framework

The MEAE furnished us with a draft of the SAFER2028 framework plan (Ref. 3) and sought our opinion and recommendations. We had the chance to review this draft in advance of our visit and asked several questions regarding the draft. Our questions largely focused on the broad topics such as: roles and processes, the doctoral education network, infrastructure, funding targets and priorities, and new research topics (e.g., SMRs). MEAE provided written responses to our questions (see Attachment J) and addressed several of them during a presentation on the future framework during our visit. We benefited greatly from the clarification provided by MEAE.

The structure of the SAFER2028 program's administration is largely borrowed from SAFIR2022, which seems to demonstrate more efficiency than the flatter structure of the KYT2022 program. In the draft SAFER2028 structure, six steering groups (SGs) are responsible for the research program in their respective fields. Figure 2 illustrates the proposed SAFER2028 program structure. The role of the reference groups (RGs) in SAFIR are replaced by technical advisory groups (TAGs) in the new program. Among the SGs, SG3 is dedicated to Nuclear Waste as a continuation of the KYT2022 program. As SAFIR-like projects often seem more mature and benefit from more support from end-users than KYT-like projects, some attention will have to be paid to how funding is apportioned for these different areas in the SAFER2028 program to ensure an appropriate balance.

The different administrative levels in the structure will guarantee independence. In the SAFIR2022 program, the research organizations participated in the MB – and while we understand the research organizations did not have a direct role in award decisions – their participation, in our opinion, created the appearance of a conflict of interest. However, we heard from the research organizations that this structure might also lead to inertia and distance. As for the former, reducing researcher participation in the management group (MG) may result in fewer innovative proposals being awarded funds. As for the latter, relegating the research organization participation to the stakeholder group may reduce the cohesion between the end-users and the researchers. In our view it is important to maintain this separation between the researchers and the MG in the new SAFER2028 structure. However, the role of the stakeholder group could be better clarified in the SAFER2028 framework.

Figure 2. SAFER2028 Proposed Program Structure (Ref. 3)



Even though more or less similar approaches existed in the past, SG5 (Doctoral Education Network or DENSE) is a novelty of SAFER2028. The evaluation team understands that there will be doctoral projects administered by DENSE itself (SG5), but research projects can also propose and have doctoral projects in parallel. Considering that education is a primary way of ensuring national nuclear energy safety expertise in the long run, we recognize the important role of DENSE. DENSE will bring funding stability to 3 or 4 year-long doctoral projects that require such stability. We underline that funding should also include costs of attendance at relevant conferences, consumables and use of infrastructure when necessary, and we made a recommendation in this area. The organization of DENSE could be better defined in the SAFER2028 framework. For instance, during the evaluation, the research organizations raised the question of interactions between doctoral students and end-users if their project is hosted by SG5.

Another goal of the SAFER2028 framework is to promote multidisciplinary research. In our view, the doctoral network could also be used to foster multidisciplinary projects by tackling challenge problems in the fields of reactor safety and nuclear waste management. An example where challenge problems were used to promote multidisciplinary research would be the Consortium for the Advanced Simulation of Light Water Reactors (CASL).

In CASL six challenge problems for advanced simulation were established that required multidisciplinary research efforts. We believe that the doctoral education network could be used in a similar manner to foster multidisciplinary research by way of establishing challenge problems and we made a recommendation along these lines.

SG6 (infrastructure) is of special importance in the long run to ensure expertise in the field of nuclear safety and waste management. Up-to-date and flexible research facilities with skilled personnel are required. Due to the cost of critical infrastructures in the reactor safety and nuclear waste management fields, funding decisions need strong feedback from primary end-users, like STUK. MEAE should consult with STUK and other end-users to develop a list of strategically important research infrastructure. We made a recommendation in this area.

Infrastructure availability is an advantage for research organizations submitting a proposal to a call. Some research organizations (e.g., VTT and LUT) benefit from VYR-funded research infrastructure. We believe these facilities should be regarded as user facilities and should be available for use by researchers from other organizations. To this end, we recommend formalizing this user availability for any VYR-funded infrastructure projects.

We understand that SG5 (DENSE) and SG6 (infrastructure) have different needs which are not correlated and should have different and independent target funding values. While we understand that the MG may establish relative targets for these SGs, we have made recommendations for a reasonable approach for setting these values, which we believe should be set independently.

In line with the Nuclear Energy Act, the purpose of the SAFER2028 program is "to ensure national nuclear energy expertise over generations". We believe that achieving this goal with a limited level of funding requires a strong and efficient knowledge management (KM) policy. The organization of KM programs inside research institutes is necessary but probably not sufficient to make sure all the areas are covered long-term. Moving forward SAFER2028 should keep a high level of dedicated KM. This point needs to be better defined and included in the SAFER2028 draft framework. For instance, KM could be clearly defined as a mission of each SG. Because of the importance of KM, both in our opinion and in the stated objective of SAFER2028, we have made several recommendations in this area (see Section 5.6 of this report).

5 Overall Findings, Observations and Recommendations

We had the opportunity to visit Finland and conduct interviews with research program stakeholders, attend technical presentations given by the researchers, and meet with government officials responsible for planning and administering the research programs. In addition to these meetings, we also had the benefit of receiving written responses to our questions that could not be answered during these meetings. Following these interviews, presentations and the review of the responses, we have compiled a list of key observations regarding the programs and also noted some recommendations for improvements where we saw a potential shortcoming.

More generally, we observed that the primary, perceived value added by the research programs in the eyes of the stakeholders, or end-users, is that these programs provide a pipeline of new talent and expertise necessary for the successful regulation of nuclear power and waste management activities in Finland. As this is a key goal of the research programs, we believe it is important to note that the stakeholders find these programs to be beneficial in exactly this manner.

In our review, we looked at the research products and found them, generally, to be of a high technical quality. This is further evidenced by the body of peer-reviewed publications generated by the research programs. We found that the research, largely, had a clear nexus with important safety significant technical questions – although, in some instances, we found the research aimed towards well-established, or mature fields of study where the value added in terms of increased knowledge or improved safety might be considered marginal or incremental. In any case, though, we could see the benefit of these activities vis-à-vis the educational benefit in training new experts in relevant fields.

Compared to the funding level, we found the scope of the research programs to be quite broad. SAFIR2022 and KYT2022 cover most important technical and non-technological aspects of safety for both nuclear energy generation and waste disposal. In addition, we must note that the current Finnish environment comprises nuclear reactors in all phases of life from design (e.g., Fennovoima, VVER1200) to decommissioning (e.g., FiR 1; TRIGA Mark II). Olkiluoto 3 (EPR) is about to start electricity production alongside the existing Olkiluoto 1 and 2 units. Fortum is pursuing license extension to operate its two VVER440s. Posiva has submitted an application for operation of its long-term waste repository. We note that the

need for regulatory expertise covers a wide range of licensing activities in Finland and the forthcoming SAFER2028 program can be expected to address topics, not only within this scope, but also for SMRs.

We had the opportunity to review the expenditures of the funding relative to the various research projects and their output. We found that, in general, the research programs produce a remarkable level of scientific output for a modest stream of funding. In some instances, we have noted that projects with a smaller scope tend to be a less efficient use of the funding due to an outsized proportion of these project resources being dedicated to administrative tasks as opposed to technical ones.

Having observed the strengths and weaknesses of the SAFIR2022 and KYT2022 programs, we were well equipped to provide feedback on the new SAFER2028 framework plan, which we have done. Our feedback focuses heavily on some of the novel elements of the framework, in particular the doctoral education network. In this area we feel there are opportunities for key improvements that could make this element more effective, and we have assembled those recommendations in this report.

This section of the report provides a detailed listing of our observations and recommendations. Our observations are intended to be neutral statements of our characterization of the programs, and not necessarily criticisms. Based on these observations, however, we have attempted to make specific, actionable recommendations to address any potential shortcomings in the programs. Our observations and recommendations have been grouped according to seven thematic areas:

- Quality and Usefulness of the Results
- Flexibility vs. Continuity
- Communication and End-user Engagement
- Education
- Competitiveness
- Knowledge Management
- Other

5.1 Quality and Usefulness of the Results

Observations

- Most end-users perceive value in the results of the SAFIR2022 and KYT2022 research programs, but primarily in the sense that they receive an indirect benefit insofar as these programs produce recent graduates with expertise in

relevant fields of study. The research products themselves are not necessarily perceived as having a strong return on the investment in a general sense.
- End-users and other program participants seem to rate the preservation and development of core competencies as being more important than the value added by the research.
- In the opinion of the evaluation team, the project researchers achieved remarkable levels of output for relatively small levels of funding.

Recommendations

- In order to increase the chance for producing meaningful results we do recommend that the end-users are more actively engaged throughout the project, including during the initial framing of the project. The SAFER2028 framework should allow, if not encourage, end-users to provide ongoing feedback and technical and material support to the projects.

5.2 Flexibility vs. Continuity

Observations

- End-users and researchers alike believe that some projects are selected for initial or continuing funding in relatively mature fields of study or in areas of low safety significance primarily to ensure graduates in "core competencies," even though the value added by the research to the field of study may be incremental or produce only modest improvements in safety.
- We understand the role of the MG in the SAFER2028 framework to balance the distribution of the funding according to several considerations. Just a few of these considerations include: (1) the relevance of the proposals to stated research priorities, (2) how effective a project would be in maintaining and developing important technical expertise and (3) how funding distributions achieve an equitable distribution of funds between reactor and waste management projects.
- End-users and researchers agree that the focus of research should be directed towards more relevant areas to safety such as: ageing, small-modular-reactors, additive manufacturing, low and intermediate level waste management and social license. There is common understanding that with fixed funding resources that to fund proposals in these areas would require reductions in funding to other areas. However, there are areas of research that are relatively mature or of low safety significance that could have funding reduced.

- There is a perception that previously funded projects will continue, even without the excellence label. There appears to be a barrier to entry for new researchers when they must compete for limited funds against well-established researchers, especially when those established researchers are pursuing familiar avenues of research. There is a concern that, in the new SAFER2028 framework, initial funding decisions will "lock-in" proposals for funding for the full six-year period even though not all project proposals will be excellence projects. If this is the case, there is the perceived risk that proposals submitted after the initial call will not have a fair opportunity to compete for funding over the six-year program duration.
- There is a recurring need for preserving competencies in areas that are very well researched or mature. This hinders the capacity of the program, within the current system, to produce novel research when its resources are focused on preserving these competencies. In academia, particularly for new doctoral candidates, there is pressure to publish novel research. This can create a challenge for universities making project proposals.
- The time-scale of the program can be a challenge as some end-users are worried that the program cannot be sufficiently flexible or agile enough to address important emergent issues that require quick answers.
- The "small projects" could be used to initiate research activities for important emergent issues in a top-down way.

Recommendations

- We recommend that MEAE ask STUK, annually, to provide a prioritized listing of future needed competencies. This prioritized listing should be utilized as part of the proposal evaluation process. The call should be transparent about how this is considered in the evaluation process.
- We understand it to be the role of the MG to make decisions about project proposal awards with several dimensions to balance and we understand that flexibility is required in MG decisions about funding to achieve an appropriate balance of funding relative to the program objectives. The SAFER2028 objectives in terms of developing and maintaining domestic expertise should be more explicit in the framework and become a transparent criterion of the steering group proposal evaluation process. We recommend that MEAE ask STUK to prioritize the competencies annually. Applications should be mapped against this list of needed competencies during the evaluation process. Where flexibilities allow, the MG should strive to balance the portfolio of SAFER2028 projects to meet the projected needs according to the prioritized competencies.

- We recommend assessing the budget distribution relative to the safety goals periodically, because it seems that these evaluation results may indicate the necessity to change research priorities. Furthermore, the safety goals should be assessed periodically whether they reflect the current safety issues.

5.3 Communication and End-user Engagement

Observations

- End-user engagement in SGs and RGs can vary widely. Therefore, in some cases the project may not get enough guidance and feedback. In some instances, end-users might perceive their role in RGs or SGs as purely an outside observer or end product evaluator but in other instances they might perceive their role as a contributor.
- End-users and researchers concur that communication between end-users and researchers and amongst researchers in different topical areas would lead to more meaningful research topics, more opportunities for multidisciplinary research, benefit proposals and improve project outcomes. Communication at every stage of project life could be improved.
- End-users can be more proactive in defining the issues that are most relevant from their perspective that would warrant attention.
- Researchers are quite engaged in international collaboration, particularly Organization for Economic Cooperation and Development - Nuclear Energy Agency (OECD/NEA) projects. End-users positively view these collaborative efforts.
- The KYT2022 program research seems quite relevant to Posiva, yet engagement between Posiva and the evaluation team and technical presenters during the evaluation period appeared to be minimal.

Recommendations

- The program organizational structure itself contain various and continuous meetings (SG, RG groups) with stakeholders, end-users, research organizations, and universities. These formalized meetings are a way to facilitate interaction between parties. However, evaluation findings show that meetings that more successfully facilitate research discussions and sharing of experience between researchers and end-users, are the informal meetings and seminars that take place. A recommendation is that the program encourage these types of informal meetings and provide means to facilitate them. Additionally, more flexible requirements for the formal meetings could be applied to increase their communicative value.

- Attention should be paid on developing methods for promoting communication on multidisciplinary projects within the SAFER2028 framework. We recommend promoting ad hoc steering groups and ad hoc technical advisory groups.
- The SAFER2028 framework should allow flexibility for researchers to propose alternative reporting and meeting schedules that reflect the scope and expected rate of progress for their research. The project dependent reporting schedule should be correlated to the size of the project.

5.4 Education

Observations

- One key objective of the SAFIR2022 and KYT2022 programs is the training of new experts. However, the KYT2022 proposal evaluation criteria consider the training of new experts equivalent with the publication of new research results. This may be counter-productive to the program objective if it results in the award of a proposal where senior researchers are more apt to publish their results.
- SAFIR2022 and KYT2022 projects fund research based on specific work packages and end products and are subject to annual changes in funding levels - but this may not be conducive to fully funding a doctoral student's education. This appears to be the motivation behind DENSE in SAFER2028.
- The implementation of the "Excellence" project approach to secure longer-term funding has been well received by the end-users and researchers alike. This is especially the case for research leading to doctoral theses.

Recommendations

- In SAFER2028 we see two branches to support doctoral students. As already performed in SAFIR2022 and KYT2022 doctoral student support could be realized within the scope of Excellence projects, if funding is guaranteed for the duration of the candidate's thesis work (e.g., 4 years). Further DENSE should give the possibility for at least three-year projects to support doctoral students, including attendance at relevant conferences. The topics of the doctoral studies should refer to the objectives of the SAFER2028 framework. The projects should also include any costs associated with consumables and use of infrastructure as necessary.
- The doctoral education network (DENSE) should be utilized to encourage education of future experts with multidisciplinary capabilities. The role of

DENSE steering group (SG-DENSE or SG5) in promoting multidisciplinary research should be clarified. To this end, the SAFER2028 framework should include a list of multidisciplinary challenge problems. The MEAE should request that STUK (or other end-users or stakeholders) develop a suggested list of specific multidisciplinary challenge problems in the fields of reactor safety and nuclear waste management. A small subset of the challenge problems from those suggested that feature important competencies should be identified in the framework plan. Proposals should be accepted to address challenge problems, but these proposals must include educating doctoral students. SG-DENSE should evaluate these proposals and convene an ad-hoc TAG comprising the appropriate subject matter experts. DENSE seminars should serve as opportunities for working group meetings on these challenge problems.

- Funding within SG5/DENSE and SG6: Infrastructure should have different and independent target values because both have different objectives which are not correlated. The DENSE target value should be derived from the need to develop important competencies. A key task of the next external evaluation team will be to evaluate the efficiency and effectiveness of DENSE. MEAE should consult with STUK and other end-users to develop a list of strategically important research infrastructure and the apportionment of funds should reflect the need.

5.5 Competitiveness

Observations

- During continued funding decisions, we have observed that budget cuts to projects conducted by universities or small firms can be much more detrimental than similar cuts to projects conducted by VTT.
- There is a perception on the part of university researchers that it would be difficult to compete with VTT for award.

Recommendations

- Established research organizations with public-funded infrastructure will have a substantial competitive edge when competing for funding through SAFER2028. This competitive edge, or the perception of this competitive edge, may dissuade researchers from submitting proposals. The MG may want to evaluate the diversity of proposal submitters under the first call and determine if action is warranted to increase the competitiveness. One

option might be to change evaluation criteria to favor projects with university participation including doctoral education. Another possible option might be to attempt a blind proposal evaluation process.

- Given the amount of public investment on the VYR-funded infrastructure, the facilities should be available for use by researchers from other organizations. We recommend that MEAE develop agreement language for the awardees that enforces the principle of this infrastructure as user facilities.

5.6 Knowledge Management

Recommendations

- In the SAFER2028 program, we recommend a reinforcement of knowledge management (KM) efforts. KM action plans adapted to the list of competencies should be defined and supervised in each SG. The MG should initiate a project on KM using a "small" project. The KM project should define a streamlined approach and adapted tools, subsequently rolled out in the research projects, and published.
- In addition, for specific competencies potentially jeopardized by retirements, we recommend encouraging mentor/mentee projects (e.g., by merging projects or through greater end-user engagement). The identification of candidate projects or actions could be under the responsibility of the TAGs.
- The call should specify that the awardees should perform KM tasks at the end of the funding period. While this can be updated based on the outcome of the KM project, a minimum requirement for these tasks can be established now. For example: (1) if the project produces new methods, documentation and electronic files should be transmitted and preserved, (2) if the project produces experimental data, these should likewise be converted to a suitable electronic format, transmitted, preserved and shared to the maximum extent allowable based on the data ownership and associated intellectual property constraints. Seminars on the research should be recorded and the recordings preserved alongside other records of the projects.

5.7 Other

Observations

- For SAFIR2022 projects, the effort spent by the project manager on project administration generally ranges from 0.5 to 1.0 person-months of effort per year, regardless of the project size. For some smaller projects this represents an outsized portion of the total budget.
- In SAFIR2022 and KYT2022 the total funding applied for annually seems to have considerably exceeded the possibilities of VYR. As most of the project proposals have been considered important and worth of funding, it seems that the typical solution has been to initiate as many projects as possible and cut the budgets, sometimes drastically. This may slow down achieving the desired results.
- KYT2022 technical presentations were delivered by senior researchers whereas SAFIR2022 presentations were delivered by a mix of doctoral students, project leads, and senior managers. We generally observed that the project presenters were very well prepared, they delivered good presentations of their research, and the quality of the work seemed high.
- In the SAFER2028 framework plan, Table 1.1 in Chapter 2.3 is inconsistent with Chapter 5.

Recommendations

- The administrative load on smaller project can be disproportionately high. We recommend if projects have an administrative load of 20 percent or more of allocated funds they should be merged as work-packages of larger projects.
- We consider administrative loads to be disproportionately high for "small" projects. We recommend either merging small projects administratively together, as above, or applying modified administrative practices on them so that the burden is a more reasonable fraction of the effort.
- Instead of the current practice of funding many projects and subsequently cutting budgets, we propose the MG consider alternative funding strategies in some cases and a more selective prioritization. One alternative strategy may be to provide a larger funding level for a shortened period.
- We have noted in some projects the importance of collaboration between interrelated projects as well as both domestic and international research institutes, yielding to synergistic benefits and sometimes also improving cost-efficiency. Thus, we recommend encouraging project applicants to collaborate with possible partners when writing their proposals. This could be encouraged through proposal evaluation criteria.

- We approve the need to express overarching topics and specific goals for the program period and milestones for 2025 and 2028. We recommend finalizing and precising the preliminary elements included in Table 1.1 of the draft framework program of SAFER2028 and making it consistent with the program aims in Chapter 5 (see Ref. 3).
- We welcome the existence also of research on non-technical nuclear safety research in the SAFER2028 framework program. In SAFIR2022 and KYT2022 the funding of the projects in this area has been quite low. We want to remind that upholding the inflow of competence and research on these topics (e.g., human and organizational factors) requires appropriate and long-term funding. The framework plans must be implemented by the MG through actual allocation of funds to projects under this important research area.
- Regarding research on societal aspects, especially, within SAFER2028, we strongly recommend more interaction between the researchers and end-users throughout the program life-span, starting from formulation of the research questions. This could be a function of the MG and stakeholder group meetings in the SAFER2028 framework. We recommend that MEAE and STUK play an active role in that process. However, this could be expanded to include the utilities and Posiva.

6 References

1. Ministry of Economic Affairs and Employment of Finland, "National Nuclear Power Plant Safety Research 2019-2022 SAFIR2022 Framework Plan," August 2018.

2. Ministry of Economic Affairs and Employment of Finland, "Finnish Research Programme [sic] on Nuclear Waste Management KYT2022 Framework Programme [sic] for the Research Period 2019-2022," September 2018.

3. Ministry of Economic Affairs and Employment of Finland, "Safety and Waste Management Research – SAFER2028 Framework Programme [sic] 2023-2028," DRAFT 2021.

4. Ministry of Economic Affairs and Employment of Finland, "SAFIR 2018 Evaluation Report," May 2018.

5. Ministry of Economic Affairs and Employment of Finland, "KYT2018 Review Report," September 2017.

Appendices

Appendix 1 Attachments

We have attached our evaluation review materials to this report. The attachments may contain sensitive information, but we have made every attempt to ensure that the contents of the report, when separated from these attachments, will not have any sensitive content. These attachments provide a comprehensive record of the written materials we reviewed during our evaluation. The manifest of attachments is as follows:

A. Schedule of Activities
B. KYT2018 Evaluation Recommendation Responses
C. SAFIR2018 Evaluation Recommendation Responses
D. KYT2022 Summary Presentation Slides
E. SAFIR2022 Summary Presentation Slides
F. KYT2022 Presentation Slides
G. SAFIR2022 Presentation Slides
H. KYT2022 Responses
I. SAFIR2022 Responses
J. Draft SAFER2028 Framework Plan Responses
K. KYT2022 Proposal Evaluation Criteria
L. SAFIR2022 Proposal Evaluation Criteria
M. SAFIR Indicators

A note from the Ministry of Economic Affairs and Employment: The attachment *C. SAFIR2018 Evaluation Recommendation Responses* and the attachment *B. KYT2018 Evaluation Recommendation Responses* are included in this evaluation report as appendices 2 and 3, respectively. Other review material can be requested from the ministry. The review material is also published in the web pages of KYT2022, SAFIR2022 or SAFER2028 research programs to the extent deemed appropriate.

Appendix 2 Response to International Evaluation of SAFIR2018

Link to evaluation report: http://urn.fi/URN:ISBN:978-952-327-325-2

Recommendations (pages 5-7)	Response
1. Develop a Strategic Roadmap More can be done to provide a strategic view of the SAFIR research portfolio and additional top-down "steering" of priorities. We believe it is important to bring together both stakeholder representatives and the best information available about scenarios for the future of nuclear power in Finland. This can help define the breadth and depth of expertise needed within the country, what is available currently in terms of scientific knowledge, tools, and infrastructures and what is in the pipeline of research projects and human resources (e.g., students). The roadmap can be used to facilitate strategic conversations as part of the standard process of evaluating projects and programs, planning new programs and generating proposals, structuring the governance and organization of programs, building communities of researchers, and modifying the roadmap as the nuclear power industry evolves.	1. SAFIR2022 Framework Plan was developed in co-operation with all the stakeholders. The understanding of the operating environment and the future development was described in the framework plan. 2. The survey of competence in the nuclear energy sector in Finland was carried out in 2017-2018 that provided background information for the SAFIR2022 Framework Plan. 3. In the programme for the steering of the research in addition to the research areas eight overarching programme level topics were developed to further develop the management of the project portfolio. During the programme it was followed how much effort was allocated for each goal in the research projects. This information was utilised by the Management Board (MB) in the specific documents made for the calls for proposals each year. 4. For each of the topic goals 2022 and long-term goals 2026 beyond the programme period were established. 5. SAFIR2022 research programme capability model was developed (see SAFIR2022 Framework Plan, Appendix 1). 6. SAFIR2022 indicators were expanded to also cover assessment of the research allocated to competences described in the national competence survey. 7. The indicators and portfolio are discussed in the programme. 8. The annual calls have had specific topics relevant to changing environment. 9. MB small projects are used to start research on topics considered important, but for which no applications have been research. 12 small studies have been carried out during the programme (the reports can be found on the extranet; one will be realised in 2022).

Recommendations (pages 5-7)	Response
2. Consider Flexible Funding to Support Diverse Projects and More New Initiatives We believe that the current funding process with annual renewals for all projects and an expectation of four years of funding is not suitable for all projects and is not encouraging of novel exploratory projects in particular. The annual renewal process creates paperwork requirements for annual assessments and proposals, and is inconsistent with projects that need guarantees of longer funding that coordinate with EURATOM or other multi-year funding sources. Instead, there could be a flexible funding cycle in which most projects would have four years of base funding, but other projects could have fewer years of funding. Further, new projects and new research teams could be encouraged by having a separate proposal category and budget for development of new ideas. For example, 20% of the annual funding could be available for new proposals, innovative and disruptive ideas, and cross-discipline projects. Typically, such projects could start with a shorter funding cycle. These projects could have their own Reference Group to provide advice, organize workshops and other developmental activities. When new projects mature, they could be moved into a different Reference Group that would provide a good community, and continuation proposals could be for longer periods.	1. Excellence in research criteria were defined and the so-called Excellence project type was developed. The Management Board (MB) was committed to continue funding as planned if the project achieved its results. The funding for the Excellence projects was granted for 2-4 years. 2. There was also lighter update of the project plan for the Excellence- projects: a new proposal each year was not required, However, an update of the project plan was done as needed and the deliverables for the next year were planned in more detail. 3. About one third of the VYR funding was allocated to the Excellence projects. 4. In the beginning of the programme, part of funding was planned to be for innovative 1–2-year projects. However, only a couple of such projects were carried out due to the lack of success in the evaluation process. 5. The small projects ordered by the MB have been very effective in developing the programme.
3. Consider Flexible Organizing to Build a Vibrant Research Community Cross-project interaction is happening to some extent, but not as much as hoped. Reference Group heads could be given more encouragement to promote interactions among projects in different ways. Various kinds of workshops, conferences, and discussions with end users could encourage interactions across projects and among various stakeholders. Newsletters and blogs could help keep projects aware of progress and opportunities for synergy. Perhaps the SAFIR2018 project manager could develop a simplified project management process that would leave more time for the Steering Groups to discuss strategic issues and the Reference Groups to have meaningful research conversations.	1. Just the contents of research of each project have been discussed in the reference group (RG) meetings. The cost reports etc. are handled by the steering groups (SG). 2. Ad-hoc meetings and small workshops have been organized. 3. There was a plan for organizing SAFER2022 event to engage new researchers and further enhance the co-operation. However, Covid-19 discretions in the society have delayed those activities. 4. Despite Covid-19 an interim seminar was organized together with KYT2022 programme encouraging co-operation between research projects in these two programmes. 5. A couple of projects have been joined by the actions of the programme management and other interaction has also taken place (joint publications, use of shared data, same equipment etc.).

Recommendations (pages 5-7)	Response
4. Develop Ways to Assess Impact It is not obvious how to assess whether the results of SAFIR programs are succeeding in the long term, although it is possible to assess short-term results by examining papers published, reports issued, conferences attended, and degrees conferred. With a stronger roadmap, as recommended above, it would be possible to compare SAFIR results against strategic needs. We believe there are other indicators of SAFIR success and impact, including examining the career paths of SAFIR researchers and their impact on research, implementation, and policy, and examining the networks of co-authorship and professional relationships that constitute the "invisible college" of research communities.	1. Enlarged indicators and capability model are new in SAFIR2022 2. Eight topics and the related goals 2022 and 2026. 3. Survey on impact of SAFIR is conducted during programme period. 4. Impact of programme and future challenges were discussed in interim seminar 5. Experts earlier conducting research in SAFIR or steering the SAFIR research are at significant positions in the Finnish organisations such as TEM DDG, STUK deputy director, heads of offices, senior advisors who have significant roles in international co-operation, nuclear safety specific area (almost all STUK experts), university professors, senior experts at the NPPs and VTT etc. 6. Wanted experts to have been trained, as an example I&C, SAFIR-> STUK-> other industry. 7. Leading EU research projects are involved (Euratom, JHR). 8. OECD/NEA delivery of codes developed in Finland Serpent, FinPSA and thermohydraulic experiments at PACTEL facility 9. SAFIR is our way to train new expert to international co-operation in research where OECD/NEA is the backbone, NKS co-operation in Scandinavian countries, there are also a several bilateral projects with Sweden. 10. SAFIR2022 Interim seminar was organised jointly with KYT2022 programme. The webinar had about 450 participants from Finland and many other countries.
5. Think of Organizational Change as a Collaborative Opportunity In contrast to technical recommendations where solutions are available, expertise is acknowledged, and the difficulties are mostly around complexity and resources, organizational recommendations (such as new roles for Reference Group leaders) are more difficult because solutions have to be invented, expertise is less available or recognizable, people have to change their responsibilities, behaviours and beliefs, and stakeholders must find ways to achieve diverse interests that sometimes seem to be in conflict. Successful change requires stakeholders to open new conversations and work together to find effective paths forward on their collaborative journey and commit to collective goals and actions.	1. The RGs were established after the first call overarching multidisciplinary discussion in mind. 2. The RG chairs were selected from STUK and NPPs so that they ones able to stimulate discussions. 3. The practices in RG meeting emphasize discussions on research topics and exchange of state-of-the-art information. 4. Ad-hoc meetings and mini workshops of the projects have been held.

Appendix 3 Response to International Evaluation of KYT2018

Link to evaluation report: http://urn.fi/URN:ISBN:978-952-327-279-8

Suggestion	Response
Suggestion S1. As a reminder, the opportunity to enlarge the research projects to post-accidental waste, NORM and operational safety of geological disposal would still be worth reassessing and, where appropriate, the non-relevance or low priority of these research areas made explicit.	Yes and No - The KYT2022 programme enables suggested research topics but has in practice focused on nuclear waste and long term safety. However, NORM is not mentioned in the draft of SAFER2028 Framework Programme and might thus be left out.
Suggestion S2. In planning of future reviews, the safety issues and associated technical/scientific needs should be introduced in more detail by the stakeholders of the KYT2018 program.	Yes - The stakeholders in the current review will be instructed to include this point of view.
Suggestion S3. The Authority should provide clear guidance to the applicants regarding the need for depicting the technical context of the proposal (state-of-the-art, remaining issues, . . .) and the added value of the expected/obtained outcomes for safety case reviews.	Yes - The safety significance and links to safety case have been emphasized in the framework programme, updates from the steering group and feedback to project managers in project funding decisions.
Suggestion S4. The Authority should display the last annual progress reports in English, as well as the slides ahead of the visit in case a deeper review of the relevance of the projects and of their scientific outputs is required.	No - The last annual report is not yet done for KYT2022 (it will be made in 2023) and is not available for the evaluation. The working language of KYT continues to be Finnish, but the working language of the new SAFER programme will be English.
Suggestion S5. A more secured budget should be preserved for the KYT multiyear projects.	Yes - Excellence projects were introduced as a project type in KYT2022, having guaranteed funding for multiple years. Excellence projects will be used as a project type also in SAFER programme.
Suggestion S6. The motivation why the project supports the safety case should always have a prime emphasis in the project planning and goal setting. Besides, innovations and research that would challenge the WMO safety case should be encouraged.	Partial - Some projects have focused on this very well (e.g. BROCTIO), while others not as well. Safety case related research has not been very actively proposed in KYT2022. The steering group has attempted to strengthen the safety case links in research with different means but the impact has been minor.

Suggestion	Response
Suggestion S7. Links with nuclear operators should be strengthened to anticipate potential further issues that would need R&D and competence building regarding nuclear waste management.	Yes - Nuclear operators are involved in the steering and reference groups. KYT2022 Framework Programme was written in a planning group named by Ministry of Economic Affairs and Employment. All nuclear operators were represented. The draft of SAFER2028 Framework Programme was written by using similar method. A competence mapping is planned for the current year in KYT.
Suggestion S8. International collaboration should be further enhanced and in this work Finnish contributions could involve all national participants together (including all stakeholders in the Finnish team: KYT2018, Posiva, STUK, utilities, etc.).	Partially - KYT2022 projects have links to EURATOM and NKS projects, but no foreign research partners directly. International collaboration was discussed widely in the SAFER planning group, and the goals and the possible partners were introduced in the draft of SAFER2028 Framework Programme.
Suggestion S9. The opportunity/benefits for KYT to enter the SITEX network and the EJP in case they take place should be evaluated.	No - KYT is not directly involved in these, however, there are links on project level (e.g. KÄRÄHDE project)
Suggestion S10. Access to CNS for KYT funded teams should be favored where requested.	Partially - Discussions have been ongoing and collaboration exists in coordinated projects, but research visits have not materialized, partly due to security requirements
Challenge	
Challenge C1. Synergies should be developed with international organizations dealing with NWM to further disseminate and exchange research results of KYT via various means.	Partially - Please see Suggestion S8 and its response.
Challenge C2. Ensure a good balance in the development of the national know-how in the NWM field which secures the needed level of independent expertise to support the authorities.	Partially - KYT2022 Programme has a guide on disqualification in handling on the project proposals. However, securing of independent expertise is difficult in a small country as Finland and in the field requiring long time to become acknowledged as an expert.
Challenge C3. The steering group must have an important role to increase the visibility of the programme and quality of the KYT2018 projects.	Partially - KYT2022 programme is recognised in publicly available and internationally recognised reports, for example National Programme (as required by directive 2011/70/EURATOM) and National Report (as required by Joint Convention) and their review meetings (ARTEMIS peer reviews and Joint Convention review meetings).
Challenge C4. CNS is a very important research asset for the whole country and it is necessary that it will be fully exploited as a part of common R&D infrastructure of the country with enhanced national and international collaborations.	Partially - Please see Suggestion S10 and its response.

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