MEAE guidelines and other publications • 5/2018

SAFIR2018 Evaluation Report

Ministry of Economic Affairs and Employment of Finland

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MEAE guidelines and other publications 5/2018
ISSN 2342-7922 (Electronic publications)
ISBN 978-952-327-325-2

Layout: TEM, 5/2018

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SAFIR2018 The Finnish Research Program on Nuclear Power Plant Safety 2015–2018

Executive Summary

The SAFIR2018 Research Program on Nuclear Power Plant Safety (2015–2018) is the most recent in a series of four-year programs funded through the Finnish Nuclear Energy Act to ensure that, should new matters related to the safe use of nuclear power plants arise, the authorities possess sufficient technical expertise and other competence required for rapidly determining the significance of the matters.

Each SAFIR program is evaluated during its fourth year. The objectives of the SAFIR2018 evaluation are:

1. to examine the results of the program and how those results have added value to end users (power companies and regulator) and how they have created external awareness in the international scientific community;

2. to assess how well the expertise of the SAFIR2018 program covers necessary fields of study and how well it develops new experts;

3. to determine how successfully the recommendations made following the SAFIR2014 evaluation have been implemented and whether these changes have had the desired impact; and

4. to identify challenges and make recommendations.

The evaluation team prepared for its evaluation by reading extensive documentation about the SAFIR program and then visiting Finland for five days from 28 January to 2 February 2018. The team met with representatives from all the key stakeholder groups, including the ministry, regulator, researchers, and power companies. The team heard presentations from all research projects and met with chairs or co-chairs of each Steering Group and Reference Group. The team toured facilities at the Technical Research Center of Finland (VTT) and Lappeenranta University of Technology (LUT).

Results of SAFIR2018 and Development of Expertise

Overall, our evaluation of the scientific and technical quality of the program is very good. Individual research projects are producing results that range from good to very good. End users and stakeholders in general are pleased with the program, although some mention opportunities for improvement. Engagement of the power companies and regulator is good and their participation facilitates the relevance and success of the research program. The infrastructure projects are coming to fruition and are an important investment in future capabilities.

The capabilities supported by the SAFIR2018 program are strong for a country of Finland's size, as demonstrated by the significant numbers of graduate theses, conference presentations, scholarly publications, and extensive international cooperation. These capabilities reside in knowledge documented in reports and publications, physical infrastructure of laboratories, tools, and models (both physical and computer-based), and most importantly in people whose expertise prepares them to deal with both expected and unexpected developments. We met many young researchers presenting their work who are articulate, energetic, and excited about their research projects and career opportunities.

SAFIR2014 Implementation

The SAFIR2014 report made many specific and general recommendations, among which we focused on five areas that we judged to be of particular importance: (1) strategic top-down steering, (2) funding for research infrastructure, (3) generating new expertise, (4) introducing new projects, and (5) cross-disciplinary connections.

Significant efforts were made to address each of the five areas, with more success in some areas than in others. Most successful has been the funding for and building of infrastructure including the RADLAB facility at VTT and the thermal-hydraulics laboratories at LUT. These two facilities now provide support for reactor and structural safety research, although it is not yet clear how these facilities will be used. The generation of new expertise has also been very successful, as shown in published research and other research reports, graduate students who worked on SAFIR projects, career paths of young researchers and engineers trained in the SAFIR program and networks of collaborative relationships within Finland and with Nordic, European, and global counterparts.

It has proved more difficult to provide strategic top-down steering, to introduce new projects, and to stimulated cross-disciplinary connections. Following the SAFIR2014 report, SAFIR2018 was reorganized into a partially-matrixed structure with three Steering Groups and six Reference Groups. But this has not resulted in a fully shared and articulated strategic vision, understanding of the diversity of stakeholders needs, or strong stakeholder ownership of the main research areas. The Steering Group structure is operating primarily as a project monitoring process. The Reference Groups are quite diverse and function differently from one another. Different stakeholders hold somewhat different expectations for the immediate future and the projects to be carried out. For example, it is natural that power companies want research results that can improve operations in the near term, whereas building capabilities for an uncertain future involves balancing many diverse needs, near term and long term, well-known and imagined. Although there are some cross-project interactions and connections, the Reference Groups have not built systematic cross-disciplinary interactions. We also believe that more opportunity and support is needed for new proposals and new ideas, despite the limited budget. It is natural that established research teams with proven productivity are in a good position to receive continued funding for the same or related projects. The proper balance may also differ between the research areas. The small fund (50K Euros each year) used to selectively fund new projects is a modest step in this direction.

Challenges

Consistent with the SAFIR2014 evaluation report, we identify continuing challenges arising from an ambitious and diverse research program serving multiple stakeholder needs with limited resources. SAFIR2018 is simultaneously organizing projects to achieve scientific research goals and also add value to end users, train the next generation of experts, capitalize on synergies across projects, support existing projects while encouraging new and disruptive ideas, minimize administrative burden, and stay within budget.

Recommendations

Beyond making observations and recommendations about individual projects, we believe the most important recommendations are about the organization of the SAFIR program as a whole:

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.

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.

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.

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.

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, behaviors 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.

Conclusions

The SAFIR2018 program is strong. Results contribute knowledge and expertise needed for the Finnish regulator, universities, research organizations and power companies to assess new challenges to nuclear safety. New infrastructure provides essential capabilities. Stakeholders are engaged and generally pleased with the value they receive. The next generation of nuclear safety researchers is emerging and contributing to the pool of expertise. Finland has an excellent international reputation and a strong network of communication and cooperation with Nordic, European, and global counterparts.

However, there remain significant challenges and opportunities for improvement. Like virtually all organizations, the SAFIR program faces challenges of leveraging limited resources, attending to multiple stakeholders with diverse interests, balancing stability and deepening of existing capabilities with openness to new and disruptive ideas, managing cross-disciplinary connections to derive synergies from individual projects, and minimizing administrative burden. Any improvements, no matter how well designed, will succeed only if stakeholders work together to secure the future of nuclear safety research in Finland.

Acknowledgements

The evaluation team greatly appreciates the assistance of Mr Jorma Aurela, MEAE, Ms Marja-Leena Järvinen, STUK and Mr Jari Hämäläinen, VTT in structuring an effective process to meet so many stakeholders and gather so much information in a short visit. The team also thanks Ms Marie Kurten, MEAE for her exquisite organizing skills in providing for the care and feeding of the team. Finally, the team appreciates the hard work and candidness of all the presenters and interviewees, whose willing cooperation is the necessary foundation for a valid and useful assessment.

1 Introduction

1.1 The SAFIR Program

Finland embarked on its nuclear power program several decades ago, and since that time has made a sustained national effort to maintain nuclear power as an important component of electricity production; nuclear power currently contributes approximately 30% of electricity generation in Finland. The government and nuclear power industry have wisely recognized that maintenance and growth of nuclear power requires education and research capabilities to provide expertise for operations now and in the future. It is also essential that the Finnish nuclear industry can participate in international networks (i.e., Nordic, European, global) of experts who are sharing new technologies, best practices, and advance warnings of emerging problems. Accordingly, Chapter 7a, Section 53a of the Finnish Nuclear Energy Act is intended to ensure that, should new matters related to the safe use of nuclear power plants arise, the authorities possess sufficient technical expertise and other competence required for rapidly determining the significance of the matters.

The Finnish Ministry of Employment and Economy (MEAE) is tasked with meeting this need for expertise. The Nuclear Energy Act of 2003 provided funding primarily through fees collected from nuclear power companies and began the first of a series of four-year nuclear safety research programs, SAFIR (2003-2006). (Research groups on nuclear safety had formed in the 1960s and national nuclear safety research programs have existed since the early 1990s.) Research projects must be of high scientific quality and results must be available for publication and not restricted in use to a single license holder. Each SAFIR program is evaluated during its fourth year. The current SAFIR2018 (2015-2018) program is the subject of this evaluation.

The SAFIR2018 program planning group defined the following mission statement in 2014 at the start of SAFIR2018:

National nuclear safety research develops and creates expertise, experimental facilities as well as computational and assessment methods for solving future safety issues.

Further articulating the mission statement was a vision of a successful SAFIR2018:

The SAFIR2018 research community is a vigilant, internationally recognized and strongly networked competence pool that carries out research on topics relevant to the safety of Finnish nuclear power plants on a high scientific level and with modern methods and experimental facilities.

Competence resides primarily in people, but also in infrastructure such as laboratories and computational software, educational and training organizations, national and international networks of cooperation, and government and industry more broadly. Hence, competence refers to being able to assemble the necessary expertise to deal with unforeseen problems, which depends on both the production and maintenance of expertise, and the structures that enable that expertise to be utilized in a timely way.

1.2 The SAFIR2018 Evaluation Process

Every four years the SAFIR program is evaluated by a team of experts with the knowledge, experience, and independence to understand the program and suggest improvements. The SAFIR2014 evaluation team made a variety of observations and recommendations, and the SAFIR2018 program responded by changing the content of research and the governance structure of projects.

The objectives of the SAFIR2018 evaluation are:

1. to examine the results of the program and how those results have added value to end users (power companies and regulator) and how they have created external awareness in the international scientific community;
2. to assess how well the expertise of the SAFIR2018 program covers necessary fields of study and how well it develops new experts;
3. to determine how successfully the SAFIR2014 recommendations have been implemented and whether these changes have had the desired impact; and
4. to identify challenges and make recommendations.

The evaluation team was commissioned by MEAE and was comprised of:

1. John S. Carroll (Chair), Gordon Kaufman Professor of Management, MIT Sloan School of Management;
2. Xu Cheng, Professor at Karlsruhe Institute of Technology and Director of the Division of Innovative Nuclear Systems;
3. Jacques Giovanola, Emeritus Professor Ecole Polytechnique Fédérale de Lausanne (EPFL) and Member of the Board, Swiss Federal Nuclear Safety Inspectorate; and
4. Timo Okkonen, consultant at Reqris Oy, with extensive experience in the nuclear power industry.

The team collectively has over 100 years of experience in the nuclear power industry as researchers, educators, consultants, program and institute directors, designers and inspectors. Notably, the team has extensive technical expertise in topics within the SAFIR2018 portfolio and significant research program management expertise.

The team prepared for its evaluation by reading extensive documentation about the SAFIR2018 program (see Appendix A), and then visited Finland from 29 January to 2 February. The team met with representatives from all the key stakeholder groups, including the ministry, regulator, researchers, and power companies (see Appendix B). We heard presentations from all research projects. We met with chairs or co-chairs of each Steering Group and Reference Group (see descriptions of these groups later). The team toured facilities at the Technical Research Center of Finland (VTT) and Lappeenranta University of Technology (LUT). A short summary of key points was discussed with members of the Managing Board toward the end of the visit. A presentation of key observations and opportunities was delivered to stakeholders and discussed on the last day of the visit.

In the remainder of this report we first briefly describe the overall SAFIR2018 program and portfolio of projects, and the process by which projects are requested, evaluated, funded, and managed. We then examine the individual projects, including the results of the program in terms of value added to stakeholders and the development of expertise (the first two objectives above). We next describe the recommendations of the SAFIR2014 Evaluation and how successfully those recommendations have been implemented. Finally, we discuss the challenges facing SAFIR and what we believe would be useful opportunities going forward, both in terms of the content of SAFIR research and the way that the program operates, including the roles of key stakeholders.

2 The SAFIR2018 Program

Governance of SAFIR programs is vested in MEAE, which appoints a Managing Board (MB) chaired by a senior manager from the Radiation and Nuclear Safety Authority (STUK) and including representatives of the ministry, power companies, national laboratory (VTT), universities with nuclear engineering programs (Aalto University and LUT), the Finnish Funding Agency for Innovation (Tekes) and the Swedish Radiation Safety Authority (SSM). The MB is responsible for the overall content and planning of the research program.

Each year the MB issues a public call for research proposals, designed around the SAFIR four-year plan and input from stakeholders. Planning of research, evaluation of research proposals, and project management of results and costs take place in Steering Groups (SGs) comprised of representatives from the end users (STUK, power companies), and which report to the MB. Steering Groups are listed in Table 1 and described more fully below. Budgets are determined annually and all projects must reapply for funding each year, although in practice many research teams receive continuing funds within the four-year SAFIR program and even longer. Projects are also grouped thematically under Reference Groups (RGs, also in Table 1) with representatives from both end users and technical support organizations (VTT, Aalto, LUT). The RGs provide opportunities for scientific discussion among project managers (from the technical support organizations) and end users. The structure of SGs and RGs arose following the SAFIR2014 Evaluation as a reorganization of nine Research Groups in SAFIR2014, intended to encourage more cross-discipline interaction and strategic thinking and to improve administrative work efficiency.

Additionally, the Nuclear Energy Act was amended to collect funds for the enhancement of infrastructure during 2015-2025, providing new facilities at VTT (hot cells) and LUT (thermal-hydraulics laboratory) and funding for Finnish participation in the European Jules Horowitz Reactor project, located in France. For 2018, the SAFIR program has an annual budget of approximately 11.2M Euros, of which 4.5M Euros is for infrastructure development.

There are 30 projects currently funded in SAFIR2018, of which 1 is an administrative project that was not evaluated in this report. The remaining 29 projects are grouped into 3 SGs and 6 RGs (see Table 1). We organize our presentations by discussing each of the 3 SGs, which include five of the six RGs, and then discuss RG6, which is not associated with an SG:

1. SG1 is Plant Safety and Systems Engineering, which includes 7 projects, 4 of which are in RG1 (Automation, Organization and Human Factors) and the remaining 3 in RG2 (Severe Accidents and Risk Analysis);

2. SG2 is Reactor Safety, which includes 11 projects, 2 of which are in RG2, 5 in RG3 (Reactors and Fuel), and 4 in RG4 (Thermal Hydraulics); and
3. SG3 is Structural Safety and Materials, which includes 8 projects, 2 of which are in RG2 and the remaining 6 in RG5 (Structural Integrity).
4. RG6 (Research Infrastructure) has 3 projects without an SG.

Examining the intersections between SGs and RGs (see Table 1), it can be seen that RG1 projects are entirely within SG1, RG3 and RG4 projects are entirely within SG2, RG5 projects are entirely within SG3, and RG6 is by itself, whereas RG2 projects are divided up among SG1, SG2, and SG3. Altogether, the eight groupings in Table 1 resemble the nine Research Groups from SAFIR2014. We will discuss the effectiveness of the organization of SGs and RGs in later sections of the report. We now present our descriptions and analyses of projects organized by SGs (including RG6 by itself).

2.1 Steering Group 1 Plant Safety and Systems Engineering

The seven projects in SG1 include a wide range of topics within the general area of "plant safety and systems engineering." Four of the projects comprise all of RG1 Automation, Organization and Human Factors and the remaining three are part of RG2 Severe Accidents and Risk Analysis; RG2 includes other projects in SG2 and SG3 (see Fig 1). Not only are projects diverse across RG1 and RG2, but those within an RG are quite distinct, and even the work within a single project can involve work packages that are essentially separate projects. Overall, we identified three groupings among the seven projects: (1) human and organizational behavior, (2) risk analysis of specific hazards, and (3) broad issues of risk analysis.

2.1.1 Human and Organizational Behavior

Two projects, both in RG1, examine human and organizational behavior: CORE and MAPS. CORE focuses on operator resilience in challenging operations situations, such as multitasking, troubleshooting, coping with stress, and communicating in emergency situations. CORE has a comprehensive approach with work packages focused on prevention, preparation, and mitigation of consequence management. The goal is to support operating personnel who need to have an in-depth understanding of plant systems in order to maintain safety, and capabilities for flexibility, adaptability, learning from operating experience and self-reflection. CORE is therefore focused on the competence of operators in highly-regulated and automated work contexts, rather than on the competence of researchers, regulators, or other industry experts. Much of the CORE approach relies on classic applications of human factors to operator behavior, however, the project also investigates newer topics such as self-reflection as a means to increase operator resilience.

CORE results are embodied in training materials and interventions, operational guidelines, human factors tools for anticipating problems, models and simulations. There is a good stream of papers and publications, as well as graduate theses. It is important to think about assessing the impact on operations beyond operator ratings of training experiences. Although operator guidance may be developed and embedded in policies and training, assessing the impact of that guidance on operator resilience is still a challenge. Has operator behavior actually changed, with demonstrable and positive results? Such an assessment could involve simulator activities, table top exercises, control room observations, and analyses of incident reports (focusing on mitigation and recovery as well as prevention and preparation). This is a challenge for the global human factors community, and Finland is well-positioned to contribute to this effort, and possibly play a leading role. Further, although CORE seeks a comprehensive approach that includes individual, work design, team, and organizational factors, the work packages are mostly designed around the individual, consistent with the heritage of the human factors field (with some exceptions, such as the goal to study distributed work teams). For example, prevention of work stress is accomplished by training operators to be fluent multitaskers, not by examining staffing levels and work organization, or by looking at interactions across operations, maintenance, engineering design, training, and management.

MAPS has an even broader set of work packages including management of complex projects involving multiple contracting organizations and multiple national cultures, understanding cultural phenomena and impacts on safety culture, and developing tools and guidance for project management and safety culture. Managing complex projects involving multiple contractors and sub-contractors, with supply chains often crossing national borders with varying legal and cultural expectations, has emerged as an important topic in many safety-critical industries, including nuclear power, oil and gas, and aviation. MAPS work packages represent an interesting set of ideas about safety culture and bits and pieces of projects, such as project alliancing and safety culture ambassadors, but it is challenging to bring these together in an integrated approach. MAPS is producing papers, publications, and graduates, but has the greater challenge of being in a less developed and more diffuse field. Both CORE and MAPS include topics such as communication, decision making, problem solving, and learning, and they sought to conduct a joint workshop and to cooperate on a joint paper, although we have not seen the results of these collaborative efforts.

These projects raise the strategic question of whether they belong in the portfolio of SAFIR2018 projects, because they represent areas of expertise that are less well-developed world-wide, less evident in Finland, and less obviously "nuclear." Although the human factors field has focused on man-machine interactions for many decades and more recently has expanded its focus to teams and organizations, organizational culture and safety culture in particular are a relatively new and contested field. Further, while recognizing that there has been a human factors group at VTT for 30 years, this group, to our knowledge, has not focused on organizational and safety culture.

Nevertheless, we believe further discussion of the priority for these areas of competence is warranted. These are areas of considerable value in safety management, as evidenced by the importance placed upon them by organizations in the nuclear power industry such as IAEA and WANO. Both projects have sought to develop expertise, in part, by reaching out beyond the nuclear power industry: CORE collaborates with the Finnish Institute of Occupational Health and MAPS has been benchmarking the Norwegian oil and gas industry. Discussion should include additional ways to support development of competence (particularly acute for the MAPS team), such as an additional university professorship, visiting scholars, support for scientific conferences, and/or an advisory board of experts.

2.1.2 Risk Analysis of Specific Hazards

Three projects analyze risks of specific hazards: SAUNA (RG1), ESSI (RG1), and EXWE (RG2). SAUNA looks at the expansion of digital automation in nuclear power plants, particularly in instrumentation and controls. It is developing analytical tools and model checking approaches to make the safety case around new information architectures and defense in depth. There are many topics being covered. Some of the work relates to culture and the MAPS projects, and work on PRA links to the PRAMEA project.

ESSI is a new project initiated after the Fukushima accident. ESSI examines accident scenarios involving common cause open phase electrical faults, lightning strikes, and the requirements of adaptive operation (load following). The goal is to identify risks through modeling and simulation as well as surveys of plant preparedness, and subsequently to specify requirements to ensure safety. There is some overlap with CORE in studying operator behavior of noticing and reacting to problems.

EXWE has an analogous goal around meteorological modeling of extreme wind and sea level conditions that could threaten nuclear plant safety, another topic that received additional attention after Fukushima. This project involves researchers from the Finnish Meteorological Institute; there are a substantial number of doctoral dissertations from Aalto University and some cooperation with a Norwegian research center.

2.1.3 Broad Issues of Risk Analysis

The remaining two projects, both in RG2, analyze broader risks and risk analysis methods: GENXFIN and PRAMEA. GENXFIN is focused on licensing issues and materials challenges with new technologies, including small modular reactor designs, fourth generation light water reactors, and fusion designs. The European Strategic Energy Technology Plan advocates new nuclear power technologies as part of de-carbonization, and this was the reason GENXFIN was initiated. GENXFIN is very active with international working groups and other national and international networks (e.g., GEN4FIN, OECD/NEA, GIF, NUGENIA, IAEA). It seeks not only to develop technological expertise, but also to nurture new business opportunities for Finnish companies in technology transfer, process development, and materials engineering.

PRAMEA is developing extensions of Probabilistic Risk Assessment (PRA) methods that would be useful for site-level (multi-unit) accidents (where disturbances in one unit initiate problems in another unit), and useful in general, such as dynamic flowgraph methods and better ways to introduce human reliability analysis (HRA) into PRA. Some of the work packages focus on improving the efficiency and usefulness of models that are unsolvable with current techniques. PRAMEA connects to SAUNA around defense-in-depth, EXWE on weather conditions and atmospheric releases, and FIRED, FOUND and CASA on analyses of fire risks, aging mechanisms and severe accidents. Research on the digital control room and human reliability in general could link to operator behavior in the CORE project. PRAMEA has strong cooperation with other Nordic countries. Because PRA is such a central topic to risk analysis and risk communication in the global nuclear power community, it is important to maintain competence in Finland.

2.1.4 Overall Evaluation

The seven projects within SG1 fit the SAFIR2018 mission and each has produced results that meet expectations for competence, in terms of papers, publications, graduate training, national and international networks, and reputation. However, the collection of projects may not constitute a coherent program. Without a strategic analysis and plan, it is difficult to know whether the program is producing the right results.

2.1.5 Challenges

- The projects in SG1 are particularly challenging because they cover a wide range of disciplines, from human factors and organizational culture to probabilistic risk analysis. Although there is general recognition that safety is more than technical defense-in-depth and must include human and organizational behavior, actually achieving valuable conversations and collaborations across diverse disciplines is very difficult. These disciplines vary greatly in how established and convergent are their approaches and methods. PRA is well-established and algorithmic, although still facing challenges of applicability to software, human behavior, system-level interactions, and other accident causes; whereas organizational culture is a relatively new field with contested theories and approaches. These disciplines also vary considerably in how much they target nuclear safety. Although PRA emerged from the nuclear power industry, as a risk analysis method it is applied to a wide range of risks. Similarly, human factors, project management, and organizational and safety culture research methods and results are applicable to any industry. Hence, in contrast to other parts of the SAFIR2018 program, the projects in SG1 are more generic and therefore raise the question of priority within a nuclear safety program. How important is it for nuclear safety to have these capabilities represented in the Finnish nuclear power community?

- This variability among projects generates the related challenge of linking across projects. It is not clear which projects need to connect with each other and how best to facilitate those interactions. Although many of the projects in SG1 have connections with each other, there is no obvious reason why some projects are together in SG1 rather than in another SG. Similarly, there is no obvious integrity or purpose to RG1 or RG2. RG1 is fully within SG1, yet they represent a diverse group. The RG2 projects in SG1 have some linkages to RG2 projects in SG2 and SG3, and some linkages to some of the RG1 projects, but a variety of groupings could be attempted.
- Further, without a clear plan, it is difficult to assess progress against the plan. How can we then evaluate competencies for handling unexpected future challenges? Our evaluation is based on the quality of the work, judged by papers and publications, and on the quality of the students and researchers in the next generation whose competence will be needed. But these indicators vary greatly depending on the stage of research, activity in the field (how many conferences and journals accept such work?), innovativeness of the approach, availability of support, and so forth. Additional indicators would be helpful, such as career paths of graduates, citation rates of papers and publications, implementation of ideas in power plants with measures of enhanced safety performance, and size and nature of networks. Such indicators take years to develop and years to see results to fruition, particularly when the work is more innovative and therefore less interpretable with existing indicators.
- The SAFIR program attempts to cover a broad range of topics with modest resources. Funding is moderate and the intention of the SAFIR2018 Framework Plan was to keep funding constant or increased slightly; however, funding was reduced noticeably from 2015 to 2016 due to loss of a revenue source. Projects responded by canceling some work packages and otherwise making do with less. Each project within SG1 funds approximately 0.5-3 researcher-equivalents per year. These are modest investments considering the number of work packages, range of topics, and results desired. It is particularly challenging for those projects that are smaller or more isolated from communities of scholars.

2.1.6 Recommendations

- The diverse set of projects in SG1 would benefit from a clear strategic plan or roadmap. This would help set priorities and determine needs regarding what has to be available within Finland in contrast to areas of expertise that can be assembled worldwide as needed (as this evaluation team was assembled). We believe that competence in human and organizational behavior is an important aspect of assuring nuclear safety, but needs thoughtful support given rapidly-changing scientific knowledge on these topics and the scarcity of expertise in Finland and many other countries.
- A stronger strategic plan should include additional guidance about what constitutes success. Current indicators such as numbers of papers, publications, and graduate theses are important but a broader range of indicators could be helpful.
- A stronger strategic plan would also strengthen arguments for additional funding. Our sense is that the SAFIR2018 program is doing a lot with a modest allotment of resources. Additional reductions in funding, such as what happened from 2015-2016, would create serious shortages. Indeed, with a clearer sense of national priorities and gaps in available expertise, stronger arguments could be made for increased funding and the value added for stakeholders.
- Finally, the organization of projects into SGs and RGs needs to be reconsidered. The projects in SG1 are a particularly varied assortment. The need for linkages across projects should be assessed. SGs and RGs could be reorganized to reflect thematic connections. Or, RG chairs could be given more authority to work together and develop creative ways to connect across projects. Consideration should be given to connections both within SAFIR and to the network of researchers and end users inside and outside Finland. These connections are of different importance to different projects. For example, MAPS could benefit from additional interactions within SAFIR (e.g., with CORE) and outside SAFIR (e.g., with the project management research community and safety culture research and implementation at IAEA).

2.2 Steering Group 2 Reactor Safety

In accordance with the objectives for SAFIR2018, the eleven projects in the second Steering Group (SG2) deal with the development, maintenance and application of infrastructure (experimental facilities and numerical tools) in “reactor safety.” They cover the experimental and numerical capacity and expertise in the following areas:

1. Reactor physics
2. Fuel behaviour
3. Thermal hydraulics (STH)
4. Multi-physics and multi-scale code coupling

Figure 1 presents the relationship between the eleven projects, which are assigned to three different reference groups (RGs).

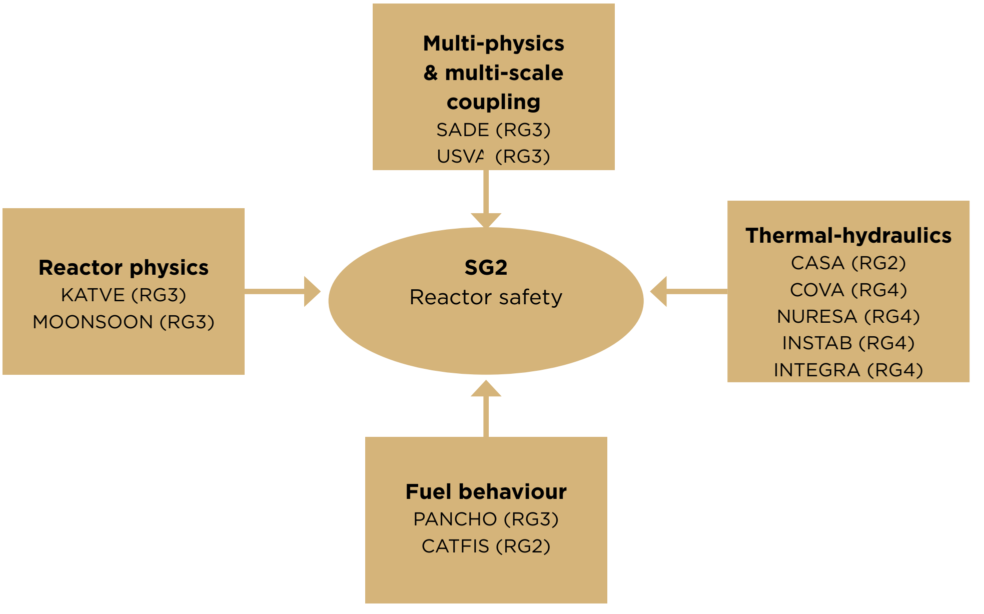

Figure 1: Eleven projects in SG2 and their relationship

2.2.1 Reactor Physics

Two projects, KATVE and MONSOON, are devoted to the further development and application of the Finnish Monte Carlo code SERPENT. Their technical work can be divided into three tasks: (1) further improvement of the SERPENT code through the implementation of an advanced method for spatial homogenization, (2) application of the SERPENT code to various technical fields such as radiation shielding, criticality analysis and material activation, and (3) maintenance of the international users' group.

The results of both projects made significant contribution to the buildup of infrastructure (SERPENT code) and the education of young researchers. It brings the Finnish research group to the top position of the international research community. Due to budget limitation, no validation work was performed in SAFIR2018. Furthermore, the wide spectrum of application fields hinders in-depth investigation of the individual phenomena. Two specific recommendations are proposed:

1. The number of the application cases should be properly reduced, to bundle the research resources to the cases with high priority.
2. Validation work should be considered in the future working plan.

2.2.2 Thermal-hydraulics

Five projects examine both experimental and numerical topics in thermal-hydraulics. Three projects are devoted to numerical tasks: severe accident analysis (CASA), system thermal-hydraulics (STH) analysis (COVA) and computational fluid dynamics (CFD) analysis (NURESA). The CASA project considers many phenomena that were given high priority by the international research community. Several internationally-accepted and widely-used codes such as MELCOR for severe accident progress, MC3D for fuel-coolant interaction and ASTEC for containment thermal-hydraulics were selected as reference tools. The main achievements of CASA are the training of young experts in the application of the simulation codes and strong interaction with the international research community.

For transient safety analysis, the Finnish STH code Apros has been internationally well-recognized. The main objective of the COVA project is to preserve competence in the development, maintenance and application of the Apros code. For this purpose, a large number of validation cases (benchmark exercises) was selected, covering both separate effect tests (SET) and integral effect tests (IET). This project also serves as the central platform for interaction with the international research community. However, there seem to be too many selected validation cases to be supported by the resources allocated to the project.

NURESA is devoted to CFD codes, including the commercial CFD code Fluent and the open source CFD code OpenFOAM. Three results can be highlighted: (1) development of new models for two-phase flow and heat transfer, (2) assessment of the CFD simulation with the international benchmarking exercises, and (3) successful coupling of the CFD code with the STH code Apros.

Both experimental projects INSTAB and INTEGRA are focused on the investigation of thermal-hydraulic phenomena with three different large-scale test facilities. The test facility PPOOLEX is used for flow and heat transfer behavior in a large water pool under accident conditions. Direct contact condensation (DCC), flow instability, thermal stratification and thermal mixing are the main phenomena to be investigated. In addition, experimental data will be used for the validation of CFD simulations and for supporting the development of the Effective Heat Source (EHS) and Effective Momentum Source (EMS) models, which were proposed by KTH. The experiments are making good progress and the results achieved so far fulfill expectations.

Two test facilities were developed in project INTEGRA. PASI was designed for the investigation of generic passive safety system performance. The construction of the test facility was finished and commissioning is foreseen in 2018. PWR PACTEL is an integral test facility for PWR safety systems. An integral test facility represents the safety research standard of a country, and thus has very high importance for the Finnish nuclear safety community.

Experiments were performed to investigate the effect of Nitrogen on the coolability of the reactor core under LOCA conditions. The main purpose of the experiment is the production of test data for the validation of STH codes such as Apros.

In general, these five projects fit well the targets of SAFIR2018, especially with respect to the buildup of infrastructure (hardware and software), expertise preservation and international interaction. The large number of publications indicates the high quality of the results. Two specific recommendations are proposed:

1. For each subject one reference code should be defined, so that more effort can be focused on the numerical codes with high priority.
2. Validation activities need to be continued. Tight interaction between the numerical groups and the experimental teams would help to produce more adequate experimental data and identify more suitable benchmark cases.

2.2.3 Fuel Behavior

PANCHO focuses on the development and validation of the Finnish code FINIX for the coupled analysis of mechanical and thermal behavior of fuel. Emphasis of the project was placed on code validation. An automated validation procedure was developed. Validation activities were carried out within international benchmark exercises and provided excellent opportunity for training young researchers. However, some benchmark cases, e.g., OECD/NEA RIA benchmark case, might not be well suited for the validation purpose, because the boundary conditions for the fuel code FINIX were provided by other severe accident analysis codes, which are known to have large uncertainties.

CATFIS investigates experimentally the behavior of fission products. Although it appears not to fit the numerical platform of SG2, there is a close technical connection to projects PANCHO and CASA. CATFIS investigates the chemistry, phase state and transport of fission products. The results could be directly applied to the numerical codes for severe accident analysis and for fuel performance analysis. The experimental results of the CATFIS project reveal completely new evidence about the phase states (gas or particle) of Iodine and Ruthenium species, have strong impact on the source term modeling and have achieved high international recognition.

Two specific recommendations are proposed:

1. The future validation of the FINIX code should be more concentrated on separate effects tests with well-defined boundary conditions.
2. The results obtained so far in the CATFIS project emphasize the deficiency in the existing models. Further efforts need to be made to develop new models for the Iodine transport and the source term in the severe accident analysis codes.

2.2.4 Multi-Physics and Multi-Scale Code Coupling

Multi-physics and multi-scale code coupling is one of the hottest research topics worldwide. Two projects investigate code coupling techniques and uncertainty analysis methodology, respectively. The SADE project is dedicated to the coupling of CFD code PORFLO with neutronic code HEXTRAN and STH code SMABRE. The main purpose of SADE is the development of an independent Finnish safety analysis platform. The coupling was successfully built and the first validation was carried out.

USVA focuses on the development and application of uncertainty analysis methodologies. It is tightly coupled with the SADE project. Uncertainty and sensitivity analysis was performed for several individual numerical codes used in SG2 as well as for the code coupling system. Most of the work was carried out within the benchmark exercises organized by the OECD/NEA working group LWR-UAM. One of the remaining challenges is modeling uncertainty propagation in the code coupling system.

Two specific recommendations are proposed:

1. For the specific code coupling system, investigation should be carried out to compare various code coupling methodologies, with respect to their numerical efficiency and numerical accuracy.
2. Future efforts should also be made on methodology development for the analysis of uncertainty propagation in code coupling systems.

2.2.5 Overall Evaluation

From the technical point of view, good results have been achieved in all four areas and also documented in numerous publications. Highlights include: (1) buildup of important research infrastructure (hardware and software), some of which have or could become among the reference facilities or reference tools worldwide; (2) further development of existing numerical codes with improved models or methodologies, such as the advanced method of spatial homogenization for SERPENT and the new two-phase heat transfer models for CFD codes, and (3) production of new experimental data for the validation of numerical tools and for more reliable modeling of individual phenomena involved in accident processes.

The central goal of the projects in SG2 is the buildup and improvement of test facilities and numerical tools for reactor safety research. Major focus was placed on the Finnish homemade codes, such as the neutronic code SERPENT, the STH code Apros, the fuel code FINIX and the CFD code PORFLO. Construction of the multi-physics and multi-scale code coupling system is making good progress. The three test facilities PWR PACTEL, PPOOLEX and PASI would facilitate Finnish safety research and maintain its top position in the international community.

The projects utilize large scale test facilities, a large number of codes covering a wide spectrum of subjects and have very active connection to the international community. They are attractive for young researchers and well suited for their education and training. The research teams consist mostly of young researchers. Several PhD theses and a large number of Master theses have resulted from the projects.

International activities are ongoing in all four areas, mainly through participation in international working groups and/or benchmark exercises. Two Finnish numerical simulation codes, the MC code SERPENT and the STH code Apros, are well established and have attracted large international user groups. The test facility PWR PACTEL has a good possibility of becoming one of the international reference facilities in reactor safety research.

2.2.6 Challenges

- Eight of the eleven projects in SG2 serve to build the Finnish independent software platform for reactor safety analysis and at the same time cover various research areas. Strong interaction among the projects would facilitate progress. In SAFIR2018 these eight projects are distributed in three different reference groups (RGs). As indicated in Figure 1, some projects from the same area belong to different RGs. This structure makes smooth and tight interaction between the projects difficult.

- The software platform for reactor safety analysis covers various scientific and technical topics. Several codes were taken into consideration for each topic. This leads to a large number of codes used in the projects and, subsequently, could hinder a deep investigation on each individual code.

- One central objective in SG2 is the development of the Finnish multi-physics/multi-scale numerical simulation platform. Effective numerical architecture and coupling methodology play essential roles and determine to what extent the simulation platform could be applied.
- Extensive and successful validation is the pre-condition for the quality and reliability of numerical codes. Selection of the most suitable validation cases requires, however, comprehensive expertise. Furthermore, production of sufficient CFD-grade experimental data from the large-scale test facilities with well-defined boundary conditions remains a very challenging task.

2.2.7 Recommendations

- More flexibility should be given to the RGs, so that they can easily organize scientific and technical meetings on a multi-RGs basis and enhance interaction among projects.

- The SAFIR research community should identify the reference codes for each research topic. This might improve usage of existing research resources.
- A working group with experienced experts would provide important support to establish a phenomena identification and ranking table (PIRT) and to define the future validation cases.
- More efforts should be made to advertise the test facility PWR PACTEL in the international community and to involve international working groups in the definition of the future test cases, with the objective that PWR PACTEL becomes one of the international reference facilities for reactor safety research.
- The technical background for all eleven projects is solely focused on light water reactors of GEN-II and GEN-III. The strategic plan should extend the application of the existing numerical codes to GEN-IV reactors and educate young researchers on next generation nuclear power technologies.
- The strategic plan should include the digital nuclear power plant, which is the future development direction of the multi-physics/multi-scale simulation technology and extremely well-suited for building infrastructure and expertise.

2.3 Steering Group 3 Structural Safety and Materials

Projects under the supervision of Steering Group 3 address mainly issues linked with aging, condition monitoring and long term operation of nuclear power plants (NPPs), including all six projects (COMRADE, FOUND, LOST, MOCCA, THELMA and WANDA) belonging to RG5 "Structural Integrity." The remaining two projects are part of RG2 "Severe Accidents and Risk Analysis": ERNEST deals with external hazards and FIRED with severe accidents. A brief description of the projects and their results follows.

2.3.1 Condition Monitoring and Long Term Operation

The effect of radiation, temperature, mechanical loading and chemical environment on the nucleation and growth of damage (mainly cracks and corrosion) and on the degradation of (mechanical) properties of polymers, carbon steels and stainless steels is investigated experimentally. Models are also developed to further the understanding of the observed phenomena and to account for them in safety evaluations.

For polymers used in parts such as seals, COMRADE attempts to establish experimental correlations between stressors (radiation, heat, oxidation, stress) and changes in material properties and then to relate changes in properties to degradation of part functionality. This information serves to develop so-called aging Master Curves and end-of-life criteria to support plant maintenance operations.

In a set of related synergistic projects, new test methods are developed to characterize the fracture resistance of irradiated pressure vessel steels and the aging and stress corrosion behavior of stainless steels and dissimilar metal welds. FOUND investigates corrosion fatigue and thermal fatigue in BWR internals and piping systems. It reviews and develops damage and failure assessment methods to support risk-informed inspection methods. In a separate task, it develops analysis methods for the dynamic structural response of piping systems.

LOST addresses the structural integrity of NPP components such as reactor pressure vessel (RPV), pipes and valves. Fast fracture in the upper shelf temperature regime of RPVs is investigated and improved methods are developed for fracture toughness measurements and crack driving force estimations for dissimilar metal welds (DMW).

MOCCA investigates the effect of water chemistry on corrosion of the secondary side of steam generators in PWR/VVER reactors with the practical goal of mitigating corrosion problems. Stainless steels and nickel base alloys are tested with various inhibition strategies for the deposition of magnetite in steam generators. The effect of lead on the corrosion of carbon steels is also studied and candidates to replace hydrazine as an oxygen scavenger in PWR are screened.

THELMA studies the behavior of nuclear materials in light water reactor (LWR) environments with special focus on the determination of thermal aging and environmentally assisted cracking in irradiated austenitic primary circuit materials, i.e., stainless steel weld and cast materials and nickel-based Alloy 690.

WANDA focuses on the development and understanding of non-destructive examination (NDE) methods in two important nuclear power plant environments: primary circuit component materials (mainly stainless steels) and concrete infrastructure. Research work of primary circuit components concentrates on the ultrasonic testing of artificial defects, simulations and probability of detection (POD). NDE research on concrete infrastructure focuses on the evaluation and calibration of the available NDE methods and monitoring systems for concrete structures. To that effect, the project focuses on the design and construction of a full-scale reinforced concrete wall mock-up for NDE testing method development and education purposes.

2.3.2 External Hazards

ERNEST is a continuation of the ESPIAC project. Its overall goal is to develop and keep up capabilities to predict the response of NPP containment under different types of loadings including aircraft impacts, earthquakes, and pressurization. This is achieved by performing dynamic and static structural experiments on concrete models, performing numerical simulations of the experiments and developing and improving the various model elements entering the simulations until sufficient validation is achieved by comparison with the experimental data.

2.3.3 Severe Accidents

FIRED aims at evaluating the fire risks of cables during plant life cycle, assessing the performance of fire-barriers, and developing, maintaining and validating fire simulation tools. It contributes new methodologies for assessing defense-in-depth in the context of fire safety and studies and models new fire retardant materials.

2.3.4 Overall Evaluation

The SG3 projects significantly contribute to and meet the objectives of the SAFIR2018 program, in terms of research results, infrastructure development, competence building, and international connections. The research performed in the projects under SG3 produces scientifically and practically relevant results of good to very good quality, as indicated in particular by the number of refereed publications. The projects demonstrate a suitable balance between experimental, modeling and simulation work and between more basic and more applied research. The research results meet in a timely manner the needs of both regulators and operators of NPPs.

Several important elements of research infrastructure have been developed and are now in use in SG3 projects. Newly developed experimental facilities or methods include:

- Polymer seals test facility (COMRADE)
- Impact test facility for reinforced concrete plates and simple structures (ERNEST and predecessors)
- Testbed with built-in generic defects for the development and evaluation of concrete NDE methods (WANDA)
- Contributions to the development and validation of the 4 mm–thick CT fracture toughness specimen (LOST)
- Tapered specimen test for investigation of stress corrosion cracking of dissimilar metal welds (THELMA)

Progress in the development of simulation and modeling tools include:

- Code to simulate NDE detection of defects and estimate probabilities of detection POD (WANDA)
- Impact simulation tools for concrete structures and improved concrete failure models (ERNST)
- Coupling of Fire Dynamic Simulator with Reactive Molecular Dynamics Code ReaxFF (FIRED)

The SG3 projects contribute to the education of a significant number of dynamic young researchers. The evaluation committee was impressed by their enthusiasm and presentation skills. However, ERNST seems to involve only seasoned researchers and does not contribute to any MS or PhD theses.

All the SG3 projects (with the possible exception of MOCCA) are extremely well connected on the international scene, being partners in Nordic, European Union or OECD projects. Collaboration with Finnish research teams is sought after in the international nuclear materials and structures community and several teams play a leading role in international projects. Thus, free access to a large body of relevant data and information is secured for Finnish researchers.

2.3.5 Challenges

Structural safety and materials research faces several challenges:

- Finnish plants present a broad spectrum of designs. In addition, these power plants are in different stages of their lives (design, commissioning, operation, life extension). These circumstances therefore require a broad range of competences by the regulators and operators to run and maintain the various plants.

- The diversity of designs and suppliers results in a broad range of materials used in the plants and for which issues of resistance, aging and degradation must be addressed. This materials diversity puts pressure on the research resources required to address materials issues. Diversity also complicates the supply chain and increases costs.

- In this environment, realistic planning and strategic choices must guarantee that research resources are not spread too thin, so as to cover the major nuclear safety needs. On the other hand, resources must be available for innovative and creative research with less direct application to oversight and operation of NPPs.

2.3.6 Recommendations

The review and evaluation of the SG3 projects leads to the following recommendations:

- It is difficult to obtain a comprehensive overview of the various research areas covered under SG3, their sometimes ambitious goals and the timeline and resources required to achieve these goals. Synergies with other non-SAFIR2018 projects, funded for instance by operators or international agencies, are not transparent. We recommend that a road map for the SG3 projects be established with short-, mid- and long-term objectives, a time line, estimated financial needs and expected financial support besides SAFIR funding. The synergies between projects should also be highlighted in realistic terms.

- Some projects cover an extremely broad spectrum of tasks (e.g. LOST, FOUND). Because of limited funding, progress in each task is relatively slow. The topical relationship between the various tasks within a project and their interactions are often not obvious. On the other hand, similar tasks are performed in different projects. We recommend that the number of topics covered in each project be reduced and that similar topics covered in two different projects be regrouped in a single project. This reorganization should provide for a better thematic focus and more efficient use of resources. It will also foster more genuine collaborations between researchers.

- Researchers and research groups tend to get entrenched in their narrow domains of activity. To a certain degree, this focus is needed to advance the research. On the other hand, it can be detrimental in a complex field such as nuclear safety. VTT may be particularly susceptible to silo mentality because it employs predominantly permanent staff. We therefore recommend that job rotations be organized at VTT (if they do not already exist), where an appropriate number of researchers move from their group to a different group to broaden their experience and exposure to technical and scientific subcultures. These rotations will also serve to facilitate the dialogue between projects. Top-down action by VTT management will probably be required to implement job rotations and the SAFIR program could provide some financial incentives to help with this implementation.

- With the trend to extend the life of existing NPP and the associated aging issues, monitoring and inspection of systems and structures gain increased importance. We recommend that more projects be dedicated to non-destructive inspection methods to complement the good effort accomplished in project WANDA. Directions for new research should be guided by the findings in materials aging projects such as THELMA, LOST and FOUND.

- More room should be allotted for innovative and basic research. Such research is necessary to sharpen competences and to attract and motivate young researchers. It is also key to solving long-term problems. Areas where a push in this direction seems desirable and where more expertise would be welcome are: 1) micromechanical modeling of the mechanical behavior of materials and in particular of DMV and 2) multi-scale multi-physics modeling of material aging processes. DMW are very heterogeneous, unisotropic microstructures, the mechanical and deformation behavior of which cannot (except in a few very specific cases) reliably be apprehended with classical continuum mechanics parameters. This limitation is particularly evident for fracture predictions for DMW. Aging phenomena invariably involve atomistic processes, which then affect microstructural morphology and macroscopic properties. Multi-scale multi-physics modeling will provide a better understanding of the aging mechanisms and will allow a significant reduction and an improved focus in the experimental effort required for monitoring aging phenomena in NPP.

- Project ERNEST should try to look at some of the results of military research on concrete penetration. While the information may be difficult to access, a lot of modeling work has been performed on the dynamic constitutive and failure response of concrete. Also, using ALE codes such as LS-DYNA could provide a valuable alternative to ABAQUS explicit for the simulation of impact problems, particularly when fragmentation and perforation become issues.

2.4 Reference Group 6 Research Infrastructure

The SAFIR2018 program has the somewhat remarkable feature that, beyond funding research projects, it also provides for funds to develop, build and occasionally maintain unique research facilities in Finland, or to access such facilities abroad. Specifically, the program finances three infrastructure projects under Reference Group 6 (RG6), INFRAL, RADLAB and JHR, which are briefly described and evaluated below.

2.4.1 INFRAL

This project is concerned with the thermal-hydraulic (TH) test facilities at Lappeenranta University of Technology (LUT), i.e., the PPOOLEX facility to investigate the suppression pool of BWR containments, the PWR-PACTEL to investigate steam generators of PWR, the newly constructed PASI test facility to investigate passive heat removal systems and the planned MOTEL modular test facility to study a wide range of nuclear power plant designs (VVER, PWR, BWR and small modular reactors). The project develops new advanced measurement techniques, including wire-mesh sensors (WMS), particle image velocimetry (PIV) and high speed cameras, as well as the associated data reduction and analysis software. It also performs the design of the MOTEL facility, and supports the maintenance of the TH test facilities and the participation in international collaborations. The TH test facilities at LUT provide the platforms used for INSTAB and INTEGRA.

2.4.2 RADLAB

Special funding in the SAFIR2018 program serves for the construction and equipment of the new Centre for Nuclear Safety (CNS) at VTT. The RADLAB project handles the equipment and commissioning of the CNS Nuclear Materials Research and Radiochemistry Laboratory (NMRRL) and its peripherals. The Laboratory is a state-of-the-art facility for research on radioactive materials (excluding fuels and fuel elements) equipped with six A-class hot-cells with manipulators and radioactive material transfer facilities. The hot-cell equipment includes, among others, machines for specimen fabrication and mechanical testing machines for tensile, compressive, Charpy impact and fracture tests. Scanning and transmission electron microscopes with analytical instruments, and equipment for preparation of metallographic samples are also available in separate enclosures with controlled environment and radiation. As the committee visited the NMRRL, operations had just started.

2.4.3 JHR

Finland is a partner in the Jules Horowitz Reactor (JHR) project, for the design and construction of a new material research reactor at CEA Cadarache, France. The JHR will be an international user facility, the operation of which will be similar to that of the Halden Reactor Project, with multinational projects and proprietary experiments. The SAFIR2018 project is tasked with representing Finland in the three working groups that will be planning the experiments in the JHR facility. A previous SAFIR project has designed and fabricated the MELODIE test setup (MEchanical LOading Device for In-core Experiments) for irradiation creep testing of Zircaloy 4 fuel cladding tubes under biaxial loading. During the current project, preliminary tests of the setup have been performed.

2.4.4 Overall Evaluation

The unique thermal-hydraulic facilities at LUT are remarkable for their size and testing capabilities. As far as we could judge during our visit, they are maintained in excellent functioning conditions and regularly updated with new state-of-the-art measurement instrumentation for investigating various safety issues in Finnish nuclear power plants. They have proved very useful in licensing the new EPR reactor at Olkiluoto 3 and will certainly also do so for the new VVER under consideration for construction in Finland.

The CNS - NMRRL infrastructure at VTT is also an extremely valuable, if not unique facility, which will afford Finland the possibility of conducting a wide range of investigations on radioactive materials. This capability is very important for the country and its operators of nuclear facilities, because:

- of the diversity of reactor types in service or planned in Finland,
- of the diversity of metallic alloys used in these reactors,
- several of these reactors are approaching the end of their design life and require life extension and aging monitoring programs.

Thus, the CNS - NMRRL will provide nuclear utilities the required state-of-the art facilities to address in a timely, efficient and flexible way their (radioactive) material problems. We salute the foresight of the Finnish Government and the nuclear stakeholders in initiating this project and bringing it to completion.

Participating in the JHR consortium is essential for Finland and the nuclear utilities for the same reasons mentioned above for the CNS. In addition, the JHR project will provide Finnish researchers and industries with an opportunity to showcase internationally their strong competencies in the field of nuclear engineering.

2.4.5 Challenges and Recommendations

The work accomplished under RG6 leadership demonstrates that the SAFIR program can successfully manage large infrastructure acquisition projects of great significance for the Finnish nuclear industry and for nuclear safety. The community must now make good use of the available infrastructure by planning high payoff experiments and studies that will positively impact modeling and simulation efforts in TH and material aging and hence nuclear safety.

One concern shared by the evaluation committee is the long-term financing of the maintenance and operation of the facilities. The chosen financing model through acquisition of commercial projects risks leaving the facilities without sufficient funding, which could lead to their slow degradation because of lack of use and maintenance. On the other hand, should numerous projects compete for use of the facilities, the need for financing could result in favoring projects with high financial returns but lower technical and scientific value over those with high technical and scientific value but lesser financial benefits. The committee realizes that crafting sustainable funding solutions requires navigating challenging political and administrative constraints. Nevertheless, we recommend that the SAFIR program should address this challenge, lest a significant investment in first-class facilities fail to achieve its potential.

3 Implementing SAFIR2014 Recommendations

An important objective of the SAFIR2018 evaluation is to understand the nature and effectiveness of responses to the recommendations in the SAFIR2014 report. This exemplifies the capabilities of SAFIR to consider feedback from the international nuclear safety community and embed new learning into its research program. We selected five areas from the report for further scrutiny, based on our judgment of their importance in the SAFIR2014 report and our understanding of the strategic priorities of the SAFIR program, now and in the future: (1) strategic top-down steering, (2) funding for research infrastructure, (3) generating new expertise, (4) introducing new projects, and (5) cross-disciplinary connections.

3.1 Strategic Top-Down Steering

The SAFIR2014 report recommended that additional top-down steering based on broad research themes and strategic objectives would complement and strengthen the overall structure of the research program, because research projects primarily emerge bottom-up. SAFIR2018 research is now divided among three Steering Groups and this appears justified based on the different nature of plant, reactor and structural safety research. This top-level structure supports top-down steering provided that there is a common understanding of the role of the research and the goals to be achieved. The SAFIR program has undergone changes in its funding mechanisms and steering structure throughout its history, while maintaining clear consensus on the top-level goal of conducting national research that generates capabilities to tackle challenging safety questions. However, we observed that different stakeholders place somewhat different expectations for the immediate future and the projects to be carried out. For example, it is natural that power companies want research results that can improve operations in the near term, whereas building capabilities for an uncertain future involves balancing many diverse needs, near term and long term, well-known and imagined. Diverse projects can contribute in different ways. It is important for the SAFIR program to sharpen and articulate its goals, create strong stakeholder ownership within each main research area, and rethink ways to steer individual projects. In this respect, the top-down steering recommendation of the previous evaluation remains valid and not yet fulfilled.

3.2 Funding for Infrastructure

In parallel with the three main research areas of the SAFIR program, a substantial investment has been made in the research capabilities of VTT, including the RADLAB facility, and the LUT thermal-hydraulic laboratories. The SAFIR2014 report had called for a review of all research infrastructure to reach a sustainable basis. These two facilities now provide physical facilities and support for reactor and structural safety research (SG2 and SG3), although it is not yet clear how these facilities will be used. For the next program, a wider view of infrastructure should include these reactor and structural safety topics that are specific to nuclear power but also recognizing that plant safety (SG1) involves more generic, non-nuclear expertise (e.g., human factors, automation) and less obvious nuclear infrastructure needs. Infrastructure issues continue to be important and an updated analysis and plan is needed for the next SAFIR program to make the best use of the new facilities. This exercise should be based on a transparent road map covering both the national research needs and a realistic view on utilization of the infrastructure by the Finnish and international customers.

3.3 Generating New Expertise

A research program of diverse projects is managed based on plans and reports. The most appreciated feature of the SAFIR program is, however, the generation of new experts. This human aspect forms quite a different dimension and it is undoubtedly embedded in all the background work conducted to come up with new project ideas and funding decisions. This becomes evident when looking at the long-term progress of the SAFIR program in generating new expertise and when listening to the new researchers tackling questions of high relevance to the end users of a specific Reference Group. The associated recommendation of the previous evaluation could be transformed to an even stronger wish for promoting activities that would truly accelerate development in areas where there is a high need for new understanding, either within the Finnish nuclear research domain or by international networking. The best results are achieved when stakeholders and researchers are enthusiastic, together.

3.4 Introducing New Projects

Flexibility to respond to a rapidly-changing operating environment really means finding a balance between on-going research projects that need continuing funding and new projects that are responding to emerging needs and emerging ideas. The SAFIR program issues a call for proposals every year, and projects are funded annually. However, in practice, projects actually need funds for multiple years and the expectation is that funds will be renewed as long as the research is making appropriate progress. It is not easy for the Managing Board to balance stability of research funding and opportunities for new proposals within a limited budget. It is natural that established research teams with proven productivity are in a good position to receive continued funding for the same or related projects. The proper balance may also differ between the research areas. The MB has used a small fund (50K Euros yearly) to selectively fund new projects, but this is a modest step. The need for more flexibility remains as expressed by the previous evaluation report and we have some suggestions for ways to accomplish this goal in the next SAFIR with a stepwise increase in funds reserved for new projects carrying a high end-user value within the mission of the SAFIR program.

3.5 Cross-Disciplinary Connections

Finally, the SAFIR2014 report emphasized the growing complexity of nuclear safety related issues and the attendant need for cross-project and cross-disciplinary communication and cooperation. The restructuring of program management from nine Research Groups into 6 Reference Groups and 3 Steering Groups was intended, in part, to create a matrix structure that would offer more opportunities for cross-project interaction. However, it seems that this structure is only partially implemented and is not working fully to facilitate the desired interactions. The SG structure is operating primarily as a project monitoring process. Only RG2 is really matrixed across SGs. The RG structure seems best-suited to creating linkages across projects but the RGs function differently from one another. What has worked best for connecting projects is when the same researcher is spending time on two projects, creating a link. But this is neither planned nor strategic. The bureaucratic functions of project management should take as little time as possible, whereas the work of connecting projects and seeking synergies should take precedence, ideally when there is a purpose for such connections. Hence, we believe the ideas of the SAFIR2014 report are still valid and not fully realized, and we have some ideas for ways forward.

4 Observations and Challenges

During our evaluation process, we worked to distill our thoughts into a small number of key observations and challenges. More detailed observations associated with individual projects were presented earlier. In this section we capture the broader, more strategic issues that cut across the SAFIR2018 program.

4.1 SAFIR2018 Project Results

Overall, our evaluation of the scientific and technical quality of the program is very good. As described in the previous sections, individual research projects are producing results that range from good to very good. End users and stakeholders in general are pleased with the program, although some mention opportunities for improvement. Engagement of the power companies and regulator is good and their participation facilitates the relevance and success of the research program. The infrastructure projects are coming to fruition and are an important investment in future capabilities.

4.2 Capabilities

The capabilities supported by the SAFIR2018 program are strong for a country of Finland's size, as demonstrated by the significant numbers of graduate theses, conference presentations, scholarly publications, and extensive international cooperation. These capabilities reside in the knowledge documented in reports and publications, the physical infrastructure of laboratories, tools, and models (both physical and computer-based), and most importantly in the people whose expertise prepares them to deal with both expected and unexpected developments. Most encouragingly, we met many young researchers presenting their work who are articulate, energetic, and excited about their research projects and career opportunities.

It is notable that human experts circulate throughout the nuclear power "ecology" or network of organizations, from universities to VTT to STUK to power companies. This network connects power companies, research organizations, universities, and government within Finland, but also reaches out to link Finland with cooperating organizations in other Nordic countries, Europe, and the broad global community. VTT has a special role to play as a training experience and a center of competence that builds capabilities for the entire network. The SAFIR program is perhaps the most important research budget within VTT. As a small country, Finland has by necessity invested selectively in capability development. The SAFIR program helps ensure that strategically important areas are represented with sufficient expertise, complementing the roles of universities, power companies, and regulators.

4.3 Organizing a Diverse Project Portfolio

The SAFIR2018 research projects are very diverse in size, technical content, time frame for completion, focus on short-term vs. long-term benefits, and nuclear-specific vs. generic content. Reference Groups, not surprisingly, also vary along many of the same dimensions, although also differing in how heterogeneous is the set of projects within each RG. RG3, RG4, and RG5 tend to group together projects that are more similar to each other, involving shared facilities, tools, methods, and personnel, in contract to RG1 and RG2 that differ greatly in topics, scientific disciplines, and project scope.

4.4 Resources

The SAFIR program attempts to cover a great range of topics with modest resources. Funding is moderate and the intention of the SAFIR2018 Framework Plan was to keep funding constant or to increase slightly; however, funding was reduced noticeably (from 8.2M Euros to 6.6M Euros) between 2015 and 2016 due to loss of a revenue source. Projects responded by canceling some work packages and otherwise making do with less, and coping with difficult trade-offs in prioritizing limited resources. There were hints of competition for resources across projects, although this did not seem widespread or serious. SAFIR only provides 70% funding for each project and expects a 30% contribution from the research organization.

SAFIR projects are only part of the total portfolio of nuclear safety research. SAFIR projects are open to public scrutiny, with results expected to be communicated broadly to the scientific and nuclear communities. Power companies with specific near-term needs and proprietary knowledge are likely to commission research separately, possibly from the same research organizations that receive SAFIR funds. Those with projects requiring international cooperation may find that the SAFIR process does not synchronize with the timing and requirements of other programs, such as EURATOM. SAFIR funds are given one year at a time, whereas EURATOM gives multi-year funding.

4.5 Cross-Disciplinary Connections

For a variety of reasons, interconnections across projects are hard to make. Everyone is very busy. The focus is on getting the work done, communicating results, and planning future research. Cross-disciplinary conversations that might spark synergistic new ideas can seem like a luxury or a risky investment in future research. The Reference Group structure was intended, in part, to facilitate such interactions, but this is not happening consistently. Some RGs have experienced leaders who are providing broad perspective and nurturing younger researchers, but others are just making sure work gets done.

4.6 Starting New Projects

Not surprisingly, given some of the challenges already mentioned, new projects are difficult to initiate and there is some sense of inertia in the SAFIR program. Existing research teams have an advantage of being funded already, their work appreciated by those who recommend and authorize funding. The danger is that new researchers will not submit proposals for innovative projects because they worry about the risks of investing in a proposal preparation process, only to be rejected. Those with new ideas also may find themselves off-cycle with the four-year SAFIR program – entering in the middle of a cycle is even more difficult since most of the projects are expected to receive continuation funding, leaving little for new projects.

5 Opportunities and Suggestions

5.1 Sample SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats)

One typical exercise to encourage strategic thinking is to assess strengths, weaknesses, opportunities, and threats, known as a SWOT analysis. As an example, we offer the beginnings of such an analysis.

It is evident that the SAFIR2018 program is doing a good job nurturing expertise, which is the primary goal it was established to meet. There are young people studying topics relevant to nuclear safety, receiving graduate degrees, conducting research, moving into the network of organizations in the nuclear power industry, and so forth. Various indicators of expertise, such as presentations, publications, international conference participation, the perceived competence of Finnish operations and research, etc. are strongly positive. Of course, more could be done, but this is a current strength.

We also believe that there is less cross-disciplinary interaction and cooperation within the SAFIR2018 program than desired in a research activity. The separated silos of researchers were a topic of concern for the SAFIR2014 evaluation and an inspiration for reorganizing Research Groups into SGs and RGs. However, for the most part the silos remain as a weakness.

There is a significant opportunity to inject new research proposals into the SAFIR program. We believe there are other researchers and other topics, including cross-discipline topics and those with international links, that could be introduced into SAFIR. Because resources are limited and there are strong expectations of continuity, there is an opportunity for balanced renewal that sustains existing projects while creating space for new ideas and new researchers.

Finally, the threat if nothing changes is slow stagnation. If we take seriously that the goal of SAFIR is to build competence to prepare for an uncertain future, then a funding process that supports incremental advances and research-as-usual will not be able to keep up with the need for a fresh and exciting set of projects. There will not be any obvious signals that anything is wrong with SAFIR, but when new competence is needed in the future, we want to make sure it is available. The cost of more novelty, flexibility, and exploration is that some results will not be useful immediately or ever, but the competence developed through these projects will be valuable beyond any specific results.

5.2 Develop a Roadmap/Evaluate Capabilities Against Needs

We agree with the SAFIR2014 evaluation report that more can be done to provide a strategic view of the SAFIR research portfolio and additional top-down "steering" of priorities. We heard that the Managing Board attempted to do this but found it too complex for the available time and resources, and then left the task to the Steering Groups, who had no better success. This is not an easy task but 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 (laboratories, simulators, support) and what is in the pipeline of research projects and human resources (e.g., students). The roadmap should include not only SAFIR, but also the connections to other projects and programs in Finland and through international collaborations. The roadmap should extend beyond the four-year funding cycle but be updated as needed. Then the SAFIR program can be evaluated for its role in supporting necessary capabilities, filling gaps, and experimenting with future possibilities. We do not believe that this roadmap can be outsourced to a consulting company or research project but that stakeholder representatives must take ownership and then partner with others (e.g., a facilitator) to provide necessary expertise and resources to develop the roadmap.

Then, the roadmap has to 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 through SGs and RGs (see the following section about flexible organizing), building communities of researchers, and modifying the roadmap as the nuclear power industry evolves. In order for it to be used, stakeholders must understand it as a shared roadmap, adequately capturing their thoughts and needs, that facilitates achieving their individual interests and the common goals of building and sustaining necessary competence in Finland.

5.3 Consider Flexible Funding to Support More New Initiatives

There is a sense of stability to the SAFIR program that carries with it some inertia and barriers to entry that are inconsistent with the goal of being prepared for an unexpected future. It would be helpful to have more openness to new ideas, accessibility for new researchers, and options for funding that would encourage new projects and collaborations within and outside Finland. The annual funding process is not suitable for all projects. It creates paperwork requirements for annual assessments and proposals, while in practice most projects are renewed for the four years of a SAFIR plan. It also creates risks for projects that need guarantees of longer funding and challenges for coordinating with other sources of funding, such as EURATOM, that expect to give funding for multiple years.

We believe that new projects and new 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, funding cycles different from one year or four years, and cross-discipline projects. But it is probably not sufficient just to make money available; new proposals and new projects need a supportive organization to nurture their development. For example, such 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 RG that would provide a good community.

5.4 Consider More Flexible Organizing to Build a Vibrant Research Community

The structure of SGs and RGs, developed partly in response to recommendations from the SAFIR2014 evaluation report intended to increase cross-project interaction and decrease unnecessary bureaucratic meetings, has not succeeded fully. Cross-project interaction is happening to some extent, but not as much as hoped. Considerable meeting time seems to be devoted to project monitoring, leaving much less time for meaningful conversations.

There are opportunities to build more flexibility into the SAFIR organization. RG 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. RG heads could work together to share good practices and organize events within RGs and across RGs. Newsletters and blogs could help keep projects aware of progress and opportunities for synergy. Job rotation programs within organizations and externally (such as visits and sabbaticals) could develop synergies and expand networks. Since SAFIR projects are by definition public projects, there are additional opportunities to link to other research in Finland and elsewhere to strengthen the SAFIR community by considering both the internal SAFIR network and the external, extended network of researchers and other stakeholders. An important capability of Finnish expertise is to act as a gateway to anticipate and sense emerging issues and then assemble expertise for application to issues that affect nuclear safety in Finland.

We recognize that everyone is very busy, and that activities added on top of existing work are likely to be perceived as a burden. It is important therefore to remove activities that are not adding value. Perhaps it is not necessary for every project to report on the same schedule, depending on project size, maturity, and other features. Perhaps the SAFIR2018 project manager could develop a simplified project management process that would not take as much of the SG (and RG) meeting time, leaving time for the SGs to discuss strategic issues and the RGs to consider substantive research questions.

5.5 Develop Ways to Assess Impact

The SAFIR program is intended to generate capabilities to address unexpected future issues of nuclear safety. 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 in terms of papers published, reports issued, conferences attended, and degrees conferred. It is also possible to examine the satisfaction of end users (power companies, STUK). With a stronger roadmap, as recommended above, it would be possible to compare SAFIR results against the strategic needs as represented in the roadmap. This would also assist in the evaluation process such as this report, by providing more structure. 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.

5.6 Think of Organizational Change as a Collaborative Opportunity

Some of our most important recommendations are organizational rather than technical. Technical recommendations are typically more straightforward to implement: solutions are available, expertise is acknowledged, and the difficulties are mostly around complexity and resources. Organizational recommendations are more difficult because solutions have to be invented, expertise is less available or recognizable, people have to change their roles, responsibilities, behaviors and beliefs, and stakeholders must find ways to fulfill diverse interests that sometimes seem to be in conflict. Note that some of the SAFIR2014 Evaluation Team recommendations were not fully implemented and have re-emerged as challenges.

The recommendations we advance are not recipes for change, but rather opportunities for stakeholders to open new conversations and work together to find effective paths forward on their collaborative journey. The idea of developing a strategic road map, for example, is both a means to articulate strategic goals and guide planning, and also a process for engaging stakeholders in conversations to achieve greater mutual understanding, assemble innovative ideas, and commit to collective goals and actions. If the road map were to be provided by an external consultant, regardless of its strategic value, it would not achieve the level of shared ownership that is necessary for successful implementation of organizational change. Similarly, conducting a SWOT analysis or designing ways to encourage new proposals and cross-disciplinary interactions are both means to identify good ideas but also opportunities to engage stakeholders and colleagues in a process that can build shared understanding and commitment to action.

6 Conclusions

The SAFIR2018 program is strong. Results contribute knowledge and expertise needed for the Finnish regulator, universities, and power companies to assess new challenges to nuclear safety. New infrastructure provides essential capabilities. Stakeholders are engaged and generally pleased with the value they receive. The next generation of nuclear safety researchers is developing and contributing. Finland has an excellent international reputation and a strong network of communication and cooperation with Nordic, European, and global counterparts.

However, there are significant challenges and opportunities for improvement. Like virtually all organizations, the SAFIR program faces challenges of leveraging limited resources, attending to multiple stakeholders with diverse interests, balancing stability and deepening of existing capabilities with openness to new and disruptive ideas, managing cross-disciplinary connections to derive synergies from individual projects, and minimizing administrative burden. These challenges are neither new nor surprising, but addressing them is not easy. The SAFIR2014 Evaluation Report made many similar observations; the recommendations of that report have not been fully implemented. We have offered our ideas for creating new opportunities and making the most of limited resources. Any improvements, no matter how well designed, will succeed only if stakeholders believe in the necessary changes and commit their support. The road map recommendation is not simply about producing a shared plan, but also represents an opportunity to engage stakeholders in the process of sharing ideas and envisioning the future of nuclear safety research in Finland.

Table 1: Steering Groups (SGs) and Reference Groups (RGs)

	SG1 Plant safety and systems engineering	**SG2** Reactor safety	**SG3** Structural safety and materials	
RG1 Automation, organization, & human factors	CORE MAPS (People) SAUNA (I&C) ESSI (Electrical)			
RG2 Severe accidents & risk analysis	EXWE (Weather) GENXFIN (New reactor designs) PRAMEA (PRA)	CASA (Thermal-hydraulics) CATFIS (Fuel)	ERNEST (Concrete) FIRED (Fires)	
RG3 Reactor & fuel		KATVE, MONSOON (Reactor physics) PANCHO (Fuel) SADE, USVA (Code coupling)		
RG4 Thermal hydraulics		COVA, INSTAB, INTEGRA, NURESA (Thermal-hydraulics)		
RG5 Structural integrity			COMRADE, FOUND, LOST, MOCCA, THELMA, WANDA (Condition monitoring)	
RG6 Research infrastructure				INFRAL (LUT) RADLAB (VTT) JHR (CEA)

APPENDIX A

Evaluation Background Material

Evaluation of the Finnish Nuclear Safety Research Programme "SAFIR2014". Ministry of Employment and the Economy, 2014.

Finnish Nuclear Energy Act, 990/1987; amendments up to 342/2008 included

Finnish Nuclear Energy Research Strategy. Energy Research Strategy Group (YES). Ministry of Employment and the Economy, Report 17/2014, 2014.

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Overall Safety and Organisations: Institutional Strength-in-Depth and National Actors. M. Ylönen, M. Kari, N. Gotcheva and H. Talja. VTT Research Report VTT-R-V-113017-16, 2017.

Report of the Committee for Nuclear Energy Competence in Finland. Ministry of Employment and the Economy, Energy and Climate, 2/2012.

SAFIR2018 Annual Plan 2017. J. Hämäläinen and V. Suolanen. VTT Research Report VTT-R-02921-17, 2017.

SAFIR2018 The Finnish Research Programme On Nuclear Power Plant Safety 2015–2018: Interim Report 2017. J. Hämäläinen and V. Suolanen. VTT Technology 294, 2017.

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SAFIR Management Board Minutes 1–17.

SAFIR Management Board Minutes 2–17.

SAFIR Management Board Minutes 3–17.

SAFIR SG1 Steering Group Minutes 3–17.

SAFIR RG1 Reference Group Minutes 2–17.

APPENDIX B

Evaluation Team Meeting Schedule

	Sunday 28 January	Monday 29 January	Tuesday 30 January	Wednesday 31 January	Thursday 1 February	Friday 2 February
Morning		09:00–12:00 Meetings with end users (MB members)	09:00–12:20 Presentation of research : SG1, SG2, RG6	9:00-12:00 Presentation of research: SG3	7:24-9:22 Train to Lappeen-ranta University of Technology (LUT) 10:00–12:30 Presentation of research projects (SG2, RG6) and infrastructure	08:00–10:00 Preparation of the evaluation report 10:00–11:00 Exit meeting
Afternoon		13:00–17:00 Meetings with end users (MB members)	13:20–13:50 Presentation of research: RG6 14:00–16:10 Meetings with end users (SG and RG chairs and SG members): SG1, SG2, RG6, RG1, RG2, RG3, RG4	13:00–14:00 Meetings with end users (SG and RG chairs and SG members): SG3, RG2, RG5 14:10–16:00 Visit to the VTT Centre for Nuclear Safety (CNS)	13:30–15:30 Preparation of the evaluation report at LUT 16:30–18:29 Train to Helsinki Feedback of MB to the draft version in the train	
Evening	17:00 Welcome and short planning meeting (Hotel)	Preparation of the evaluation report	Preparation of the evaluation report	Preparation of the evaluation report Delivery of a draft version to MB	Dinner 19:30 Sokos Hotel Vaakuna Restaurant Loiste, Helsinki	
	Helsinki (HOTEL)	Helsinki (MEAE)	Espoo (VTT)	Espoo (VTT)	Lappeenranta (LUT) Helsinki (HOTEL)	Helsinki (MEAE)

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