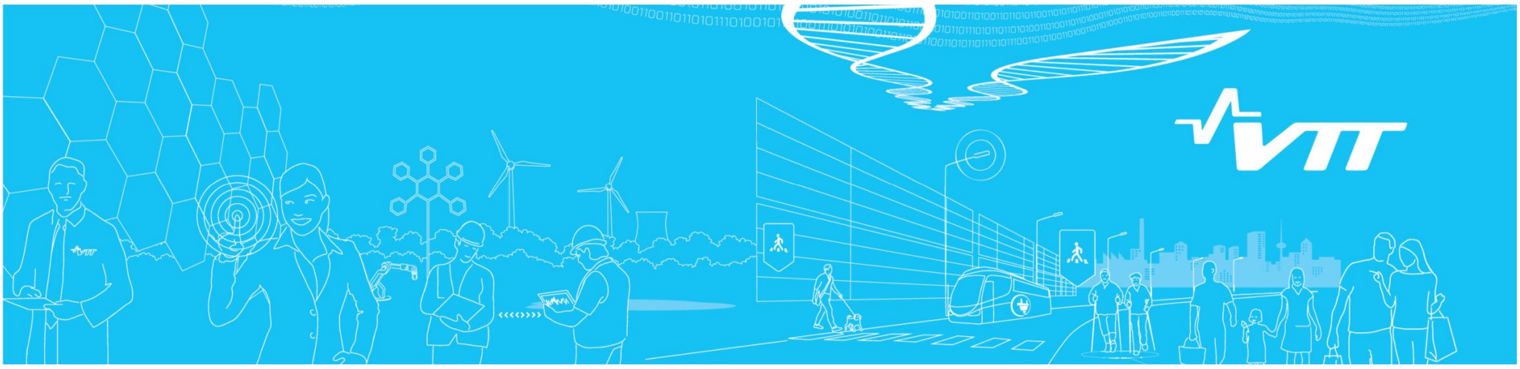
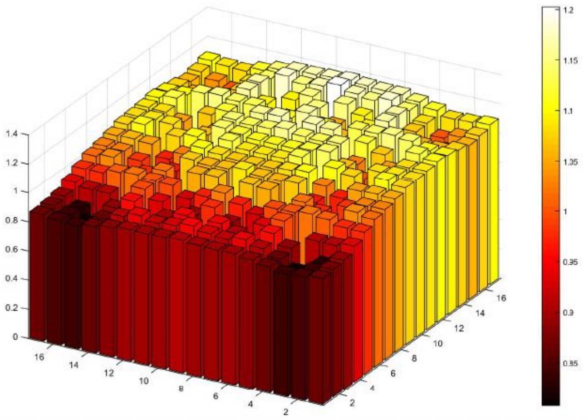


RESEARCH REPORT

VTT-R-01745-16



SAFIR2018 Annual Report 2015

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Summary

The mission of the National Nuclear Power Plant Safety Research programme 2015-2018 (SAFIR2018) is derived from the stipulations of the Finnish Nuclear Energy Act, concerning ensuring of expertise. The programme is continuation to a series of earlier national nuclear power plant safety research programmes that have proven their worth in maintaining and developing know-how.

SAFIR2018 Management Board is responsible for steering and planning of the research programme and consists of the representatives of the Radiation and Nuclear Safety Authority (STUK), the Ministry of Employment and the Economy (MEE), Fennovoima Oy, Fortum, Teollisuuden Voima Oyj (TVO), Technical Research Centre of Finland Ltd (VTT), Lappeenranta University of Technology (LUT), Aalto University (Aalto), Finnish Funding Agency for Innovation (Tekes), and Swedish Radiation Safety Authority (SSM).

The actual volume of the SAFIR2018 programme in 2015 was 8.5 M€ and 63 person years. Main funding organisations in 2015 were the Finnish State Waste Management Fund (VYR) with 5.3 M€ and VTT with 2.0 M€. The programme was divided into three research areas and in 2015 research was carried out in 28 projects.

This report provides a summary of the results of individual projects and overall financial and administrative issues. Summaries of project publications, international cooperation, academic degrees, travels and personnel are presented in the Appendices.

Confidentiality	Public

Espoo 9.5.2016

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Appendices

1. Introduction

In accordance with Chapter 7a of the Finnish Nuclear Energy Act enacted in 2004, the objective of the National Nuclear Power Plant Safety Research programme 2015-2018 SAFIR2018 is 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. High scientific quality is required of the research projects in the programme. The results must be available for publication and their exploitation shall not be restricted to the power plants of a single licence holder.

The SAFIR2018 programme's planning group, nominated by the Ministry of Employment and the Economy in March 2014, stated the following mission for national nuclear safety programmes:

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

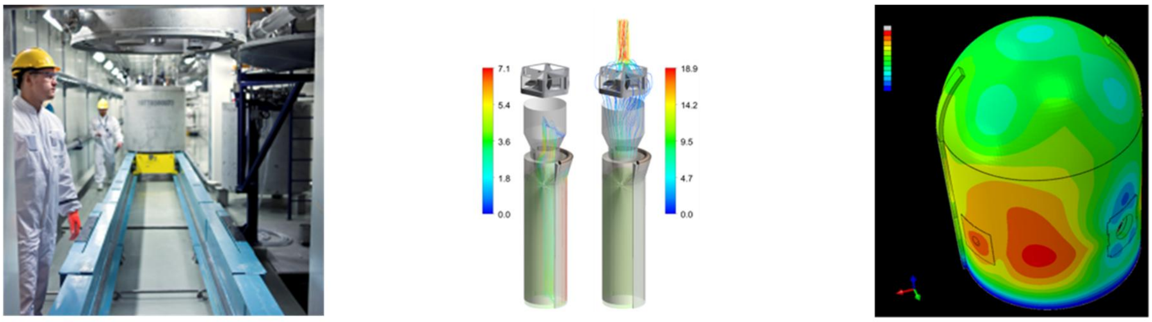
The vision of SAFIR2018 was defined as follows:

> *The SAFIR2018 research community is a vigilant, internationally recognised 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.*

The Framework Plan [1] describes the research to be carried out in SAFIR2018. The new programme essentially covers the themes of the preceding SAFIR2014 programme [2].

SAFIR2018 management board was nominated in September 2014. It consists of representatives of the Radiation and Nuclear Safety Authority (STUK), the Ministry of Employment and the Economy (MEE), Fennovoima Oy, Fortum, Teollisuuden Voima Oyj (TVO), Technical Research Centre of Finland Ltd (VTT), Aalto University (Aalto), Lappeenranta University of Technology (LUT), and the Finnish Funding Agency for Innovation (Tekes). In 2015 the management board was completed with a representative of Swedish Radiation Safety Authority (SSM).

A public call for research proposals for 2015 was announced in the beginning of September 2014. After the closure of the call, SAFIR2018 management board, taking into account the evaluations made by the steering groups, prepared a proposal for the MEE regarding the projects to be funded in 2015. The funding decisions were made by the Finnish State Nuclear Waste Management Fund (VYR) in March 2015. In 2015 the programme consisted of 28 research projects and a project for programme administration.



Plant safety and systems engineering Reactor safety Structural safety and materials

Figure 1.1. SAFIR2018 research areas.

VYR funding is collected from the Finnish utilities Fennovoima Oy, Fortum and Teollisuuden Voima Oyj based on their MWth shares in Finnish nuclear power plants (units in operation, under construction, and in planning phase according to the decisions-in-principle). In addition to VYR, other key organisations operating in the area of nuclear safety also fund the programme.

The planned [3] and actual volumes of the SAFIR2018 programme in 2015 were 8,5 M€ and 8,5 M€ and 55 and 63 person-years, respectively.

This annual report summarises the results of the individual projects (Chapter 2) and provides financial statistics of the research programme (Chapter 3). Administrative issues are summarised in Chapter 4.

Project publications are listed in Appendix 1, information on international co-operation in Appendix 2, list of Academic degrees obtained in Appendix 3, list of international travels in the projects in Appendix 4, and Appendix 5 contains list of the persons involved in the programme in the Management Board, Steering Groups, Reference Groups and in the projects.

This report has been prepared by the programme director and project co-ordinator in cooperation with the managers and staff of the individual research projects.

2. Main results of the research projects in 2015

The SAFIR2018 research programme is divided into three major research areas:

1. Plant safety and systems engineering
2. Reactor safety
3. Structural safety and materials.

The research areas are presented with more detailed descriptions of their research needs during the programme period 2015-2018 in the SAFIR2018 Framework Plan [1]. The research areas and research needs are based on the knowledge at the time of making the framework plan. The Framework Plan will be updated during the programme period, if necessary.

In 2015, the research was performed in altogether 28 research projects. The total volume of the programme was 8.5 M€ and 63 person years. The research projects in the various research areas with their planned and realised volumes are given in Table 2.1.

Summaries of research project results are given in the following subsections.

Table 2.1 SAFIR2018 projects in 2015.

Research area	Project	Acronym	Organi-sation(s)	Planned costs (k€)	Actual costs (k€)	Planned volume (person months)	Actual volume (person months)
1. Plant safety and systems engineering							
	Crafting operational resilience in nuclear domain	CORE	VTT, FIOH	422	414	32	37
	Extreme weather and nuclear power plants	EXWE	FMI	275	323	26	37
	Management principles and safety culture in complex projects	MAPS	VTT, Aalto, University of Oulu, University of Jyväskylä	280	285	22	23
	Probabilistic risk assessment method development and applications	PRAMEA	VTT, Aalto, Risk Pilot	398	403	32	33
	Integrated safety assessment and justification of nuclear power plant automation	SAUNA	VTT, Aalto, FISMA, Risk Pilot, IntoWorks	571	560	46	44
2. Reactor safety							
	Comprehensive analysis of severe accidents	CASA	VTT	280	280	22	24
	Chemistry and transport of fission products	CATFIS	VTT	261	262	15	21
	Comprehensive and systematic validation of independent safety analysis tools	COVA	VTT	305	305	20	25
	Couplings and instabilities in reactor systems	INSTAB	LUT	212	213	16	18
	Integral and separate effects tests on thermal-hydraulic problems in reactors	INTEGRA	LUT	320	322	24	28
	Nuclear criticality and safety analyses preparedness at VTT	KATVE	VTT	229	231	18	22
	Development of a Monte Carlo based calculation sequence for reactor core safety analyses	MONSOON	VTT	148	149	13	13
	Neutronics, burnup and nuclear fuel	NEPAL15	Aalto	95	96	11	10
	Development and validation of CFD methods for nuclear reactor safety assessment	NURESA	VTT, Aalto, LUT	250	257	18	19

	Physics and chemistry of nuclear fuel	PANCHO	VTT	340	341	28	30
	Safety analyses for dynamical events	SADE	VTT	156	156	13	15
	Uncertainty and sensitivity analyses for reactor safety	USVA	VTT, Aalto	214	215	22	23
3. Structural safety and materials							
	Experimental studies on projectile impacts against concrete structures	ESPIACS	VTT	44	44	3	3
	Fire risk evaluation and Defence-in-Depth	FIRED	VTT, Aalto	220	220	18	20
	Analysis of fatigue and other cumulative ageing to extend lifetime	FOUND	VTT, Aalto	542	542	35	39
	Long term operation aspects of structural integrity	LOST	VTT	77	77	5	5
	Mitigation of cracking through advanced water chemistry	MOCCA	VTT	96	96	7	6
	Numerical methods for external event assessment improving safety	NEST	VTT	333	334	20	22
	Thermal ageing and EAC research for plant life management	THELMA	VTT, Aalto	351	359	22	26
	Non-destructive examination of NPP primary circuit components and concrete infrastructure	WANDA	VTT, Aalto	346	347	20	22
4. Research infrastructure							
	Development of thermal-hydraulic infrastructure at LUT	INFRAL	LUT	313	313	15	23
	JHR collaboration & Melodie follow-up	JHR	VTT	40	40	2	2
	Renewal of Hot Cell infrastructure	REHOT	VTT	1008	1008	48	60
0. Programme administration							
	SAFIR2018 administratiion and information	ADMIRE	VTT	327	324	11	11

The costs of ADMIRE are for period 1.1.2015-31.3.2016. The costs include two subcontracted small study projects and value-added tax 24%.

2.1 Plant safety and systems engineering

In 2015 the research area “Plant safety and systems engineering” consisted of five projects:

1. Crafting operational resilience in nuclear domain (CORE)
2. Extreme weather and nuclear power plants (EXWE)
3. Management principles and safety culture in complex projects (MAPS)

4. Probabilistic risk assessment method development and applications (PRAMEA)
5. Integrated safety assessment and justification of nuclear power plant automation (SAUNA).

2.1.1 CORE - Crafting operational resilience in nuclear domain

The aim of the CORE project is to improve safe operation of nuclear power plants by developing guidance, training interventions, and other practical solutions that promote resilience for the three general defence levels of prevention, preparation, and consequence management. Regarding prevention, the aim is to support operating personnel to succeed better in challenging work tasks by being more reflexive, engaged, and self-conscious and aware of high-level goals, instead of being solely guided by fixed and predetermined procedures. The aim is also to develop new Human Factors guidelines, models and tools and interventions that will be tested and examined in simulated test environments and in workshops. Regarding preparation, operating personnel needs generic skills and abilities to master difficult, unfamiliar, and ‘knowledge-intensive’ operational situations. They need skills to cope with excessive acute stress in demanding operational situations. There is also need to collect operating experiences from successful actions and decisions and analyse the lessons learned from these experiences. Regarding consequence management and recovery, it is required that risk is efficiently detected, recognized, interpreted, and communicated so that a collective response is mobilized promptly. Therefore, such methods and tools are needed in crisis management that help stakeholders with different responsibilities to coordinate their actions to achieve a common operational picture.

Specific goals in 2015

First, we have carried out a literature review that identifies theories that define success. This literature review allowed us to prepare a preliminary set of success criteria that we have used to design the empirical studies and that will also serve as a starting point for developing the framework for identifying successful actions and decisions in NPP context. Some of the main findings in our literature review were that success, especially as it is related to learning, is more than merely achieving a pre-specified task outcome. Success also contains such elements as social construction, criteria dynamics, outcome dynamics, hierarchy and stakeholder multiplicity and process boundaries. We have also carried out case studies in one Swedish (Ringhals) and one Finnish (Fortum Loviisa) NPP. The case studies provided us empirical data which allowed us to help identify principles to capture successful performance adaptations and to refine and validate the preliminary success criteria.

The second goal was to provide the basis for the accomplishment of a training development method with the NPP operators. Upon initial interviews it came out that the operating organization possesses several practical and administrative restrictions for taking new training methods into use, and in practice, as there is limited space in the existing training curriculum for new kind of training, the new training method should enhance the existing training by introducing new features to it. The scope of this task was thus enlarged to include considerations of the learning aspect in the simulator sessions, while less emphasis was given to the comparison of the collected data with future data. The aim was also to elaborate the concept of interpretative practice with the operators themselves at workshops, and to explore the needs and views of the trainers and HR-personnel and to raise their awareness of the different work orientations in order to combine the elements of a learning method that supports the learning of interpretative work practices.

Third, we have studied the impact of multitasking and interruptions/distractions on work performance in safety-critical domains by preparing a literature review, and a method has been developed for the identification and classification of distractions in operator work, and it has been tested in the analysis of simulated accidents. According to the literature review, interruptions and distractions that divert attention away from the task at hand to another task have typically a detrimental effect on performance. However, if the distraction is related to the primary task and add new information that is helpful in task execution, its effect can be positive. Even in the latter case the effect may be negative, if the information is not directly associated with the task the worker is just performing. In addition, functional situational models of the TVO Olkiluoto simulation runs have been prepared which will be used in the analysis of simulation test data, and a literature review on troubleshooting in operative work has been prepared, including a description of the development of MAPS-based notation system for troubleshooting modelling.

Fourth, we have tested various psycho-physiological measurement devices and protocols in order to determine the most suitable measurement setups for NPP simulation settings. The devices were evaluated in terms of data quality, appropriateness and non-intrusiveness. The laboratory measurements combining HRV and EDA provided the highest accuracy in predicting stress and performance. Our aim has also been to measure and quantify the stress and workload of the NPP control room operators in incident and accident situations, and evaluate the effects of stress and workload on performance. The actual measurements were carried out in autumn at TVO Olkiluoto NPP. Additionally, although the stress is well known to effect performance, this information is not systematically taken into account in NPP personnel training. For the power plant personnel to be motivated to take part in the physiological recordings, and for the effectiveness of their stress management, they need to be aware of the direct practical consequences of the physical stress reaction to their performance on the accident and incident situations. During 2015, this awareness has been increased by sharing information and educating the power plant personnel.

Fifth, the conceptions of the key players participating in emergency exercises are studied, that is, those responsible for planning and organizing the exercises in the two Finnish functioning nuclear power plants and one person responsible for participating and evaluating the exercises from STUK. Some exemplary reports of the exercises from both plants are also available for the study. From the state of the art point of view, emergency exercises are contemplated from the resilience engineering point of view. This way the structure and logics regarding the emergency exercises as well as developmental needs, especially regarding collaboration, are revealed.

The sixth aim has been to identify the current HF conceptions, practices and tools used by the nuclear safety organizations (NPPs and STUK), as well as evaluate user experiences of the use of the HF tool (Figure 2.1.1.1). Data concerning current HF guidelines and practices in safety management procedures (risk analysis, reporting, investigation, training, etc.) was collected and analysed. After finding out that currently NPPs are using mainly one investigation method, namely AcciMap or actually, modification or some main characters of that method, this current method was compared to the use and outputs of the HF tool by analysing operational events both with the current and with the new HF tool. Results of the analysis were revealed and similarities/differences modelled out at the final of the workshop. The translation of the HF tool to suit the context of nuclear safety was conducted successfully.

Deliverables in 2015

- Preliminary version of the principles for identifying and learning from successes and of the framework for capturing successes.
- Suggestions on how to promote interpretative practice by enhancing training in NPP operation.
- State-of-the-art report on multitasking and the impact of interruptions/distractions on work performance in safety-critical domains.
- Functional situational models of the TVO Olkiluoto simulation runs.

- State-of-the-art report on troubleshooting in operator/maintenance personnel work has been prepared, including a description of the development of MAPS-based notation system for troubleshooting modelling.
- Lectures/lecture notes on the topics of physiological stress, effects of stress on performance in general and specifically in critical situations and complex environments, as well as on stress management.
- State-of-the-art of principles and practices of emergency exercises.
- HF Tool modified for nuclear domain.
- Draft of a scientific article on applying the HF Tool in a nuclear energy industry.

Figure 2.1.1.1. HF Tool (in Finnish) modified for nuclear industry.

2.1.2 EXWE - Extreme weather and nuclear power plants

The general objective of the EXWE project is to enhance scientific understanding of the environmental conditions of the nuclear power plants' (NPPs) sites and to predict how they may change in the future, possibly posing external threats to the plants. The outcomes of the project can be used to improve the safety of existing NPP units and the design of future units. Four themes are covered: 1) extreme weather incidents and 2) extreme sea level events, 3) extreme magnetic weather; and 4) atmospheric dispersion modelling of accidental releases. Both instrumental records and model simulations are utilized in the work. The end-users are the power companies designing and running NPPs as well as the Finnish and Swedish nuclear safety authorities defining the safety regulations for NPP constructions and operations.

Specific goals in 2015

The specific topics in 2015 were severe warm- and cold-season convective weather events, freezing rain, meteotsunamis, simultaneous occurrence of high sea level and high wind waves, extreme space weather i.e. solar storms and geomagnetic disturbances, and dispersion and dose assessment. Extreme weather and sea level events affect the design principles of nuclear power plants and might pose external threats to the plants. In addition, geomagnetic effects of extreme solar storms may reduce the reliability of the external power transmission grid.

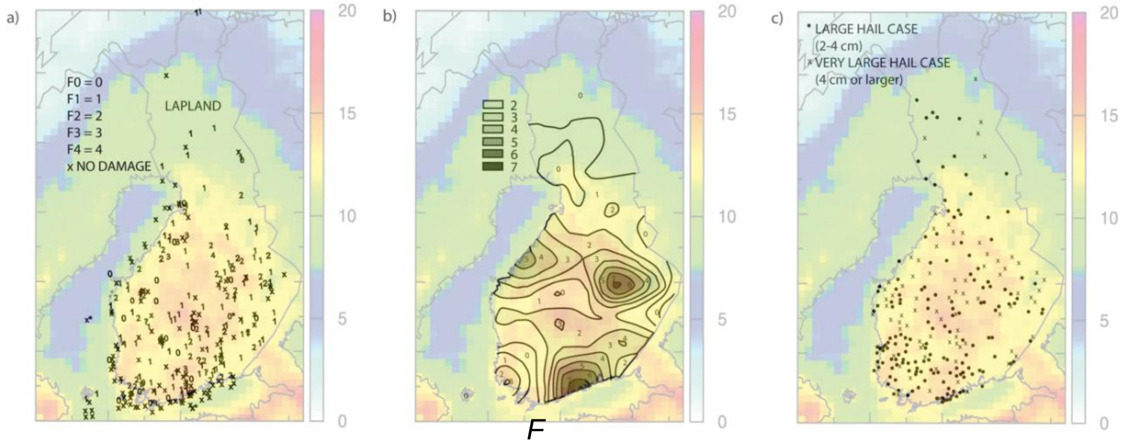
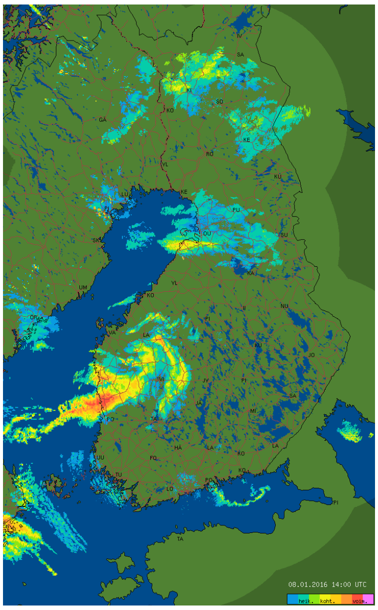


Figure 2.1.2.1. Geographical distributions of (a-b) tornadoes and (c) severe hail in Finland, overlaid on the average annual number of thunderstorm days per day. a) All tornado cases in 1796–2007, classified according to their intensity (the Fujita-scale in the legend). b) Annual probability (in percent) of at least one significant tornado in an 80 km x 80 km area based on the 1930–2007 statistics. c) Severe hail cases in 1930–2006. (Based on Tuovinen et al. 2009; Mäkelä et al. 2011; Rauhala et al.2012.)

<u>Past cases of extreme warm-season convective weather in Finland</u>: Thunderstorms, lightning, tornadoes, downbursts, large hail and heavy precipitation are most common in the period from May to September, with peak in the midsummer. Diurnally, the most prominent time of occurrence is the late afternoon. Extreme convective weather (ECW) is always related to convective clouds; however, only a small fraction of convective clouds produce severe weather with notable economic or societal losses. During past decades, FMI has collected observations and damage descriptions of ECW episodes in Finland. Based on these data, climatological information has recently been summarized, and some of the most intense events have been examined in detail. The research findings indicate that ECW may occur practically anywhere in the country, although in general the probability of occurrence is smallest in northern Finland (see Fig. 2.1.2.1 for tornadoes and large hail). Impacts of climate change on the occurrence of ECW is a challenging question; however, the warmer atmosphere is generally considered to have more potential for generating more intense ECW events. This topic needs further studies with high-resolution and state-of-the-art climate models.

<u>Past sea-effect snowfall cases and predictors of extreme cold-season convective weather</u>: The origin and main source of energy of wintertime ECW in Finland is most commonly the Baltic Sea, and ECW materializes as sea-effect snowfall. A list of potential past cases of sea-effect convection in 1961–2014 was produced by combining the list created previously in 2014 with outcomes of a new method that utilizes information about convectivity of precipitation, i.e., the portion of snowfall as convective showers. This information was derived from assimilation-based reanalysis of past meteorological data, and radar image archive was

used for verification purposes. Based on the results, the majority of the sea-effect cases occur above the Northern Baltic or the Sea of Bothnia (see Fig. 2.1.2.2 for a recent example).



Three past sea-effect snowfall cases were selected for further analysis. They were simulated with an operational numerical weather forecast model used at FMI. The results from the simulations are in accordance with the weather radar observations, although some differences can also be found. More simulations will be needed in order 1) to better evaluate the functionality of the new method for identification of the past sea-effect snowfall cases and 2) to form a way to combine the results from the weather forecast model simulations with climate model data, with the ultimate goal to assess possible future changes in the occurrence of sea-effect snowfall.

Figure 2.1.2.2. Sea-effect snowfall, as observed by FMI weather radars, on 8 Jan 2016 at xxx. During that event, snow cover increased by 73 cm at Merikarvia, on the coast of the Sea of Bothnia.

<u>Freezing rain</u>: Climatological information about the occurrence of freezing rain (FZRA) across Europe was produced by applying a precipitation typing algorithm to 6-hourly ERA-Interim reanalysis data of 1979–2014. The algorithm is based on vertical profiles of relative humidity and temperature, and it utilizes threshold values that were refined in EXWE. Compared to observations of FZRA at manually-operated weather station, the annual numbers of FZRA cases in northern, central and southern Europe could be reproduced moderately well. FZRA is not as commonly observed in Finland (1-2 events/year/grid cell) as in central Europe (2-4 events/year/grid cell), but the FZRA season is longer, lasting from September to May (from October to April in central Europe). The developed method performs relatively well at weather stations of Finland, but slightly overestimates the total 1979-2014 numbers of FZRA events per station compared to the observed numbers. Based on available information, it is difficult to say if the observed number is too low compared to reality (observational uncertainty) or if the predicted number is too high (method and predictor data related uncertainty). More research focusing on the FZRA and other related freezing phenomena in different synoptic situations is needed to further minimize the uncertainties.

<u>Meteotsunami probabilities at the Finnish NPP sites</u>: The statistics of meteotsunami occurrence in the Gulf of Finland was complemented using archived tide gauge records from Hanko and Hamina 1980–1989. Potential meteotsunami events were digitized (7 events from Hanko and 9 from Hamina) and their meteorological origin was studied using archived barograms (air pressure charts) from nearby stations. After including the events from the 1980s, the full time series consists of 45 events from Hanko 1922–1989 (of which 27 or 60% have been confirmed from air pressure data) and 42 events in Hamina 1928–1989 (26 or 62% confirmed). Typical meteotsunami heights recorded by the tide gauges are 10–30 cm from crest to trough and 5–20 cm compared to the sea level prevailing just before the event.
The long time series of meteotsunamis recorded by Hanko and Hamina tide gauges were used to sketch first estimates of exceedance probability distributions of meteotsunamis on the Finnish coast. The largest problem in determining the distributions is the lack of statistics concerning larger meteotsunami events (heights 50–100 cm or more) which have been reported by eyewitnesses but are not included in the statistics recorded by the tide gauges. The eyewitness observations represent events in which the wave is locally amplified through resonance mechanisms related to coastal bathymetry. The distributions were extended

towards stronger meteotsunami events by a simple scaling, backed with refraction model results, but more research is needed to bring the distributions to a firmer basis.

Joint effect of high sea level and high wind waves: The observed sea level is always a combination of both sea level and wind generated waves. Wave height varies greatly along the Finnish coastline, and while the archipelago acts as an efficient shield against the largest waves, part of the energy of the waves passes through the archipelago and penetrates to the shoreline. Local wave height conditions can differ greatly depending on the shape of the shoreline and irregular topography of the seabed. A new method of combining sea level and wave height distributions as a single probability distribution was developed and estimates of the joint effect of sea level and waves for several different locations in the archipelago area off Helsinki were calculated.
Short-term sea level distributions were based on the last 30 years (1982–2011) of hourly observations from the Helsinki tide gauge. Long-term sea level changes used in the study were based on mean sea level rise scenarios for Helsinki, and wave observations were based on individual wave buoy measurements conducted at several sites in the Helsinki archipelago during 2012–2014. The new method can be used as a cost-effective tool for evaluating high sea level events including the effect of waves, and to achieve more accurate location-specific flood risk estimates.

Extreme space weather: Extreme space weather refers to the conditions where extremely strong magnetic fields and large amounts of fast and energetic particles have entered from the solar wind into the magnetosphere and atmosphere during an extremely strong solar storm. Solar storms are known to induce currents up-to 44.8 nT/s to power networks and up-to 57 A currents to gas pipelines. In space, even a single solar energetic electron may damage an entire satellite. That happened during a series of the so-called Halloween solar storms on October-November 2003. The Halloween solar storm event continued for about two weeks with major disturbances about half of the time. Such an interval has a potential to disrupt the power supply from several hours to days, and thus possibly affect the nuclear power supply. In US nuclear power plants (Salem and Seabrook) have been affected by solar storms at least in 1989 and 2011.

In EXWE, we examined extreme solar storms and extreme magnetic weather conditions close the Earth, focusing on the NPP locations in Finland. Based on our results, geomagnetic weather in the Hanhikivi area is geomagnetically more disturbed (geomagnetic disturbances occur more frequently) than in Loviisa and Olkiluoto. However, the probabilities of getting extreme geomagnetic disturbances are a bit larger in Olkiluoto and Loviisa compared to Hanhikivi. Extreme solar storms are estimated to occur once in 100 - 150 years. The drivers of magnetic weather changes in central Finland differ from the drivers of the magnetic weather changes in southern Finland. Central and northern Finland is strongly driven by stream interaction regions, high-speed streams and related structure while southern Finland is also driven by interplanetary coronal mass ejections. Stream interaction regions and high-speed streams typically cause extreme magnetic disturbances on ground in 27-day periodicity, each time from several days to over a week. Such long-lasting changes have the potential to cause the slow degradation of infrastructures, such as transformers and should be better evaluated and examined in future projects.

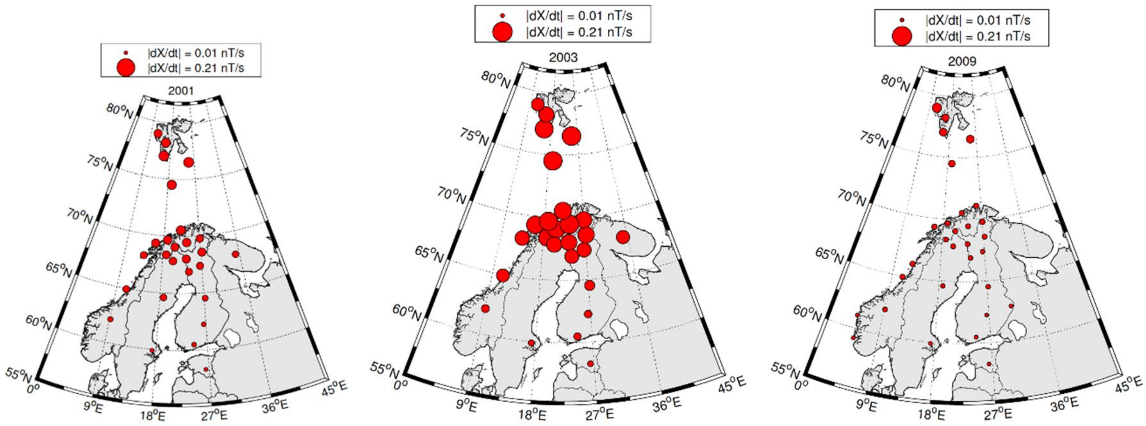


Figure 2.1.2.3. Yearly averages of ground-based magnetic disturbances during solar maximum (on the left), during declining solar cycle phase (middle), and during solar minimum (on the right).

Towards an integrated radiation dispersion and dose assessment tool. In EXWE in 2015, a series of discussions and a technical meeting were organized between FMI and VTT, aiming at better understanding of the existing SILAM model capabilities, available tools in VTT and the most-efficient way to proceed towards an integrated radiation dispersion and dose assessment tool.

At present the most-used instrument for dose assessment is VALMA, a model developed a long ago as a post-processor to that time Lagrangian SILAM model. The two models were connected via a trajectory interface files that are still used today. The level of details and technical capabilities of this construction are clearly insufficient and require development of next-generation tools. Particular issues include reliance on limited number trajectories that can be passed between SILAM and VALMA via the interface without overloading the VALMA system. A functionality of transferring the Eulerian concentration and deposition grids is absent completely. This is in sharp contrast with the modern SILAM model, now capable of Eulerian radioactive simulations, which is the only way to analyse large-scale accidents, such as Fukushima. Secondly, even in Lagrangian environment and regional-scale problems, SILAM is currently dealing with millions of trajectories, which exceeds the interface and VALMA capabilities by 2-3 orders of magnitude.

The dose assessment tool should be separated from a broader-scale flexible user-friendly tool (VTT) for analysis of sociological, economical, public-health related and other consequences of radioactive contamination, dose rates, and doses. The dose computation methods differ between risk-assessment applications and emergency-response tasks. The probabilistic nature of the risk-assessment task requires certain efforts to be properly reproduced by deterministic dispersion and dose assessment models. The emergency-response computations are simpler and constitute a “subset” of the computations needed for the risk assessment. A methodology suitable for risk assessment was presented, with appropriate remarks on the emergency-response task simplifications.

Deliverables in 2015

- A report on past sea-effect snowfall cases and predictors of extreme cold-season convective weather was written.

- A report was written about the present status of knowledge and the level of uncertainty regarding extreme warm-season convective weather cases in the past.

- A peer-reviewed article about significant hail-producing storms in Finland was finalized.

- A peer-reviewed article about validation of automatic observations of cumulonimbus clouds (associated with thunderstorms) was finalized.
- A manuscript about the occurrence of freezing rain based on synoptic weather station data has been submitted.
- A manuscript about methodology to estimate freezing rain climatology from ERA-Interim reanalysis over Europe has almost been finalized.
- A report was written on results from the meteotsunami studies
- A report was written on the joint effect of high sea level and high waves
- A report on extreme space weather and a scientific paper
- A report was written about a way towards the Integrated Tool Development and application in a dispersion case study.

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2.1.3 MAPS - Management principles and safety culture in complex projects

The general objective of the MAPS project is to enhance nuclear safety by supporting high quality execution of complex nuclear industry projects. Project Management Institute defines *project* as “a temporary endeavour undertaken to create a unique product, service or result” (PMI, 2013), and *complexity* as a “characteristic of a program or project or its environment that is difficult to manage due to human behaviour, system behaviour, and ambiguity” (PMI, 2014). New build projects and plant modernizations are such complex projects, carried out often by multinational networks of companies. In the context of wide diversity and large number of actors in the project network, it is challenging to ensure that the safety and quality requirements are adequately understood and fulfilled by each party. MAPS focuses on advancing the understanding of applying the concept of safety culture and safety management models and practices in dynamically changing project networks. This is an interdisciplinary project, which is building bridges between safety culture, governance of complex projects, construction industry network management, societal research on safety regimes and system dynamics modelling.

The four year project is aimed at the following objectives:

(a) Identifying the generic safety principles of managing complex projects in the nuclear industry.

(b) Clarifying the cultural phenomena in major projects and the influence of time, scale, governance models, and the diversity of the involved actors on safety culture, and thus on safety.

(c) Facilitating management and safety culture of ongoing and planned major projects by providing practical tools and guidance on e.g. facilitating communication, organising decision making in unexpected situations, encouraging openness, and distributing knowledge and lessons learned.

Specific goals in 2015

First, we have carried out a systematic literature review to understand typical project governance models from a safety perspective. We carried out nine baseline interviews at Fortum, TVO and Fennovoima to provide an initial understanding on the characteristics of complexity in nuclear industry projects in Finland, and to highlight the features that are challenging from management of safety point of view. We studied three projects - two modernization & modification projects and a new build project. The results indicated that organizational and emergent dimensions of project complexity are challenging from management perspective. The study creates knowledge basis for further advancement of conceptual theory and method development for understanding and tackling complexity and its effects on safety in projects.

Related to this task, since another aim is to educate newcomers in the nuclear industry field, in late 2015 Matilda Starck has started her Master's thesis work at Aalto University on the topic "Governance models in safety critical projects". The focus of the thesis is on exploring and examining both theoretically and empirically what are the key elements in project governance and how they affect safety.

Second, we focused on the nuclear specific requirements for complex projects, with emphasis on studying the regulatory perspectives on governance of safety and complex projects by conceptual and empirical analysis. The aim was to gain understanding about the sources of complexity and the means to govern safety and complexity in projects from regulatory and industry perspective. Interviews with six experts from STUK and six experts from the power companies, as well as documents, were analysed. Results indicated that main sources of complexity in projects are the requirements (YVL-guides), the scale of the project and long supply chains, cultural and organisational aspects, technical complexity, interconnectedness and schedules, and the overall safety. The YVL guides were seen as both a source of and solution to complexity.

Third, safety culture in complex network organizations was studied. The goal was to develop preliminary theoretical framing and description of cultural complexity and safety culture challenges in project contexts, based on literature review and interviews data analysis. The literature review discussed the concept of cultural complexity and existing frameworks. It also provided a summary of recent quality and safety-related challenges experienced in complex projects in the safety critical domain and other related industries. The results indicated that subcultural variety and dynamics require balancing between dealing with fragmentation and utilizing richness of perspectives, flexibility and identification of emergent risks as potential advantages for enhancing nuclear safety in projects.

Forth, we studied the applications of system dynamics modelling in complex projects. The task focused on conducting a literature review on the use of system dynamics modelling in complex safety critical projects to form an understanding of the existing uses of system dynamics to project management issues in general, as well as for analysing and improving safety culture in particular. The literature review report indicated that key issues in the existing project management models, such as the number of undiscovered errors, have implications for safety, yet the current models are mainly discussed from financial perspective, focusing on cost overruns and schedule slippages

The fifth goal was to internally integrate and disseminate the results. We have been working on developing a shared understanding in the interdisciplinary research team of MAPS by regular internal project meetings and workshops to brainstorm and integrate research perspectives and creating an inclusive project culture. Another aim was to disseminate the results of our work: the on-going MAPS project and its preliminary results in 2015 have been presented at a dissemination seminar for the nuclear industry, international project business workshop and scientific conferences.

Deliverables in 2015

- State-of-the-art review of typical project governance models of complex projects from safety point of view: a systematic literature review was carried out and summarized in a conference article
- Literature review and baseline interviews analysis to identify the characteristics of complex projects in the Finnish nuclear industry and their effects on nuclear safety were summarized in a working report
- Analysis of cultural characteristics of the Finnish nuclear safety regulation, summarized in a conference article
- Draft of a scientific article on characteristics of safety regulation: comparison between Finnish nuclear industry and Norwegian petroleum industry
- Draft of a scientific article on modelling the cultural complexity and safety culture challenges in project networks
- Literature review of systems dynamics applications in complex safety-critical projects, summarized in a working report.
- MAPS dissemination seminar presentations on the following topics:
    - Project governance and safety: Key dimensions of project governance and their effects on safety
    - Regulatory perspective on safety management in complex projects: Understanding nuclear specific regulatory requirements
    - Cultural complexity and safety culture in project networks
    - Applicability of system dynamics modelling in complex nuclear industry projects

2.1.4 PRAMEA - Probabilistic risk assessment method development and applications

The general objective of the PRAMEA project was to develop methods and tools for probabilistic risk analysis (PRA) of digital systems and to utilize them in practical case studies. The project covered most of the topics relevant to the PRA of nuclear power plants. PRAMEA provided literature reviews on human reliability analysis (HRA) for advanced control rooms and on state of the art in multi-unit PRA, specified requirements for the HRA of digitalized control rooms, developed further the level 2 probabilistic safety analysis (PSA) analysis tool FinPSA Level 2, participated in writing a guidance document on level 3 PSA, developed importance measures for the schedule risks of emergency operations, and submitted a scientific manuscript on risk-based optimization of pipe inspections to a refereed journal.

Specific goals in 2015

The objectives of the task on HRA of digitalized control rooms were to perform a literature review about HRA of digital control rooms, organise a workshop or ad hoc meetings for the national regulator and nuclear power companies, and based on the findings of these refine the scope and objectives for the research for the coming years.

The objective of HRA study about the benefits of qualitative analysis was firstly to determine whether it is possible to use the qualitative human factors validation methods for HRA purposes and secondly what the potential application areas for HRA methods and results outside PRA are.

The objective of the task on dependencies in HRA was to evaluate existing methods and develop supplementary guidance for the assessment of dependencies in HRA. The task was performed in collaboration with a Nordic PSA Group (NPSAG) project, carried out by Lloyd's Register Consulting. The NPSAG project performed a literature study and case studies in Sweden. The specific objective within PRAMEA was to perform at least one case study in Finland.

The objective of the Multi-unit PRA modelling task was to review the state-of-the-art. Three points of view were considered; multi-unit risk measures, multi-unit PRA modelling and tool support for multi-unit PRA modelling. Additionally, an objective was to make an action plan for 2016-2018 regarding multi-unit PRA development.

The objective on level 2 integrated deterministic and probabilistic safety analysis (IDPSA) task was to study previous IDPSA research conducted at VTT in order to be able to perform further research in the forthcoming years.

Level 2 method support objectives were knowledge transfer to new developers and renewal of outdated SPSA application. Actions were needed because SPSA does not natively work in computers of today and existing models included important knowledge. The planned work provided new features for level 2 method support including risk integrator, better overall usability, quality and informative error messages.

VTT has developed in 2014 a pilot to analyse the radiological consequences of the radionuclide release of the Fukushima Daiichi source term of 2011 in the imaginary case that the inhabitants of five major cities close to the NPP site would have been in place (instead of having died in or been evacuated due to the March 2011 earthquake and tsunami) when the release occurred. In 2015, the objective was to improve on this pilot to make it more realistic.

Emergency operations – e.g. recovery from a loss of coolant accident at a nuclear power plant – contain risks (schedule risk, end product quality risk, cost risk, side effect risk, injury risk) that can be analysed by applying methods from project management. In 2015, the objective was to study methods of analysing schedule risks when resources available for the operation are limited. The methods were to be applied to a small case.

The objective of reliability analysis of defense-in-depth in organizations focuses on two topics in relation to defense-in-depth strategies: (i) the assessment of the impact of communication and coordination errors on organizational decision-making processes and thus the implementation of activities in support of safety goals; and (ii) the development of robust strategies for ensuring the safety of systems, especially when there is a need to detect and eliminate errors through cost-effective deployment of inspections.

Deliverables in 2015

- A workshop on the HRA of digital control rooms was arranged. Representatives from all Finnish power plants and STUK participated. The participants presented their current state and wishes concerning the topic.

- A literature review on the HRA of advanced control rooms has been conducted. Digital HSI changes the secondary tasks and team collaboration. The most active methodological progress during recent years has come from Korea and China, including proposals for new performance shaping factors and typical error types when using soft controls.

- The objectives and scope of the PRAMEA research concerning HRA of advanced control rooms of have been refined for the years 2016 – 2018 based on the findings from a literature review and stakeholder workshop performed in the project in 2015. The main objective is to improve the task analysis and the treatment of performance shaping factors for computerised human-system interfaces in modernised and new control rooms.

- Benefits from qualitative analysis in HRA have been analysed. The study scrutinised various types of HRA methods – actual and recommended - and it was concluded that the methods used in human factors validation are applicable and possibly also included among those which are used as HRA methods. Familiarising in the practise of validation methods may also broaden the methodology to be used for HRA purposes. The HRA methods were concluded to be applicable not only for HRA or validation purposes but also for other objectives which serve to develop operations in the nuclear domain; in operator training, when developing present or new emergency operating procedures or when evaluating the details of the concept of operations for control-room operators.

- Case studies on methods for handling of dependencies in HRA have been carried out:

    - The case study on dependency between multiple pre-initiator actions examined the treatment in Fortum's HRA of the calibration error of two redundant thermostats due to a common cause failure. It was concluded that Fortums's dependency model was in line with the commonly used THERP-method and in reasonable agreement with international recommendations e.g. NUREG-1792 Good Practices for Implementing HRA. Some development ideas were also suggested.

    - The second case study on dependences between operator actions to recover a LOCA during shutdown highlighted the analysis steps required for the identification of relevant actions in a complex scenario as well as the quantitative impact of assuming full or high dependency between rather closely related actions.

- Participation in a seminar presenting the results of the NPSAG and SAFIR HRA dependencies project. The seminar and related project reports provide a thorough picture of the state-of-the-practice of the treatment of dependences in today's PSA studies.

- A literature review on state-of-the-art in multi-unit PRA has been carried out. Three viewpoints were considered: multi-unit risk measures (safety goals), multi-unit PRA modelling, and tool support for multi-unit PRA modelling. A large part of the research seems to focus on identifying and accounting for different kinds of dependencies and on external hazards.

- A summary report on previous IDPSA studies carried out by VTT has been written. Case studies demonstrated the use of IDPSA in level 2 PRA. Information on level 2 phenomena and modelling capabilities was obtained.

- New features to the FinPSA Level 2 code were introduced. Risk integrator combines analysis results from multiple CETs: weighted values, statistical parameters and CET contributions are calculated. In addition, density function and discrete scatter plots for collected variables are drawn. Multi-CET simulation control has been implemented to support efficient analysis. Data exchange for reporting is based on rtf format and out form of FinPSA; this feature was extended from FinPSA Level 1 to Level 2. In addition, statistical analyses for one CET were extended and improved. These extensions included computation of correlations between chosen variables and export functions for simulation and statistical results. Finally, a user guide for level 2 analysis and result reporting was prepared.

- FinPSA Level 2 code was also improved in other ways. Error messages and CETL syntax checking have been improved. The program can function after abnormal situations with higher confidence. More precise reporting of run-time errors has been implemented. Several bugs in the code have been fixed.

- Tests were planned and specified for 34 properties of the level 2 FinPSA software. The tests covered risk integration and error reporting. Testing importance values were calculated to find out the current priority order of the tests. Of the specified tests 33 were performed. All performed tests passed.

- The pilot of level 3 PRA from 2014 has been improved in different ways. In the model itself, wind speed calculations were implemented using a Weibull distribution; using a continuous distribution, rather than three discrete values (as in 2014) makes the model more realistic. Evacuation modelling was also improved. More comprehensive uncertainty analysis was developed including uncertainty of the source term and effects of weather conditions.

- Draft architecture for a new level 3 PSA code, to be possibly developed by VTT in the future, was specified. The code utilizes free and open source software (FOSS) to as large an extent as meaningful. Such software was reviewed, and it turned out that especially for atmospheric dispersion estimation, geographic information management and analysis, and statistical and mathematical analyses, good FOSS programs exist. The proposed architecture is based on a multi-tiered architectural style.

- A method for applying importance measures to schedule risks in emergency operations was developed. The method allows easy calculation of importance measures from simulation (or experimental) data. The method was applied in a case study of clearing fallen trees from roads leading to a nuclear power plant.

- A scientific paper on risk-based optimization of pipe inspections was written and submitted to *Reliability Engineering and Safety Science*. It has been conditionally accepted for publication subject to minor revisions.

- A conference paper on the same topic was presented by Michele Compare at the ESREL 2015 conference on Safety and Reliability of Complex Engineered Systems in September 2015. In August 2015, Compare made a two-week visit (i.e., Short-Term Scientific Mission) to Aalto University, supported by the COST Action IS1304 on *Expert Judgment Network: Bridging the Gap Between Scientific Uncertainty and Evidence-Based Decision Making*.

- An optimization methodology for the design and implementation of cost-efficient defense-in-depth strategies has been developed and reported in a manuscript that is at an advanced stage.

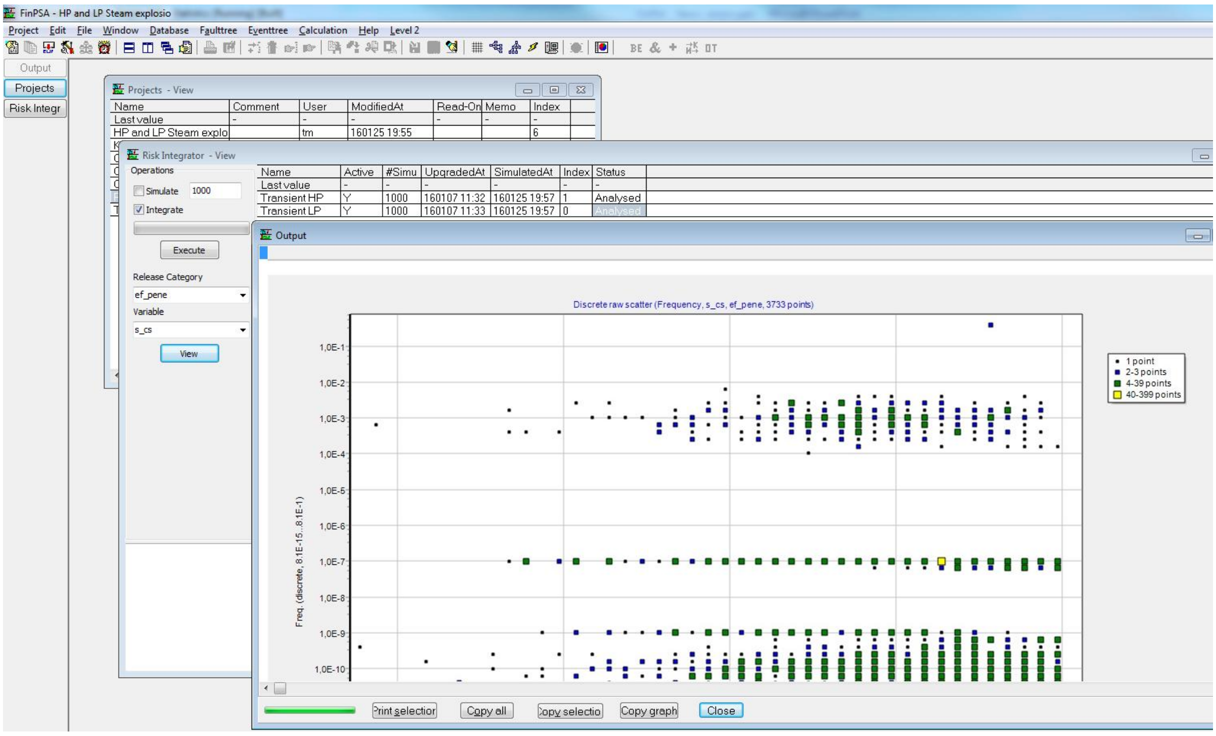


Figure 2.1.4.1.. FinPSA Level 2 user interface view, with risk integrator and its output in the foreground.

2.1.5 SAUNA - Integrated safety assessment and justification of nuclear power plant automation

The general objective of SAUNA (2015-2018) is to develop an integrated framework for safety assessment and transparent safety demonstration of nuclear power plant instrumentation and control (I&C) systems. Traditionally, safety assessment tends to focus on technical issues, single faults or limited combinations, deterministic analysis and PRA, and a document-based approach (SARs). In SAUNA, the research theme is overall plant safety. A key challenge is therefore to consider 1) all types of hazards, including rare and extreme conditions, 2) all disciplines and types of system elements (technical, human, environmental…), and 3) all life-cycle phases and activities.

Through a multidisciplinary research strategy, SAUNA will look at plant operations in the context of the whole plant and investment project, while keeping the focus on I&C systems. The different work packages will 1) build a shared understanding of the underlying challenges, concepts, and Systems Engineering principles, 2) develop dedicated methods and tools for assessing the safety of systems and their development processes – particularly focusing on the efficient integration of different approaches – and 3) tie the results together into an integrated, structured, model-based approach to safety demonstration and licensing.

Specific goals in 2015

WP1 of SAUNA focuses on clarifying the terminology and Systems Engineering principles in order to provide a common basis for various research activities on NPP safety. In 2015, the focus was on models of SE processes, Defence-in-Depth concepts and challenges, and case examples for sharing and demonstrating different ideas.

A Systems Engineering Management Plan (SEMP) can serve as a reference model for Systems Engineering life-cycle processes, promoting systematic working practices, which are critical for safety-related design. While used by ITER Organisation and in certain applications like the U.S. Yucca Mountain Waste Management System project, nuclear engineering projects have generally not used a SEMP. The objective in 2015 was to create a first reference SEMP (a SEMP template) to help NPP organisations to create their own SE process reference models. The SEMP will include, among others, NPP life cycle stages reference model, description of main SE processes, concept models of engineering data, role and collaboration model, and potentially a tool integration model.

Defence-in-Depth (DiD) is a key issue in NPP safety, but there is a need to reconsider its interpretations and ways of implementing it in practice. Various interdependencies and fault propagation between different systems are a major concern. On the other hand, full independence of defence lines is difficult in practical solutions. Further challenges arise from human and organisational factors. The overall objective in SAUNA is to create a DiD model that takes into account the sociotechnical system as a whole (Figure 2.1.5.1). In 2015, the goal was to review existing approaches for modelling and analysing DiD architectures. While focusing on the I&C architecture, the overall plant and surrounding process and electrical systems, and human operators were also considered. Important terms (such as, e.g., functional isolation) were clarified.

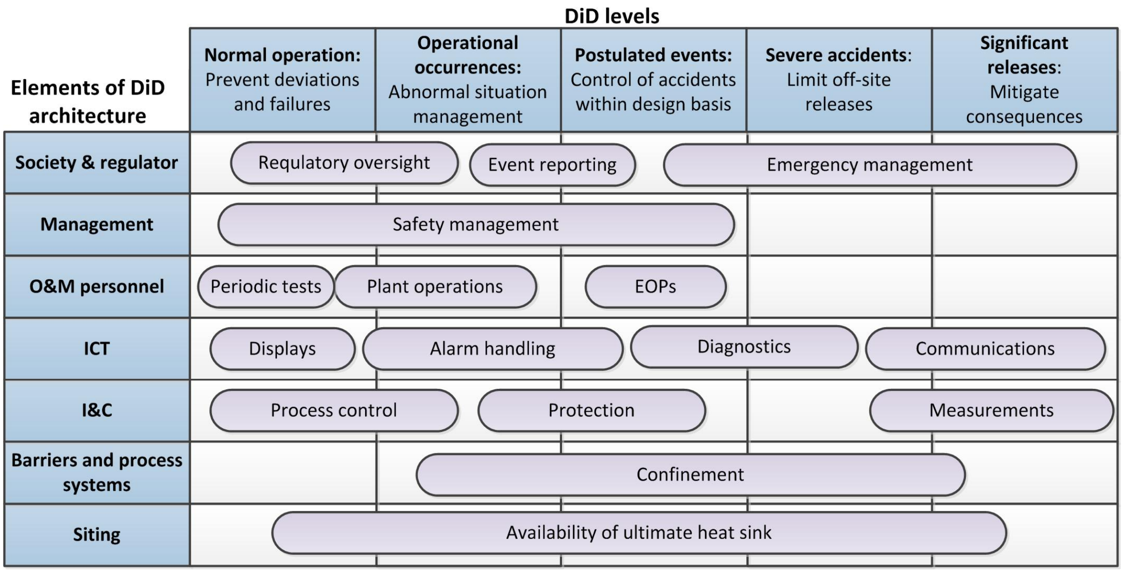


Figure 2.1.5.1. An extended Defence-in-Depth architecture, with DiD levels allocated to different technical systems, organisations and processes/procedures.

The objective with the subproject MODIG (MOdelling of DIGital I&C) was to explore probabilistic and deterministic assessment of defence-in-depth with emphasis on I&C, to outline an approach to analyse spurious actuations (a subcategory of functional failure modes for e.g. I&C), to develop further the approach for software reliability analysis and to initiate international collaboration on improved failure data collection.

One of the goals in WP1 was to provide a functional reference I&C architecture which could eventually be used for experimenting with various deterministic safety and security analyses methods. The DIGREL plant model was selected as a basis for the work. Relevant Finnish regulatory and standards requirements on the design of the I&C architecture were to be considered in the design work. A related objective for 2015 was also to update the DIGREL demonstration SharePoint site to accommodate the presentation of different safety architecture models, and to serve as a common demonstration repository.

WP2 of SAUNA looks at the assessment methods and tools for specific technical, human, and systemic safety issues. In 2015, the focus was on integrating formal verification methods (model checking) with simulation models, requirement engineering, probabilistic reliability assessment, and structure-based testing. In terms of process assessment, the Nuclear SPICE method was further developed.

Model checking is a powerful formal verification method that has been effectively put to practical use in the Finnish nuclear industry. One of the concrete challenges is that the currently used "open-loop" I&C models do not take into account the feedback of the controlled process, which means that analysts have to spend time with processing results that are practically irrelevant. A closed-loop approach would filter out unrealistic scenarios, and lead to computationally less complex models. In 2015, the objective was to outline an approach for combining the currently used I&C models with (e.g. simulation) models of the plant.

An additional (an perhaps the most crucial) challenge for the practical application of model checking is that the systems properties to be checked have to be specified in terms of formal languages that are challenging to use, even with some expertise. Earlier research in SAFIR2014 has shown that natural language templates can be useful, but due to the dynamic nature of the controlled plant processes, I&C requirements have to deal with different timing issues and complex sequences. Flexible and expressive (preferably visual) requirement specification languages are therefore needed. In 2015, I&C domain specific specification languages were reviewed.

To increase the coverage of testing, tests against system specification can be complemented with tests derived from the system structure. Structure-based testing is required in many applications, and by regulators such as U.S. NRC. A concept technique and a prototype tool for generating efficient test suites based on model checking was developed in the SAFIR2014 programme. Further development is still needed to make the technique applicable. In 2015, the goal was to extend the existing methodology to allow for its use for a wider range of function block systems, specifically to address time-dependent behaviour.

Model checking and Probabilistic Risk Assessment (PRA) focus of different aspects of plant safety, while still being based on partially similar input information (e.g., the system architecture, hardware configuration, I&C software design). A unified safety assessment approach calls for better integration of these complementing methods – via a common plant models, or by using the result data from one tool to support the analysis based on the other. In 2015, the goal was to identify the most promising integration approaches, and perform a feasibility study. These approaches may include both novel work practices and modelling concepts, and integration of existing tools.

Process assessment for systems and safety engineering requires development of the current Nuclear SPICE assessment method. The key research goal was to specify how the assessment model can be strengthened with systems engineering processes of ISO/IEC 15288. An exemplar model is needed to analyse and validate the required changes. The basis for this task is in thorough consideration of process assessment stakeholder needs and possible new use cases of the method. The aim is to reach higher coverage of the regulator requirements especially for safety class 3. Additionally, information product adequacy must be analysed to improve coverage of safety class 2 requirements. The result of the work will improve efficiency in the qualification process by systematic collection of evidences from the development process point-of-view.

WP3 of SAUNA aims to provide recommendations, insight, new viewpoints, and tools for planning, documenting and communicating the safety demonstration, and enabling the licensees to efficiently carry out the licensing process.

In Finland, demonstration of nuclear safety has traditionally been based on reports and narrative. In order to clarify requirement traceability, configuration management, and especially safety argumentation, more structured practices are needed. In 2015, the objective was to 1) review the prevailing qualification and licensing process in Finland, and to provide a basis for finding more structured and formal ways for performing it, 2) analyse the state-of-the-art in other critical industries, where structured approaches have been successfully used, and 3) analyse the current practices and activities on safety demonstration within the nuclear field in other countries.

In order to enhance the communication between nuclear experts on more detailed guidance on planning and performing qualification and licensing, an international expert group was to be established in NKS project PLANS (Planning safety demonstration). Through a series of workshops in Finland, Sweden and Norway, research results were to be disseminated and experiences shared. In 2015, VTT's goal was to take part in this work, by reporting Finnish activities on safety demonstration, actively participating in the workshops, and reporting back to SAFIR interest groups.

Results in 2015

- An overview of a Systems Engineering approach for managing the life-cycle of a NPP I&C system, and a reference model for a Systems Engineering Management Plan (SEMP) for the nuclear domain implemented as a SharePoint site.

- Terminology and modelling concepts related to the design and analysis of Defence-in-Depth and I&C architectures in NPPs. Observations on the current challenges in addressing DiD issues in model-based engineering. Potential topics for further research in SAFIR2018.

- A method for analysing functional failure propagation across systems which are uncoupled during normal use, validated with a case study of a pressurised water nuclear reactor.

- A report on the probabilistic and deterministic assessment of defence-in-depth, analysis of spurious actuations in PRA and advancements in software reliability analysis, including a joint workshop together with the NKS project PLANS with more than 40 participants from seven European countries.

- A report on how the design process of a nuclear reference I&C architecture is to be performed, including the steps of design work performed so far.

- A SharePoint site for demonstrating reference models of nuclear power plant automation systems.

- A framework for closed-loop model checking and counterexample-guided simulation of safety-critical systems, and a requirements engineering approach for such systems based on restricted natural languages.

- A review of user-friendly property (requirement) specification methods for I&C model checking, including templates, patterns, and visual languages. Approx. 600 specifications were also collected from VTT's practical customer projects to serve as case data for later research.

- An automatic technique for creating structure-based test cases for function block diagrams, using model checking, with particular focus on time-dependent behaviour.
- A feasibility study on the integration and coupled use of model checking and probabilistic risk assessment (PRA), and a small case experiment.
- A conference paper was prepared to discuss new use cases for a systems engineering process assessment method. A research report specifies detailed requirements for an extended assessment model, using one process as an exemplar. A workshop was organized to receive comments on the development plans of a 15288-based Nuclear SPICE assessment method.
- A research report has been written that introduces the key concepts, practical challenges, and terminology related to structured safety demonstration, qualification and licensing, as well as identifies directions for further research.
- Two international industrial workshops were organized, one of them together with MODIG project. A Nordic expert network on digital I&C safety demonstration (NordicNSEC) was established.
- A report on challenges of qualification and preparing safety demonstration was published together with IFE and Solvina in the NKS PLANS project.

2.2 Reactor safety

In 2015 the research area “Reactor safety” consisted of twelve projects:

1. Comprehensive analysis of severe accidents (CASA)
2. Chemistry and transport of fission products (CATFIS)
3. Comprehensive and systematic validation of independent safety analysis tools (COVA)
4. Couplings and instabilities in reactor systems (INSTAB)
5. Integral and separate effects tests on thermal-hydraulic problems in reactors (INTEGRA)
6. Nuclear criticality and safety analyses preparedness at VTT (KATVE)
7. Development of a Monte Carlo based calculation sequence for reactor core safety analyses (MONSOON)
8. Neutronics, burnup and nuclear fuel (NEPALS)
9. Development and validation of CFD methods for nuclear reactor safety assessment (NURESA)
10. Physics and chemistry of nuclear fuel (PANCHO)
11. Safety analyses for dynamical events (SADE)
12. Uncertainty and sensitivity analyses for reactor safety (USVA).

2.2.1 CASA - Comprehensive analysis of severe accidents

This project brings together a large spectrum of phenomena related to the thermal hydraulics of severe nuclear power plant accidents. The objective is to develop safety analysis methods which benefit the safe and sustainable use of nuclear energy in Finland. The capability of simulation tools in use, including integral codes and several specialised programmes to model phenomena related to severe accidents will be assessed. If needed, the codes and methods will be further improved in collaboration with colleagues around the world. Reinforcing international networks will bring the most recent relevant knowledge to the use of Finnish nuclear community. The objective is not only to follow the international actions but to adopt the latest information to Finnish context.

Specific goals in 2015

Fukushima accident provides a unique opportunity for gaining more information on the progress of severe accidents and their prevention and mitigation. Finland was accepted to participate phase 2 of the OECD NEA BSAF (Benchmark Study of the Accident at Fukushima) project. The objective in analysing the accidents are 1) improving expertise in severe accident modelling, using data from a real full-scale reactor accident; 2) gaining a better understanding of the events in the Fukushima reactors; 3) getting insights into the capabilities and weaknesses of the integral codes in simulating severe accidents.

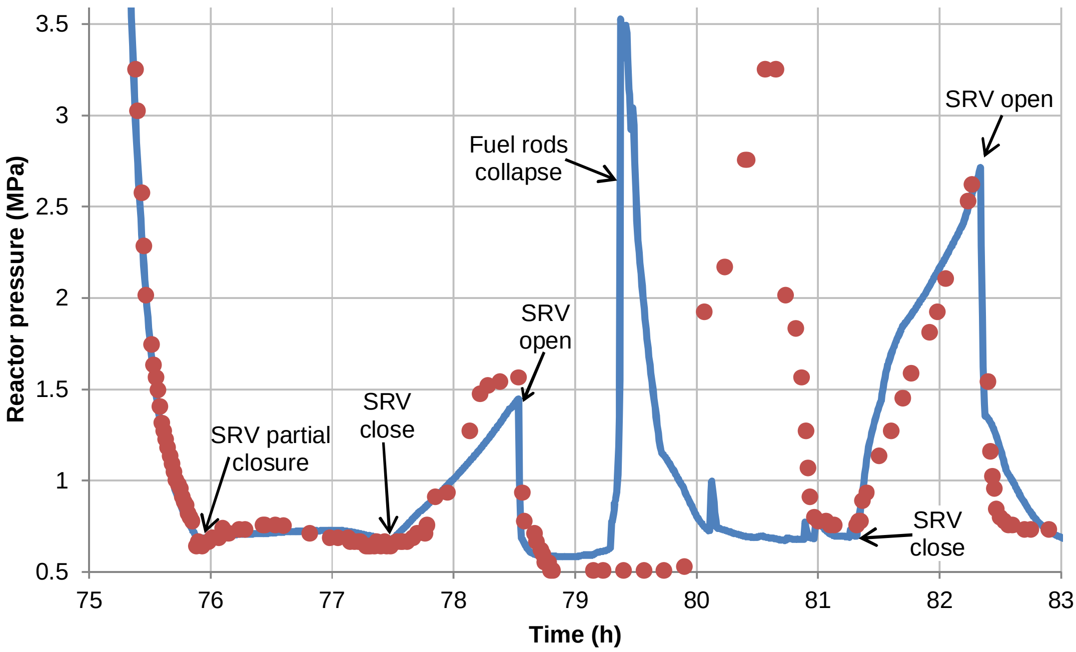


Figure 2.2.1.1. Fukushima unit 2 Reactor pressure from 75 to 83 h. Red dots indicate the measured values. Operation of SRV (Safety Relief Valve was adjusted based on measurement data.

Second version of VTT’s MELCOR model of Fukushima unit 2 accident was developed. Compared to the first version, newly published plant data was utilized, and some additional plant data was obtained from the OECD BSAF project. New MELCOR best practice guidelines were taken into use. The calculation reproduces the measured pressures in the reactor and in the containment well during the first 81 h. This required manual adjustment of the RCIC (Reactor Core Isolation Cooling) system flow rates and flooding rate of the torus room, so that a good match to the measurements is obtained. Many of the uncertainties in the calculation are still caused by lack of plant data.

If the vessel integrity is lost, the long-term cooling of the melt must be ensured ex-vessel. Preparing the final synthesis of the results of the COOLOCE experiments on the effect of geometry on debris bed coolability was an important objective for 2015. The main results of the synthesis were: 1) the coolability of the debris bed depends on both the flooding mode and the height of the bed; 2) multi-dimensional flooding increases the dryout heat flux and coolability in a heap-shaped debris bed by 47–58% compared to the dryout heat flux of a classical, top-flooded bed of the same height; 3) heap-like beds are higher than flat, top-flooded beds, which results in the formation of larger steam flux at the top of the bed, this counteracts the effect of the multi-dimensional flooding; 4) the maximum height of a heap-like bed can only be about 1.5 times the height of a top-flooded, cylindrical bed in order to preserve the direct benefit from the multi-dimensional flooding.

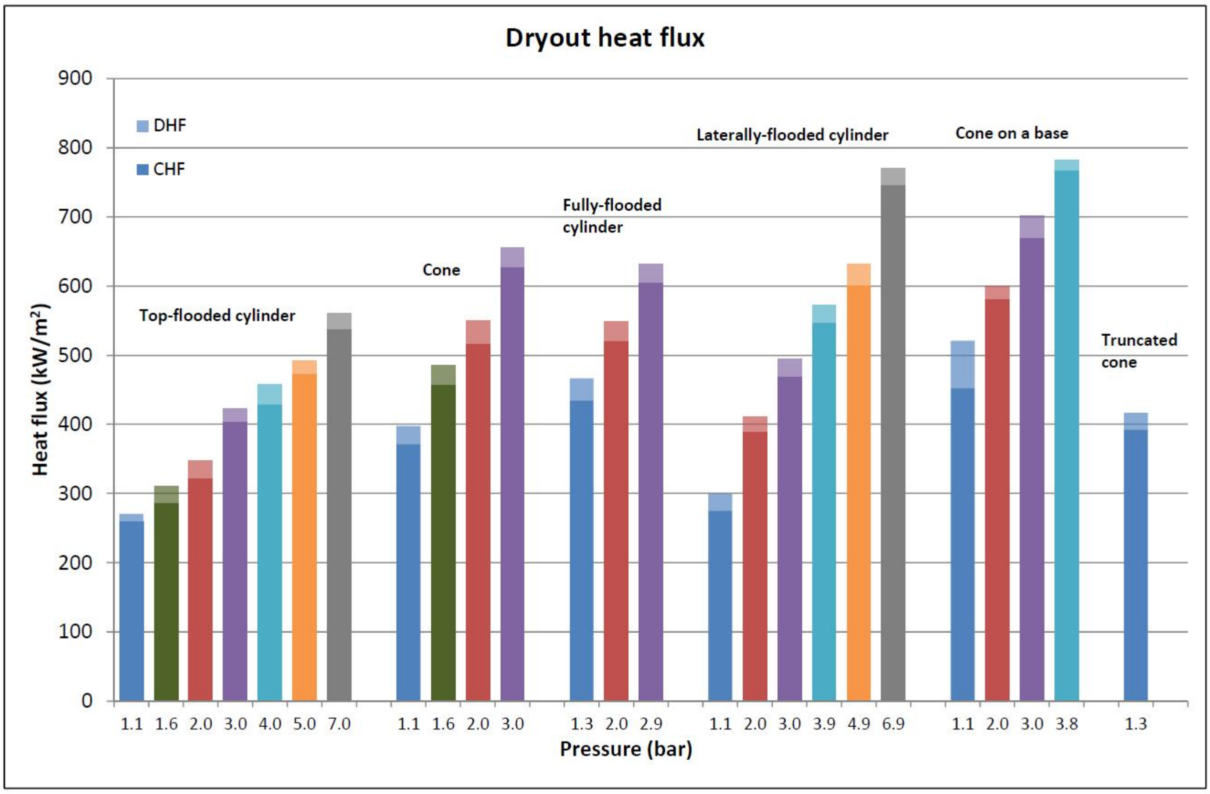


Figure 2.2.1.2. The dryout heat fluxes (DHF) in the COOLOCE experiments for the different geometries and pressures. Critical heat flux (CHF) is the maximum coolable power and the zone with lighter colour at the top is the error margin DHF-CHF.

Methods for analysing operation of core catchers should be readily available. Distribution of heat between the different surfaces is an important factor in evaluating the core catcher performance. The melt stabilization phase of the Water-Cooled Basemat (WCB-1) experiment, which is the only public experiment of water-cooled basemat with real reactor materials, was analysed to improve expertise in assessing performance of various core catcher designs. Heat transfer coefficients in the experiment were compared with free convection correlations. At the period when conditions were relatively stable, Steinberner & Reineke correlations overestimate the average heat transfer coefficient upwards by a factor of 2 and downwards by a factor of 3. Consequently, the correlations underestimate the up/down power split by a factor of 1.5. Accident analyses based on these correlations would be conservative with respect to containment pressure and heat flux to cooling channels, but non-conservative with respect to melt temperature and solidification.

Preserving of knowledge of steam explosions is important still today, since the risk of steam explosions during a severe nuclear accident cannot be excluded in our current nuclear power plants. The effect of key input parameters to the steam explosion loads was examined. Three different breaking locations were taken into consideration. Non-axisymmetric breaking cases required 3D analysis. Parameter sensitivity was studied only for the central break always selecting the trigger time yielding the strongest explosion. Parameters that were varied were: water level in the cavity, melt temperature, coolant temperature and drop size of fragmenting melt. Simple MELCOR calculations were made to find realistic boundary condition limits for the parameters. In many of the analysed cases, the overall differences were small and consistent behaviour in the loads as a function of the varied parameter was difficult to observe.

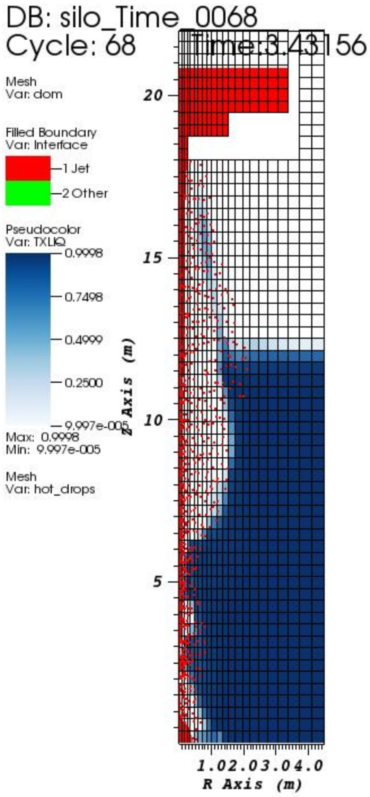


Figure 2.2.1.3. Premixing conditions at a time just before the triggering.

Well-founded dose estimates are needed when licensing the operation of instrumentation and automation systems and containment penetration seal materials under severe accident conditions. The objective of the work in 2015 was to test the capability of integral code ASTEC to produce the dose rates in the containment. The selected test case was a large LOCA in a Nordic BWR plant. The source term to the containment was defined based on NUREG-1465 report. At the same time, existing input for analysing possible Nordic BWR plant accidents was developed further. Highest dose rate in gas phase, 28.34 Gy/s, was assumed to take place in the drywell. In cavity the highest gas phase dose rate was 16.4 Gy/s and in the wetwell 2.1 Gy/s. Dose rates on walls were higher: in the drywell the maximum dose rate was 78.5 Gy/s and in the cavity 104.5 Gy/s. In total 97.2 % of the released fission products retained in the containment, i.e. were not directed to the venturi scrubber in the rupture disk venting line. Most of the fission products were retained in the wetwell pool water, some were deposited and also a small part was trapped to the wetwell atmosphere.

Fukushima Daiichi accident caused remarkable radiation dose levels in the environment of the power plant, even at longer distances. As a consequence of this event IAEA started to develop recommendations which consider emergency planning outside protection and emergency planning zones. Therefore studies of the expected doses beyond 20 km are needed. Probability distributions of radiation doses from different exposure pathways at distances up to 300 km from the power plant were determined using different release magnitudes. Weather data used in the calculations consists of FMI's winding trajectory data for one year. The calculated dose estimates were compared with the threshold values given in the recommendations of IAEA. The results of VALMA analyses indicate that if the release magnitude exceeds significantly the criterion value for the severe accident the offsite dose levels may exceed IAEA's criteria for countermeasures up to 200 km. This presumes that the release fraction of iodine and caesium is 20 %. Acute health effects are not expected but the risk of stochastic effects could be reduced. According to analyses performed this far, it seems that statistically the results are similar with straight line Gaussian type dispersion model and when utilizing complex weather data. Also four month weather data resulted similar results as one year weather data.

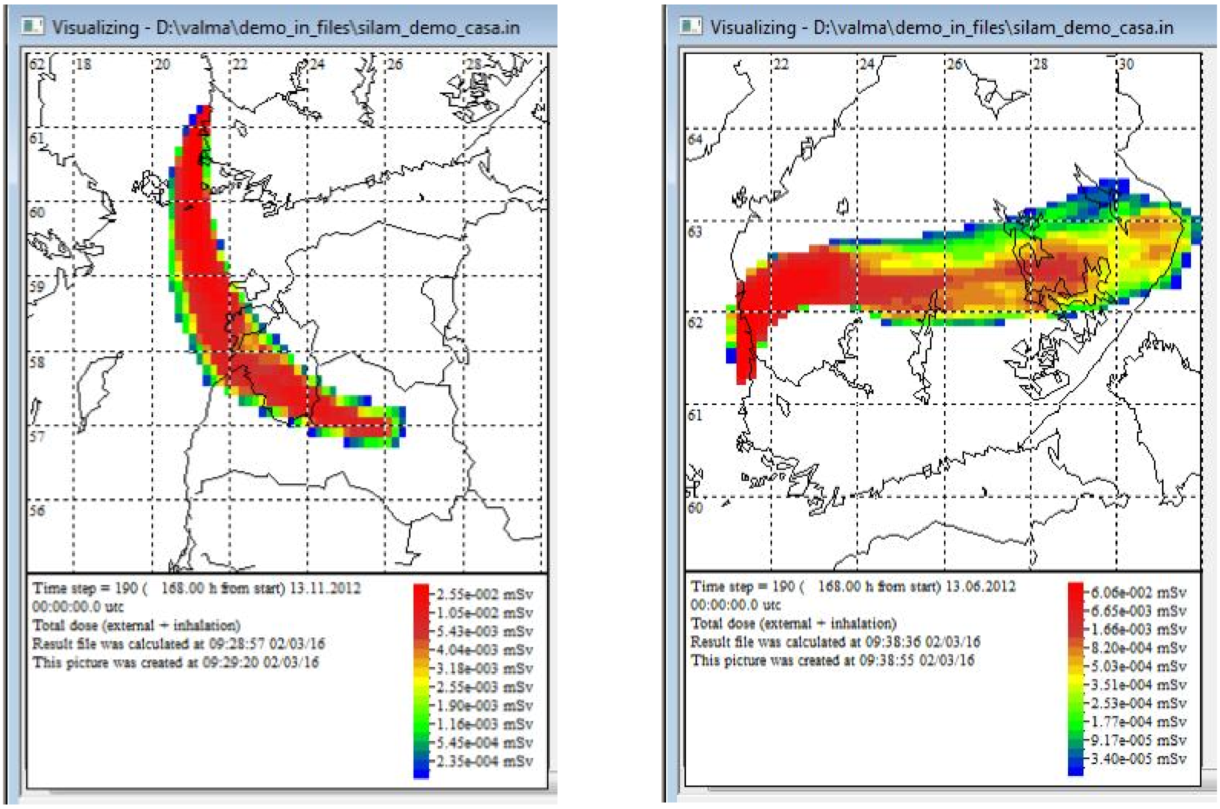


Figure 2.2.1.4. Examples of the VALMA GUI outputs. Total dose in one week is presented with two different release starting times.

Deliverables in 2015

- Fukushima analyses have been reported for the Unit 1 accident in a scientific publication and for the Unit 2 improved analyses in a research report. In both cases some manual adjustment was needed to achieve good correspondence with the measured pressures. In the case of unit 1, it was the recirculation pump and containment leak rates and in the case of unit 2 it was the RCIC (Reactor Core Isolation Cooling) system flow rates and flooding rate of the torus room.

- A travel report from the CSARP/MCAP meeting did summarize the most interesting presentations. A major topic in the meeting was filtered containment venting.

- Results of the experimental debris bed coolability studies in the COOLOCE programme at VTT were extensively summarized in a doctoral thesis and a journal article. In addition, the key question of transferring the experimental results and the small-scale simulations onto a reactor scale was considered. A research report on the topic focused on outcomes achieved during 2015, and will be submitted to NKS as one of the final deliverables of the DECOSE project.

- WCB-1 experiment was performed at Argonne National Laboratory in the frame of the OECD MCCI-2 project. The first analysis of the measurement data is presented in a research report. The heat flux downwards was lower than expected.

- A master’s thesis is on steam explosion analyses in Nordic BWR with MC3D is nearly finished.

- A research report was written on defining dose rates inside the Nordic BWR containment with ASTEC. In total 100 % of the noble gases, 30 % of I and Br and 25 % of Cs and Rb were supposed to be released to the containment. Dose rates on walls were notably higher than dose rates on gas phase due to the amount of deposited aerosols.

- Probability distributions of radiation doses at distances beyond 20 km from the power plant, when three different severe accident release magnitudes were used, were presented in a research report. It was also evaluated, what types of countermeasures were possibly needed up to 300 km from the power plant.

2.2.2 CATFIS - Chemistry and transport of fission products

The objective of the project (2015-2018) is to study the behaviour of fission products in severe accident conditions. In particular, the aim is to increase understanding of revaporisation and transport of iodine in primary circuit and containment of a nuclear power plant. The primary circuit study has been conducted in close co-operation with IRSN Cadarache research centre for the determination of iodine chemistry. The objective of the primary circuit study at VTT is to determine iodine compounds released due to the reactions on the surface of primary circuit piping. At the same time IRSN is focused on the gas phase chemistry of iodine in similar experimental conditions. The measurements with EXSI-PC provide information on high temperature chemistry and facilitate validation of for example iodine chemistry codes. The second aim is to find out the effect of primary circuit conditions on the transport and speciation of ruthenium. These experiments are conducted with VTT´s Ru transport facility in collaboration with Chalmers University of Technology as part of NKS-R activity. As a third aim, radiolytical reactions by various radiation sources in containment conditions is studied using EXSI-CONT and BESSEL facilities. The objective is to verify the possible oxidation of iodine into particles and also the formation of nitric acid. In addition, the gathered data in all experiments is used to derive models for the studied reactions, which can eventually be implemented in severe accident analysis codes.

International collaboration is also conducted by participation in the work of OECD/NEA STEM-2, OECD/NEA BIP-3 (both starting in 2016) and NUGENIA programmes. The data of experiments performed as part of SAFIR2018 will also be shared within these forums, as well as information related to the progress of programmes will be distributed to SAFIR2018 members.

Specific goals in 2015

The main goal in 2015 was to study the effect of reactions of iodine containing deposits on primary circuit surfaces on the release and transport of iodine. Fission product deposits on primary circuit surfaces can act as a source of gaseous iodine even in the late phase of a severe accident. However, that is not considered in the severe accident analysis codes currently. The primary circuit experiments were conducted using the updated EXSI-PC facility. The second goal was to examine the effect of aerosols and air radiolysis products on the transport of ruthenium through a reactor coolant system. In general, the previous small-scale studies on Ru transport have mainly been conducted with pure Ru oxides in air. Therefore, the current study with VTT´s Ru transport facility provides information on Ru behaviour in more realistic conditions.

Another goal was to study the formation of nitric acid (HNO_3) by radiation. The aim was to verify the capability of beta radiation to produce nitric acid in humid air simulating containment conditions in a severe accident. The objective was to compare the results with the previous gamma radiation results. The fourth goal was to study the effect of HNO_3

generated by beta radiation on the pH of containment pools. This was performed utilizing the data of experiments (in the above task) in ChemPool calculations. The effect of beta radiation e.g. on the formation of nitric acid is currently poorly known, although beta decay corresponds for a significant fraction of the accumulated radiation dose in the containment atmosphere.

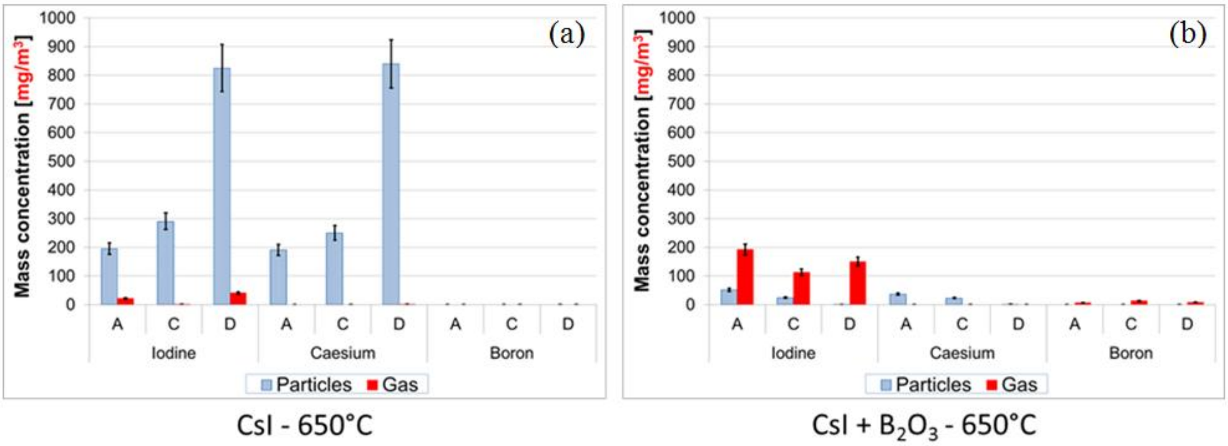


Figure 2.2.2.1. The transported mass concentrations [mg/m^3] of iodine, cesium and boron in gaseous and aerosol forms under A: Ar/H_2O, C: Ar/H_2O/H_2 and D: Ar/Air atmospheres. When the CsI precursor was heated to 650 °C (a), iodine was mainly transported as aerosol. The addition of B_2O_3 to CsI precursor at 650 °C reaction temperature (b) increased the transport of gaseous iodine significantly.

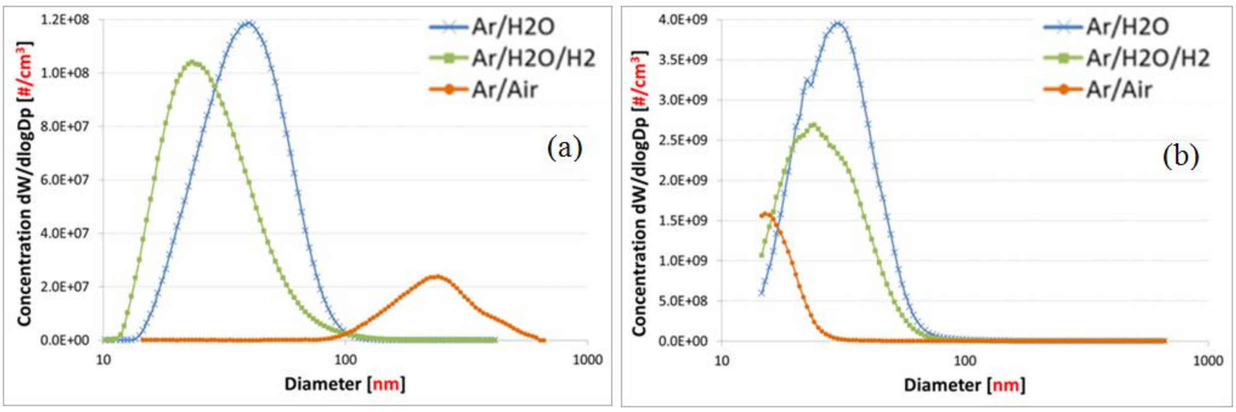


Figure 2.2.2.2. The average particle number size distributions during the vaporisation of (a) CsI and (b) CsI + B_2O_3 mixture at 650°C under Ar/H_2O, Ar/H_2O/H_2 and Ar/Air atmospheres. The particle number concentration decreased an order of magnitude as the oxygen potential was increased (a), but at the same time the diameter and mass of particles increased significantly. When B_2O_3 was added to the precursor (b), the number concentration of particles and the diameter of particles decreased with the increasing oxygen potential.

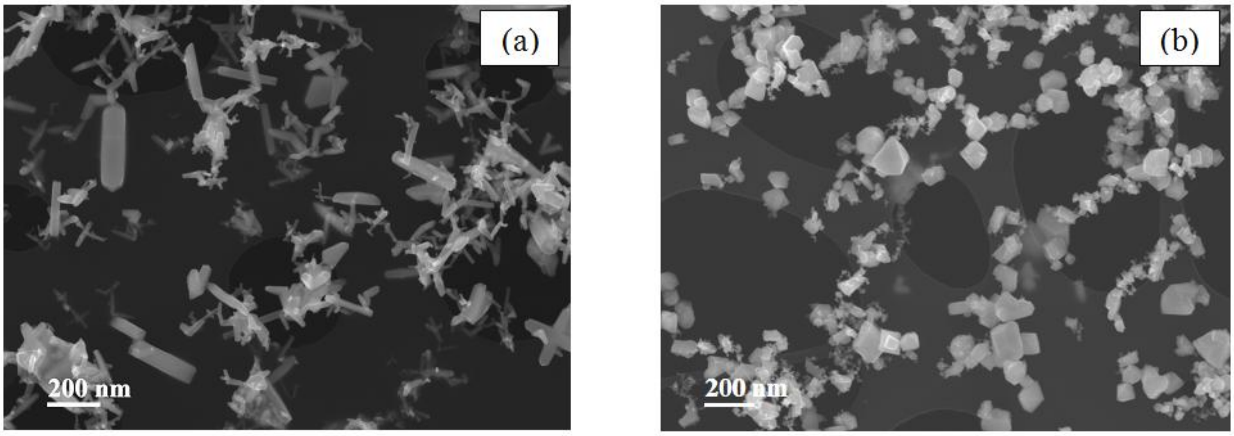


Figure 2.2.2.3. The typical crystalline needle-shaped form of RuO_2 was clearly evident and dominating form of ruthenium in (a) experiments with pure RuO_2 in air atmosphere. The feed of $AgNO_3$ droplets into the flow of ruthenium oxides (b) seemed to have an effect on the shape of ruthenium particles. The needle-shaped RuO_2 crystals were not observed anymore. Instead, a variety of different size cubical crystals was formed. Similarly shaped crystals were also observed in a NO_2-N_2-O_2 atmosphere (composition close to technical air). However, the concentration of the formed particles was very low due to the high formation of gaseous ruthenium and thus only a few particles were observed on the grid for the analysis.

Deliverables in 2015

- In the primary circuit studies the source of iodine was CsI powder which was evaporated at 650 °C on ceramic surface under Ar/H_2O, Ar/H_2O/H_2 and Ar/Air atmospheres. The surface of the reaction furnace tube, made of stainless steel, was pre-oxidized before the experiments. Several mixtures of CsI with B_2O_3 and/or CsOH additives, simulating boric acid dissolved in the primary coolant in Pressurized Water Reactor and to increase the ratio of Cs/I, have been tested. To summarize the main outcome of experiments, the addition of boron releases higher gaseous iodine fraction compared to the vaporisation of only caesium iodide under the same conditions, see Figure 2.2.2.1. Boron affected also on the properties of aerosol, see Figure 2.2.2.2. Based on experiments it seemed that the formation of solid, glassy caesium borate, as well as the formation of gaseous iodine, increased when the steam concentration in the atmosphere was increased. Different caesium borate glasses seemed to be formed from CsI+B_2O_3+CsOH and CsI+B_2O_3 mixtures.
- The continuation of previous studies in 2014-2015 verified, that the transport of ruthenium through a model primary circuit was influenced by the composition of atmosphere. The oxidizing air radiolysis product NO_2 increased the fraction of gaseous RuO_4, whereas silver particles decreased it significantly. When both were fed in form of $AgNO_3$ to the flow of Ru oxides, the transport of RuO_4 increased moderately. The feed of CsI particles seemed to increase the transport of gaseous Ru even more than the feed of NO_2. In these experiments, the observed transport of gaseous Ru seemed to be several orders of magnitude higher than in the previous experiments with only pure Ru oxides in the air atmosphere. This is not considered in the current severe accident analysis codes due to the lack of experimental data. Other tested additives in the experiments were N_2O and HNO_3. The effect of atmosphere composition on ruthenium particle formation is presented in Figure 2.2.2.3.
- The formation of nitric acid by beta irradiation in humid air simulating containment conditions in a severe accident was verified. The G-value for nitric acid formation was derived. The gathered data was utilized in the Chempool analysis of containment pool

pH. As a result, the nitric acid formed in air by beta radiation decreased the pool pH. It was concluded, that the effect of beta radiation on the containment chemistry should be studied in detail and also that the amount of NaOH needed for pH control of water pools can be higher than previously expected.

- In 2015, CATFIS project was invited to give a presentation on “Fission products behaviour in a severe accident” in CLADS seminar (CLADS Seminar -International Collaboration toward Advanced Decommissioning of Fukushima-Daiichi Nuclear Power Plant- Nov. 9-13, 2015, JAPAN).

- The results of iodine and ruthenium studies in SAFIR programmes (previous CHEMPC and TRAFI projects and current CATFIS project) have also been presented in ERMSAR2015, Iodine Workshop and NUGENIA TA2.4 Workshop meetings in March/April 2015. Altogether, there were five oral presentations (4 conference papers - as an invited speaker in three of them) and one poster.

2.2.3 COVA - Comprehensive and systematic validation of independent safety analysis tools

The COVA project aims at developing and promoting a rigorous and systematic approach to the procedures utilized in validation of independent nuclear safety analysis tools. The process enhances the expertise in thermal hydraulic area of Generation II and III LWR reactors and includes as an essential part training of new experts to this relevant area of reactor safety. Main part of the work is carried out with the system-scale safety analysis tool Apros that has been developed in Finland in cooperation between VTT and Fortum and that is currently used in safety analysis work both at the regulatory side and by Finnish utilities Fortum and TVO. The U.S. NRC’s TRACE code that is currently used by VTT for the Finnish regulatory body STUK provides suitable benchmark in the validation process as an independent, widely used and well validated safety analysis tool. Participation in international research projects related to nuclear safety research in the field of thermal hydraulics forms an essential part of the project: experimental data produced in these activities is directly utilized in the validation work carried out within COVA, and on the other hand, these validation activities support conduction of the experiments, in addition to promoting international cooperation and networking in the field of nuclear safety research.

COVA is divided into four work packages: Validation matrices, Analyses of new experiments, Management and international cooperation and Participation fees. The actual research work dealing with analysis tool validation is carried out in the first two work packages, with the first one concentrating on the fundamental aspects of the validation work with Apros, and the second in application of Apros and TRACE to validation using primarily integral-scale experiments with proper quantification of output uncertainties. Third work package contains all the administrative work in the project and all costs arising from participating in the international projects and reporting of their results to the Finnish research community, with the exception of the participation fees. The fourth work package includes the participation fees of international research projects and nothing else.

Specific goals in 2015

For the assessment of Apros’ TH model’s validation OECD separate effect test (SET) validation matrix was familiarized and 26 phenomena were identified as important for safety. Some of these phenomena included multiple sub-topics. A list of current Apros validation cases was then collected and the results were compared to the list of important phenomena. As a result a list of 69 important phenomena or cases were identified which require further validation. The two-fold validation methodology used in Apros validation was found to be adequate.

For the Apros containment a similar assessment validation was done against OECD Containment code validation matrix (CCVM). As a result it was concluded that Apros containment is capable of calculating the most important containment behaviour in design based accidents. The following lists of recommendations were made:

- Recommended experiments for further validation
- Recommended new calculation cases
- Recommendations for documentation
- Recommendations for code modifications

HYMERES MISTRA HM 2-1 and 3-2 experiments were calculated with Apros containment using a model where radiation heat transfer was improved between the test facility's walls. The model produced results that were a clear improvement over the previous results. Gas temperatures were considerably closer to the measured temperatures and gas mixing was improved.

ATLAS A5.1 small break loss of coolant benchmark was calculated in blind phase and results were submitted to the organizer. As no data is yet available from the experiment or other participants, in-depth analysis of the simulation cannot yet be made.

FONESYS FO 02 critical flow benchmark was calculated in blind phase using 2 geometries. This exercise isn't based on any actual experiment but is purely a comparison of participants' results against each other. Report on the collected results has not yet been published by the organizer.

Separate effect experiments were calculated based on the preliminary findings of the TH validation assessment deliverable. The first test case was LOTUS vertical air-water annular flow experiment. In these simulations it was discovered that the rate of entrainment was significantly underestimated at high water mass fluxes. Also the onset of the entrainment with the low water mass flux rates occurred a little bit too late. The underestimation of the entrainment rate caused also error in the pressure loss calculations. It resulted into too highly weighted bubbly flow ratio and thus significant overestimation in the pressure loss on the region where entrainment onset is limited. At higher water mass fluxes the error caused by underestimation of entrainment rate was not as large but still notable. In the second case experiments on convective heat transfer and bundle friction factor in a 19-rod bundle were analysed. Calculated heat transfer turned out to be higher than those obtained in the experiments. The reasons behind that could be the unreliable way of defining of outside wall temperature in the experiments and the fouling effect occurred on the outside wall surface. Distributions of uncertainty coefficient turned out to obey the normal distribution with good accuracy. Bell curves for uncertainty coefficients obtained in these separate effect tests can potentially be used as an input data in following uncertainty analyses of bigger-scale phenomena.

Six international cooperation programmes were followed in COVA project. These were OECD/NEA ATLAS, HYMERES, WGAMA and PKL-3, USNRC CAMP and FONESYS network. A young scientist was sent to the 33rd Short Courses on Multiphase flow course.

Participation fees were paid for OECD HYMERES & ATLAS and USNRC CAMP.

Deliverables in 2015

- Apros' TH model's validation was assessed against OECD separate effect test matrix. Recommendations were given for future validation.
- Apros' containment model's validation was assessed against OECD separate effect test matrix. Recommendations were given for future validation.
- Three friction and bundle heat transfer experiments were calculated based on the preliminary findings of TH validation assessment deliverable.
- FONESYS FO 02 critical flow benchmark was participated in blind phase. The results have been submitted to the organizers.
- ATLAS A5.1 small break loss of coolant accident benchmark was participated in blind phase. The results have been submitted to the organizers.
- HYMERES MISTRA HM 2-1 and 3-2 experiments were calculated with Apros' containment package. Modelling radiation heat transfer between the facility walls led to considerably better results but the gas mixing was still lower in the simulation than in the experiment.

2.2.4 INSTAB - Couplings and instabilities in reactor systems

The INSTAB project aims to increase understanding of the phenomena related to BWR pressure suppression function to enhance capabilities to analyse Nordic BWR containments under transient and accident conditions. Particularly, additional information is needed on the effect of SRV spargers, RHR nozzles, strainers and blowdown pipes on mixing and stratification of the pool as well as feedbacks between wetwell water pool and spray i.e. formation and mixing of thermally stratified water layers in the suppression pool due to spray operation. A combined experimental/analytical/computational program is carried out where Lappeenranta University of Technology (LUT) is responsible for developing an experimental database on pool operation related phenomena in the PPOOLEX test facility with the help of sophisticated, high frequency measurement instrumentation and high-speed video cameras. LUT, VTT and KTH will use the gathered experimental database for the development, improvement and validation of numerical simulation models. The project outcome will allow the end users to analyse the risks related to different scenarios of safety importance in the drywell and wetwell compartments of a Nordic BWR. Networking among international research organizations is enhanced via participation in the NORTHNET framework and NKS/COPSAR project.

Specific goals in 2015

Specific goals in 2015 included a test series with a Safety Relief Valve (SRV) sparger in the PPOOLEX facility, single spray nozzle tests in a separate test station and designing a spray system to be constructed to the PPOOLEX facility. In the CFD calculations task the extensive database gathered in the previous PPOOLEX studies was utilized at LUT by performing CFD simulations of direct contact condensation experiments with NEPTUNE_CFD code.

The pressure suppression pool in a BWR serves as a primary heat sink during a loss of coolant accident (LOCA) or when the reactor is isolated from the main heat sink. The pool surface temperature defines the saturation steam pressure in the containment. Steam condensation creates a source of heat in the pool. In case of small steam flow rates, thermal stratification could develop and significantly impede the pressure suppression capacity of the condensation pool. Experimental studies have shown that once steam flow rate increases significantly, momentum introduced by the steam injection and/or periodic expansion and collapse of large steam bubbles due to DCC can destroy stratified layers and lead to mixing of the pool water. Accurate and computationally efficient prediction of the pool thermal-hydraulics with thermal stratification, mixing, and transition between them, presents a computational challenge.

KTH is developing the Effective Heat Source (EHS) and Effective Momentum Source (EMS) models and implementing them in GOTHIC code. The models aim to capture thermal stratification and mixing during steam injection into a large pool of water. They can be implemented also in system codes, such as APROS. The models have already been validated against PPOOLEX experiments where the dynamics of free water surface in the blowdown pipe with different steam mass flow rates and transient times was studied. KTH has now broadened the validity of the EHS and EMS models to spargers. To verify the models also for the sparger case a test series with a scaled sparger model was conducted at LUT in 2014-2015 according to a detailed test plan written by KTH on the basis of pre-test calculations.

The model of the sparger was designed and scaled by KTH. The goal of the scaling was to define the conditions of the PPOOLEX tests with a sparger in order to cover the ranges of thermal hydraulic phenomena and regimes relevant to a steam discharge into a water pool in prototypical conditions of a BWR pressure suppression pool operation. The sparger model used in the tests had 32 Ø8 mm holes drilled radially in the lower part (sparger head) of the DN65 (Ø76.1x4.0) sparger pipe (Figure 2.2.4.1). The load reduction ring (LRR) was 700 mm above the pipe outlet and it had eight downwards pointing Ø8 mm holes. A grid of temperature measurements was installed in the pool in front of the injection holes of the sparger head for determining how far the steam jets reach. Four trains of thermocouples were installed in the pool below the water level for detecting vertical temperature distribution.

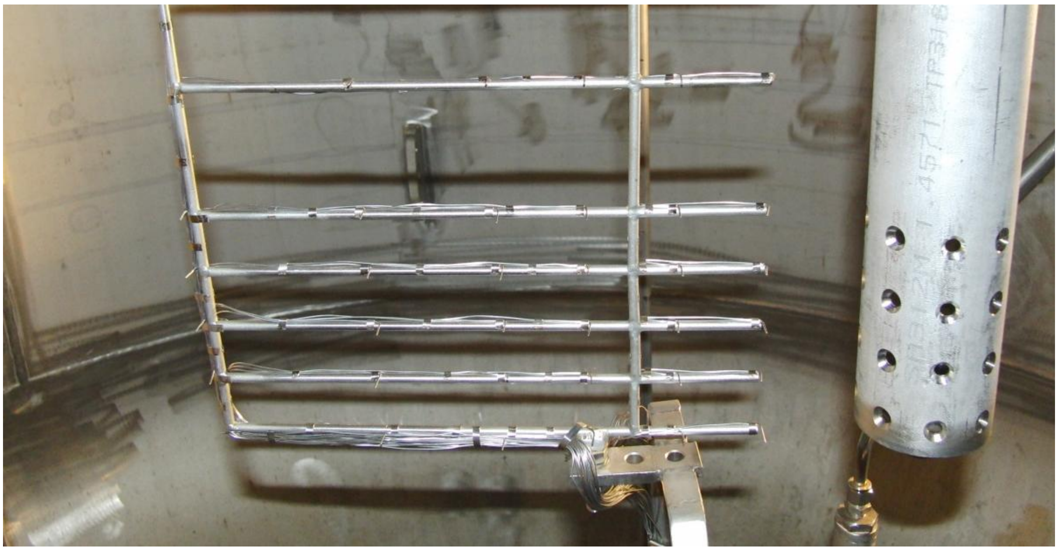


Figure 2.2.4.1 Scaled sparger model and a TC grid used in the PPOOLEX tests.

The path of the two sparger tests in 2015 defined by steam mass flux and pool bulk temperature can be marked on the condensation mode map for a sparger of Chan and Lee (Figure 2.2.4.2). In the tests steam flow was either through eight injection holes in the sparger head or in the LRR. Both tests had two stratification periods and two mixing periods. An extra stratification period was included at the end of the first test.

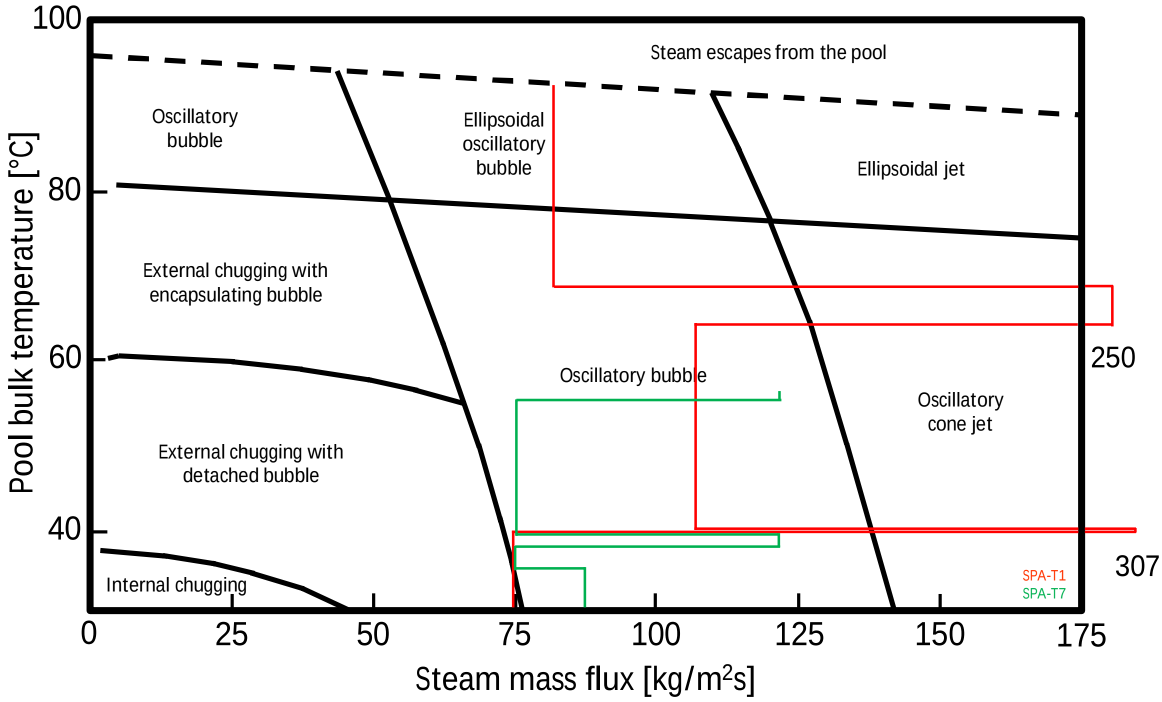


Figure 2.2.4.2. Paths of the sparger tests marked on the direct condensation mode map for pure steam discharge of Chan and Lee.

When steam injection was vertically downwards from the LRR, the transition region between the cold and warm pool water at the end of the stratification period was much deeper in the pool than in the horizontal injection case. The vertical length of the transition region was also longer in the LRR case.

Oscillatory cone jet mode was the prevailing flow mode during the mixing periods in the horizontal injection case. Mixing of the thermally stratified pool happened either through internal circulation (in the higher flow rate case) or through erosion of the layers of cold water (in the lower flow rate case). It can be noted that in the earlier tests with all the injection holes of the sparger head unblocked a considerably larger flow rate was not enough to mix the pool.

In the vertical injection case the dominant flow mode during the mixing periods was the oscillatory bubble mode. Less turbulence and internal circulation was created and, as a result, complete mixing took a longer time than in the horizontal injection case. However, the downwards direction of the steam jets increased the mixing effect and complete mixing was achieved even with a quite small injection rate (Figure 2.2.4.3).

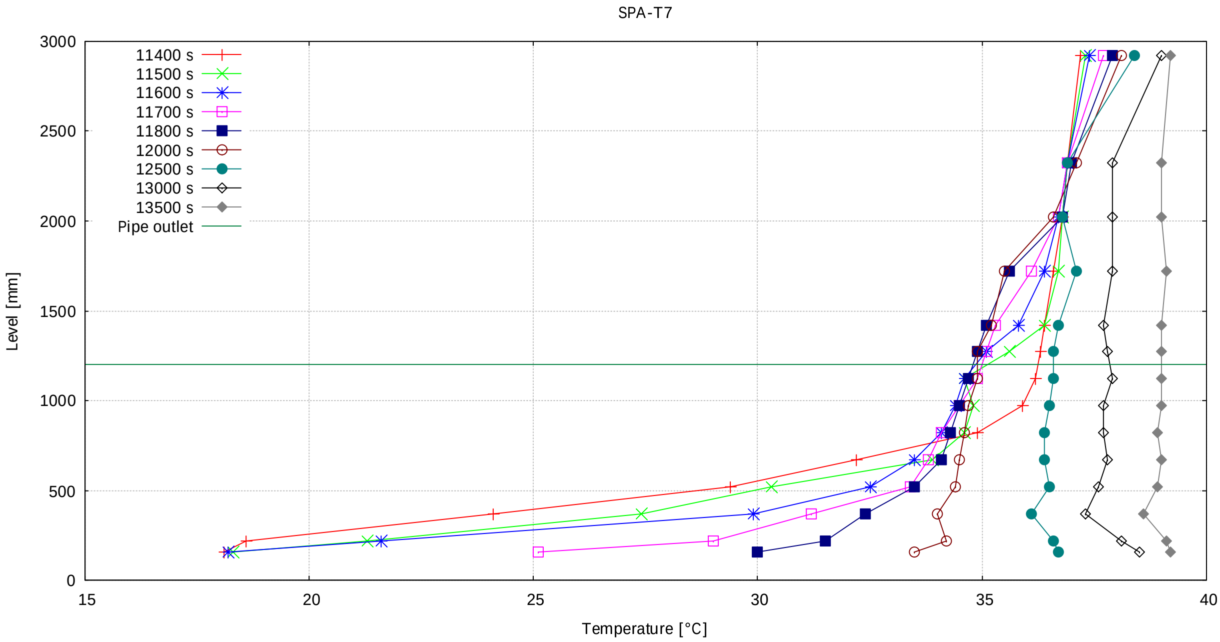


Figure 2.2.4.3. Progression of mixing in pool water when steam is injected vertically through the load reduction ring of the sparger pipe.

These additional sparger tests in PPOOLEX verified that the existing flow mode of injected steam is a crucial factor in the success of a mixing process of a thermally stratified water pool. Mixing with a larger absolute flow rate can be less successful than with a smaller flow rate if the flow mode after dividing the flow to smaller jets in a sparger head is such that not enough momentum and internal circulation is created in the pool for complete mixing to take place.

The main objective of the single spray nozzle tests was to get experience from the use of the shadowgraphy application (light diffuser and software upgrade) in order to be able to evaluate its suitability for demanding measurements of different characteristics of spray nozzles. The tests were carried out in a testing station specifically built for this purpose at LUT in 2015. Water was injected through a spray nozzle and the developed droplet distribution was measured with the shadowgraphy application of the PIV system.

Five different measurement positions were selected underneath of the spray jet to be used in the tests. The interest was to find out if it has any effect on the droplet size distribution when the measurement area is shifted vertically and horizontally. The majority of the droplets were in the size range of 0.2-0.8 mm in the centreline positions whereas the droplet distribution was broader in the two other positions, which were 300 mm away of the centreline axis (Figure 2.2.4.4).

The measured droplet size distributions revealed that the scaling factor of the used application was too large for these tests in order to get a full range of different droplet sizes. In future spray nozzle tests the camera of the PIV system should always be placed as close to the measurement area as possible in order to get the scaling factor to be as small as possible.

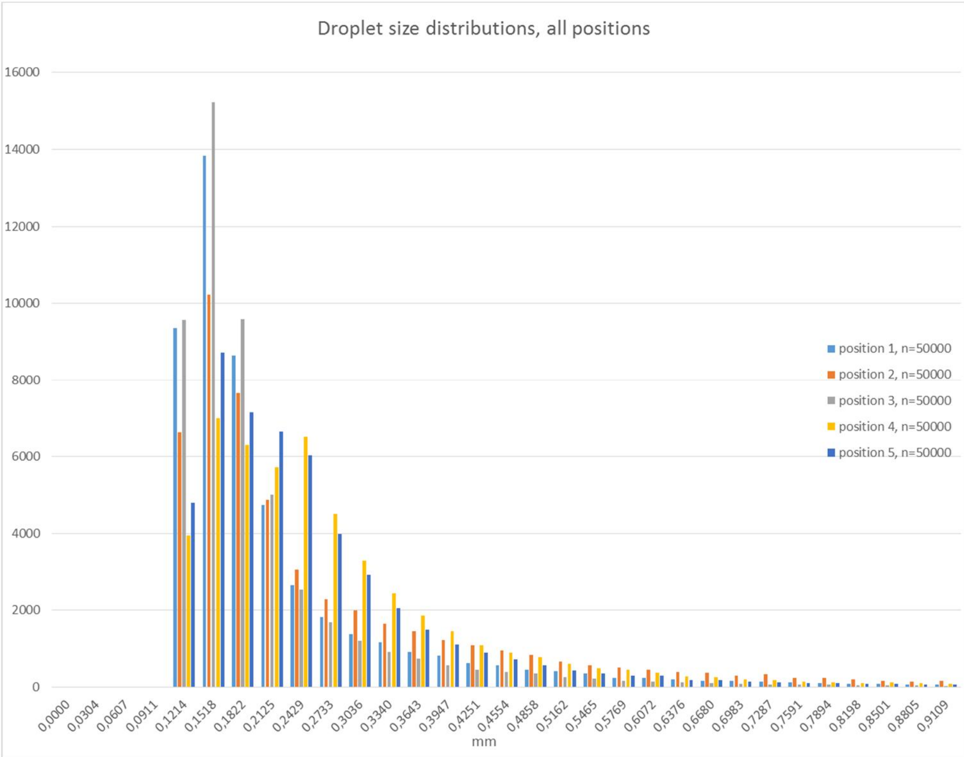


Figure 2.2.4.4. Droplet size distributions in all measurement positions in the single spray nozzle tests.

It has been found out earlier that the used NEPTUNE_CFD simulation model of PPOOLEX does not satisfactory lead to chugging conditions observed in the tests. The drywell-wetwell system revealed stricter requirements for physical capabilities of condensation modelling. Although different interfacial drag models had significant effects on the results, the main reason for poor results was the interfacial area density modelling with the used computational grid resolution. Two ways to improve DCC modelling were tested: 1) the usage of high resolution grids, and 2) a separate model for modelling the interfacial area increase under acceleration.

The dense grid simulation indicated better chugging behaviour than obtained with coarser grids. As a drawback, such transient simulations were found numerically expensive even with the 2D model tested. To simulate chugging with coarser grids, a Rayleigh-Taylor Interfacial area model proposed by Pellegrini et al. (2015) was implemented to NEPTUNE_CFD code and tested. With that model, chugging was reproduced in 2D simulations with some stratified flow DCC heat transfer models. The chugging frequencies were notably near the frequencies seen in the tests.

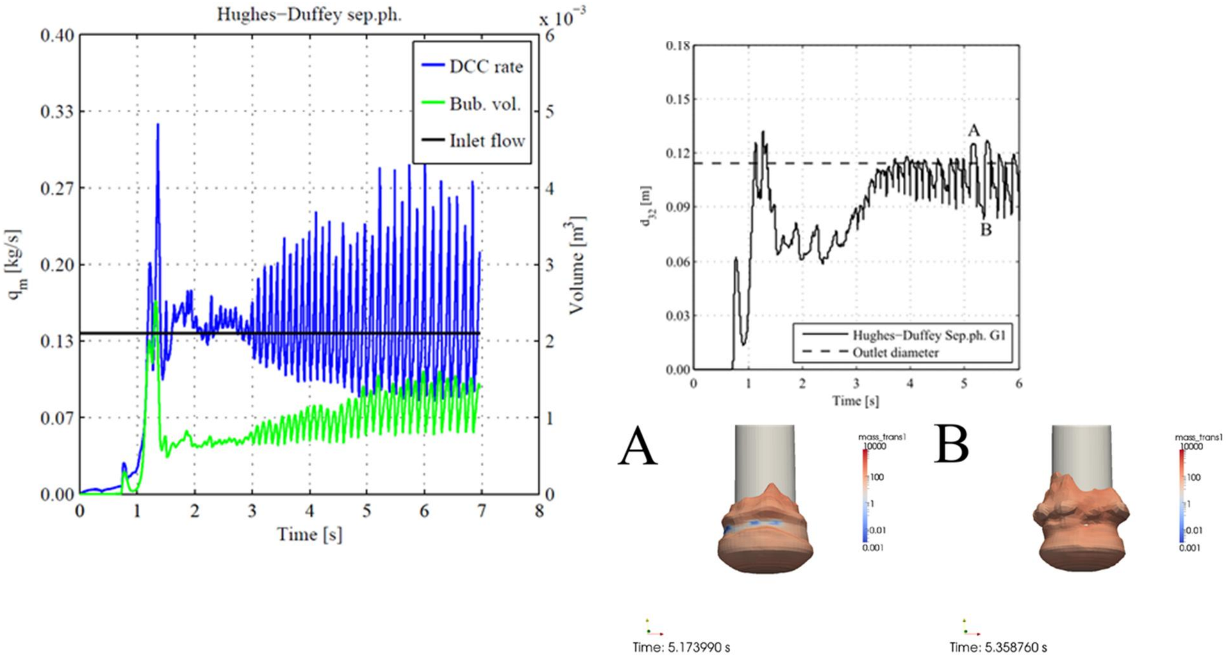


Figure 2.2.4.5. DCC rate and bubble volume (left) and Sauter mean diameter and corresponding maximum and minimum bubble shapes (right) in NEPTUNE_CFD simulation of PPOOLEX test.

Deliverables in 2015

- A series of sparger tests was carried out in the PPOOLEX test facility. Either horizontal steam injection through the sparger head or vertical injection through the LRR was used. The location and length of the transition region between the cold and warm pool water depended on the injection direction. Mixing of the thermally stratified pool happened either through internal circulation or through erosion of the layers of cold water. The test results will be used by KTH to further develop and validate the EMS and EHS models to be implemented in GOTHIC code in order to reduce uncertainties and improve accuracy in predictions.

- Single spray nozzle tests were conducted in a specially built testing station to get experience from the use of the shadowgraphy application of the PIV measurement system for characterising spray nozzles. Droplet size distributions were determined in five different horizontal/vertical positions from underneath the spray nozzle. The majority of the droplets were in the size range of 0.2-0.8 mm in the centreline positions whereas the droplet distribution was broader in the two other positions, which were 300 mm away of the centreline axis. The results revealed that the scaling factor of the used application was too large for these tests in order to get a full range of different droplet sizes.

- A preliminary design of a spray nozzle system to be installed to the PPOOLEX test facility for studying, for example, the effect of spray operation on the development and break-up of thermal stratification in a wetwell pool has been outlined. The system will be constructed in 2016.

- A Rayleigh-Taylor Interfacial area model proposed by Pellegrini et al. (2015) was implemented to NEPTUNE_CFD code in order to improve direct contact condensation modelling. With the model chugging was reproduced in 2D simulations and chugging frequencies were notably near the frequencies seen in the reference tests in PPOOLEX.

2.2.5 INTEGRA - Integral and separate effects tests on thermal-hydraulic problems in reactors

The objective of the project is to improve the understanding of thermal hydraulic system behaviour by performing integral and separate effects tests, in particular regarding the impact of noncondensable gases on core cooling and reliability of natural circulation loop decay heat removal. Carefully designed experiments are the most reliable way to obtain fundamental understanding and reliable data of the phenomena. This data will be used in the development and validation of computer codes for the safety analyses of nuclear power plants.

LUT participated in the OECD/NEA PKL Phase 3 project with PWR PACTEL experiments. The OECD/NEA PKL Phase 3 project was performed with the financial support of the Finnish Research Programme on Nuclear Power Plant Safety (SAFIR2014 and SAFIR2018), the Finnish power company Teollisuuden Voima Oy (TVO), and the partners participating in the OECD/NEA PKL Phase 3 project. The authors are grateful for their support to OECD Nuclear Energy Agency (NEA), the members of the SAFIR2014 and SAFIR2018 Reference Group 4 and the members of the Program Review Group and the Management Board of the OECD/NEA PKL Phase 3 project. The data from the experiments in the OECD/NEA PKL Phase 3 project will be available to the NEA member countries via their CSNI representative organizations three years after the end of the project. The OECD/NEA PKL Phase 3 project will continue to end of April 2016.

Specific goals in 2015

Specific goals in 2015 were to carry out the last experiments in the OECD/NEA PKL Phase 3 project and to investigate the fundamentals of passive systems in order to observe and detect the physical phenomena which could prevent the system to function as designed.

The experiments in the OECD/NEA PKL Phase 3 project were carried out according to the plan accepted in the Programme Review Group and Management Board meetings of the OECD PKL Phase 3 Project on 12th-13th November 2014 in Erlangen. The objectives of the experiments were to investigate the conditions leading to flow reversal under natural circulation and the amount of the U-tubes experiencing flow reversal.

In previous experimental studies it has been shown that during the natural circulation conditions in pressurized water reactors with inverted U-tube steam generators the flow reversing in some U-tubes may exist. In the vertical steam generators the pressure difference between the inlet and outlet plenum decreases with an increasing mass flow rate under low flow conditions. In this region, the mass flow rate is not a single valued function of the pressure drop and flow excursions can occur. The primary side flow is stable only if the flow rate is higher than a specific threshold value.

Basic nodalization based upon lumped modelling features are generally used to represent complex real nuclear power plant systems and geometries in system code simulations. In such modelling the interaction between U-tubes, such as flow reversal in some tubes that may occur under natural circulation flow, is thus neglected. Consequently, this can lead to the overestimation of the natural circulation mass flow rate.

The review on passive heat removal system characteristics includes term descriptions and passive heat removal characterizations. Further, the review presents a collection of various concerns and hazards derived from references under the topic of endangered operability of a passive heat removal system. The review collects issues on factors that can hamper operability or block the safety system functions. The review also presents descriptions of the today utilized or designed passive heat removal systems for the NPP types in Finland (operating, under construction or under application process). The review includes a selection of some publicly available references with more information on these systems.

The review also describes the LUT experimental thermal-hydraulic research efforts on the cases where the focus has been set on passive systems or parts of those systems. The review shows possibilities and expertise at LUT premises to provide further thermal-hydraulic experimental studies on the passive heat removal systems. The review provides based arguments on chosen path for further experimental studies. The review presents a passive containment cooling system (refers to the PHRS-C system of AES-2006 design) to be chosen as the subject for further practical experimental thermal-hydraulic studies.

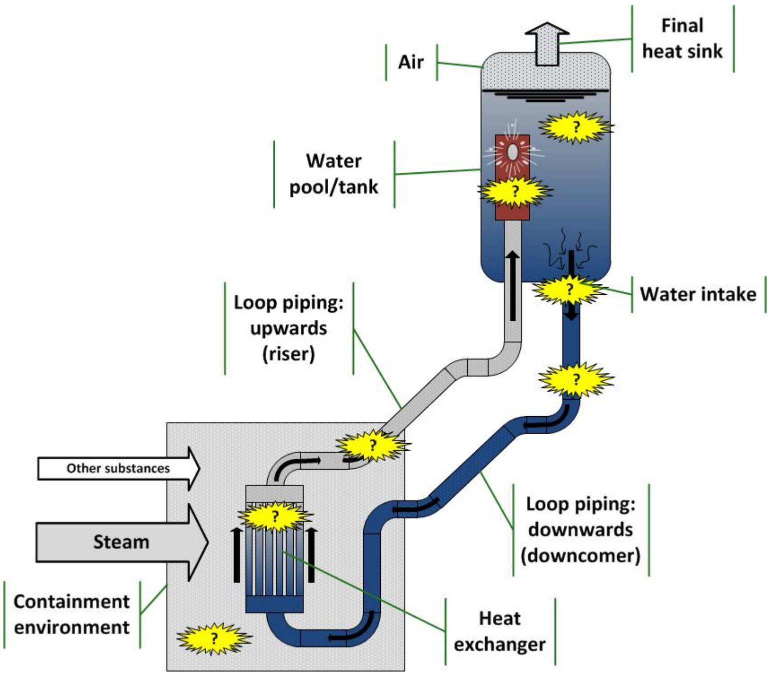


Figure 2.2.5.1. Sketch of an open natural circulation loop system.

Deliverables in 2015

- The PWR PACTEL flow reversal experiments in the OECD/NEA PKL Phase 3 Project were performed.
- The review on factors affecting the operation of passive heat removal circuits was done (published in January 2016).
- The preliminary experiment plan to study the effect of nitrogen in LOCA situations with PWR PACTEL was done (published in January 2016).

2.2.6 KATVE - Nuclear criticality and safety analyses preparedness at VTT

The general objective of the KATVE project is to maintain and develop the domestic competence in various nuclear safety analyses that may be required by the authority or the utilities. The safety analyses covered in the project are mainly related to reactor physics and radiation transport, but also heat transfer and fuel integrity analyses are included in a comprehensive safety study of a dry storage cask, which will be completed during the four year project. In practice, the KATVE project involves development and validation of calculation tools required for safety analyses, studying the domestic and international standards and requirements, and performing practical safety analyses which provide valuable experience for the research personnel.

Specific goals in 2015

One of the main objectives in 2015 was the development of gamma transport capabilities in Serpent. The photon transport calculation mode was implemented in Serpent version 2.1.24, which was published in June, is capable of photon transport calculations. The interaction physics is partly based on the reaction modes available in the ACE file format of MCNP, but the models are completed using data from other sources. The supplementary data library is publicly available on the Serpent website. Also a new feature for generating the gamma source based on radioactive decays occurring in a material has been developed and implemented in the same Serpent version. Main applications for the new features include modelling of gamma shielding problems, modelling of detector responses, calculation of geometry and self-attenuation corrections for gamma spectrometry, and dose rate analyses for spent nuclear fuel.

The photon interaction physics was thoroughly tested and compared against MCNP6 with good results. The development and testing has been documented in an extensive M.Sc. thesis. The gamma transport was also used in a conference article to calculate the gamma dose rate distribution within ITER immediately after shut-down.

Second of the main objectives was to analyse the heat transfer of a dry storage cask filled with spent nuclear fuel. The main goal of the analysis is to determine the largest cladding temperature within the storage cask, which will be used in fuel integrity analyses later in the project. The decay heat source for the heat transfer calculation was first calculated in a 3D burnup calculation on fuel assembly level using Serpent: a PWR fuel assembly from BEAVRS benchmark was depleted to 50 MWd/kgU burnup, after which the fuel was cooled down for 7 years. The CFD heat transfer analysis was performed for a CASTOR-V/21 dry storage cask, filled with 21 of the spent PWR assemblies. The calculation grid for the CFD analysis system was generated using 2 separate tools, and the rather massive OpenFOAM calculation took approximately 15 days with 60 processors. The maximum cladding temperature in the cask, corresponding to 7 years of cooling, was 493 K.

Performing valid criticality safety analyses requires that the calculation system, consisting of a transport calculation code and the cross section library, is validated for criticality safety analyses. In practice, this means modelling a large series of criticality experiments with the calculation system and comparing the computational results against the experimental data to obtain an estimate for the bias of the system. To automatize the validation of the calculation codes, a validation script is being developed. The script runs a series of calculations with Monte Carlo codes Serpent and MCNP, and automatically analyses the results. The number of criticality experiments included in the validation package increases by the year, and in 2015 the number of available cases was increased to 62 for MCNP and 190 for Serpent. All the validation cases were from 3 independent series of experiments. More independent series need to be added in the collection of experiments before the validation package can be considered complete.

The codes previously used for activation analyses in the reactor periphery, such as DORT/TORT, are quite cumbersome to use and their support is also about to end, which calls for updating the calculation system. MAVRIC, which combines deterministic solvers together with multi-group Monte Carlo methodology, was recognized as a very potential replacement for the old codes. In 2015, the preparedness in activation analyses was increased by attending a MAVRIC training course and calculating a slightly modified version of the Kobayashi benchmark using the code. Also related to activation analysis, an article on previously calculated radionuclide inventories in the FiR-1 reactor was prepared in 2015 and accepted for publication in the Nuclear Technology journal.

Also the competence in neutron dosimetry was increased by developing tools for performing rigorous spectrum adjustments. Usually there is a mismatch between the calculated neutron flux or fluence spectrum and the reaction rate information obtained from neutron dosimeters. To get a minimum-variance estimate for the neutron flux spectrum, the calculated spectrum needs to be adjusted using the data from neutron dosimeters. When using spectrum adjustment codes like the LSL-M2, the adjustment procedure involves a lot of mechanical cross section processing, and also the covariance of the input parameters needs to be specified. In 2015, a Matlab program was developed for the estimation of the covariance of measured neutron dosimeter activities, and also other parts of the neutron spectrum procedure were studied such that it was possible to adjust the neutron spectrum in the central thimble of the FiR-1 reactor. However, in this adjustment the covariance of the calculated neutron spectrum was estimated only roughly. More rigorous determination of the covariance of the calculated spectrum was recognized as an important future research topic.

One of the goals for year 2015 was to prepare a state-of-the-art report on the burnup credit practices in Finland and abroad. This work was started in 2015, and also a short preliminary version of the report was prepared. The reference group, however, suggested that the report should be completed in its originally intended extent in 2016, with help from an ad hoc criticality safety group including members from the utilities and the authority. Thus, the publication of the state-of-the-art report is postponed to 2016.

In addition, KATVE project 2015 included international collaboration. The OECD/NEA Nuclear Science Committee (NSC) meeting and several meetings of the Working Party on Nuclear Criticality Safety (WPNCS) were attended. Also a meeting of the AER-E group, a meeting of the European Working Group of Reactor Dosimetry (EWGRD), the ICNC2015 conference and the 5th Serpent User Group Meeting were attended in 2015.

Deliverables in 2015

- Master’s thesis on the development and testing of photon transport in Serpent 2. The methodology was implemented in Serpent 2 Monte Carlo code together with a new radioactive decay gamma source feature. The thesis will be published after it is accepted by Aalto University.

- A conference article accepted in the PHYSOR2016 conference, in which the gamma transport of Serpent was used to calculate the dose rate distribution within ITER immediately after shutdown. Also the new radioactive decay gamma source was tested in the same article.

- A report on the heat transfer of a CASTOR-V/21 dry storage cask, filled with 21 PWR assemblies with 50 MWd/kgU burnup which have been cooled for 7 years. The report describes both the decay heat source generation with Serpent, and the CFD analysis with OpenFOAM and auxiliary programs.

- Status report on the development of the criticality safety validation package for Serpent and MCNP in 2015. The package itself can also be considered a deliverable.

- Report on the calculation of the Kobayashi benchmark using MAVRIC code.

- Publication on FiR-1 inventory calculations in the Nuclear Technology journal. The article has been accepted for publication, and its publication is scheduled in April.

- A report on neutron spectrum adjustment with LSL-M2 program. A Matlab program for the estimation of the covariance of measured dosimeter activities was also developed during the work.

- Travel report on the NSC meeting
- Travel report on the ICNC2015 conference.

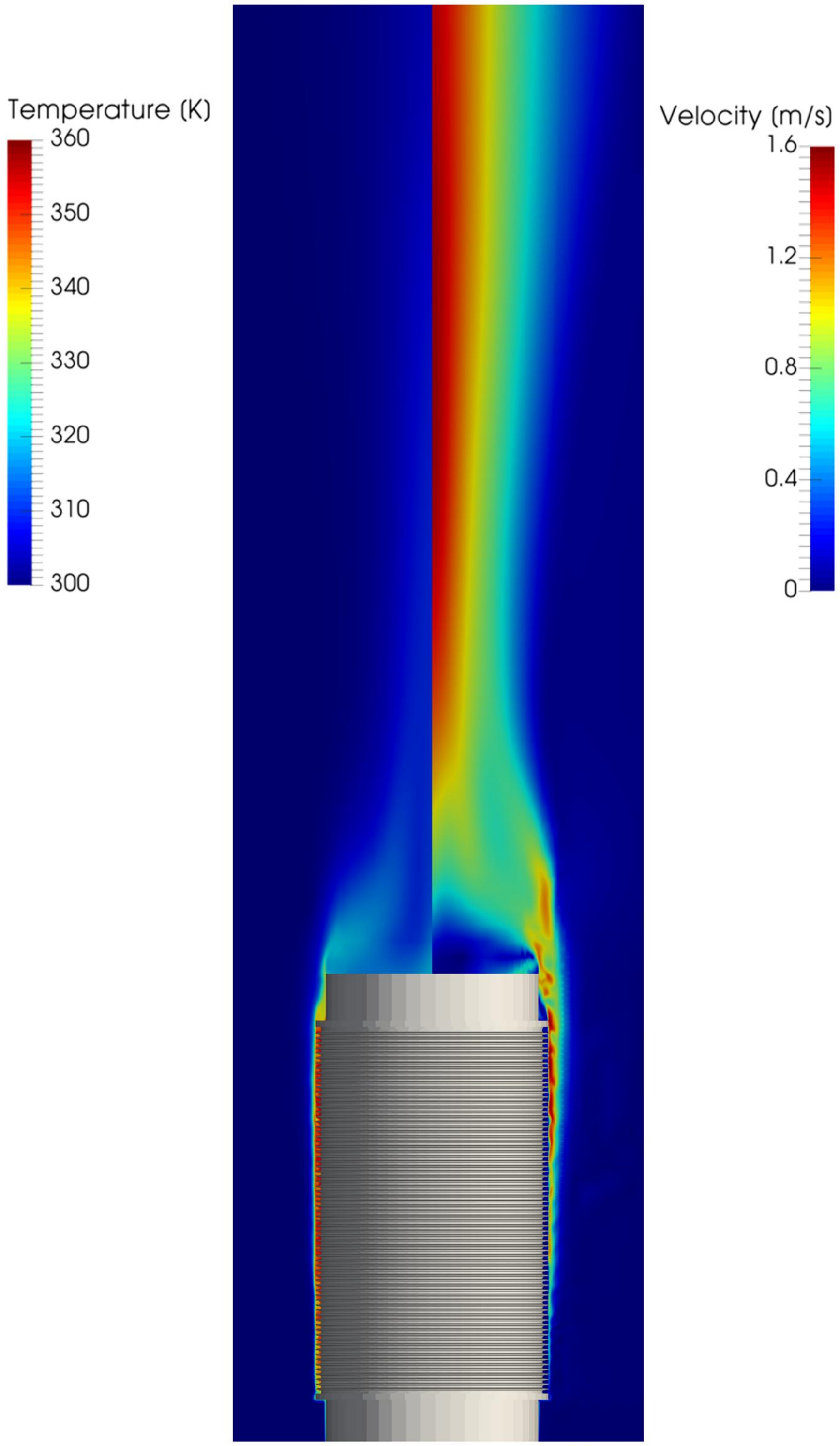


Figure 2.2.6.1. The heat transfer of a CASTOR-V/21 dry storage cask, filled with 21 spent fuel assemblies, was calculated with CFD.

2.2.7 MONSOON - Development of a Monte Carlo based calculation sequence for reactor core safety analyses

The MONSOON project continues the development of the Serpent Monte Carlo code, started in 2004, and carried out within the previous SAFIR programmes, such as the KÄÄRME project in SAFIR 2014. Compared to KÄÄRME, the work is more focused on a specific field of applications, namely spatial homogenization, i.e. the production of group constants for deterministic fuel cycle and transient simulator codes. The primary objective and expected result is a first of a kind Monte Carlo based calculation tool, capable of performing group constant generation in a routinely manner. The code can be used to complement or even replace current state-of-the-art deterministic lattice physics codes, bringing the advantages of the continuous-energy Monte Carlo method to spatial homogenization. The developed methodologies are thoroughly validated and put to practice in the calculation schemes used at VTT for the independent safety analyses of Finnish power reactors.

Specific research topics include developing methodologies for 3D homogenization to account for the effects of axial discontinuities in LWR core geometries, and including fuel temperature feedback in assembly burnup calculations, in an effort to study new approaches to state-point parametrization. Before moving to these new research topics, the state-of-the-art methodology developed within the KÄÄRME project is finalized and comprehensively validated. In practice this implies moving from proof-of-concept to practical applications. The project shares topics and collaboration with the KATVE, SADE and PANCHO projects.

The international success of the Serpent code and the importance of developing a fully independent calculation system accompanied by source-code level understanding of the methodology was recognized in the SAFIR 2018 Framework Plan, where it was also recommended that the range of applications should be broadened. The plans for MONSOON 2015 were drafted based on these specific recommendations.

Specific goals in 2015

The realized volume of the project was reduced to 50% from what was applied, which meant that many of the new research topics and in general the broadening of the range of applications had to be postponed to later years. Instead, the project focused on completing the work started in the KÄÄRME project in SAFIR 2014, which had to be accomplished before moving on to new challenges.

The first goal of the project was to develop Serpent into a practical tool for group constant generation, in such way that this task could be handled by relatively inexperienced users with only basic skills in reactor physics. In other words, such that Serpent could replace current deterministic lattice transport codes in the traditional multi-stage reactor physics calculation scheme. In the original plan the work was focused on group constant generation for five simulator codes currently used at VTT:

1. ARES – Steady-state nodal diffusion code for the fuel cycle simulations of western LWR's, developed at STUK
2. TRAB3D – Time-dependent nodal diffusion code for the transient analyses of western LWR's, developed at VTT
3. HEXTRAN – Time-dependent nodal diffusion code for the transient analyses of VVER reactors, developed at VTT
4. HEXBU – Steady-state nodal diffusion code for the fuel cycle simulations of VVER reactors, developed at VTT

5. PARCS – Steady state / time-dependent nodal diffusion code for the fuel cycle and transient analyses of LWR's, developed at Purdue University

The physics of spatial homogenization is very similar for all codes based on nodal diffusion methods, but there are differences in the practical implementation. The cross section model in VTT's simulator codes TRAB3D, HEXTRAN and HEXBU is also used by the Apros system code, so the work also supports the calculation scheme for nuclear power plant simulations.

Because of the reduction in project volume, the research topics had to be limited to work already started in SAFIR 2014, involving the first two simulator codes in the list - ARES and TRAB3D. Work on the Serpent-ARES calculation sequence was started during the last year of the KÄÄRME project, with the MIT BEAVRS benchmark involving a 1000 MW Westinghouse PWR as the test case. In MONSOON 2015 the calculations were extended from hot zero-power initial core calculations to full power conditions and fuel cycle simulations.

The Serpent-TRAB3D calculation sequence was demonstrated earlier using the initial core of the EPR reactor as the test case. The plan for 2015 involved validation of the pin-power reconstruction module in TRAB3D, followed by studies on the effects of partially-inserted control rods and other axial heterogeneities in the accuracy of nodal diffusion calculations. The work was carried out as a special assignment and an M. Sc. thesis for Aalto University.

Including fuel temperature feedback in the assembly burnup calculation performed for the purpose of spatial homogenization was listed in the original work plan as one of the major research topics. Because of the reduction in budged, the work was focused on fuel performance code coupling, leaving studies related to new approaches to state-point parametrization to later years.

In addition to the actual research topics, work was also allocated to dealing with practical challenges in spatial homogenization, in particular the development of an automated burnup sequence capable of handling state-point variations. The process of group constant generation requires repeating the assembly-level transport calculation hundreds or even thousands of times, in order to cover all fuel assembly types and reactor operating conditions. The automated management of input and output data is an absolute necessity for accomplishing this task.

The project also included sub-tasks for international collaboration and the preparation of Serpent 2 for public release. These sub-tasks involved participation in the activities of the international reactor physics community, organization of Serpent user group meetings, as well as the preparation of an input manual and new cross section libraries for Serpent 2.

Deliverables in 2015

All tasks planned for 2015 were completed. Specific deliverables are listed below.

- The Serpent-ARES calculations involving the MIT BEAVRS Benchmark were extended to hot full-power conditions and fuel cycle simulations. The comparison of ARES results to reference Serpent 3D calculations showed good agreement for radial and axial power distributions for the HFP state. Control rod worths and boron dilution curve for the first operating cycle were in good agreement with experimental measurements provided in the benchmark specification. The results will be published in a paper submitted to Annals of Nuclear Energy.

- The ARES calculations demonstrated that it is possible to use the continuous-energy Monte Carlo method for producing the full set group constants for fuel cycle simulations, albeit at a high computational cost. It was also demonstrated that the automated burnup sequence developed during the course of the project for this purpose works as intended.

The burnup sequence, and the methodology used in Serpent for group constant generation, will be covered in a paper submitted to Annals of Nuclear energy.

- Work on assembly burnup calculations with fuel temperature feedback was started by coupling the latest version of the FINIX code to Serpent. FINIX currently lacks the routines to model incremental changes inflicted by burnup, so the calculations will be first carried out using external coupling to the ENIGMA code. Preliminary test calculations were carried out using Peach Bottom 2 assemblies as the test case, and the work continues in 2016.

- A special assignment for Aalto University on the validation of pin-power reconstruction module in TRAB3D with Serpent-generated group constants was completed.

- An M. Sc. Thesis for Aalto University on the modeling of axially heterogeneous systems using nodal diffusion methods (TRAB3D) was started, and will be continued in 2016.

- The international Serpent user community grew from 380 users in February 2015 to 500 users by the end of January 2016. The code has users in 150 universities and research organizations in 37 countries around the world.

- Two source code updates (2.1.23 and 2.1.24) were distributed to Serpent users in 2015.

- The 5th Annual Serpent User Group Meeting was hosted by the University of Tennessee in Knoxville, TN, on October 13-16, 2015. The four-day event brought together 41 Serpent users from 18 Organizations around the world, making it the largest Serpent user group meeting so far.

- A Serpent workshop was organized at the 7th International Conference on Modeling and Simulation in Nuclear Science and Engineering in Ottawa, ON, Canada on October 18-21, and followed by another workshop with CNL at Chalk River.

- International collaboration also included participation in the Executive Committee of the Reactor Physics Division of American Nuclear Society. Two meetings were attended in 2015.

- An invited seminar titled: “Past, present and future challenges of developing the Serpent Monte Carlo code” was presented to the students of Massachusetts Institute of Technology in December.

- Writing of a User Manual for Serpent 2 was started as an on-line Wiki, and the work is continued in 2016.

- Cross section libraries based on the JEFF-3.2, ENDF/B-VI.1, JENDL-4.0 and FENDL-3.0 evaluated nuclear data files were produced and the comprehensive testing of the data was started. The work continues in 2016.

- A doctoral thesis on the development of a stochastic temperature treatment technique for Monte Carlo neutron tracking was completed in May, and awarded as the best physics doctoral dissertation from the Department of Physics at Aalto University School of Science in 2015. The research for the thesis was in part carried out within the KÄÄRME project of SAFIR 2014, which can be considered the predecessor of MONSOON 2015.

2.2.8 NEPAL15 - Neutronics, burnup and nuclear fuel

The Fission and Radiation Physics Group at Aalto University School of Science concentrates on developing calculation methods for reactor physics, modelling basic physical and chemical phenomena in nuclear fuel, and researching new fuel cycles and next generation nuclear reactors. The activities seamlessly combine education and research of nuclear engineering. The essential field of know-how of the group covers physics-based analyses and numerical computation, especially development of Monte Carlo codes.

The objective of NEPAL15, a direct continuation of the NEPAL project in SAFIR2014, is to increase our knowledge on burnup calculations on one hand and nuclear fuel behaviour on the other hand. We explore new methods in an academic manner, but we have practical applications in sight for the longer term.

The main purpose of NEPAL15 is education of new experts in the field. In the preceding NEPAL project, one DSc thesis, one MSc thesis and one BSc thesis were produced, and all by different authors. In NEPAL15, one of the deliverables is a BSc thesis.

Specific goals in 2015

In the burnup calculation task, our postdoc works at Oak Ridge National Laboratory (ORNL) and develops various methods of mutual interest. These include the advanced depletion coupling schemes developed by us and the CRAM solver developed at VTT. Additionally, runtime and memory enhancements are investigated and implemented in various codes.

In the task on mesoscopic fuel model, the objective is to further increase the realism in our model. In order to produce quantitative predictions more information and models are needed on the percolation threshold, growth rate of damages and thermal creep failure. The simulation results are to be compared to empirical measurements. This work was planned as a Bachelor’s thesis or special assignment, but we did not manage to recruit a summer student for the task.

In RG meeting 1/2015 it was agreed that this part of NEPAL15 funding is used for another Bachelor's thesis where a BSc student optimizes cross section libraries for Serpent 2 under the supervision of DSc T. Viitanen (VTT). It has been observed that the cross section libraries in Serpent 1 are not accurate enough for all reactor systems. On the other hand, the memory consumption has to be kept under control, so the accuracy shall be increased sensibly. This optimization was done in a BSc thesis.

Deliverables in 2015

The 2015 deliverables of NEPAL are the scientific publications listed in the separate document `Publications_NEPAL15_15.doc`. In addition, a travel report was written and distributed to the reference group and a BSc thesis was written on optimization of cross section libraries. The development of the fuel model was frozen in 2015 and the model is one of the deliverables. The context of these deliverables is described below.

Burnup calculation methodology (A. Isotalo)

In the first part of A. Isotalo’s work at ORNL, he implemented a CRAM depletion solver to the ORIGEN module of SCALE. The new CRAM solver is superior to the old solver of ORIGEN in every way, and should eventually replace the old solver in all applications.

In addition to implementing CRAM, A. Isotalo developed three new capabilities for it. The first of these is a way to include a source term in the calculations, which has previously not been possible with CRAM. This allows CRAM to be used for modelling systems, such as molten salt reactors and reprocessing facilities, with material flows. The new method can even handle sources term with general polynomial time-dependence. Using time dependent source term of any kind has previously not been possible with any depletion algorithm capable of handling the full system of nuclides.

The second new capability is internal substepping which further improves the already remarkable accuracy of CRAM with only a modest effect on running times. Even decay problems, where there have previously been concerns about the accuracy and reliability of CRAM, can now be solved with ten correct digits for all nuclides with atomic fraction above an arbitrary limit.

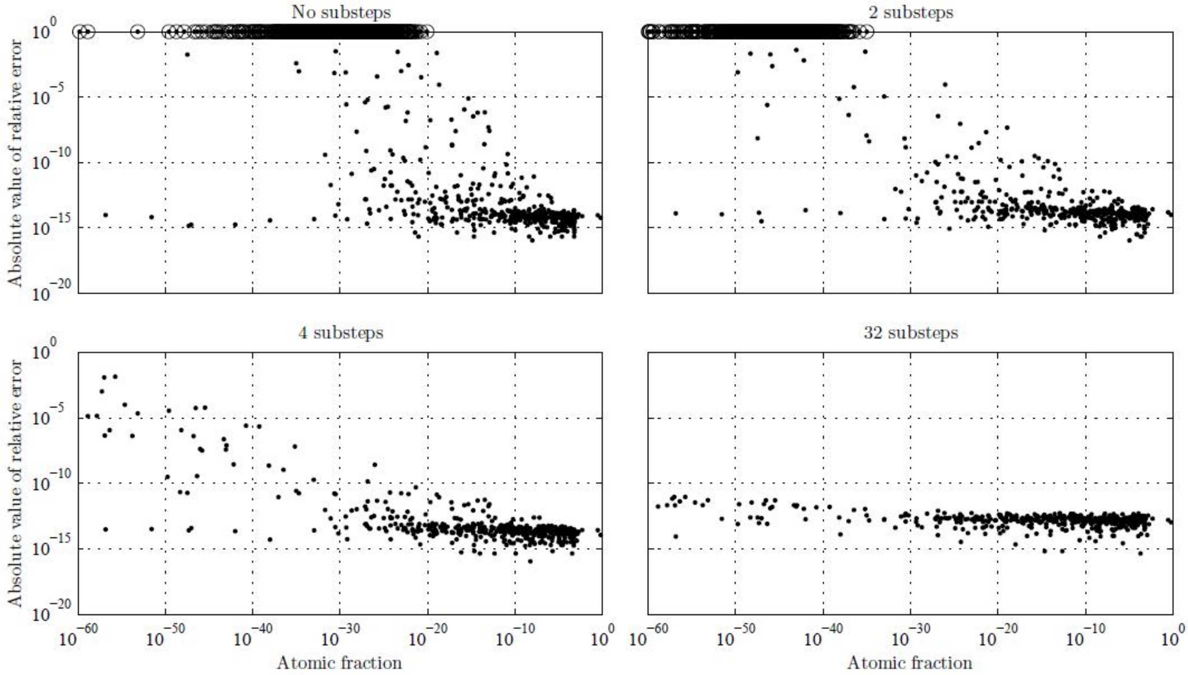


Figure 2.2.8.1: Relative errors with different numbers of internal substeps when old fuel is decayed for 365 days. Circles indicate errors that have been reduced to 1 for plotting. [Isotalo, Pusa 2015]

Finally, A. Isotalo developed a new method for calculating the time-integrals or averages of any and all quantity that are weighted sums of the atomic densities as a part of a single depletion solution with CRAM. Examples of such quantities are time-average atomic densities, the number of fissions, and the amount of energy released during a depletion step. The new method is fast and extremely accurate, which enables these quantities to be used in ways that have not previously been realistic.

A. Isotalo also participated in developing and implementing an internal burnup calculation capability for the new high performance Monte Carlo transport code called Shift. In particular, he implemented the higher order neutronics-depletion coupling schemes developed as a part of his PhD research. The capability has now been completed and is being tested. A conference paper will be written that describes the implemented burnup calculation capabilities.

In addition to regular code development activities, A. Isotalo used Shift to study the use of flux renormalization in constant power burnup calculations to further improve the implemented burnup calculation methodology. This includes developing a new renormalization method that leverages the new CRAM capabilities, a comparison of different renormalization strategies, and scoping on how much of a difference renormalization actually makes.

Mesoscopic modelling of nuclear fuel (M. Ovaska)

During the four-year NEPAL project in the SAFIR2014 programme, M. Ovaska developed a computational model for simulating the microstructural evolution of nuclear fuel. The model includes damage accumulation from thermal creep deformation and from fission gas buildup within the pellet. Damage accumulation is linked with increasing porosity of the fuel, as microcracks and gas bubbles are formed. Diffusion of fission gases is simulated from the viewpoint of percolation theory: gas flows through interlinked pores, and can only reach the surface of the pellet through continuous pore pathways.

In 2015, it was our plan to continue this modelling as a Bachelor's thesis or special assignment under supervision of M. Ovaska. Due to manpower limitations, this plan was not realized.

Processing cross section libraries for Serpent 2 (O. Hyvönen)

In O. Hyvönen's BSc thesis, optimal reconstruction parameters for cross section libraries used with neutron transport calculation code Serpent 2 were sought. The nuclear data processing system NJOY, operated with a wrapper code SFFER by D.Sc. Tuomas Viitanen, was used to generate the cross section libraries. The essential reconstruction parameters in question were *err*, *errint* and *errmax* of NJOY's RECONR module.

Accuracy of the generated libraries was tested with Serpent 2 using simplified models of two thermal (HTGR, PWR) and one fast reactor (LFR). Fresh fuel calculations were used to establish a fundamental baseline for accuracy, and depleted fuel calculations were performed to examine if the presence of hundreds of different nuclides in the fuel affects how the reconstruction parameters should be chosen. Results of a simulation were compared to the reference result of the same simulation, calculated with highly accurate libraries.

As a result, the suggested reconstruction parameters for optimal thermal libraries are *err* = 0.005, *errint* = $2.5 \cdot 10^{-7}$ and *errmax* = 0.05. However, a library used for fast reactor simulations should not be generated with these values, as the integral thinning property they enable in the RECONR-module impairs the accuracy of the library with fast reactors. However, it seems that the Serpent default library reconstructed with *err* = 0.01 and with integral thinning disabled by choosing *errmax* = *err* is accurate enough.

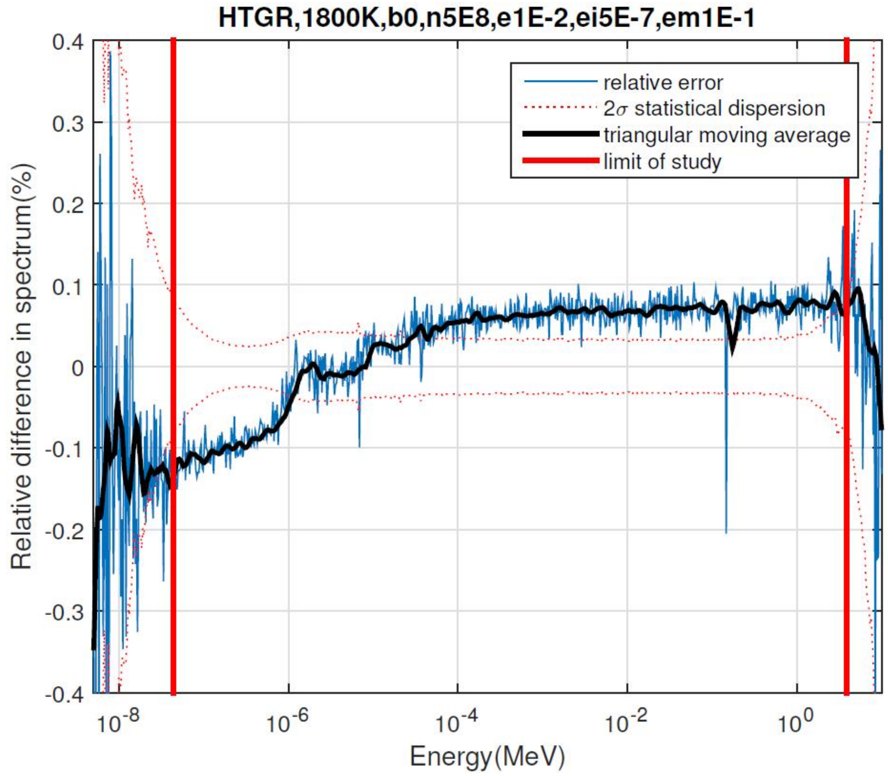


Figure 2.2.8.2: A relative difference neutron spectrum utilized in the parameter optimization. The title contains all relevant information about the simulation: case (HTGR), temperature (1800 K), fuel burnup (b0 = 0 MWd/kgU), number of neutron histories (n5E8 = $5 \cdot 10^8$), err (e1E-2), errint (ei5E-7) and errmax (em1E-1). [Hyvönen 2015]

2.2.9 NURESA - Development and validation of CFD methods for nuclear reactor safety assessment

In the NURESA project, Computational Fluid Dynamics (CFD) methods are developed and validated for the identified most important topics in nuclear reactor safety assessment. In Work Package 1 (WP1), international single-phase mixing benchmarks are participated. In WP2, PPOOLEX spray experiments are modelled with CFD codes in co-operation with Swedish partners. In WP3, CFD models for departure from nucleate boiling (DNB) and dry-out are developed for the OpenFOAM code in co-operation with international partners. WP6 consists of the coordination of the project.

Specific goals in 2015

In WP1, the international blind benchmark in the Hydrogen Mitigation Experiments for REactor Safety (HYMERES) programme is participated. The benchmark exercise is PANDA experiment HP1_6_2, which focusses on the hydrogen stratification and erosion of density layer by turbulent mixing processes. The benchmark is calculated by using the ANSYS Fluent CFD code.

In WP2, spray experiments performed at LUT are modelled with CFD simulations. Single spray nozzle experiments performed at LUT are calculated. CFD model for the Spray Testing station is constructed and calculations of the preliminary spray tests are performed. Finally, CFD model for PPOOLEX spray tests is constructed and a pre-simulation of an experiment is performed.

In WP3, OpenFOAM CFD solver is developed and validated for nuclear reactor safety assessment. At VTT, subcooled nucleate boiling and wall heat transfer models are integrated to the Eulerian two-phase solvers of the official OpenFOAM release. At Aalto, heat transfer in fuel rod bundles is calculated with OpenFOAM. At LUT, OpenFOAM simulations of POOLEX chugging tests are done and models for direct-contact condensation are developed. In the in-kind contribution of Fortum, heat transfer in VVER-440 fuel rod bundle is calculated.

In WP6, project coordination is done. In addition, Northnet Roadmap 1 and Roadmap 3 Reference Group Meetings are participated.

Deliverables in 2015

- The OECD/NEA HYMERES benchmark on hydrogen mitigation has been participated. The blind benchmark on the PANDA Test HP1_6_2 was calculated and the results were submitted to the organizers of the benchmark. The erosion of the stratified helium layer was slower in the CFD calculation than in the experiment. The results were presented in HYMERES project meeting at PSI. Report on the CFD calculations was written. See Figure 2.2.9.1.

- CFD calculations of single spray nozzle experiments performed at LUT have been performed. First, CFD model for the Initial Spray Texting Station for single spray nozzle experiments was constructed. Calculations were performed by using available information on the sized distribution of the droplets. Model for the size distribution was made. Second, CFD model for the new Spray Testing station was constructed. CFD calculations of the experiments were performed by using the model for the size distribution for the droplets. Report on the calculations was written.

- Pre-calculation of a PPOOLEX spray experiment has been performed. Spray model was added in the model of the PPOOLEX test facility. A pre-calculation for the wet well spray system consisting of four sprays was performed. Report on the calculations was written.

- New Eulerian compressible or incompressible solver with multi-phase, multi specie, chemistry, interfacial specie diffusion and thermal phase change support has been included in the official OpenFOAM 3.0.1 release (reactingEulerFoam solver family). Framework for modelling of thermal phase change was implemented in the solver and tested. Support for wall boiling was added to the framework. A wall boiling wall function with fixed phase change mass flux as well as the RPI wall boiling model were implemented and tested. A heat flux boundary condition with inter-phase coupling and thermal wall function for multiphase convective heat transfer were also implemented and tested. All of the above were also integrated into the official OpenFOAM-dev code repository and are publicly available.

- Report has been written documenting the implemented models of the subcooled nucleate boiling solver of the official OpenFOAM release.

- Report has been written on the validation of the subcooled nucleate boiling model. Simulations of DEDALE, DEBORA, SUBFLOW and PSBT rod bundle experiments were carried out. Recalculations of the test simulations with the publicly available solver version were performed. See Figure 2.2.9.2.

- At LUT, Comparison has been performed of the Eulerian OpenFOAM and the NEPTU-NE_CFD results for chugging condensation mode. Simulations of POOLEX experiment (STB-28-4) of chugging were completed with compressible two-phase solver of OpenFOAM. Results revealed that the averaged condensation rates of OpenFOAM simulations were comparable to the previous NEPTUNE_CFD results of Tanskanen (2014). Qualitative differences still existed. The PPOOLEX simulations were started with

2D-axisymmetric grid with compressible two-phase solver of OpenFOAM. Implementation of Rayleigh-Taylor instability model of Pellegrini to the OpenFOAM two-phase solver was started. Report on the comparison of Eulerian OpenFOAM and NEPTUNE_CFD results for chugging condensation mode was written. See Figure 2.2.9.4.

- At Aalto, behaviour of subcooled nucleate boiling model was investigated. Simulations were made for a grid-sensitivity study in the case of high-Reynolds-number turbulence modelling. Debora 5 experiment was used as test case. This study was reported as a diploma work at Aalto.

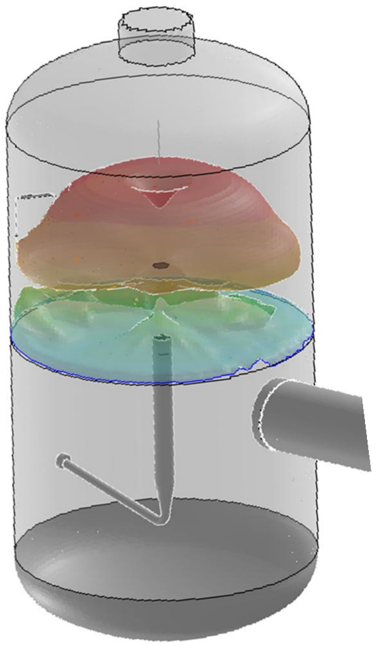


Figure 2.2.9.1. Erosion of stratified helium layer by a vertical steam jet was calculated with ANSYS Fluent CFD code. The experiment was performed with the PANDA facility at the Paul Scherrer Institute, Switzerland.

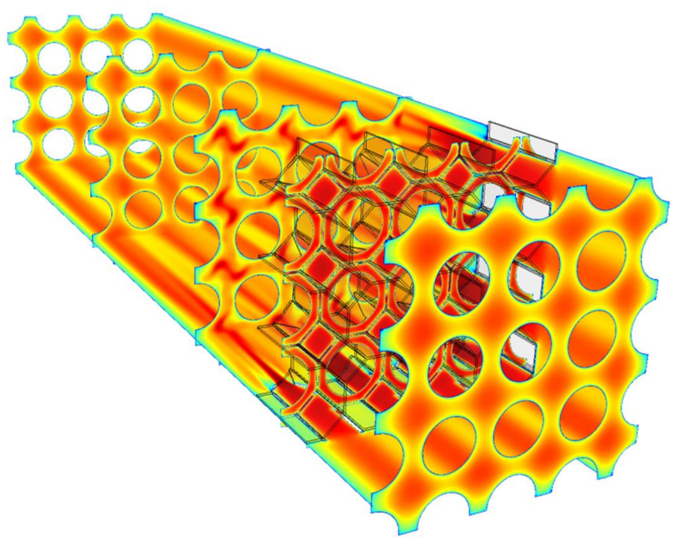


Figure 2.2.9.2. Liquid velocity in a two-phase flow in a fuel rod bundle. Isothermal SUBFLOW experiment was performed at the Paul Scherrer Institute by Juha-Pekka Hyvärinen (2014). The experiment was calculated with OpenFOAM CFD code.

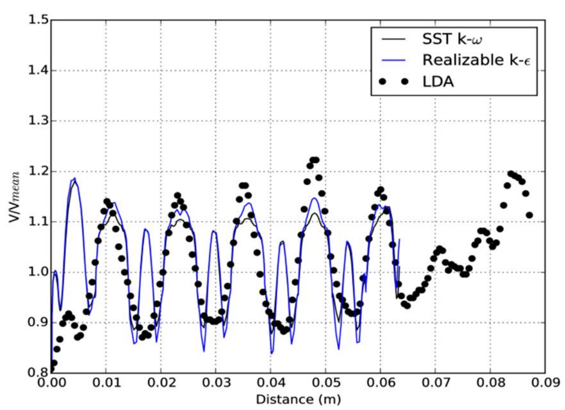


Figure 2.2.9.3. Comparison of flow velocities calculated with OpenFOAM to results obtained with LDA measurements. Flow in a VVER-440 fuel rod bundle one centimetre after spacer grid is considered. Results obtained with two different turbulence models are shown.

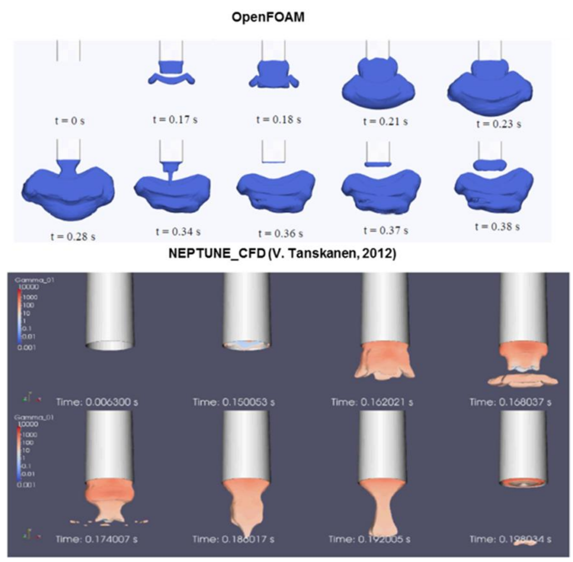


Figure 2.2.9.4. Penetration of steam jet into a water pool has been calculated with the OpenFOAM CFD code. The results are compared to earlier calculations of Tanskanen (2012) performed with the NEPTUNE_CFD code.

- At Aalto, heat transfer in a fuel rod bundle has been investigated. Various grid topologies and OpenFOAM solvers were used for a fuel rod bundle. With better initial conditions heat-transfer effects could be included with smaller computational grids. Different turbulence models were used with high-Reynolds-number grids. Two grid topologies made by grid generator (Pointwise) failed to produce a proper OpenFOAM format. Pointwise was informed about this. Report has been written on the heat transfer calculations. See Figure 2.2.9.3.

- At Fortum, heat transfer calculations for VVER-440 fuel rod bundle have been performed. This part of the work is an in-kind contribution of Fortum to the project. Mesh generation for the current Loviisa fuel bundle geometry was finished. The CFD model includes solid and fluid regions, and realistic boundary conditions, including heat flux profiles for fuel rods. OpenFOAM calculations were started. Report on the calculations will be written.

- Project was coordinated by VTT. Northnet Roadmap 1 meetings were participated in May and November. Northnet Roadmap 3 meetings were participated in March and October.

2.2.10 PANCHO - Physics and chemistry of nuclear fuel

Nuclear fuel both produces the energy in nuclear power plants and acts as the first two barriers to the spread of radioactive fission products. The UO2 matrix of the fuel pellets contains approximately 99% of the born radionuclides, while the cladding tube contains the rest. Therefore the integrity of the fuel during normal operation and accidents is of utmost importance. Traditionally fuel performance has been analysed with integral fuel codes that contain semi-empirical correlations deduced from experiments. These correlations and models become more and more mechanistic as the understanding and the demands increase.

The project PANCHO – Physics and Chemistry of nuclear fuels investigates the integral fuel behaviour as well as combines the experimental and the modelling approaches in studying several topical features of nuclear fuel behaviour. These topics are the chemistry of the fuel pellet and the mechanical response of the cladding.

Specific Goals in 2015

Focus for 2015 was in development of FINIX fuel code, coupling of SCANAIR to thermal-hydraulic sub-channel code GENFLO and the investigation of both cladding and fuel special properties such as creep models and leaching studies. The international co-operation such as fuel behaviour part of VTT - Halden Reactor Project in-kind work, participation in working groups OECD/CSNI WGFS and ETSON SAG, as well as the following of CABRI progress is done under this project.

Deliverables in 2015

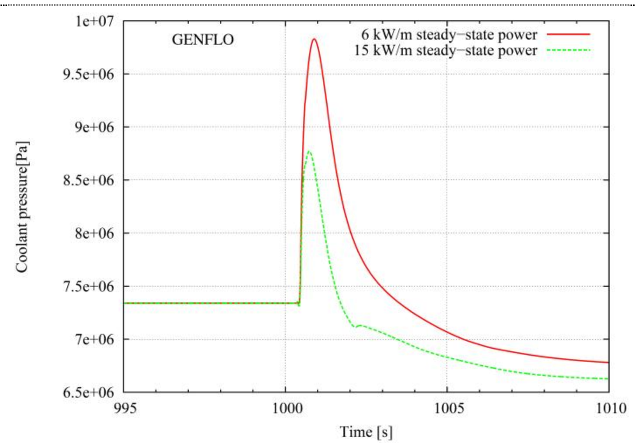
- FINIX data structures have been completely redesigned. All the data FINIX requires or calculates is now stored in C structures instead of large arrays. Also the variable names have been changed to better describe their purpose. These changes make the code easier to understand and update. The new version of FINIX can also read FINIX and FRAPTRAN input files, and allows the user to print new types of output files.

- A new cladding mechanical model was implemented in the FINIX fuel performance code and a new version, FINIX-0.15.12, was released. The new mechanical model covers time-independent cladding plasticity, and FINIX is now able to model fuel rods under high cladding stresses more realistically.

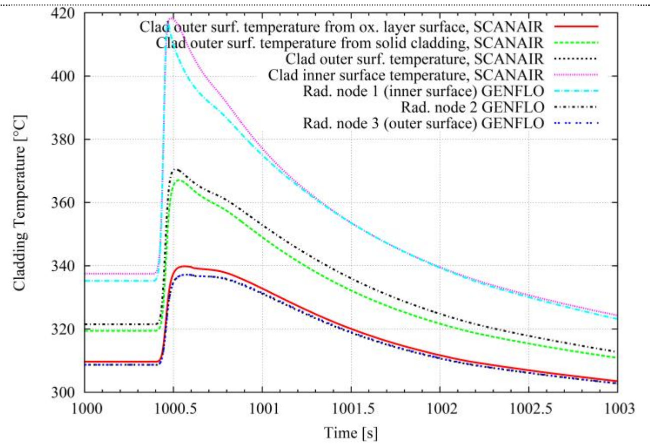
- A software development plan was written for a new general-purpose validation system. The development plan guides the programming work that begins in 2016. The first version of the validation system can be used for assessing the validity of fuel performance codes used at VTT.

- Fuel Modelling in Accident Conditions (FUMAC) is an IAEA Coordinated Research Project (CRP) that was launched in 2014. The aim of the project is to support the participants from different countries in their efforts to develop reliable tools for modelling of fuel behaviour during accidents. VTT's contribution in the first phase of the project was to calculate a set of AEKI separate effect tests and an integral VVER LOCA test performed at the Halden reactor. The code used in the calculations was FRAPTRAN-GENFLO. The simulation results will be compared to the results calculated by other participants in a later phase of the project.

- The coupling between SCANAIR and GENFLO was introduced in 2014 in PALAMA project as a yearly in-kind work for IRSN. The coupling was successfully implemented in a way that GENFLO calculates the cladding outer surface temperature in addition to the thermal hydraulic behaviour, and passes the axial cladding outer surface temperatures on-line to SCANAIR. Then, SCANAIR simulates the fuel thermo-mechanical + FGR behaviour. When testing the first set-up of the coupling, some difficulties were encountered. The most important issue left to be solved was the drastic fluctuation in the calculated coolant pressure. The pressure evolution affects the whole thermal hydraulic solution, and therefore is should be correctly evaluated. It revealed that with the coupled code, very small time steps are required even during the initialization phase prior to the transient, and those removed the abnormal pressure fluctuations. With the thermal-hydraulic coupling, improvement to the existing SCANAIR modelling is anyhow evident.



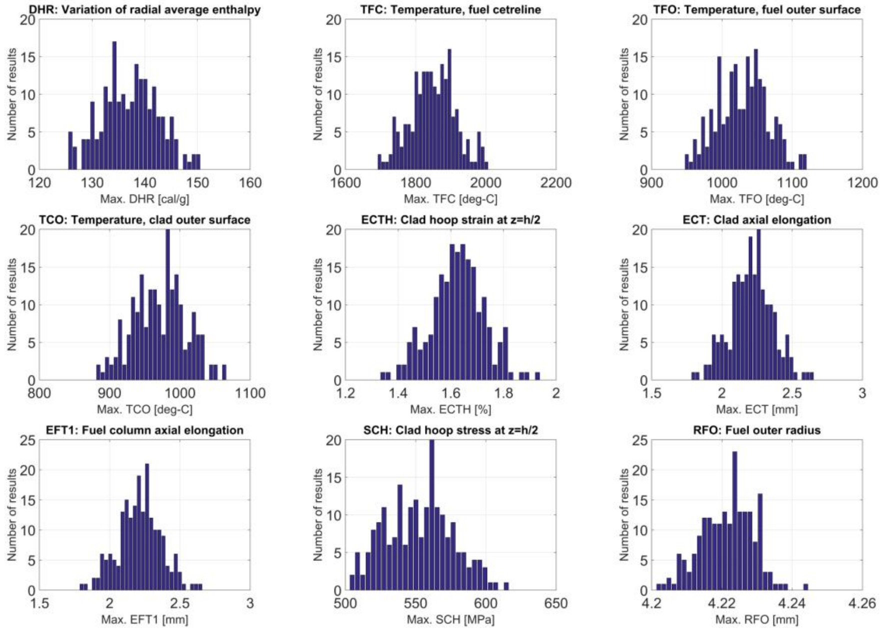
Coolant pressure evolution in transient starting from two different power levels, as calculated by GENFLO.



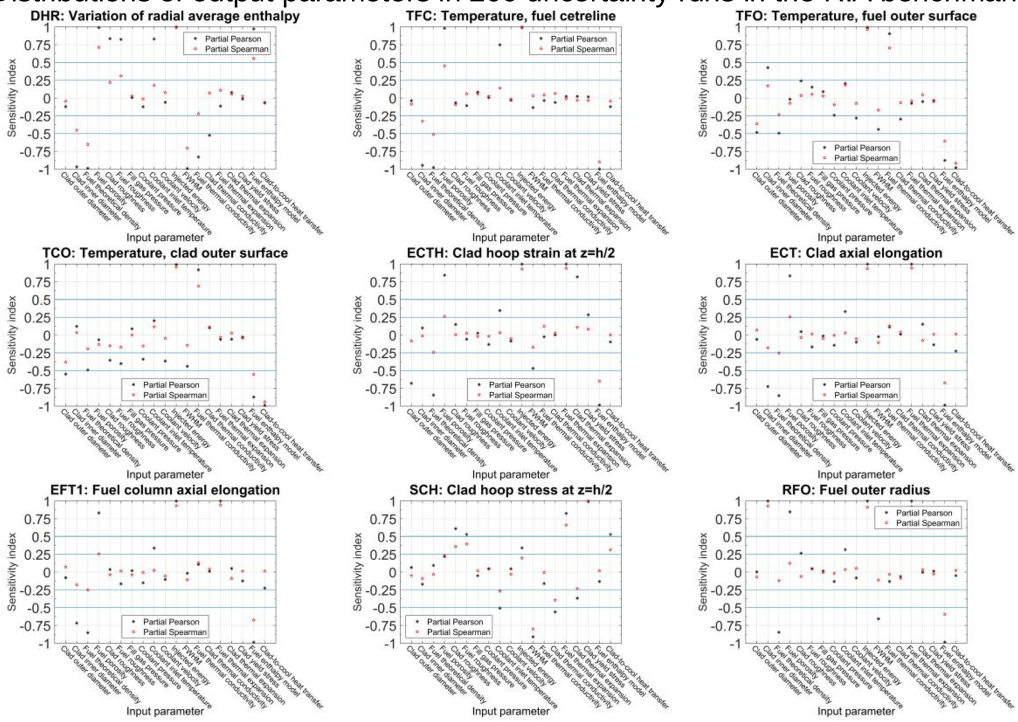
Cladding temperature evolutions plotted from outer radial nodes from SCANAIR and GENFLO (axially from the middle of the rod). Cladding outer surface temperature solved by GENFLO is passed to SCANAIR.

- Phase II of the RIA modelling codes benchmark is divided into two Activities. In 1st Activity, 10 simplified RIA cases were simulated. In 2nd Activity, uncertainty and sensitivity analysis was done for a selected case from Activity 1. The number of uncertainty runs was 200. VTT participated to both activities with SCANAIR V_7_4 and V_7_5 by simulating all the specified simplified cases and uncertainty runs, and by performing the sensitivity analysis.

Phase II of the benchmark was initiated in spring 2014 followed by the first meeting in September 2014 (Paris) and the second in April 2015 (Brussels). Third meeting of Phase II was held in September 2015 in Paris (see the conclusions from the travel report). In the third meeting, the final comparisons of results from all the participants concerning 1st Activity were presented, and the proposed conclusions. Also, a draft report of the 1st Activity, prepared by IRSN, was discussed. Analysis results concerning the 2nd Activity were presented by the participants. Some minor modifications (mainly new output parameters) were done for 2nd Activity specifications based on the discussions in the meeting. The participants were asked to revise their calculations, when needed, and add the new outputs, and submit their final results before end of March 2016.The final meeting to present and discuss the final results and the draft report will be held on 20-21 June 2016 in Lucca, Italy.



Distributions of output parameters in 200 uncertainty runs in the RIA benchmark.



Partial Pearson and Spearman correlation coefficients (at the time when the output has its maximum) calculated between the input and output parameters in the RIA benchmark.

- Halden cladding creep tests were analysed and reported as HWR-1189 as the 2015 Halden in-kind work. The analysis shows that the Halden results can be reproduced with quite straightforward models, however the correlations fitted to power reactor operation do not work in the heavy water using test reactor conditions. This is most likely due to the effect of the low fast flux. Also effect of the driving force and the oxidation were shown and discussed.

- The dissolution experiments were carried with 6 ThO_2 pellets in MQ-water at 80 °C under Ar atmosphere. Two of the pellets had history of 534 days dissolution in 0.01 M NaCl solution under Ar glove box conditions (O2 in gas < 10 ppm, T= 25 ± 1 ºC). Other 2 were dissolved 6 days in MQ water in glove box prior to experiments and 2 pellets were intact. The previously dissolved pellets dissolved less than the intact ones. This could indicate that the surface had been stabilized in some extent during the previous dissolution. No remarkable difference was seen in the solubility at 80 °C compared solubility measured in previous experiments conducted in 0.01 M NaCl under Ar at 25 ºC. The manuscript of the previous experiments conducted in 0.01 M NaCl under Ar at 25 ºC and in which ^{229}Th tracer was used to study contemporary dissolution and precipitation at the surface of the pellet will be submitted in February 2016.

- A dissertation “Modelling nuclear fuel behaviour and cladding viscoelastic response” was finished. Tulkki defended the thesis on October 23rd 2015 at Aalto University.

- A creep strain modelling approach (Logistic Creep Strain Prediction LCSP) for nuclear fuel cladding material Zircaloy-4 was reviewed and evaluated in steady state and transient creep conditions. Based on the evaluation, conclusions and recommendations for further research were made. During the study, a literature review on the experimental creep data for Zircaloy-4 was carried out. Based on the review, a creep test matrix for zircaloy-4 fuel cladding material was suggested to characterize the anisotropic creep properties of zirconium based fuel cladding materials and to support the modelling activities. The deliverables 3.3.1 (Plan for experimental campaign) and 3.3.2 (Report on implementing a transient creep response to LCSP) were reported in the “LCSP creep strain model performance in steady state and transient creep conditions” research report.

- HPG and WGFS meetings were attended and reported to the reference group.

In addition to this, a full day seminar “Fuel day” was held on June 17th 2015 discussing national and international projects and progress in the field of nuclear fuel research.

2.2.11 SADE - Safety analyses for dynamical events

Aim of the project is to model transients and accidents in such a way, that we can give more reliable answers to the safety requirements set in the YVL guides. The main idea is to improve VTT's modelling capabilities by routine coupled use of the CFD-type thermal-hydraulics solver PORFLO and the reactor dynamics codes HEXTRAN and TRAB3D. Also the neutronics modelling needs to be more detailed and the whole safety analyses methodology revised to get the full benefit on the accuracy of the thermal-hydraulics modelling. The goal is to have a tool, which is more accurate and still fast and robust enough for practical safety analysis. Own code and in-depth understanding of it enables the best possible expertise on safety analyses. The developed computational tool set of coupled neutronics, system codes and real 3D thermal hydraulics will be tested and demonstrated in cases relevant from safety analyses point of view. Objective is that by the end of the project we have calculated several transients and accidents of real interest.

Specific goals in 2015

The project has two main research areas. The objective of the first work package is further development of neutronics modelling of VTT's three-dimensional reactor dynamics codes. Development of the solution methods and codes is also an efficient way to study nodal codes in depth. Aim is also to have at VTT a fully self-developed calculation system which can be used for the whole calculation sequence from basic nuclear data to coupled 3D transient analyses. During the SAFIR2018 the project aim is that cross sections can be routinely created with SERPENT-ARES codes for transient analysis performed with reactor dynamics codes.

Second work package focuses on whole core transient analyses especially in cases where mixing in reactor pressure vessel and open core geometry play an essential role. Tools that enable more realistic modelling of the transients will be further developed and transients will be simulated with these improved tools. Modelling and development has two parallel branches: development of the tools such as internally coupled HEXTRAN-SMABRE that could be routinely used for safety analyses already during the SAFIR2018 program, and modelling of transients with the CFD-style codes that have more detailed description.

Third work package involves work that support actual research aims and promotes the usefulness of the code system. Work package includes international co-operation, documentation, quality assurance and small-scale development of the code system so that it is constantly available for safety analyses. Work package also includes administration work demanded by SAFIR2018 program.

Deliverables in 2015

- Tools for the analysis of Serpent-TRAB3D code sequence have been created.
- TRAB3D pin power model has been improved to consider several other variables in addition to burnup and moderator density. TRAB3D simulations were done using cross sections created by Serpent 2. The results have been compared with Serpent 2 calculations to verify the successful application of the model, Figure 2.2.11.1. EPR core model used in testing was improved e.g. by more detailed albedo description. Work has been reported in the special assignment.
- Thorough analyses has revealed a need for improved modelling of axial heterogeneities and such a work was started. Results on the use of axial discontinuity factors are complete for several single assembly cases and for an EPR startup load case. Writing of a Master's thesis on the subject has been started and will be finished during spring 2016.

- First version of the internal coupling between HEXTRAN and SMABRE has been done. Several VVER-440 and VVER-1000 transients have been calculated with the new code using both the old parallel and the new internal coupling scheme. Results of the internally coupled model are good, Figure 2.2.11.2. Work has been documented in a research report.
- The internally coupled HEXTRAN-SMABRE has been further coupled with the 3D thermal hydraulics solver PORFLO. The coupling is based on TCP/IP Sockets. A new CFD mesh for the VVER-400 RPV was has been created. The AER 7th benchmark transient, re-connection of an isolated circulation loop filled with low-temperature coolant was first calculated with one-way coupling between PORFLO and parallel version of HEXTRAN-SMABRE, and then using source code level two-way coupling between PORFLO and the internally coupled HEXTRAN-SMABRE, Figure 2.2.11.3. Work will be documented in a paper that is in preparation.
- The project included participation in the meetings of the OECD/NEA Working Party on Scientific Issues of Reactor Systems WPRS and Expert group on Uncertainty Analysis in modelling EGUAM
- The project included also participation in the AER working group D meeting, where the presentation on simulation of the AER 7th benchmark with PORFLO and HEXTRAN-SMABRE was given.
- Also workshop of OECD/NEA O2 stability benchmark was participated. Presentation on TRAB3D simulation of O2 benchmark was given. Modelling and simulation of the benchmark exercise was done during SAFIR2014 program.
- Simulation of VVER-440 transients with HEXTRAN using the fuel behaviour module FINIX has been presented in two conference papers concerning multiphysics simulations. One paper was presented in the TopFuel 2015 conference and the other in the 11th International Conference on WWER Fuel Performance. In addition to these conference papers one previously written paper that included TRAB3D-FINIX and TRAB-FINIX simulations was published in Annals of Nuclear Energy.
- Work done during the predecessor of SADE project was presented also in the poster that was done for SAFIR2014 final seminar.

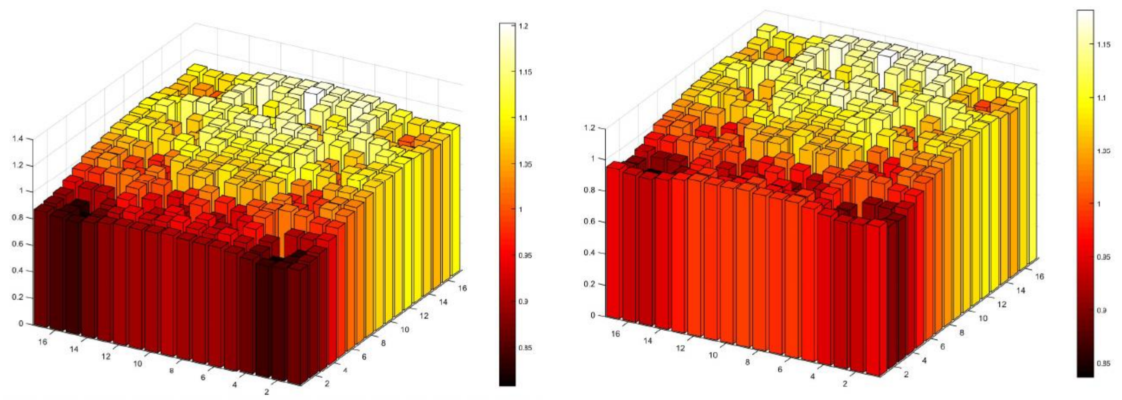


Figure 2.2.11.1. The relative pin powers of the center node of the EPR core reconstructed by TRAB3D (left) and calculated by Serpent 2.

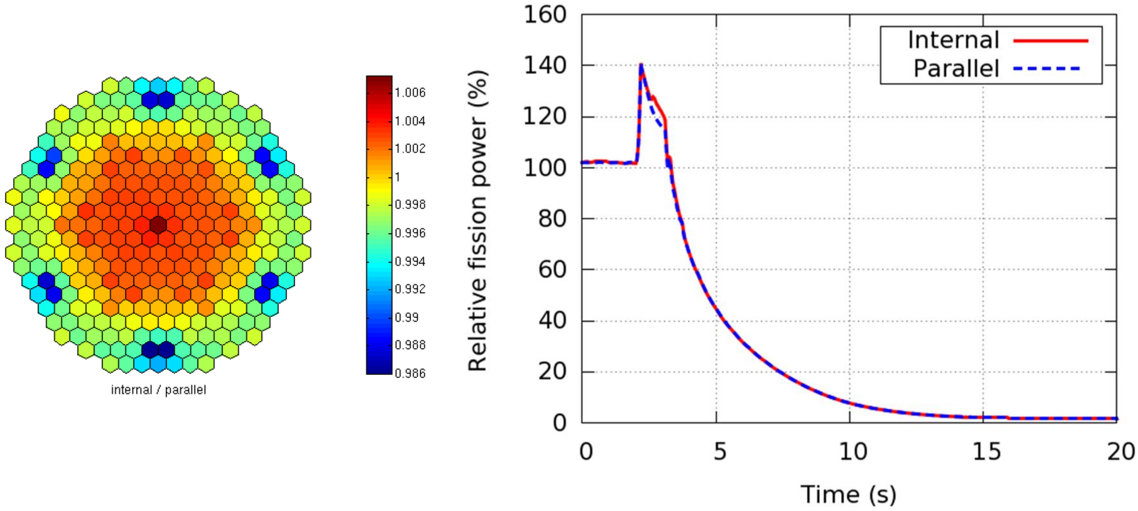


Figure 2.2.11.2. VVER-440 control rod ejection transient with HEXTRAN-SMABRE version 4060. On the left power distribution at the initial state of transient with the internally coupled model versus parallel coupled model. On the right relative fission power during the transient.

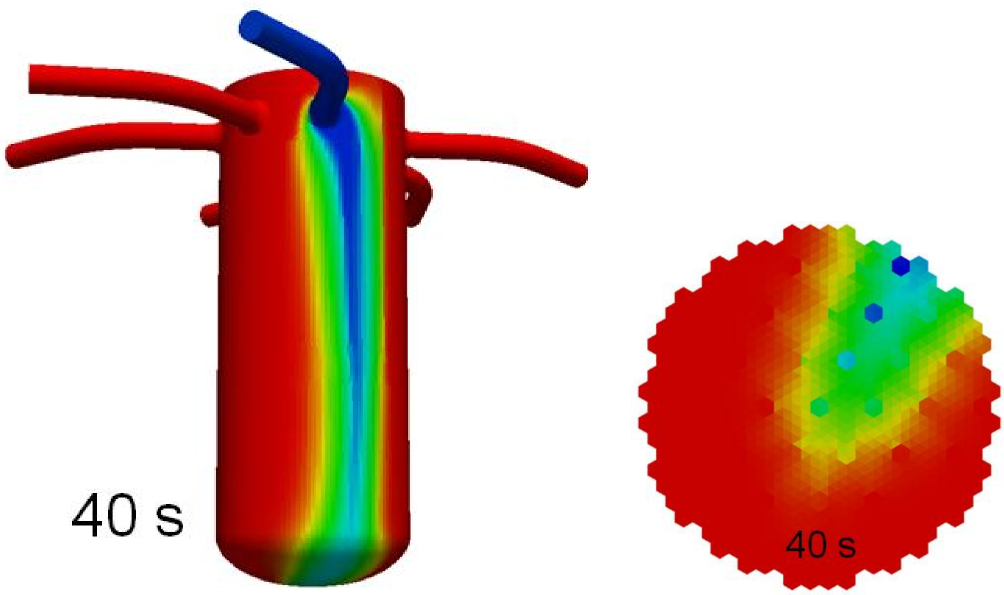


Figure 2.2.11.3. PORFLO and HEXTRAN-SMABRE with code level two way coupling: calculation of AER 7th benchmark transient, reconnection of an isolated circulation loop filled with low-temperature coolant in a VVER-440. On the left coolant temperature in the downcomer (outer shell) and on the right coolant temperature at core inlet, shown at 40 s from the initiation of the transient.

2.2.12 USVA - Uncertainty and sensitivity analyses for reactor safety

The purpose of uncertainty analysis is to estimate how the uncertainty of model parameters propagates to responses dependent on the solution of this model. Sensitivity analysis studies the changes in the responses due to perturbations in the parameters. The recently updated YVL guides grant the possibility to use the best estimate plus uncertainty (BEPU) methodology in nuclear safety analyses instead of a conservative approach. Full-fledged uncertainty analysis methodologies are still lacking, especially in the case of coupled simulation codes and long calculations sequences. The general goal of USVA is to develop methods and practices in uncertainty and sensitivity analyses of multi-physics problems and calculation sequences related to the modelling of nuclear reactors. The goal supports the long-term aim of establishing a comprehensive methodology for uncertainty and sensitivity analysis in nuclear safety.

Specific goals in 2015

In 2015, USVA had objectives related both to the development of methods and practises for sensitivity analysis (WP1) and to uncertainty analysis in multi-physics simulations (WP2).

In the development of methods and tools for sensitivity analysis, the goals of 2015 were related to the modelling of nuclear fuel behaviour. A large break loss of coolant accident (LB-LOCA) in an EPR type power plant had previously been studied at VTT. In this work, the number of failing fuel rods was evaluated statistically by computing global scenarios with the system code APROS and simulating 1000 rods per scenario with the fuel performance code FRAPTRAN-GENFLO. The analysis consisted of an estimation of the percentage of failing rods but the underlying causes of failure were not studied in detail. In 2015, the goal was to analyse the existing data using statistical methods to find correlations between the input parameters and rod failure. In addition to finding the most sensitive parameters, the applicability of the different methods was to be assessed.

Due to complexity of the existing data computed with a long sequence of computer codes (SIMULATE, APROS, FRAPCON, FRAPTRAN-GENFLO), first the relevant input parameters for the sensitivity analysis had to be specified. Data visualization with a cobweb graph was used for the screening. Then, selected sensitivity measures were calculated between the input and output parameters. The sensitivity indices calculated were the Borgonovo's delta measure, the first order Sobol' sensitivity index, and squared Pearson correlation coefficients. The first mentioned is a novelty in this context. As an outcome, the most relevant parameters with respect to the cladding integrity were determined to be the decay heat power during the transient, the thermal hydraulic conditions in the rod's location in the reactor, and the steady-state irradiation history of the rod as represented in this analysis by the rod burnup.

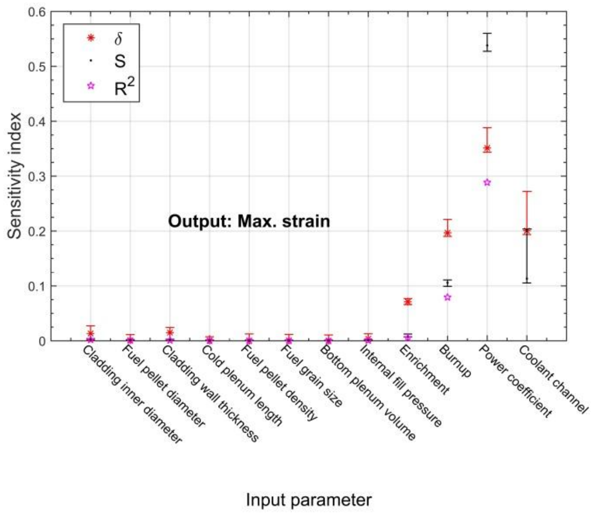


Figure 2.2.12.1. Sensitivity indices calculated between the input parameters and the output cladding maximum plastic hoop strain in LB-LOCA sensitivity analysis (δ = Borgonovo's delta measure; S = Sobol' sensitivity index; R2 = squared Pearson correlation coefficient).

Another goal related to the development of sensitivity analysis practises was to analyse the influence of uncertainties in fuel performance simulations. Based on previous experience, there was a need to review the various commonly used and also novel statistical methods that can be used to extract sensitivity information from the computational model. Such a comparison was done on an existing data set of FRAPCON simulations, revealing several intricacies in the data. Depending on the considered output, the required fidelity varies. Hence, relying on a simple analysis method is not advisable. Instead, as a result of the work, a strategy is proposed that uses a mixture of various methods efficiently, so that comprehensive information can be extracted at a modest computational cost.

In the multi-physics framework, the goals in 2015 were related to both uncertainty analysis of coupled code systems and calculation sequences. In the case of coupled code systems, the objective was to study the combined uncertainty analysis of coupled neutron transport and fuel behaviour codes for a simple test case and to complete a master's thesis on the topic. Firstly, a computational system coupling the fuel behaviour code FINIX and the reactor physics code DRAGON was set up and applied to the PWR pincell test case of UAM benchmark and a special assignment was completed on the topic. Secondly, the nuclear data code NJOY was coupled to the calculation system to allow uncertainty analysis. A Master's thesis is being written on the uncertainty analysis of the coupled code system.

In the context of calculation sequences, the idea was to continue the work carried out in the CRISTAL project of SAFIR 2014 programme. Adjoint-based sensitivity and uncertainty analysis capability had previously been implemented to the assembly-level reactor physics code CASMO-4. The implementation enabled the uncertainty analysis of assembly constants that are then passed on to codes simulating a full reactor core. In order to be able to propagate uncertainty through core-level simulations in a consistent manner, the methodology needed to be extended to reflector regions and the calculation sequence automated. The goal in 2015 was to accomplish these tasks and apply the calculation system to the PWR test case of the UAM benchmark. In addition, one objective was to test the methodology for a transient simulation with TRAB-3D/SMABRE. All these goals were achieved.

Deliverables in 2015

- Three journal papers and two conference papers were completed in 2015:

  Arkoma, A., Ikonen, T. "Sensitivity analysis of local uncertainties in large break loss-of-coolant accident (LB-LOCA) simulations", submitted to Nuclear Engineering and Design.

  Ikonen, T. "Global sensitivity analysis in fuel performance modelling", In proc. of TopFuel 2015, September 13 – 17, Zurich, Switzerland (2015).

  Ikonen, T. "Comparison of global sensitivity analysis methods – Application to fuel behavior modeling", Nuclear Engineering and Design 297, 72-80 (2016).

  Pusa, M. "Uncertainty analysis of assembly and core-level calculations with application to CASMO-4 and SIMULATE-3", submitted to PHYSOR 2016.

  Vanhanen, R. and Pusa, M. "Survey of prediction capabilities of three nuclear data libraries for a PWR application", Annals of Nuclear Energy, 83 (2015)

- Several global sensitivity analysis methods were compared to assess their efficiency in applicability to nuclear fuel performance simulations. The implications of large input uncertainties and complex models were analysed and discussed. Alternative strategies to perform sensitivity analyses were proposed. The results and findings were published in

Nuclear Engineering and Design and presented as a conference paper in TopFuel 2015 in Zurich, Switzerland.

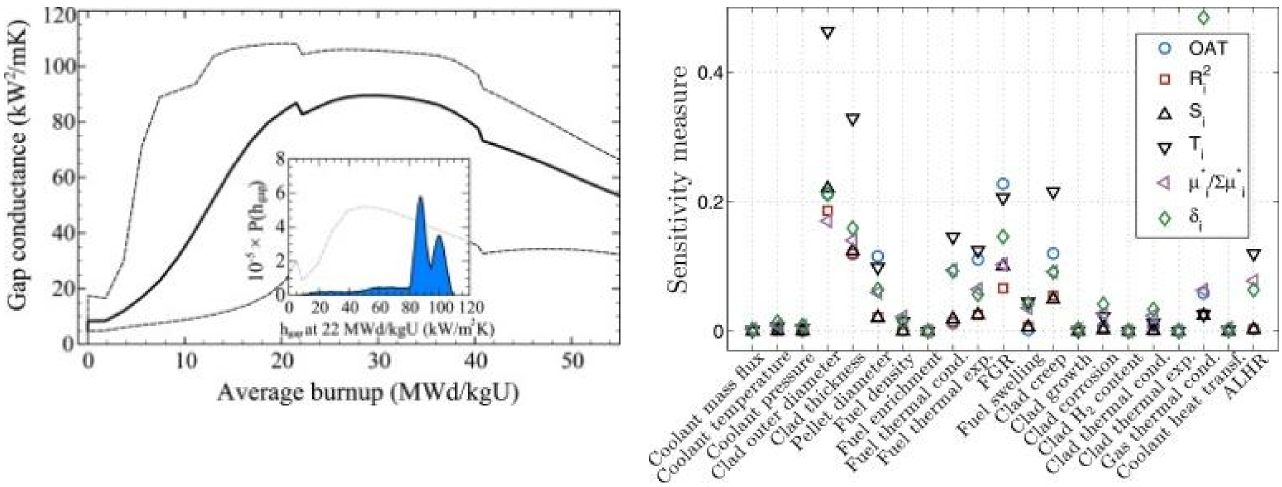


Figure 2.2.12.2. The uncertainty distribution of the gap conductance (inset of left panel) and the sensitivity measures evaluated for the various input factors at the burnup of 22 MWd/kgU in a TMI-1 PWR rod according to FRAPCON simulations. The scatter in the sensitivity measures between the various methods and the multimodal probability distribution reveal the complexity of the data that calls for specific sensitivity analysis strategies.

- Sensitivity analysis of fuel failure simulations of EPR LB-LOCA was carried out. First the parameters were screened using a cobweb graph and then selected sensitivity measures were calculated between the input and output parameters. A journal paper was written on the topic.

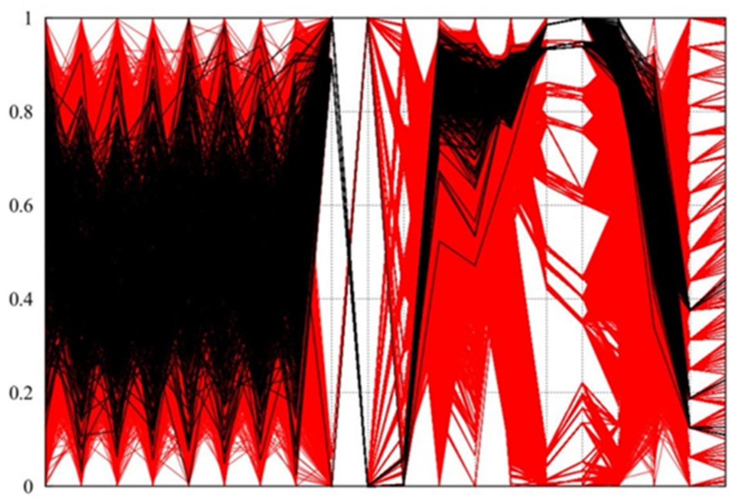


Figure 2.2.12.3. A cobweb graph used in the screening of the parameters for the sensitivity analysis of rod failures in LB-LOCA

- As an outcome of the rod failure sensitivity analysis, the most relevant parameters with respect to the cladding integrity in rod failures of the LB-LOCA were determined to be the decay heat power during the transient, the thermal hydraulic conditions in the rod's location in the reactor, and the steady-state irradiation history of the rod as represented in this analysis by the rod burnup.

- A computational system coupling the fuel behaviour code FINIX, the reactor physics code DRAGON and the nuclear data code NJOY was successfully implemented and it is currently being applied to the PWR pin cell exercise of the UAM benchmark. A special assignment was completed on constructing the FINIX-DRAGON calculation system.

- The adjoint-based sensitivity analysis capability developed previously to CASMO-4 was extended to reflector calculations. An automated calculation system was developed for propagating nuclear data uncertainty through assembly-level homogenization calculations with CASMO-4 in fresh fuel cases.

- Nuclear data uncertainty was propagated through the CASMO-4 – SIMULATE-3 (See Fig. 2.2.12.4) and CASMO-4 – TRAB3D-SMABRE calculation sequences with application to the PWR TMI-1. A paper titled “Uncertainty analysis of assembly and core-level calculations with application to CASMO-4 and SIMULATE-3” was written on the topic and submitted to PHYSOR 2016.

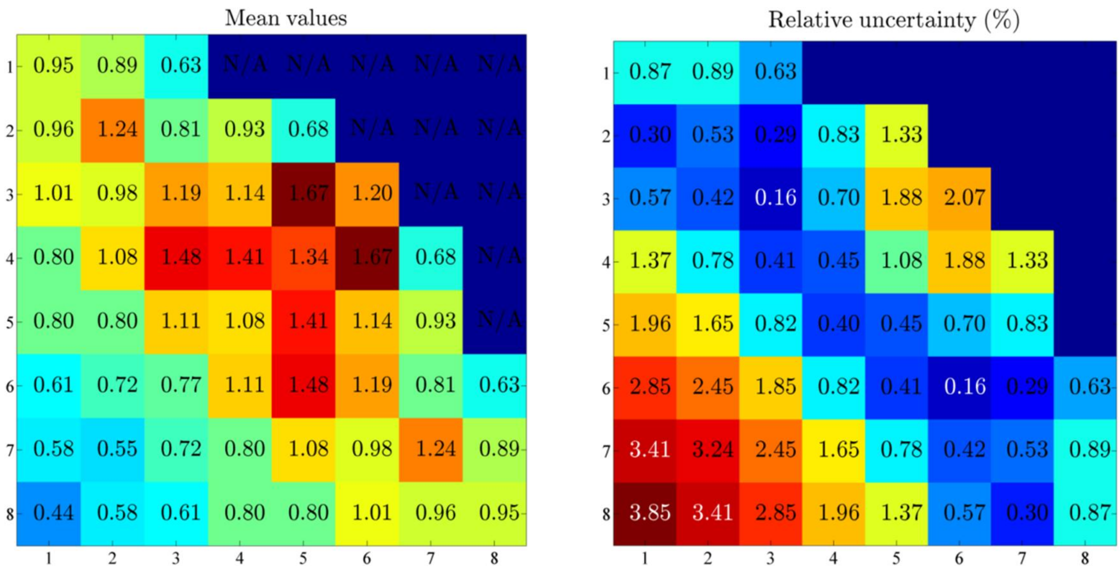


Figure 2.2.12.4. Radial power distribution and respective uncertainties for a PWR modelled using CASMO-4 -- SIMULATE 3 uncertainty analysis sequence

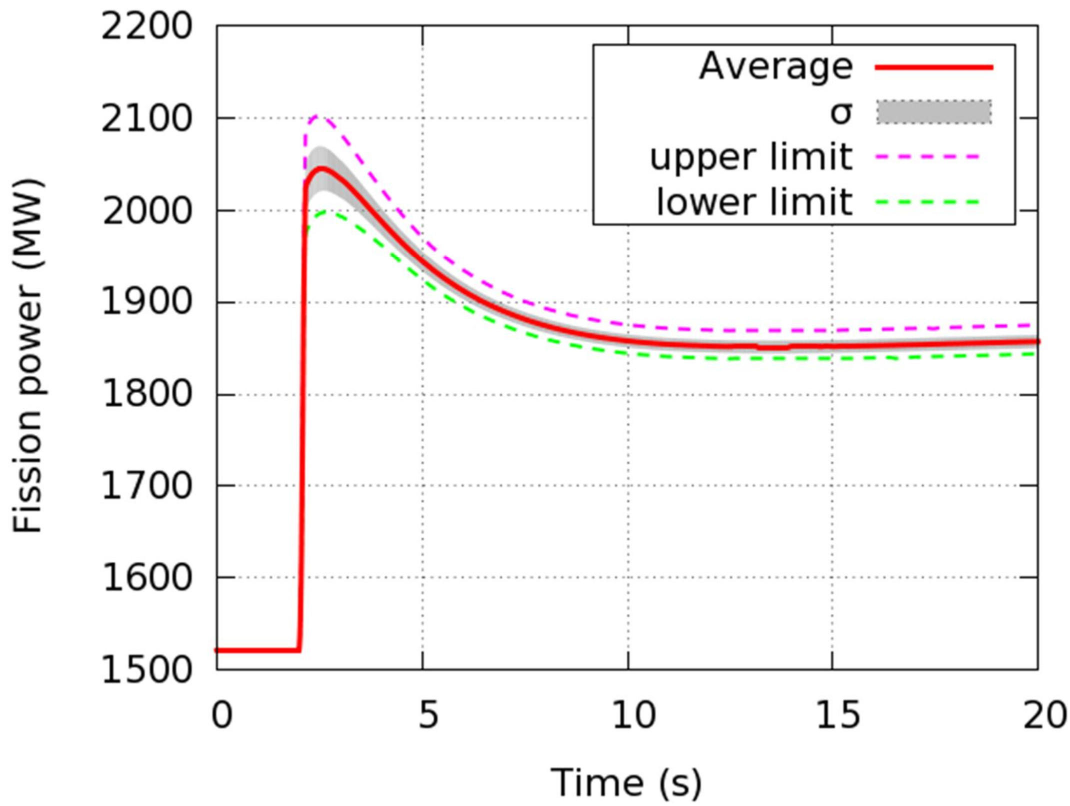


Figure 2.2.12.5. PWR control rod ejection transient simulated with CASMO-4 – TRAB3D uncertainty analysis sequence.

2.3 Structural safety and materials

In 2015 the research area "Structural safety and materials" consisted of eight projects:

1. Experimental studies on projectile impacts against concrete structures (ESPIACS)
2. Fire risk evaluation and Defence-in-Depth (FIRED)
3. Analysis of fatigue and other cumulative ageing to extend lifetime (FOUND)
4. Long term operation aspects of structural integrity (LOST)
5. Mitigation of cracking through advanced water chemistry (MOCCA)
6. Numerical methods for external event assessment improving safety (NEST)
7. Thermal ageing and EAC research for plant life management (THELMA)
8. Non-destructive examination of NPP primary circuit components and concrete infrastructure (WANDA).

2.3.1 ESPIACS - Experimental studies on projectile impacts against concrete structures

The general objective of ESPIACS project is to generate reliable and relevant experimental data on different types of impacts on different types of reinforced concrete structures to be used for validation of computational methods and models. The experimental data should cover the phenomena that are found in an airplane crash against a reinforced concrete structure, such as a nuclear power plant reactor building or its safeguard building. The experimental data is to be obtained from tests that are carried out at VTT with a test bed designed and constructed specifically for this purpose. Since the cost of each test is very high, the plan is to draw several other funding organizations to participate in the testing activities so that relevant amount of tests can be designed and carried out. The obtained tests results are intended to be used in SAFIR2018 project NEST, which concentrates in developing of computational methods and models that can be used when analysing a real scale aircraft crash.

Specific goals in 2015

One of the goals for 2015 was to analyse the data obtained from a soft impact test series carried out with a wall-floor-wall reinforced concrete structure in an earlier testing project. After analysis of the data, the next goal was to write a conference paper about it for the SMiRT 23 conference and to present the paper in the conference. In a final phase, the goal was to write a journal article regarding the test series.

Currently, an in-house software developed with LABVIEW platform are used for acquisition, processing and presentation of the data measured in the tests. One of the goals was to update the software so that it would be more user-friendly and provide more insight into the data.

In addition to plans, a short numerical preliminary study was carried out related to a static test which is planned to be carried out within the project in 2016.

Deliverables in 2015

- Modified data acquiring and presenting software
- VTT technical report describing the work carried out in 2015 within the project
- An article submitted for peer review and to be published in Nuclear Engineering Design –scientific journal. The article discusses a series of soft impact tests that were carried out with a wall-floor-wall reinforced concrete structure in 2014 within a previous testing project.
- A conference paper published in Proceedings of The 23rd International Conference on Structural Mechanics in Reactor Technology (SMiRT23), held on 10-14 August 2015 in Manchester, United Kingdom. The paper was presented in the conference. The subject was the same than in the scientific article.

2.3.2 FIRED - Fire risk evaluation and Defence-in-Depth

The main objective of the FIRED –project is to develop the tools for fire risk evaluation and create a new methodology for assessing the defense-in-depth in the context of fire safety. In general, the results may be divided into three cathegories: First one is the basic research that increases understanding and contributes to future work, second is the education of experts and developing the current methodology, and the third one are the direct applications to NPPs. The results of FIRED work packages are illustrated in Figure 2.3.2.1.

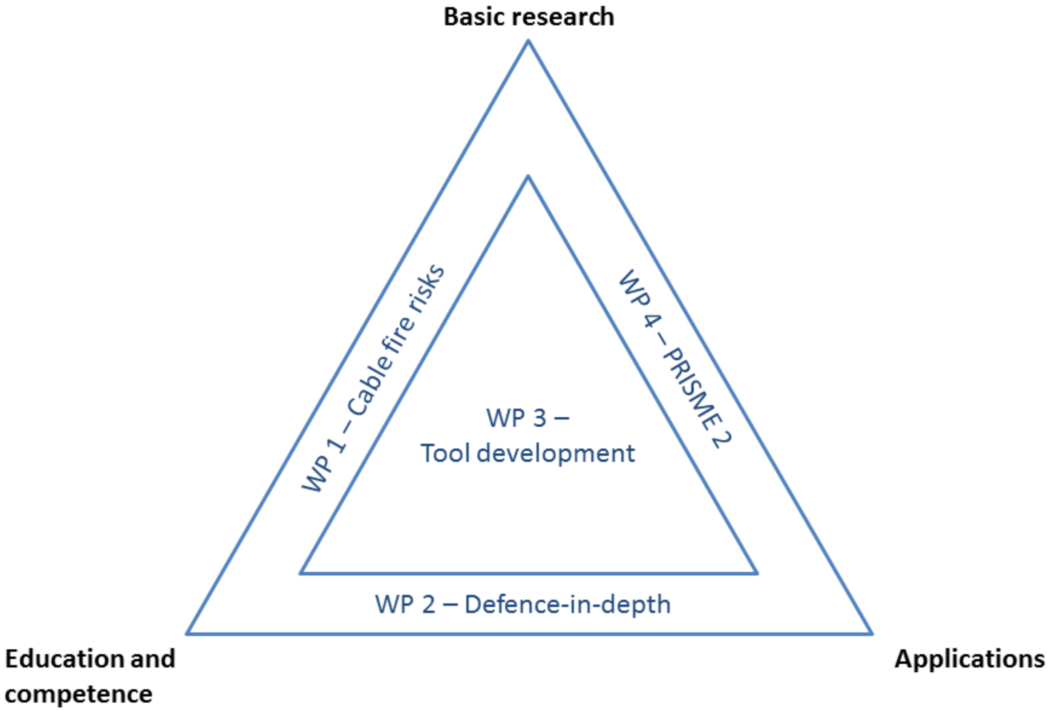


Figure 2.3.2.1. Result categories in WPs of FIRED.

Specific goals in 2015

The main topics of FIRED are:

- WP1 Cable fire risks during plant life cycle
- WP2 Fire-barrier performance assessment
- WP3 Fire simulation development, maintenance and validation
- WP4 Participation to PRISME2.

WP1 had two active Tasks during 2015. The first phase of Task 1.1 is reserved for testing a computational chemistry method for predictive pyrolysis modelling of flame retardancy in traditional and novel cable materials. The method of choice was Reactive Molecular Dynamics (RMD), using the ab initio based ReaxFF force field approach. The results were promising. The enthalpy of reaction could be determined with decent accuracy. Research in phase one will be brought to a full conclusion during 2016. Phase two has been rescheduled.

In Task 1.2., relevant cable materials were selected based on their use in plants, availability and existing literature. Accelerated ageing of cable samples and experiments were completed during summer 2015. The ageing of cables did not have an appreciable effect on the fire behaviour of the cables. Further research that includes the effects of irradiation is planned for year 2016, in which the effect of radiation induced aging is considered.

The second work package develops the assessment methods for fire-defense-in-depth and explores means to improve the fire safety though interdisciplinary consideration of fire safety in different processes affecting the failure probability of the sequential fire-DID levels (ignitions, detection, suppression, barriers, compartments).During 2015, the work was started to develop a new FEM-based heat conduction solver for the Fire Dynamics Simulator (FDS) program. Initial Matlab-version was developed and tested for the heat conduction problem.

Adding the reactions and shrink-ing/swelling capability was started. Additionally, the FDS2FEM-tool was extended towards the support for Comsol Multiphysics -tool, which is a FEM-solver for structural heat transfer and mechanical problem, and presumably lighter and easier to use than the traditional models like Abaqus and Ansys.

WP3 had two active tasks in 2015.In Task 3.1 the main target was developing the simulation of fast fuel droplets (after liquid filled missile impact) and the particle cable model. On the topic of fast fuel droplets, a manuscript of a journal article was written. The article provides further validation for the methodology used to simulate fires resulting from aircraft impacts. This work builds upon the research on liquid filled missiles conducted in SAFIR2014. The data from the experiments was used to validate the spray model in Fire Dynamics Simulator for use in modelling the liquid dispersal from airplane impacts. General capability of FDS to predict sizes and lifetimes of fireballs was tested against empirical correlations. FDS was then used for a full scale simulation of aircraft impact on a nuclear island. The overall conclusion is that the initial fireball from the impact is intense but short lived. Physical separation of systems on opposite sides of the reactor building seems to be adequate. However significant amount of fuel may accumulate in front of the building.

Cable modelling has been one of the main interests in previous SAFIR projects. In this project the focus is on improving the coupling of sub-grid-scale cable models and the overall flow simulation. This year, modelling of aerodynamic drag of cable bundles in Fire Dynamics Simulator using sub-grid-scale models developed for porous media was investigated. Markedly better predictions were achieved in simulations of full scale fire tests when compared to simulations utilizing single cylinder drag coefficients for cable models. Further validation work is however needed.

The second active task of WP3 was the development of PyroPlot. Pyroplot is a tool for estimating parameters needed for modelling the thermal decomposition of materials. These parameters are needed for predictive simulations of fires. The overall goal for this year was to make the newest version of Pyroplot an open and practical tool for any fire researcher or engineer who needs to estimate pyrolysis parameters. In 2015 the focus was on improving the usability of Pyroplot and bugs fixes. Some analytical estimation methods were also added.

WP4 covers the participation to the OECD/NEA PRISME2 project. A new PRISME project is currently being planned for after 2016. Current ideas for the new project were presented to the reference group (electric cabinet fires, vertical smoke spreading), the reference group was asked to provide feedback and opinions about the necessity of participating to the next project, and to provide research ideas (also beyond cables and pool fires).

Deliverables in 2015

- Tests on accelerated ageing of cables were conducted with selected two cable types. Results showed no significant difference in fire behaviour between fresh and aged cables. A research report was written describing the analysis and the results.

- The proof of concept phase for atomistic modelling of novel flame retardants was started. A report has been written.

- Modelling the aerodynamic drag of electric cables in the context of fire simulations was studied. It was found that modelling the effect of cables using sub-grid-scale models developed for “porous media” produced better agreement with experimental results compared with the standard drag model.

- Pyroplot software was significantly enhanced during 2015. Changes included updates to documentation, user interface and parameter estimation algorithms

- FDS2FEM tool was modified by adding a simple Comsol support
- Matlab version of FEM-based conduction solver implemented and verified. Second version with a correct treatment of shrinking/swelling was prepared. Report has been written
- Article based on SAFIR2014 work on liquid pool fires was published in Fire Safety Journal. Work was also presented at 2nd European Symposium on Fire Safety Science.
- Journal manuscript on simulation of fast fuel droplets resulting from aircraft impact has been prepared.

2.3.3 FOUND - Analysis of fatigue and other cumulative ageing to extend lifetime

Project FOUND concerns cross-disciplinary assessment of ageing mechanisms for safe management and extension of operational plant lifetime. It develops deterministic, probabilistic and risk informed approaches in computational and experimental analyses with education of new experts. It consists of 7 scientific work packages (WPs).

The focus areas are: WP1 Probabilistic structural safety assessment of NPP piping systems; WP2 Susceptibility of BWR RPV internals to degradation mechanisms, including a dissertation; WP3 Fatigue usage of primary circuit, with emphasis on environmental effects and transferability; beginning with a master's thesis; WP4 Fatigue and crack growth caused by thermal loads, with emphasis on modelling, and including a licentiate thesis; WP5: Development of RI-ISI methodologies, including participation to ENIQ Task Group Risk (TGR) activities; WP6 Dynamic loading of NPP piping systems; and WP7: Residual stress relaxation in BWR NPPs.

Specific goals, results and deliverables in 2015

Each of the work packages of the project had separate and distinct goals. The deliverables of each work package is presented directly after the chapter.

WP1 was dedicated to investigation of the propagation of the uncertainties and confidence in the structural integrity assessment. Another research issue was assessment of safety margins using probabilistic approaches. Safety margins were achieved by performing a literature study and example analyses concerning NPP piping components with possible crack like defects in the welds. A collection and review of the Finnish safety factor definitions applied to structural integrity analyses of piping components was performed as well as representative analysis examples showing the effect and underlying uncertainties concerning the safety factors. The work showed that it is difficult to define the total safety margin due to various sources of conservatisms included in the integrity analyses. The analyses would benefit from more specific safety factor definitions that would give a more accurate assessment of the total safety. Currently the total safety factor has to be assessed with probabilistic methods. A study on the uncertainties in stresses due to thermal loads was performed using a small representative set of computation examples. The stresses resulting from different load assumptions with more straightforward computations (1D methods) were compared against more accurate results (3D CFD methods) in terms of quantifying the effect of uncertainties in loading to the accuracy of the stress results. The results show that the frequency of the thermal load has the largest effect on thermal mixing pipe wall stresses.

The deliverables of this work package are:

- Review of the status of the safety margin assessment practices

- Evaluation of the uncertainties in stresses due to pipework loading for thermal mixing case

WP2 provides an investigation on the susceptibility of BWR RPV internals and their supporting structures to various relevant degradation mechanisms. The work consists of a literature review, covering available relevant literature and databases (performed in 2015) and of a set of computational analyses, including development of new computational applications (planned for 2016-2017). The computational part will cover both deterministic and probabilistic approaches. The main purpose of the WP during the four years is to prepare a dissertation. The 2015 results concern a literature survey on degradation mechanisms, degradation mechanisms affecting BWR RPV and its internals, as well as original features describing some new computational developments. This is the only deliverable of this WP.

WP3 studying fatigue usage of primary circuit aims to educate new experts and gain practical knowhow and learn of international progress and challenges related to transferability of laboratory fatigue data to primary circuit fatigue assessment and usage monitoring. Strain-controlled fatigue experiments using the FaBello facility in hot and pressurised reactor coolant water were performed (Figure 2.3.3.1 below). International networking was achieved through participation and presenting in scientific forums. The main objective of WP3 is to reveal the underlying mechanisms and develop a model to quantify effects of hot water environment in fatigue of stainless steel. A Master's Thesis focusing on strain waveform effects was completed in early 2016. Limitations of current F_{en} methodologies were identified with test results, which suggest plastic strain rate is a more relevant parameter than total strain rate.

The deliverables of this work package are:

- Master's Thesis evaluating the environmental effect of reactor coolant on fatigue of stainless steel

- Conference publication on direct strain-controlled fatigue testing in simulated PWR water

- A work plan formulating the next steps in developing the F_{en}-model

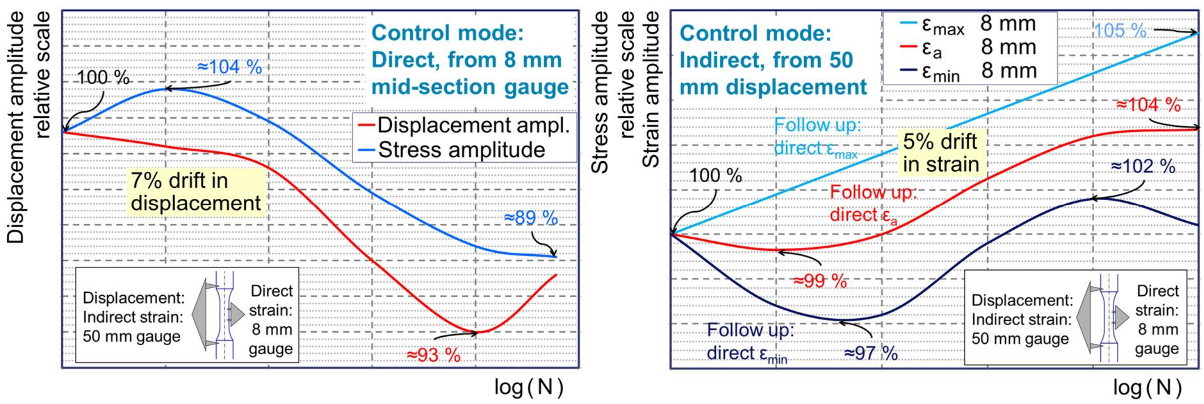


Figure 2.3.3.1. Comparison of direct (8mm) and indirect (50mm) strain measurements during tests with austenitic stainless steel (alloy 321). Left: direct strain controlled test, Right: indirect strain controlled test; both aimed to strain amplitude 0,3 %.

WP4 concerns the thermal and structural evaluation of mixing loads and their effects on piping components. CFD modelling of thermal mixing experiments was performed and the resulting loads were transferred to a fracture mechanical evaluation of the mixing tee. Large-eddy simulation (LES) and structural calculations of thermal mixing in a T-junction were performed. The near-wall temperature fluctuations showed increase with mesh resolution. The peak temperature fluctuations with the Smagorinsky and WALE models were of similar magnitude but having somewhat different locations. Simulations with wall functions yielded higher wall heat fluxes than the ones without wall functions, in contrast to earlier studies. The WALE model tended to predict higher wall heat fluxes than the Smagorinsky model. In simulations without wall functions, refining mesh resolution lead also to higher wall heat fluxes. Crack growth rates were calculated both using accurate 3D CFD loads and simplified sinusoidal loads. The accuracy and conservatisms of the simplified method were assessed. 1D and 3D crack growth simulations were compared using turbulent thermal load from LES (3D) and turbulent and sinusoidal loads (1D, 3D) 1D crack growth times spanned several orders of magnitude depending on frequency and pipe wall thickness. Circumferential and axial cracks experienced initially practically same growth rate, but the axial crack grew faster as the cracks got deeper. Rates for thin and thick pipe walls showed significant differences only for deeper cracks. 1D and 3D models with the same load agreed well. The SIN method was fairly realistic provided that the frequency and heat transfer coefficient were selected accurately. In addition, the crack growth and component lifetime in Trueflaw's crack manufacturing experiments using tailored thermal load cycles were studied. The case corresponds to low-cycle conditions with considerable cyclic plasticity induced by thermal load. The results indicated that including the crack in the analysis is needed to obtain realistic crack driving forces as uncracked stresses resulted in overestimated growth rates. Considerations on the crack initiation cycles and effect of growth on the crack driving forces are needed for accurate lifetime estimations.

The deliverables of this work package are:

- Research report presenting the CFD and fracture mechanical calculations of Thermal Mixing in a T-junction

- Research report presenting the evaluation of the driving forces and growth of cracks induced by low-cycle thermal fatigue loads

WP5 provides further development of risk assessment procedures, as well as supplementation and update of quantitative VTT RI-ISI analysis procedure. These developments and improvements were tested in detailed pilot/benchmark analyses. The joint paper “Comparative Analysis of Deterministic and Probabilistic Fracture Mechanical Assessment Tools”, by Qais Saifi (VTT) and Klaus Heckmann (GRS) benchmarking the VTT RI-ISI procedure won the European Technical Safety Organizations Network (ETSON) award. The purpose of the paper was to present a comparative analysis of fracture mechanical assessment tools developed by VTT and GRS. In addition, connection between PRA and RI-ISI analyses was investigated. The current situation in the connection between PRA and RI-ISI and development ideas were surveyed and presented in the report. The development ideas include improved software support for the connection of PRA and RI-ISI, more detailed PRA modelling to support RI-ISI, uncertainty analysis for RI-ISI and ageing PRA development. To take better into account the effect of inspections in RI-ISI analyses, a survey on applicable probability of detection (POD) functions was made, and the library of POD functions in VTT RI-ISI analysis tools was extended. The effect of the POD function on the break probability of piping welds was studied. Break probabilities of the three nuclear plant piping welds after the selected operation intervals were calculated. The result summary includes 180 cases involving different combinations of the inspection intervals, residual stress loads and initial crack distributions. The two different detection functions resulted in a marginal difference in the break probability. The work in this WP includes also international co-operation by participating to NUGENIA TA8 ENIQ TGR activities.

The deliverables of this work package are:

- Conference paper presenting the benchmarking of VTT RI-ISI procedure
- Research report outlining the first steps in PRA and RI-ISI connection
- Research report on the implementation and effects of new POD functions with VTT RI-ISI procedure

WP6 assesses both the dynamic behaviour of piping systems and the stresses experienced by restraining pipe supports and developed methods for reducing computational effort of nonlinear piping analyses. The engineering methods combining dynamical spectrum and time-history analyses as well as the effect of damping to the experienced stress cycles were developed. A Master's Thesis evaluated different nonlinear gap and friction support linearization methods found in literature and their applicability and limitations was prepared. A discussion on the applicability of the methods for NPP piping cases was given. The work is later planned to be continued with applying the methods in frequency-domain. The load and result combination methods have been studied from research reports and from design codes. Methods for combining the results have been studied analytically and numerically by using moment sets with random moment components. The results showed that the level of conservatism is reduced as computational effort increases. In addition, the effective number of cycles has been studied analytically by assuming simplified expressions for fatigue curve. The effective number is independent of initial amplitude if a highly simplified fatigue curve expression is used, but more complex expression leads to mathematical difficulty. A procedure for determining the effective number numerically from an actual fatigue curve has been proposed.

The deliverables of this work package are:

- Master's Thesis on the linearization of piping supports
- Research report presenting different moment combination methods and a new procedure for calculating number of effective cycles for decaying stress or strain signal.

During year 2015, focus on **WP7** was on development of residual stress measurement methods. The contour method was developed with introduction of white light interferometer measurement. This allowed significant improvement of spatial resolution of 2D-residual stress maps. The new measurement method also necessitated significant development throughout the measurement pipeline and highly optimized code for evaluation of residual stresses based on interferometer measurements were developed. Additional contour development was completed using skewed line measurements to get transverse stresses on welds as function of distance from the weld centerline. Nuclear weld samples manufactured in previous projects were measured with the newly developed methodology and analysed further. In addition, EBSP measurements of cumulated plastic strains and FEM-analysis on the effect of thermal cycles on expected residual stresses and plastic strains completed.

The deliverables of this work package are:

- Master's Thesis on plastic strain and relaxation of residual stresses in BWR pipe welds
- Project report on the development of residual stress measurement techniques.

2.3.4 LOST - Long term operation aspects of structural integrity

The general objective of the long term operation aspects of structural integrity (LOST) is to develop methods and tools for structural safety analysis of reactor pressure vessel (RPV) and piping. In 2015 the project covered tasks related to fast fracture in the upper shelf area for RPV like materials, experimental methods for dissimilar metal welds (DMWs) that are important parts of pipes and thirdly, international cooperation. In the tasks related to fast fracture and DMWs state of the art knowledge was gathered related to fast fracture in the upper shelf area and eta factor in DMWs. Additionally, a conference paper related to experimental characterisation of DMWs was done.

Objectives and results in 2015

One objective in 2015 was to make a review of fast fracture events in the upper shelf area. The research topic is justified by the requirements in the Finnish regulatory requirements that state following; In connection with the strength analysis of Safety Class 1 pressure equipment, an assessment shall be given on the potential for a fast fracture occurring in the upper shelf area where temperatures exceed the transition temperature zone.

Physically, upper shelf is defined as the temperature range where brittle fracture cannot occur. Probability of fast fracture in upper shelf area during operation conditions is small, due to the high tearing resistance of the RPV material. It is more probable that fast fracture could occur in thick-walled components which undergo rapid cooling under high pressure. Therefore, investigations of tearing resistance under transient temperatures are important.

The paper discusses also the effect of temperature and loading rate on tearing resistance of RPV like steels. Tearing resistance showed a minimum in the temperature range between 200 and 400 °C. Depending on loading rate and the temperature minimum tearing resistance was moved to higher temperature as the loading rates were increased.

Another objective related to fast fracture task was to find RPV material to the experimental part in 2016 and 2017. A laser 460 MC PLUS heavy plate material for the experimental part was found. The plate has strength properties that are equal to RPV steels and thus, is suitable to characterise tearing resistance during temperature transients.

Related to this work package, advanced structural integrity, the objective for the whole SAFIR2018 period is to develop new advanced structural integrity methods to describe the ductile crack growth during a temperature transient accounting for temperature history effects. The work done in 2015 is a framework for the experimental research done in the upcoming years. The upcoming work consists of experimental investigations of ductile tearing resistance during transient temperatures. Transient temperatures are used, because fast fracture events are most likely to occur under transient conditions.

Another objective was to investigate the local stress-strain properties of near interface zones (NIZs) and the effect of the strength of these zones on tearing resistance in welds and DMWs. The interface region of dissimilar metal welds (DMW) consists of narrow microstructural zones with varying fracture mechanical and mechanical properties. The narrowest zones can be just few micro meters wide and between adjacent zones there can exist a major difference e.g. in strength properties. As the material fractures the properties of these adjacent and other zones interact. This interaction affects the tearing resistance. Even if the fracture occurs in a zone with nominally high tearing resistance, the mechanical properties of the adjacent zones can lower the tearing resistance.

Another issue related to this heterogeneity in the interface region is measurements of tearing resistance of dissimilar metal welds. The plastic strain in front of the crack tip can be constrained to a small region. In a homogeneous specimen of the same material as the narrow zone the strain would be constrained in a larger region. This change in constraint can have an effect on the measured displacement that is used to calculate tearing resistance.

The current standards do not take into account changes in displacements due to heterogeneous structures. The current standards are developed for homogeneous specimens. The effect of heterogeneity could be taken into account by developing specific eta factors for dissimilar metal welds interface regions or more generally, specific eta factors dependent on strength mismatch of different zones. Eta factor is a parameter which relates the measured plastic work to the tearing resistance (J-integral).

In 2015 a research report was made on experimental and analytical eta factors. In the report eta-factors for welds and dissimilar metal welds were reviewed. This literature review showed that the eta factors derived for similar metal welds are dependent on: strength mismatch, hardening properties, strength, weld width, crack location and FE analyses route (3D or plain strain). Form the literature eta factors and equations derived for welds were found.

The importance of accurately defined eta factors for DMWs was also discussed in the report. Currently, eta factors are calculated on FE based methods. However, the current FE models used for derivation of eta factor for DMWs are incomplete. The properties of narrow zones of the interface region that can have high strength mismatch were not considered in these models. This can lead to errors in the calculated values. In 2016 accurate eta factors for the interface region of DMWs are derived in LOST, with accurate information of mechanical properties of the narrow zones in the interface region. After the eta factors have been derived with accurate models, there is knowledge of regions where homogeneous solutions can be applied and of regions where more precise eta factors are needed.

The objectives of the third task were to publish a conference paper and to publish experimental results related to DMWs. The paper was based on results from European research projects MULTIMETAL and relies also on knowledge gained from BIMET, ADIMEW, STYLE, PERDI and National research projects SINI and FAR. The conference paper that was written in 2015 and sent to EFC21 (European conference on fracture) discussed tearing resistance curves measured with 10x10 and 10x20 SE(B) specimens. The initial crack was located in the interface region between a ferritic steel and weld metal Inconel 52 of a DMW. These tearing resistance curves measured with the two specimen geometries were compared.

The results showed that for 10×20 SE(B) specimens tearing resistance is highest in the weld close to the fusion line, second highest in HAZ close to the fusion line and lowest at the fusion line. The measured J-R curves of SE(B) 10×10 and 10×20 differ from each other. As the J-R curves of the specimens are compared the toughness and scatter in the J-R curves is different. Analyses of the fracture surface revealed that one reason for these differences is that the crack progresses in different material zones within the interface. Because the initiation location in the heterogeneous interface of DMWs has a big impact on tearing resistance, a standard developed for heterogeneous materials shall contain guidelines on microstructural characterisation of the fracture initiation location.

The objective for the whole period of the SAFIR2018 programme (related to DMWs) is to develop advanced tools for material characterisation of DMWs in terms of fracture toughness testing with associated J-integral calculation and the quantification of crack deviation driven by local strength mismatch state. The results achieved in 2015 support these objectives. The report on eta parameter is related to developing methods for taking into account the local strength mismatch state in fracture toughness calculations. The conference paper on tearing resistance of DMWs is related to development of tools for characterisation of DMWs.

The purpose in the final work package was to participate in to ASTM Committee E08 Fatigue and Fracture executive committee in May 2015 and November 2015. In 2015 Research Professor Kim Wallin participated in these two meetings.

Deliverables in 2015

- Research paper of the effect of temperature on ductile tearing resistance. At high temperatures (200-400 °C) tearing resistance of RPV like steels reach a minimum. Increasing loading rate moves the tearing resistance minimum to higher temperatures.
- Contribution to ASTM Committee E08 Fatigue and Fracture executive committee in May 2015 and November 2015. Kim Wallin participated in two ASTM meetings in 2015. A high light of these meetings was the possible standardisation of SE(T) specimens. The standardisation of SE(T) specimen is useful for the nuclear industry, because the constraint of SE(T) specimen resembles constraint in pipes. However, more work is required to verify and validate the SE(T) specimens. Thus in 2016 a workshop is held related to the SE(T) specimen.
- Research report on experimental and analytical eta factors. Eta factor is a parameter which relates the measured plastic work to the tearing resistance. This parameter can be different for heterogeneous specimens than for homogeneous specimens on which the eta factors in standards are based on. Therefore, the eta factors are not necessary directly applicable to heterogeneous materials like welds. The research report is a review of the research done related to eta factors derived for welds (structures with strength mismatch). The upcoming tasks in 2016 and 2017 are related to this report.
- Conference paper on DMW experimental work. Outcome: characterisation of crack propagation location in the interface region is crucial and shall be included to guidelines on experimental characterisation of DMWs.

2.3.5 MOCCA - Mitigation of cracking through advanced water chemistry

Corrosion problems in the pressurised water reactor (PWR) secondary circuit are mostly related to deposition of magnetite (Fe_3O_4) into steam generator (SG) and enrichment of impurities into crevices within the circuit. The enrichment is typically driven by boiling. Water entering the crevices within a SG (e.g. between tube and tubesheet or under a magnetite deposit on a straight tube) boils letting volatile species escape as steam and leaving non-volatile species (salts, lead, copper etc) in the small water volume of the crevice. After some time of operation, the crevice chemistry can become very aggressive due to impurity enrichment, causing pitting corrosion, denting and stress corrosion cracking.

There are three main routes to mitigate the corrosion problems caused by magnetite deposition. The first one is to modify the water chemistry so that the source term of magnetite particles, corrosion of carbon steel components along the feed water line is minimised. This can be done e.g. by controlling the secondary side water pH to be between 9.6 and 10, which coincides with the minimum in magnetite dissolution rate and thus minimises the carbon steel corrosion rate. The second route is to select the water chemistry so that the magnetite particles keep in colloidal form and can be removed by filters before they have time to deposit into the SG. This can be done by adding a dispersant (such as polyacrylic acid, PAA) or by selecting a suitable combination of amines for the pH control. The third route is to prevent the detrimental action of the already existing magnetite deposits.

This can be done by removing the deposits during outages frequently enough or by introducing crevice inhibitors (such as TiO2 or a film forming amine).

The general objective of the MOCCA project is to develop knowledge and (PWR) secondary side water chemistry programs enabling minimisation of magnetite formation in the feed water line and deposition of magnetite into SGs as well as for mitigation of corrosion phenomena in SG crevices related to deposition and impurity enrichment. The expected outcome will improve the knowledge basis on which decisions on advanced secondary side water chemistries are made. Specifically, as a result of the study the benefits of using film forming amines as passivating agents for carbon steel and inhibitor for lead assisted stress corrosion cracking (PbSCC) will be clarified.

Specific goals in 2015

The specific goals in 2015 with regard to the effects of water chemistry on corrosion related degradation in the secondary circuit were

- to clarify the effect of octadecylamine (ODA) on carbon steel corrosion under PWR secondary side water chemistry conditions
- to study possible benefits of using octadecylamine (ODA) as a corrosion inhibitor for Cu-containing components
- to prepare a state-of-the-art study on current problems in SGs related to SCC (especially PbSCC), experimental and calculation methods used to investigate susceptibility to SCC in SG crevice conditions
- to prepare a scientific journal publication on the effect of ammonia, ethanolamine and morpholine on the surface charge of magnetite under secondary side water chemistry conditions. Results from experiments performed in earlier SAFIR 2014 –research programme using the streaming potential technique are collected in this paper and where necessary complimented with additional experimental data.

In addition, the goals set for international cooperation were to strengthen the international network in the area of water chemistry of NPPs and the application of water chemistry programs for mitigation of stress corrosion cracking. The main forums for international cooperation in 2015 were the meetings of the International Cooperation Group on Environmentally Assisted Cracking of Water Reactor Materials (ICG-EAC) and the European Cooperative Group on Corrosion Monitoring, ECG-COMON, which e.g. organises Round Robin programs on corrosion monitoring technologies.

Deliverables in 2015

- The literature study on lead assisted stress corrosion cracking (PbSCC) revealed that nickel base alloys typically used for SG tubing in PWRs as well as low-alloyed steels (e.g. SG body) are susceptible to PbSCC, while stainless steels apparently are not. This indicates that in case of WWER 440 type reactors such as Loviisa NPP, the main concern in relation to PbSCC should be on the SG body (low-alloyed steel) while less focus should be laid on the SG tubing and tube support structures (stainless steel). Lead was found also to accelerate general corrosion (PbGC), affecting Alloy 690 (most common SG tube material in PWRs) moderately.

- Film forming amine (octadecylamine, ODA) was experimentally shown to be able to improve passivation of carbon steel by a factor of x3 in PWR/WWER secondary side conditions, both at the feed water inlet temperature (T = 228°C) and at the SG hot leg temperature (T = 300°C), see Fig. 2.3.5.1. The protective ODA-film was shown to be stable on carbon steel at the hot leg conditions at least for the monitored period of about 10 days. During ODA application copper corrosion was accelerated, while after the formation of ODA film on copper the corrosion rate was very low. The previously developed deposition model was extended and used to predict the effect of ODA and the effect of changing the SG materials on magnetite deposition into a SG.

- A study on pre-passivation practices during Hot Functional Testing (HFT) period of WWER plants (before the first fuel loading) showed that there is no single WWER document that describes the rationales for controlling individual chemical species and the limit values recommended. Thus sources of information concerning the water chemistry during HFT of WWERs are sparse and a systematization of the available information on the process is needed.

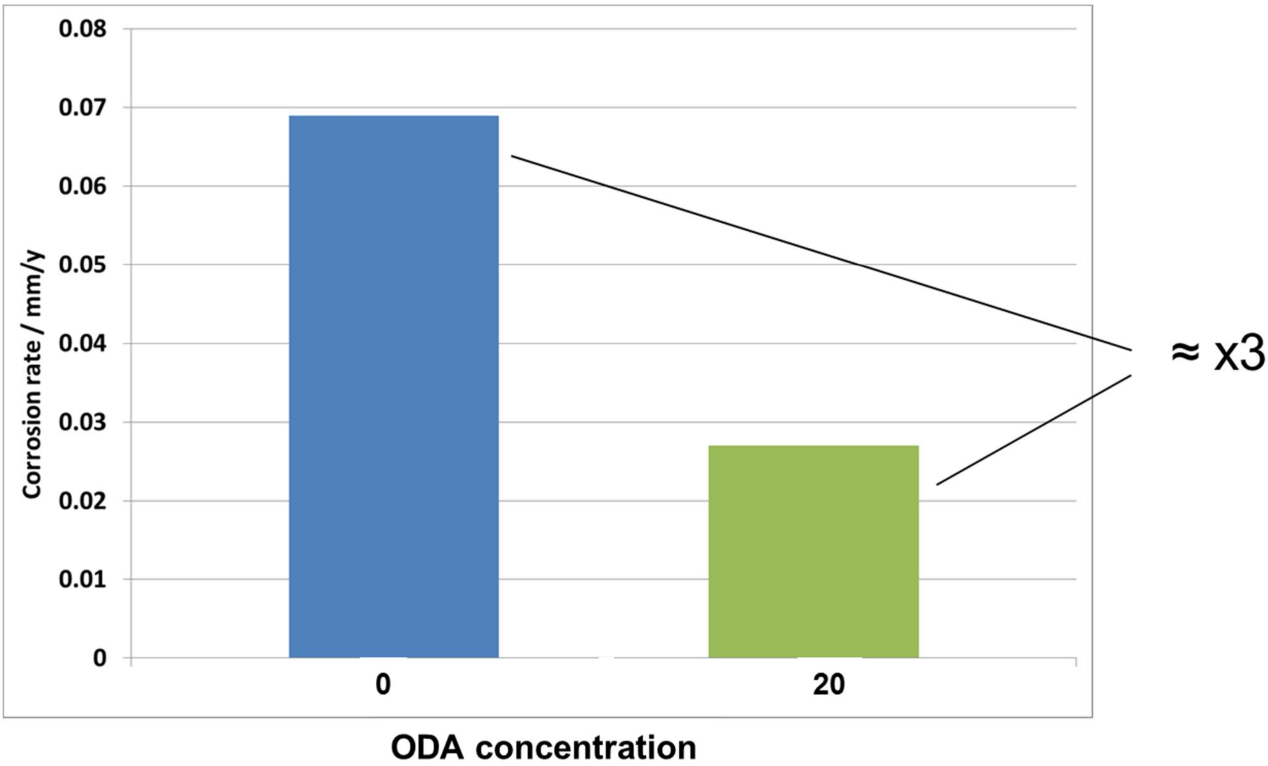


Figure 2.3.5.1. Corrosion rate of carbon steel decreases by a factor of x3 when introducing 20 ppm of octadecylamine (ODA) in the PWR secondary side water similar to that used in Loviisa nuclear power plant. Temperature T = 300°C, i.e. the steam generator hot leg temperature at Loviisa NPP.

2.3.6 NEST - Numerical methods for external event assessment improving safety

External hazards threatening the integrity of nuclear power plants (NPPs) can have devastating consequences. Countering them implies preparing for the unknown, in the sense that loading scenarios involved are so extreme that no previous experience usually exists to easily engineer a defence solution. The lack of observations/measurements pushes designers to work-around methods. Scaled experiments are executed to generate data for understanding more deeply the physical phenomena. Empirical observations from small intensity events are extrapolated to the hypothesised extreme event. In all cases, there is a limit to how far these observations can be useful, with direct need of reliable tools to help bridge to the really extreme loads needed for the design. In this project we propose to develop, calibrate, feasibility-assess and employ high-end numerical modelling techniques for several threats crucial for NPP safety, such as impacts, explosions, earthquakes and fires.

Modelling techniques and tools are under continuous development and the computation capacity is exponentially increasing. Thus, more and more realistic numerical simulations can be carried out with reasonable efforts. Different types of numerical methods can now be coupled to solve multi-physical problems. Modelling of an earthquake starting from movement of the fault up to the vibrations in NPPs is about to yield trustable results, or, reproducing an impact of a heavy projectile on a NPP wall can give design accuracy level prediction concerning the mechanical response of the internal components and instruments. Same physical phenomena are present in research areas that at first glance seem different. E.g. methods for numerical simulation of induced vibrations in damaged concrete need to developed and taken in use. The competitiveness of the proposal comes from allowing modelling techniques to be developed to cover similar areas and from allowing cross-fertilizations of ideas.

The main aim of this work is to develop and take in use improved methods and modelling techniques which are validated against experimental data.

Specific goals in 2015

A model of a large passenger aircraft was created. A simulation of a realistic aircraft impact was carried out by using the coupled approach with the fairly detailed finite element model of the aircraft. This was compared to a corresponding simulation where the aircraft model is replaced with a force-time function calculated with the Riera method.

Models and methods for assessing structural integrity of impact loaded reinforced concrete structures were developed and validated utilising experimental data. In practice, post calculations of impact tests are an important way to identify needed development work. Knowledge transfer and education of new experts is carried out within this kind of working process.

A finite element model of VERCORS test containment was created and used for the calculation benchmarks. Expertise in numerical modelling of concrete aging from the structural integrity point of view was developed. It is especially important as lifetimes of NPPs are extended. This work was carried out in cooperation with experienced colleagues at Scanscot Technology AB (Sweden).

Deliverables in 2015

- Task 1.1 Detailed data analysis for identifying comparison cases for the model outputs (NKS report “Modelling as a tool to augment ground motions date in regions of diffuse seismicity – Progress 2015, L. Fülöp, V. Jussila, B. Lund, B. Fälth, P. Voss, J. Puttonen, J. Saari, P. Heikkinen)

- Task 1.2 Developed PYTHON tools for COMPSYM to model earthquake scenarios and to extract and interpret surface vibrations. The models are in calibration phase. Submitted a paper in related topic to Nuclear Engineering and design (NED), with the title “Statistical analysis of the variation of floor vibrations in nuclear power plants subject to seismic loads” – being handled as submission NED-D-16-00094.

- Task 1.3 ÅF-Consult generated synthetic accelerograms data (seismic load) for sensitivity analysis for floor spectra of NPP's (ÅF-Consult report NE-4557).
- Task 2.1 A model of a large passenger aircraft has been created. It is ready to be used in coupled analyses. A VTT research report has been written (VTT-R-02907).
- Task 2.2 A scientific paper on combined bending and punching studies has been finalised and published (Nuclear Engineering and Design Volume 295C, 2015, Pages 730-746). Also, a conference paper has been written and presented.
- Task 2.3 Numerical studies have been carried out on vibration behaviour tests V1A-f. A conference paper has been written and presented. An international joint article is being written and almost ready.
- Task 2.4 A model of prestressed containment has been created. Structural analyses have been completed and results have been sent to EDF. A VTT research report (joint report with Scanscot Technology AB, Sweden) has been written (VTT-R-00016-16).

2.3.7 THELMA - Thermal ageing and EAC research for plant life management

The objective of the joint VTT – Aalto THELMA project is to support the safe operation of NPP´s through increased understanding of the influence of light water reactor environments on the behaviour of nuclear materials, with the emphasis on thermal ageing. To meet these goals, several tasks are pursued dealing with thermal ageing of stainless steel cast material and weld metals and of wrought Alloy 690 material. The crack initiation susceptibility of nuclear materials is investigated, focussing on developing an accelerated method for testing, while the latest research results on corrosion fatigue assessment are brought to the programme through participation in an EU-project and reporting the results within THELMA. International co-operation is important as a tool to bring the latest knowledge to Finland and benchmark the scientific level of our own research. Knowledge transfer and continuous education will secure uninterrupted availability of high-quality expertise for ageing management.

Specific goals in 2015

The THELMA 2015 project has several goals dealing with the long-term behaviour of nuclear materials.

The long-term behaviour and ageing mechanisms of 316L type welds are investigated using thermally aged materials up to 40 000 h in co-operation with MIT, USA. The characterisation of the materials is performed in THELMA, while the mechanical characterisation as well as the influence of LWR environment is investigated at MIT. In 2015, characterisation of the materials, including FEG-TEM investigations, was started and a scientific publication on present results was written.

The thermal ageing of cast stainless steel of type CF8M is investigated in co-operation with doctoral student M. Bjurman from KTH, Sweden. The materials, delivered to the project by the supervisor Professor Pål Efsing, Vattenfall and KTH, are from the cold and hot leg from a steam generator and have been thermally aged for 70 000 h at 291°C and 325°C, respectively. In 2015, FEG-TEM investigations on the materials were started.

The characteristics and properties as well as the thermal ageing mechanisms of Alloy 690 materials (totally 36 conditions) are determined using thermally aged materials received from KAERI, Korea. In 2015, detailed characterisation of 4 conditions was made using micro- and nanohardness measurements, X-ray diffraction, tensile testing using digital image correlation, SEM/EBSD and FEG-TEM/EDS.

The latest new test results and development of assessment methods for environmentally assisted fatigue are made available to the SAFIR2018 programme through participation in the EU-INCEFA+ project.

An accelerated crack initiation test method is developed in co-operation with European laboratories taking part in the Nugenia MICRIN+ project. In 2015, testing using tapered specimens and a Si-alloyed stainless steel was performed.

The optimum method to determine strain-induced α'-martensite in Type 304L stainless steel is evaluated.

The latest knowledge is brought to Finland by international co-operation and participation in conferences.

Knowledge transfer from senior experts to younger researchers is promoted. In 2015, an advanced course on nuclear materials was arranged followed by a seminar. Part of the course lectured by Prof. D.S. Samokhin, MEPhI, Russia, was related to the VVER-1200 reactor design.

Deliverables in 2015

- An increase in indentation hardness of Type 316L weld metal δ-ferrite was observed while the indentation hardness of austenite stays the same during aging, as expected. The DL-EPR tests did not show any corrosion in the as-welded and at 300°C for 40 000 h aged specimens, whereas the specimens aged at 430°C for 5000 and 10 000 h show a clear corrosion attack on the whole surface and features in the δ-ferrite phase indicate G-phase, which was confirmed by FEG-TEM/EDS, Figure 2.3.7.1. The G-phase is an FCC Ni-Si rich phase ($M_{(6-7)}Ni_{16}Si_7$), where M corresponds to transition metals stabilizing the phase and depending on the steel grade can be Mn, Mn/Mo, Ti, Nb. Sometimes small quantities of the M component may be substituted with Cr or Fe. No G-phase was observed in the specimen aged at 300 °C, and thus the increase in ferrite indentation hardness is due to spinodal decomposition only in this specimen.

- Atom probe tomography (APT) analyses of the CF8M cast stainless steel from the SG hot-leg (70 000h/325°C) showed clearly the elemental redistribution due to thermal ageing, indicating spinodal decomposition as well as the formation of G-phase precipitates. In the crossover-leg (70 000h/291°C), the elemental redistribution is much weaker. The FEG-TEM investigations though have not revealed any well resolved microstructural features affiliated neither to spinodal decomposition nor to formation of G-phase, Figure 2.3.7.2, in the studied cast stainless steels. Though, taking into account results of APT analyses, further studies of the SG hot-leg material are considered as the next step. It is planned to cut TEM specimens from different locations of the SG hot-leg in order to take into account the inherent inhomogeneity of cast materials.

- All four Alloy 690 conditions, i.e., solution annealed (SA), 20% cold worked (SACW), thermally treated 700°C/17h (TT) and thermally treated and cold worked (TTCW), showed evidence of short range ordering (SRO) with lattice contraction in the range of 0.02-0.06% with relatively short ageing times (3000 and 10 000 h), Figure 2.3.7.3. The effect of ordering is seen in the solution annealed (SA) condition through an increase of the local misorientation, which can be related to the strain level. No apparent change has been visible in the thermally treated (TT) condition, yet. However, higher hardness levels and lower lattice parameter in the TT condition suggest that thermal treatment promotes some ordering prior to ageing. Cold work (CW) nearly doubles the overall hardness of the material in both SA and TT conditions, but seems to limit the effect of ordering as the hardness increase is reduced in the SACW and TTCW samples. However, cold worked samples show the highest lattice contraction indicative of a higher level of ordering. Especially, the lattice contraction from 0 to 3000 h ageing is very strong for these conditions, suggesting that CW can promote SRO in the early stages of ageing. To be noted is that the lattice parameter of the TTCW condition prior to ageing is higher than that of the TT condition, showing that CW after thermal treatment destroys the order structure.

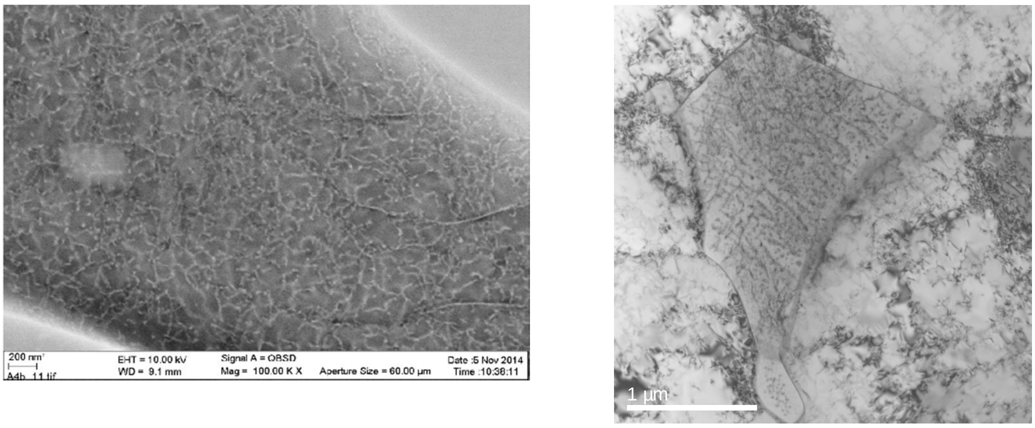
- The EU-INCEFA+ project kick-off meeting was held in June 2015. The state of the art has been completed through internal in-kind contributions from all consortium members concerning (i.) the current status of environmental fatigue assessment capabilities [in different countries], (ii.) data which provides evidence of problems in the current assessment of environmental fatigue and (iii.) ideas for INCEFA+ improvements. The state of the art also isolated the three important sensitivities which will be studied in the framework of the INCEFA+ project: (i.) mean strain, (ii.) hold time and (iii.) surface condition. The material procurement is ongoing and the common, Type 304L, material, to be distributed by EDF is due to arrive at VTT soon. The position paper on effect of hold time concludes a beneficial effect of hold times of fatigue life.

- Slow strain rate tests on Si-alloyed stainless steel material using tapered specimens has been performed in PWR and BWR environments by the MICRIN+ partners (including VTT) using different strain rates. The preliminary results show a decreasing apparent stress threshold for initiation of environmentally assisted cracking with decreasing strain rate. Some scatter was observed in the results originating from difficulties to differentiate between true EAC-cracks and strain-induced tearing.

- A study was made on α´-martensite formation in metastable Type 304L stainless steel during deformation and detection of it with different methods available at VTT. The phenomena itself are well recognized, though still relatively actively researched and similar test series have been done in Finland and also internationally. The motivation for this work was recent cases of VTT customers asking about α´-martensite detection from stainless steel, as this is regarded harmful in austenitic stainless steels in nuclear applications. Based on the results the most useful method for α´-martensite detection is a Ferritescope, due to its inherent ease of use and the need for very little preparation prior to measurements. The analysis volume of the method seems to be suitable at least for the 4 mm plate used for the task, as it gave relatively consistent bulk results. Although, as shown by optical measurements of etched samples, Ferritscope can miss high local variation in α´-martensite content, from 14 to 50% measured on single 200x magnification optical image covering an area of 650x500 µm within a single as-received sample strained to true strain of 40,5%. EBSD is a reliable, but work intensive method to quantify martensite amount. A linear correlation between hardness and degree of deformation was observed, but hardness cannot directly be used for determining the amount of martensite, though. An important confirmation was also the current non-suitability of automatic grinding/polishing device for preparing sensitive metastable samples, as α´-martensite was formed during sample preparation. Metastable samples shall be polished electrolytically.

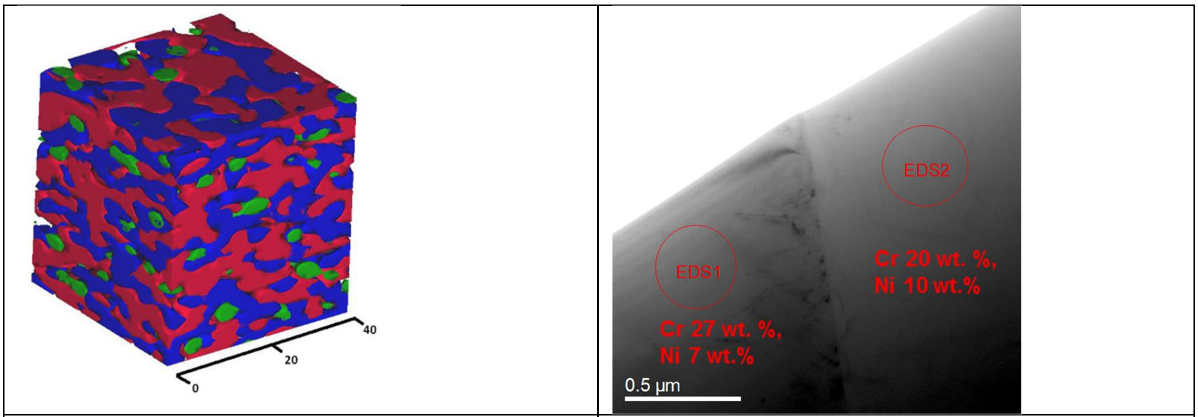
- In total 39 persons (4 from the THELMA project team) participated in the advanced course on nuclear material, at which also Professor Dmitry S. Samokhin, Reactor Development and Design Department Obninsk Institute for Nuclear Power Engineering, National Nuclear Research University "MEPhI" gave lectures on the AES2006 reactor design. Totally 8 doctoral students from STUK, Aalto and VTT made additionally the seminar papers, which were presented at a seminar in October 2015 and are published in the proceedings.

- THELMA team members presented four papers on THELMA and ENVIS results at the 17th International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors. The feed-back on the performed investigations and the new contacts from the meeting are valuable for the further research.



(a) (b)

Figure 2.3.7.1. FEG-SEM- (a) and FEG-TEM (b) image of a DL-EPR specimen aged at 430°C for 10 000 h. Features indicating presence of G-phase are visible in (a) and confirmed by FEG-TEM to be G-phase through appearance (b) and composition.



(a) (b)

Figure 2.3.7.2. Iso-concentration plot of hot leg CF8M material, thermally aged 70 000 h/325°C with red α-, blue α´- and green G-phase (result from KTH, Sweden) (a). The size of the box is 34x34x37 nm³. FEG-TEM image of the same material (b) showing ferrite and austenite phases of the material.

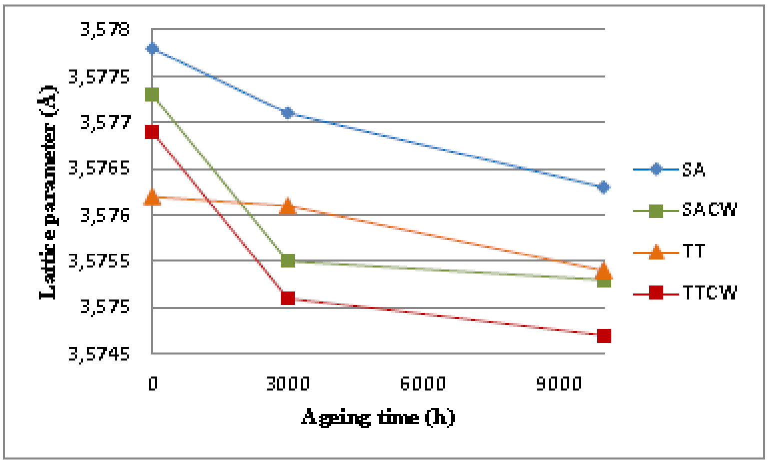


Figure 2.3.7.3. Lattice parameter before and after aging at 475°C for 3000 and 10 000 h for Alloy 690 in SA, SACW, TT and TTCW conditions.

2.3.8 WANDA - Non-destructive examination (NDE) of NPP primary circuit components and concrete infrastructure

A profound understanding of the reliability of non-destructive examination (NDE) methods is needed for safe operation of nuclear power plants (NPP). The project of NDE on NPP primary circuit components and concrete infrastructure (WANDA) applied to the SAFIR2018 programme is focusing on the development and understanding of NDE methods. WANDA consists of two work packages. Work package 1 (WP1) addresses NDE on NPP primary component materials and WP2 focuses on the NDE of NPP concrete infrastructure.

The ISI for primary circuit components is mostly performed in a short time period with limited accessibility. NDE techniques are the main tools to inspect the structural integrity of the primary circuit components in the NPP. The development of the NDE techniques towards more reliable and efficient ISI promotes the safety of NPP. Artificial defects are typically used as a reference when the performance of an NDT procedure is demonstrated. Because of the lack of real defects, artificial defects are needed for certification and training of the inspectors. According to the previously performed studies in MAKOMON project in SAFIR2014 on artificial defects, the ultrasonic response varies with the type of the defect and with the technique used. To be able to evaluate the severity of the detected defects, it is highly important to know the exact type of the artificial defects in the reference samples and their correspondence to the actual defects. The use of artificial defect can lead to an error, if the limitations of the artificial defect used for the NDE procedure design or qualification compared to ISI -defects (e.g. stress corrosion crack) is not known. Also in recent years, there has been increasing need to better quantify the expected performance and, in particular, to obtain quantitative data on POD for the used inspections. This information is needed, for example, to better facilitate risk-informed in-service inspection.

Figure 2.3.8.1. Phased array ultrasonic examination of the open piping test block.

One of the NDE development targets is the inspection of steam generators (SG). Especially detecting the corrosion product, magnetite, in the secondary circuit. Corrosion products in SGs have caused serious tubing degradation in the past. Deposit induced corrosion problems still remain a serious issue regarding nuclear safety. Deposits can be removed during outages by mechanical means such as sludge lancing or by chemical dissolution treatments. In order to determine the extent and nature of deposit formation more precise NDE techniques need to be developed. Eddy current method (ET) has been proved promising as a detection method, and needs more development to become a quantitative and reliable tool. The basis for such detection has been laid down in WANDA –project.

The safety significance of NPPs reinforced concrete structures, especially the containment, combined with the current trend towards life extension and the regulatory authorities' demands for even higher levels of safety assurance, emphasises the importance of effectively controlling ageing degradation. The inspection of NPPs concrete structures present challenges different from those of conventional civil engineering structures. As a result, there is a need for NDE of RCS to be able to undertake compliance testing, collection of specific data or parameters, condition assessments, and damage assessment.

Determination of the condition of NPP concrete infrastructure is achieved through a structural condition assessment, initiating with a detailed visual assessment of the structure, followed by determination of need for additional surveys or use of destructive or non-destructive testing and evaluation of the NDT methods. The objective is to characterise the existing performance and the extent and causes of existing degradation.

NPP reinforced concrete structures (RCS) present a unique challenge for development of performance acceptance criteria because of their large size, limited accessibility in certain locations, the stochastic nature of past and future loads, as well as that of mechanical and durability performance characteristics due to ageing and possibly degradation, and the qualitative nature of many non-destructive evaluation methods. Improved guidelines and acceptance criteria to assist in the interpretation of condition assessment results, including development of probability-based degradation acceptance limits, are required.

The application of NDT methods to NPP RCS has several challenges: infrastructure wall thicknesses; dense and complex reinforcement detailing; penetrations or cast-in-place items; limited accessibility; severe environments; inaccessible structures; limited experience with NDE methods for NPP and lack of specific equipment or knowledge for NDE of NPP RCS.

It is understood that there is a clear need for means of ensuring concrete structures meet their design criteria, during and immediately following construction, where NDE methods can provide quality control and verification. However, with time, NPP RCS are subject to ageing resulting in their degradation and consequently deterioration in their performance. NDE methods can be used to characterize material properties, measure performance, and provide valuable input for the assessment of the RCS performance.

There is still a clear need for NDE methodologies to continue to evolve. Research has shown the need for realistic specimens should be developed to allow direct comparisons between various techniques, with consideration given to ensuring a broad range of defects, and to ensure the probability of detection for a method can be properly determined.

Figure 2.3.8.2. View of the Betatron tests to the steel/concrete composite beam.

Specific goals in 2015

One of the main focuses of the WANDA project is to maintain the expertise level of Finnish NDE research of the NPP component materials and to raise that of NDE of concrete infrastructure. Also one of the important factors for the future is the transfer of know-how in the area of NDE to a younger generation of scientists. Objectives also are: to analyse the differences in artificial defects and further verify the reliability of NDE simulations, to improve the eddy current inspection technique to map the existence of the magnetite piles in SG, to participate the international cooperation within U.S. Nuclear Regulatory Commission (NRC) PARENT (Program to Assess the Reliability of Emerging Nondestructive Techniques) and its follow-on program, to critically assess the NDT techniques and monitoring systems currently in use to fulfil the needs of NPP infrastructure evaluation in Finland, to develop guidelines for the use of NDE techniques in design and condition assessment, for the implementation of monitoring systems, and for performance based design and ageing management of the concrete infrastructure.

Deliverables in 2015

- Ultrasonic tests for fatigue cracks in a tubular austenitic specimen with weld have been done. The artificial defects in cooling line welding have been inspected with ultrasonic techniques for the part of Mechanical fatigue cracks.

- Simulation work comparing two different simulation tools for modelling magnetite on SG tubing have been finished with results that show the advantage of both simulation tools. Simulation of the effect of the magnetite on eddy current indication has been done CIVA and COMSOL softwares. The comparison for the softwares shows equality in the results. This is a new approach to the magnetite research.

- Classified the reinforced NPP concrete structures, critically assessed the NDT techniques currently in use, and built a selection matrix for non-destructive testing of NPP concrete structures. The purpose of the created NDT selection matrix was to identify and describe the effective use of NDT technologies that can detect and characterize deterioration in NPP concrete structures. The NDT selection matrix is useful for effective selection of the suitable NDT technique for NPP concrete structures based on their building materials and in-service age.

- An assessment of monitoring technologies and sensing techniques for reinforced concrete structures was documented. The work focused on identifying the potentials of different available techniques, equipment and/or procedures, including a determination of existing monitoring methods and techniques as well as the identification of limitations and restraints of the technology readiness with respect to their application in thick-walled reinforced concrete structures, as commonly used for e.g. NPP containments.

- An overview of the research on non-destructive testing methods being used for NPP and similar type structure; what difficulties were encountered, and what has been achieved. Results of this study contribute to providing an improved basis for the preparation of the mock-up conceptual design. The report provides an overview of NPP concrete structures in Finland, including a brief section on testing and inspection requirements according to the YVL guidelines. A compilation of information from other research projects, and the lessons learnt relevant to the construction of a mock-up for non-destructive evaluation are tabled.

- Six research institute reports have been written.

- Personnel have attempted the conferences of the NDT field.

2.4 Research infrastructure

In 2015 the research area “Research infrastructure” consisted of three projects:

1. Development of thermal-hydraulic infrastructure at LUT (INFRAL)
2. JHR collaboration & Melodie follow-up (JHR)
3. Renewal of Hot Cell infrastructure (REHOT).

2.4.1 INFRAL - Development of thermal-hydraulic infrastructure at LUT

The up-to-date experimental research infrastructure is essential for the modern nuclear safety analyses. The implementation of novel measuring techniques in the thermal-hydraulic experiments is needed for the validation of the Computational (Multi-)Fluid Dynamics (C(M)FD) methods. Important part of the INFRAL project is the further development of the techniques related to the advanced measurements and their applications. The goal is to build good in-house expertise in the use of recently acquired techniques to facilitate the needs of computational modellers in the future experiments in the best way if it is technically possible. The CFD grade measurements can give new insights into the physics behind the different flow phenomena that may ultimately lead in the improvements in the safety of nuclear power plants. Furthermore, the goal of the project is to secure the operability of the PACTEL test facilities and to launch a study on the new major test facility to prepare for the post-PACTEL era.

Specific goals in 2015

The acquisitions of advanced measurement systems to Lappeenranta University of Technology (LUT) have been carried out during the last few years in a timely step-wise manner. In 2015, various activities were carried out to strengthen the in-house expertise and the know-how related to the measurement systems. It is essential that the researchers are familiar with their equipment and can also acknowledge the possible limitations.

The Particle Image Velocimetry (PIV) system was applied for the shadowgraphy measurements of spray droplets. Previously, the PIV system had only been applied for the traditional velocity field measurements. Now, the task was to support the use of spray nozzles in the INSTAB project by studying how to perform the spray experiments. There are several variables which may influence the obtained results such as the scaling factor (i.e. the number of pixels per a droplet) and the measurement location. The measurements were carried out in two parts. One set of experiments was performed in the spring with a simple set-up and the other one with the improved test arrangements in the autumn.

The Wire-Mesh Sensor (WMS) technique was used to study the performance of the recently designed and constructed Axial WMS (named AXE). The sensor alignment offers new possibilities for the data processing and analysis. Optical flow methods that are commonly applied for the video images can now be applied for the analysis of the velocity field if some flow and method related limitations are considered. However, the sensor disturbs the flow more than the cross-sectional WMSs. Figure 2.4.1.1 presents some selected results from the counterpart experiments and confirms lower axial velocities measured with the axial sensor (Air-Water two-phase flow in the HIPE test facility).

Third advanced measurement system, three High-Speed Cameras (HSC), was used to capture the rapid and visible behaviour of gaseous phase in the steam suppression pool environment. The quality of the results depends on the cameras, but also on the applied algorithms that are used to extract the numerical information from the HSC images. These methods were further developed and new data extraction procedures were added.

In order to guarantee the availability of the PACTEL facilities, steps were taken to replace the original power control hardware. Unexpected malfunctioning of the system could cause severe delays to the experimental campaigns in the lab. In addition, computer system acquisitions were carried out to bring the post-processing capabilities of simulation and advanced measurement data up to date. The new post-processing server will be added to the existing modelling cluster at LUT.

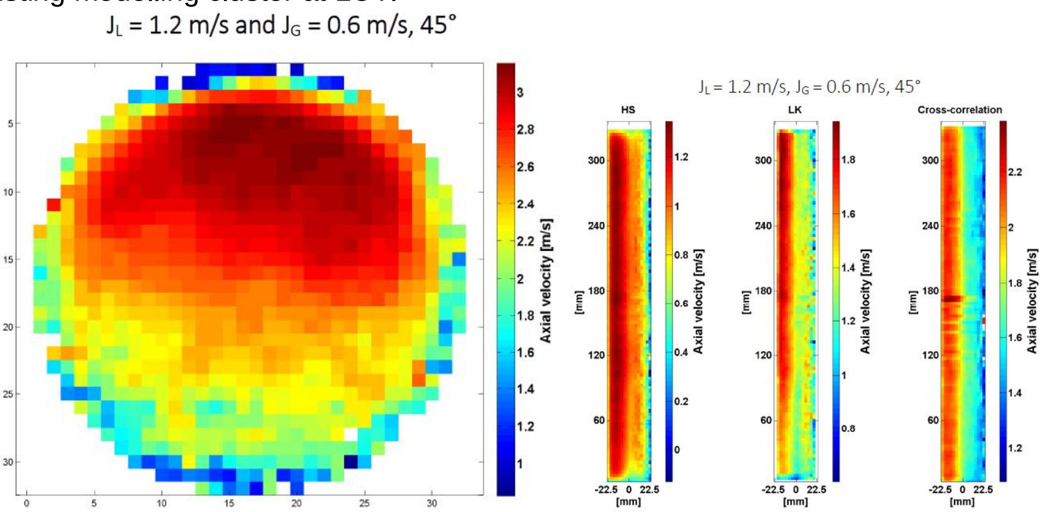


Figure 2.4.1.1. Time-averaged axial velocity distributions of gaseous phase measured using the cross-sectional Wire-Mesh Sensors (left) and the Axial Wire-Mesh Sensor (three different calculation methods, right).

Deliverables in 2015

- The applications for the advanced measurement techniques were actively studied. The PIV system was applied for the spray droplet measurements using so-called shadowgraphy technique. The new application for the WMS technique was studied with the axial sensor design in the HIPE test facility. The first results were presented in the NURETH-16 conference (September 2015). The algorithms for the pattern recognition from the HSC data were further developed and new procedures for the extraction of parameters of interest were added. This is essential in order to numerically compare the experimental results with the CFD simulation predictions.

- Original power control hardware of the PACTEL test facility (from 1989) will be replaced with a new control system that was acquired late 2015. The new system (12 units of Gefran GTF250 power controllers) solves the problem with the local power utility's phase trip alarms caused by the old system as the power control is now performed in a different way. Currently, the system is in a testing phase.

- The work with large calculation meshes and vast amounts of simulation data is highly CPU/GPU intensive process. Up-to-date post-processing computer was acquired to speed up the work flow and simplify the post-processing of the data.

- International activities were related to the advanced measurement techniques. The development of high temperature and pressure Wire-Mesh Sensor at ETHZ was closely followed as such a sensor could be installed in the new thermal-hydraulic test facility at LUT. In addition, a research visit related to the WMS studies was planned with University of Michigan and the visit is scheduled for September 2016.

2.4.2 JHR - JHR collaboration & Melodie follow-up

The general objective of the JHR project was to follow the progress of the Jules Horowitz Reactor (JHR) project by participating in the work of three Working Groups (WG), namely Fuel WG (FWG), Materials WG (MWG), and Technology WG (TWG), established within the JHR consortium. Furthermore, participation in the performance of the Melodie in-core experiment in collaboration with CEA was one of the main goals.

The objectives of the WGs are the determination of experimental needs, the planning of future experiments, and the development of experimental devices and infrastructure. Some of the experimental devices are based on existing technologies, but also new types of devices are being developed, extending the experimental capabilities and bringing new information on the subjects studied. The Finnish in-kind contribution to JHR gives an access to these technologies and enables international collaboration in the future experiments.

The participation in the three WGs brings knowledge on nuclear fuel and irradiated materials research as well as on the preparation and execution of in-core experiments to Finland, and this knowledge will be disseminated to the SAFIR2018 community. Through the participation in the working groups it is possible to bring forward our national interests with regard to nuclear materials research.

The second work package of this project focuses on following the Melodie experiment and bringing the knowledge on the feasibility of the technology as well as the data back to VTT and the SAFIR2018 community. The delivery of the Melodie device was part of the Finnish in-kind contribution, and in this part the work was successfully completed in 2012. The Melodie in-core experiment, carried out in the Osiris reactor at CEA Saclay research centre in 2015, aimed at validating the use of the device and its novel technology for future experiments in JHR.

Specific goals in 2015

In 2015, the project members participated in two WG meetings and the annual JHR technical seminar. The goal was to participate in the planning work of the WGs and enable a bidirectional exchange of information; the project members collected the input and ideas from the Finnish nuclear society to be implemented in the international experiments matrix, and state-of-the-art information from the planning was delivered to the Finnish nuclear society.

The first meeting of the MWG and FWG was organised in Rez, Czech Republic in January. TWG held a meeting in February. In the MWG and FWG common meeting the ranking grids for potential topics of interest for future experiments in JHR were discussed, and a common set of criteria for carrying out the ranking was established.

The fifth annual JHR Technical Seminar was held at CEA Cadarache in April 2015. This year the feedback from the three WGs had more emphasis in the seminar program than in previous years, which allowed a wider discussion about the role of the WGs and about the roadmap for their work.

Another WG meeting took place in October 2015 in Studsvik, Sweden, with all three WGs together. In this meeting the WGs discussed the contents of a synthesis document to be delivered to the GB by the end of October 2015 and a position paper to be delivered by the end of December 2015. The synthesis document describes the work carried out by the WGs so far and the objectives for the future. The position paper includes a proposal for two irradiation experiments to be carried out before the start-up of JHR. One of the experiments is dedicated to LWR fuel and the other one to structural material irradiation.

In the Melodie follow-up, the goal was to prepare and perform the in-core experiment during 2015 before the final shutdown of the Osiris reactor at the end of the year. Furthermore, the goal was to test the functionality of the Melodie device in as varied situations as possible, e.g. changing the stress ratio and performing sweeps. Irradiation creep data produced during the in-core experiment will be gathered and analysed in more detail later, but initial results could be studied already at the end of the year while the experiment was still ongoing.

Deliverables in 2015

- Progress report on JHR collaboration describing the work carried out within the working groups during 2015 was written.
- Technical report on the Melodie in-core experiment describing the preparation of the experiment and the initial results was written.

2.4.3 REHOT - Renewal of Hot Cell infrastructure

The objective of the REHOT project was to plan and execute the hot cell and hot laboratory portion of the infrastructure renewal, including the planning and making of critical equipment investments for the facility, and training of the technical personnel that will be staffing the facility, carried out in tandem with the design and construction of the Centre for Nuclear Safety (CNS). The project was executed in 5 main work packages: the first one focused on the hot cell design, fabrication and commissioning process; the second one tasked with hot laboratory equipment procurement; the third one dedicated to self-built research facilities; the fourth one aimed at self-built facilities for handling and storage of radioactive materials and waste; and finally, in light of the integral nature of this work with the realization of the VTT CNS, a fifth work package focused mainly on the organization and ramp-up of the VTT CNS.

Specific goals in 2015

The design and construction of the hot laboratory facility involves defining and guiding the technical aspects of the hot laboratory portion of the new building in tandem with the engineering design of the CNS. Central to 2015 was completion of the Engineering Design of the hot cells, carried out as a subcontract to Isotope Technologies Dresden, GmbH, in accordance with the documentation laid out in the tender executed in 2014.

Development of remote operation methods and skills is important for effective utilization of the new infrastructure. In 2015 these methods focused on completion of the wire EDM centrifuge circuit's remote handling device development, assessment of the applicability of semi-automatic robotic manipulation by purchasing and using a remotely-controlled, motorized robotic arm, and arrangement of an extended visit by a hot cell engineer in a hot cell abroad.

The work on nuclearization and in-cell devices in 2015 was driven by the need to make device selections for the 3-D models of key in-cell devices, for ITD to model their remote operation (manipulator reach, window visibility, etc.). In 2015 it mainly focused on remote machining operations, which are important for opening surveillance capsules.

Procurement of research equipment for installation in the hot facilities is an important area of effort in the infrastructure renewal. The principle piece of equipment for purchase in 2015 was the scanning electron microscope and its analysers. The specifications and procurement process for a transmission electron microscope slated for purchase in 2016 was also planned. Procurement also included selection of an impact test hammer with semi-automatic specimen feeding and a universal mechanical testing system (MTS) with an environmental chamber for integration into the hot cells. Finally, a hardness testing device was to be purchased in 2015.

Some research and testing devices are not readily available on the market, but rather, require custom design. Development and construction of those research devices is carried out with the experts involved in utilizing the equipment for producing research results, and are then fabricated by in-house assembly of parts bought from component suppliers, or made by in-house or outside workshops. An important goal in 2015 was the design of the hot autoclaves and water circuit, to be located in a dedicated room of the basement of the CNS.

The VTT CNS requires a number of supporting facilities for its research and testing operations. It was determined that the facilities for handling and storage of radioactive materials and waste could be more cost effective for VTT to design, fabricate and install themselves, rather than to try to include them as a part of the main hot cell suite contract. Self-built supporting facilities in 2015 aimed at the development of the facilities for three main areas: laboratory radioactive waste handling, radioactive research material logistics, and orderly temporary storage of radioactive specimens. These systems are mainly to be located in the basement of the CNS.

In 2015 the construction of the VTT CNS climaxed, requiring finalization of the smallest details of the systems, fixtures and furnishings, while preparing for moving into the office wing. In anticipation of completion and release of the laboratory facilities to VTT in 2016, efforts in 2015 were dedicated to planning the practical utilization of the new facility. An objective was to set up an Ad Hoc group involving VTT and the domestic power companies to work together towards successful utilization of the new infrastructure. A goal was also to produce a Road Map addressing the facility commissioning, radioactive materials research and testing competence development, and development of funding and income possibilities for the new facility.

Deliverables in the REHOT Hot Cells work package in 2015

- The engineering design process proceeded by first producing a 3D-model of the conceptual design integrating models of the main in-cell equipment, and this was then developed throughout the engineering design process. Weekly meetings were held with the hot cell contractor (Isotope Technologies Dresden) to develop the hot cell engineering design. Formal design reviews were held in July at ITD premises, in October at VTT, and the final design review at ITD in December. ITD visited VTT several times to gather on-site information about in-cell equipment, as well as installation conditions.

- The final layout of the cells and initial version of the Design Specification Document were formally approved on 5.5.2015. Based on the conceptual design, a floor loading plan was made and delivered to CNS structural engineers to verify the building's floor loading capacity was sufficient. Descriptions of the design were made as a VTT report that was reviewed and delivered to the Safir consortium, and a publication was prepared for HOTLAB 2015.

- A 3-D model of the detailed concept was completed by the end of the project year. It includes structures, shielding, in-cell devices, ventilation, electrical, automation, fire suppression, and the transport casks. ITD evaluated the expected radioactivity levels outside the cells based on the shielding specified in the Tender, showing that at least the minimum requirements were met, and generally exceeded. A more than satisfactory result was achieved.

- In the Quality task, subcontractor Qualfinn Engineering Ltd. assisted VTT in the assessment of the ITD Quality Plan versions, which were iterated with ITD until a satisfactory result was achieved. The main deficiencies were in the degree of precision recognizing the particulars of the VTT hot cell delivery, which was ultimately brought to a satisfactory level.

- In terms of personnel training and method development, the KUKA programmable robotic manipulator was delivered in the beginning of April. On-site training for the device was held 14-17.4.2015, with four VTTers participating. The device was demonstrated for RG6 members in October. It has also been trialed for use in remotely sawing open surveillance capsules, and as such, allocation for installation of such a device has been made for hot cell 3.1.

- Attempts made to arrange an extended visit at a hot cell were initially unsuccessful (direct declines from SCK-CEN and KIT, no answer from CEA). However, a positive response from PSI was pursued further at the HOTLAB conference (September) and after a personal visit by Jari Lydman in December, PSI ultimately agreed to host him for a 3 month visit to their hot lab during the period 29.2.-27.5.2016. It was agreed that his activities there will include utilizing in-cell analytical equipment and mechanical test devices, and practicing remote handling manually and with a programmable robot.

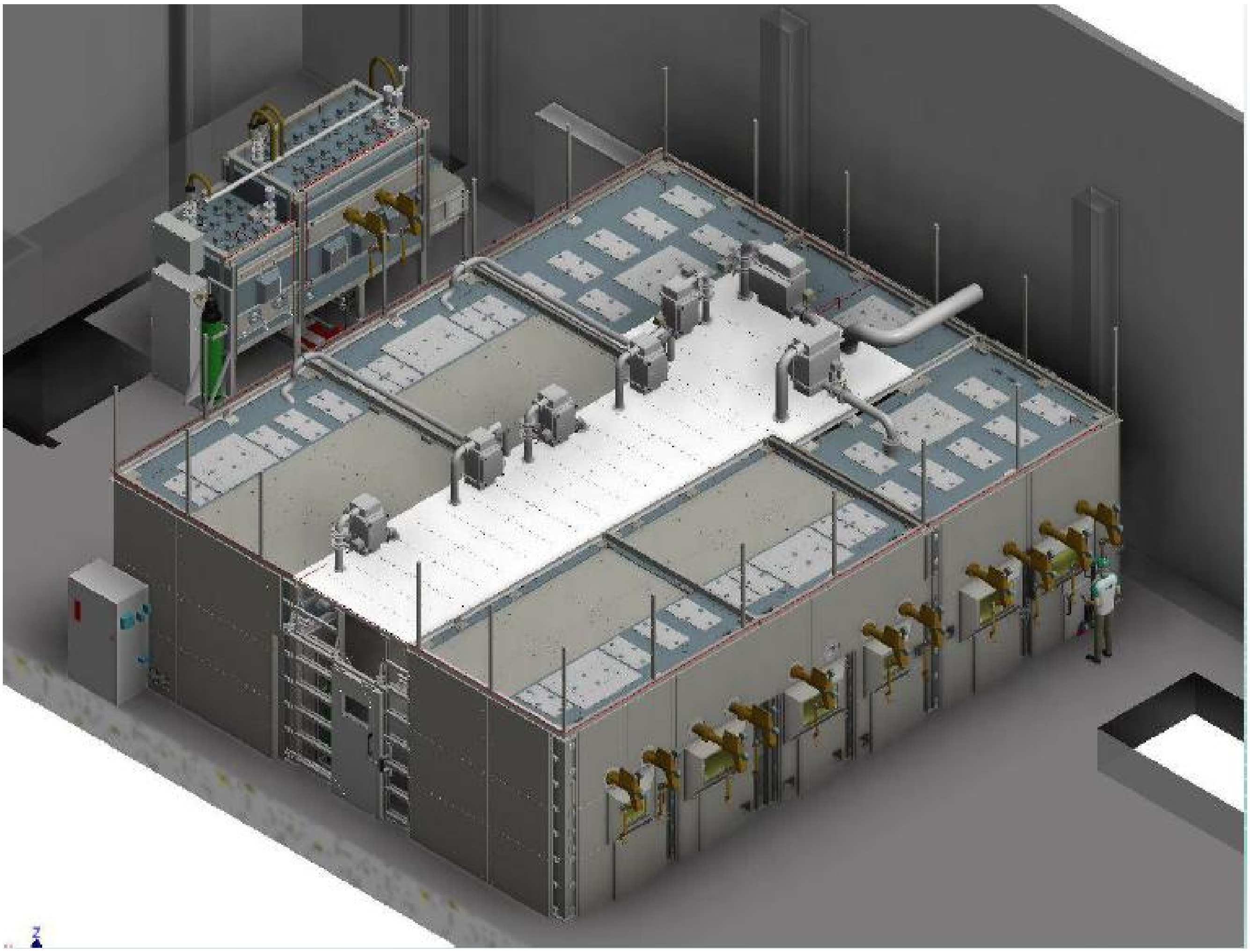


Figure 2.4.3.1. Engineering model of the hot cell configuration produced by Isotope Technologies Dresden GmbH for the main floor of the Centre for Nuclear Safety radiological laboratory. Beyond the simple conceptual design, the engineering design integrated the details and functionality of the structures, shielding, manipulators, windows, in-cell devices, ventilation, electrical, automation, fire suppression, and transport casks.

Deliverables in the REHOT Equipment Procurement work package in 2015

- The procurement of the new SEM proceeded with the final round of negotiations being held with potential suppliers in Q1/2015, after which direct-purchase procurement justification was acquired for a Zeiss Crossbeam 540 SEM. Acquisition of a FIB add-on in collaboration with another department at VTT was recommended for 2016. The instrument was delivered in the last week of September to begin nuclearization, while the analyzers were procured in an independent process. Analyzer selection was made before the end of September. EDAX was chosen as the supplier for all three detectors (EBSD, WDS, EDS). The analyzers were delivered at Christmas and taken into use in January. Preliminary training was provided by EDAX to several users, but more training is scheduled.

- The procurement process for the new TEM has been going for several years, but in 2015 it proceeded with more intense negotiations with the principal suppliers. While Hitachi had been discarded, leaving a JEOL microscope as the principle candidate, FEI reasserted their interest by offering their new Talos microscope. Introduction to a real FEI Talos was had at the M&M conference in August, where other users and their accomplishments with the Talos instrument raised the level interest in procuring one. In late September two VTT microscopists visited the FEI demo center in Eindhoven to test a

Talos with VTT's own (non-irradiated) foils. After FEI's Talos budgetary offer was proven to be competitive, an internal decision was reached to purchase at Talos with its built-in 4-sector EDS analyser and EELS system. VTT purchase approval was attained and signed by the new CEO. An informal order was placed with FEI for a Talos to reserve a manufacturing window. Formal procurement was launched, but then placed on hold following CNS Steering Committee request for investment prioritization process. An extension to the end of February was attained for FEI's offer, to maintain the manufacturing slot.

- The procurement of the in-cell hardness tester began by identifying two hardness tester alternatives suitable for hot-cell installation: Struers DuraScan-70/-80 and a Zwick/Roell device. Detailed comparisons were made to develop the tender specification. Zwick did not answer our request for proposals, so a direct purchase decision was taken for the Struers device. The order was placed in early October, and the device was delivered 7.12.2015. Installation was made at Kemistintie 3 manipulator practice station for remote-operation tests.

- The procurement of the in-cell mechanical test devices proceeded primarily by discussions with Zwick regarding the devices to be integrated by ITD into hot cell 1.4. Zwick offers both an instrumented Charpy and a tensile testing device for integration in a hot cell. The Zwick device fair in Germany was used for three-way discussions between ITD, Zwick and VTT for selection of in-cell devices. The discussions continued in December with a VTT-ITD-Zwick meeting, including specifically in-cell features for the environmental chamber, and the technical implications of choosing a heavier-duty load frame. A satisfactory chamber design has now been agreed, and the decision was reached to change the tensile tester to a 250kN load frame.

- Dedicated in-cell pre-fatigue devices were also explored in 2015, comparing a Romul off-the-shelf device to a hot cell ready custom device designed by SCK-CEN. A final decision was not yet reached on which device offers overall better value and suitability for the needs.

Deliverables in the REHOT Research Equipment work package in 2015

- Space allocation and facility services in the CNS were finalized for the autoclave facilities and its water loop, and the design concept was completed. The research device is a pressure vessel instrumented with pull rod, load cell, pressure gauge, temperature sensor and electrochemical sensors, connected to a water recirculation loop in which the test solution is maintained. This enables mechanical testing of materials in simulated nuclear power plant primary and secondary circuit conditions.

- Modelling of surveillance capsule opening by a roof-mounted power manipulator was done to evaluate its potential versus a conventional 3-axis machining station, and demos of both approaches were undertaken. The high cost quoted for even renting a conventional 3-axis mill made in England meant machining tests were conducted with a conventional mill instead. Alternative suppliers for a 3-axis machining station equipped with CNC were sought from the Alihankinta 2015 -messu. In parallel, successful remote machining of a capsule mock-up was demonstrated using the KUKA robotic manipulator pilot set-up, and that method was taken into the hot cell 3.1 design process as the primary machining method over the 3-axis milling machine. Nonetheless, the work table in cell 3.1 can also accommodate a conventional 3-axis mill if that is ultimately deemed preferable at a later date.

Deliverables in the REHOT Supporting Facilities work package in 2015

- The waste handling facilities were a significant area of emphasis in 2015, including both the EDM water handling circuit (single biggest producer of liquid waste) and the rest of the radioactive waste processes for the facility operations. For logistics, systems for handling transport casks, waste barrels and facility casks were designed in tandem with the waste handling facilities and the hot cell design process, but are to be procured in part as their own devices beyond those systems.

- The conceptual design of the overall waste handling was started in March 2015 through a consultation contract with Platom Oy. Definition of waste types, waste sources, and space reserved for waste handling in the new facilities was done, and an evolved conceptual design report was made with Platom Oy. The decision was then made to assemble the systems ourselves by procuring the key components. The more detailed design began at the end of May 2015 by VTT. Definition of solutions included input from the hot cell design and experimental work in the current facilities. The waste handling infrastructure devices were then defined for investment preparation, including for a free-standing bridge crane that would be purchased for waste barrel handling.

- With regards to the EDM water circuit, a reusable, reversible filter was piloted in the circuit. Results were positive, so a decision was made to purchase such a reversible filter to use either in-line with the centrifuge, or possibly to completely replace the centrifuge unit itself in the water circuit.

- In conjunction with hot cell design, a heavy-duty, self-propelled pallet truck was selected as the best alternative for handling casks and barrels within the radiological boundaries; the supplier was chosen to be Genkinger-HUBTEX GmbH, which has representation in Finland. Delivery of the device it to be directly to ITD for use in the FAT of cell 3.1, after which ITD will ship it to Finland.

- Through a subcontract with Fraktio Oy, a specimen storage database concept was produced to help produce an adequate tendering specification for realization of the system in 2016. The process was initiated by testing the existing specimen storage database functionality when making a radioactive materials inventory, providing important design requirements. It proceeded to a version 1 stage internally with VTT IT experts and end-users, which was then improved via discussions with several different outside IT companies to enable reliable tendering of the conceptualization. A contract was then placed with Fraktio Oy for the conceptualization of the database system. That involved discussions and idea sharing, interviews with the expected end-users, and then Fraktio wrote the description of the concept.

Deliverables in the REHOT VTT CNS work package in 2015

- Continuing the momentum built up in 2014, construction on the Centre for Nuclear Safety proceeded on schedule. The ridge-raising celebration was held in the first week of June, with the building taking on its final shape, as shown in Figure 2.4.3.2. In parallel, follow-up of the detailed facility design process mainly consisted of deciding particular details of specific aspects and cost-savings opportunities of the building systems, structures and furnishings, mainly with the help of the detailed 3-D design model and discussions held around drawings of particular features.

- Preparation of a Nuclear Safety business plan at VTT was carried out in two stages, first at the beginning of the year, and then an updated one when VTT hired a new Business Development Manager for the Nuclear Safety unit. That effort formed the back-drop for the Road Map specific to the CNS, which was begun in Q3. The Road Map document was completed in late December, reviewed, and distributed January ’16.

- The Centre for Nuclear Safety commissioning project (KORY) held its kick-off meeting on 26.8.2015. The KORY coordinates the commissioning process of the new facility, which involves familiarization with the functionality and maintenance of the facility technology, move-in and installation of end-user equipment, and assurance of building functionality. The members include key members from VTT (end-user), Senaatti-kiinteistöt (owner), A-Insinöörit (construction consultant), SRV (principle constructor), and the building facilities maintenance contractor.

- The high-level MEE-VTT-power company "Ydinturvallisuustalon ad hoc tukiryhmä" group met several times during the year, and concluded its 2015 mandate with the signing of a Memorandum of Understanding between VTT-MEE-and the power companies. The new mandate enveloped by the MoU is to develop the international business of the CNS in a cooperative fashion, with the goal of helping to alleviate the costs involved in the new infrastructure. An example action has been the prioritization of equipment investments that was made in January 2016.

- Oversight by external stakeholders in the CNS included a site visit by TVO construction experts on 9.9.2015 to learn more about the design and construction choices of the facility, as well as an inspection tour on 24.9.2015 by STUK and EURATOM representatives for nuclear materials safeguards.

Figure 2.4.3.2. Progress on construction of THE VTT Centre for Nuclear safety in 2015 CW from upper left, January, March, July and December.

3. Financial and statistical information

The planned and realised volumes of the SAFIR2018 programme in 2015 were 8,50 M€ and 8,52 M€ and 55 and 63 person years, respectively. The funding partners were VYR with 5.266 M€, VTT with 2.014 M€, Aalto University with 0.212 M€, Lappeenranta University of Technology with 0.206 M€, NKS with 0.178 M€, and other partners with 0.642 M€. The planned and actual funding by the major funding partners are illustrated in Figure 3.1. The planned and actual costs by cost category are shown in Figure 3.2. The personnel costs make up the major share.

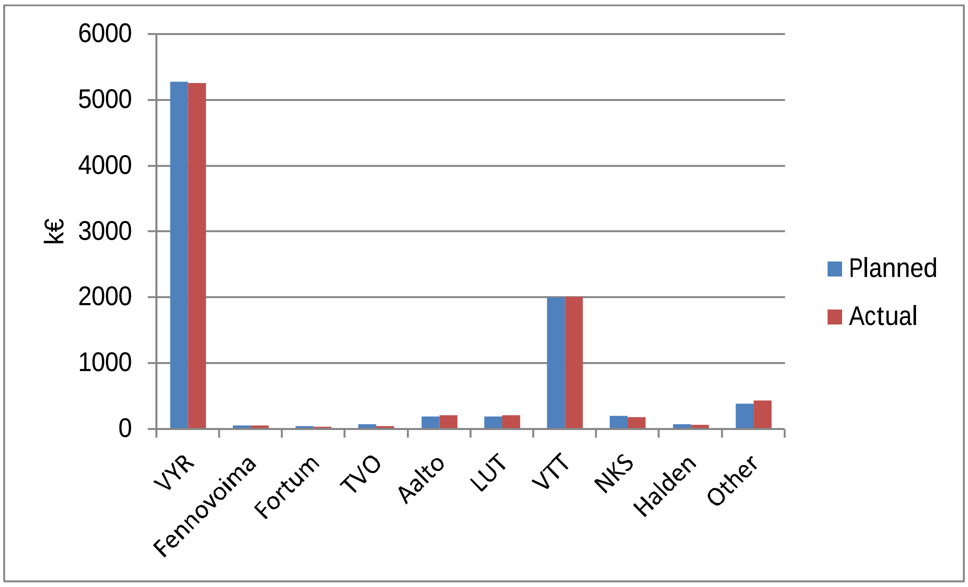


Figure 3.1. Planned and actual funding of the SAFIR2018 programme in 2015.

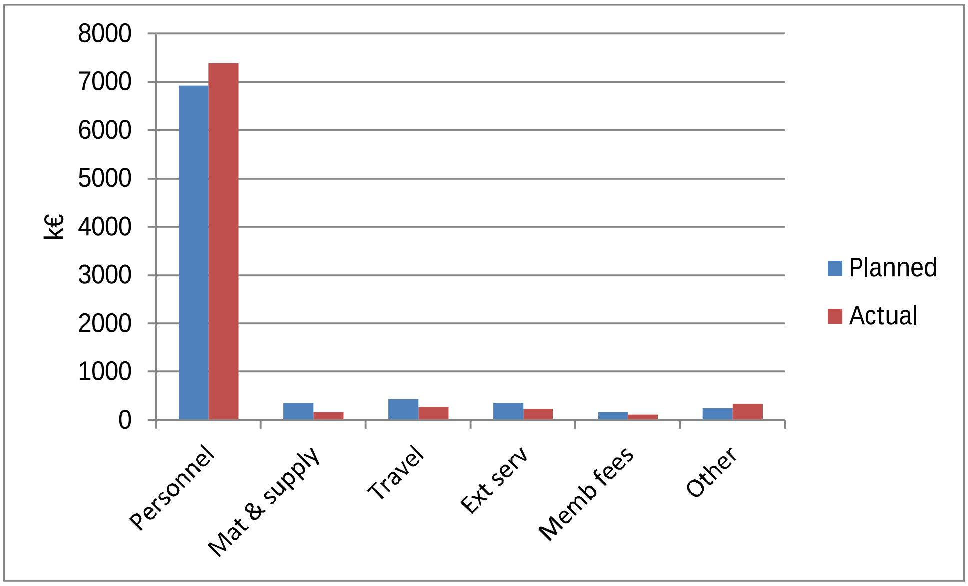


Figure 3.2. Planned and actual costs of the SAFIR2018 programme in 2015.

Figures 3.3-3.6 show the cost and volume distributions by research area. In the figures the following abbreviations are used for the steering group research areas: SG1 Plant safety and systems engineering, SG2 Reactor safety, SG3 Structural safety and materials, and RG6 Research infrastructure.

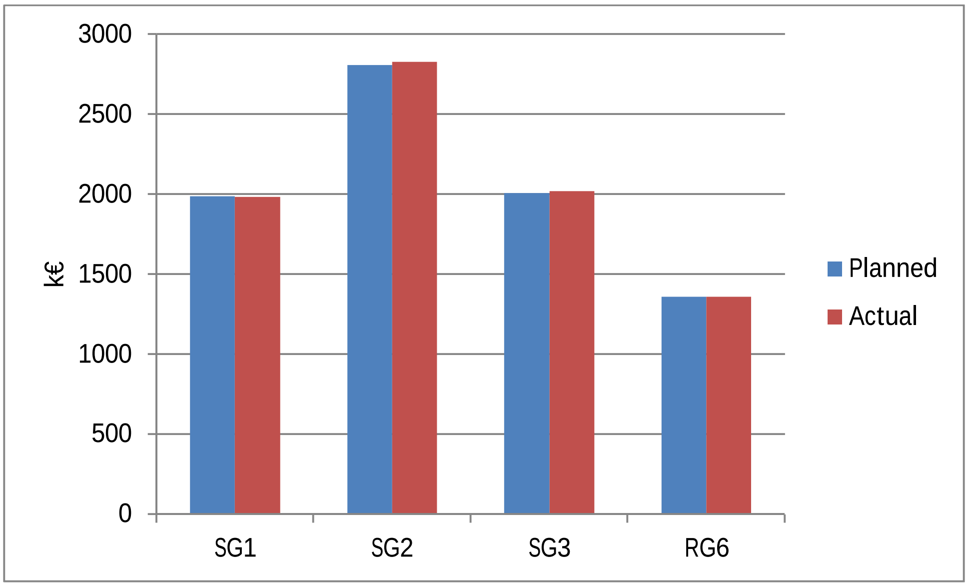


Figure 3.3. Planned and actual costs by research area in 2015.

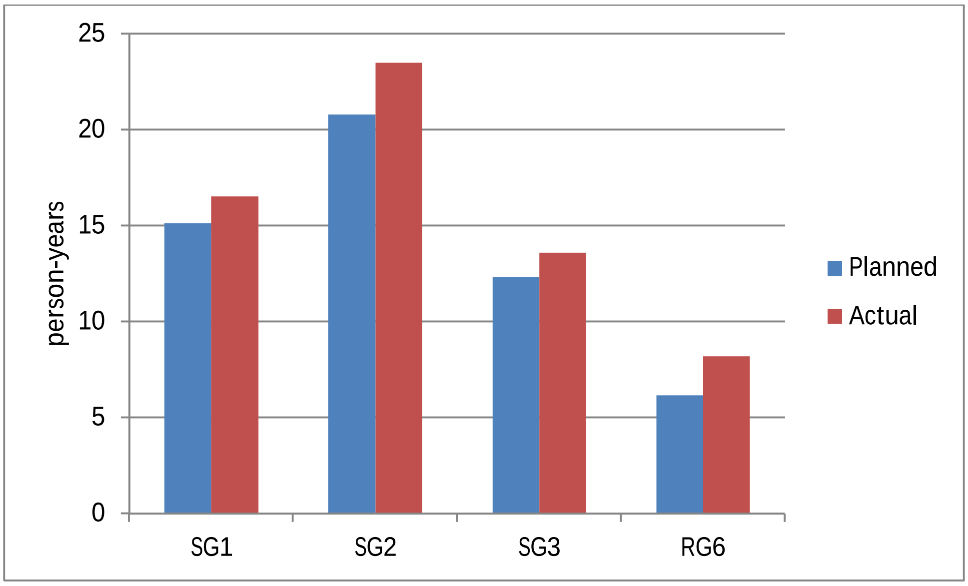


Figure 3.4. Planned and actual volumes by research area in 2015.

The actual costs coincided well with the planned costs in all research areas (Figure 3.3). On the other hand, the actual volumes in person-years were higher than the planned volumes (Figure 3.4). The fact is also reflected in the higher actual than planned personnel costs (Figure 3.2).

In the area Research infrastructure (RG6) the share of person-years was lower than the share of total funding because of infrastructure investments (Figures 3.5-3.6). In SG1 and SG2 the shares of the person-years were bigger and in SG3 smaller than the shares of the total funding, respectively.

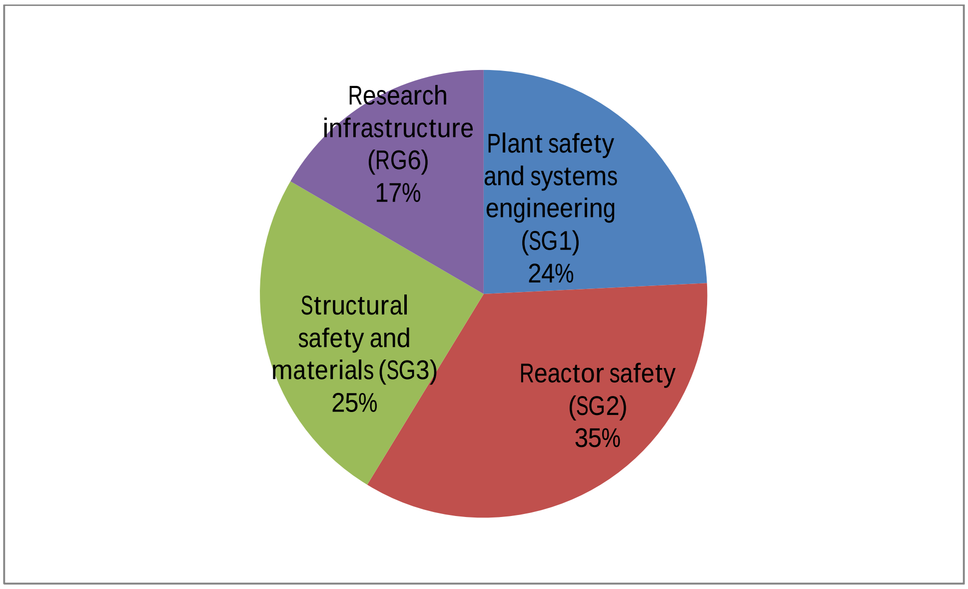


Figure 3.5. Distribution of total funding in SAFIR2018 research areas in 2015.

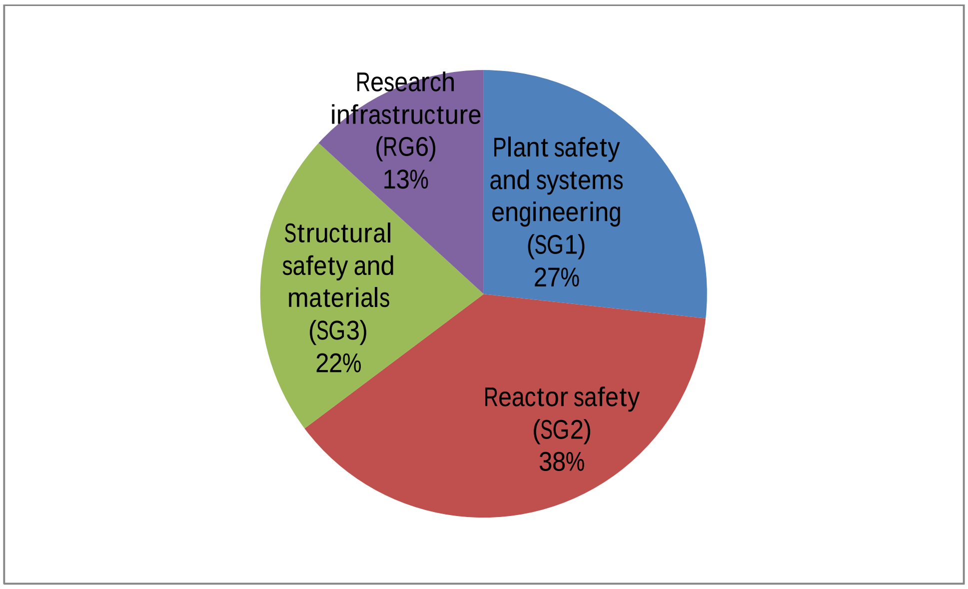


Figure 3.6. Distribution of person-years in SAFIR2018 research areas in 2015.

The numbers of different kind of publications made in SAFIR2018 research projects during 2015 are listed in table 3.1. The programme produced 290 publications in 2015 consisting of 49 scientific journal articles, 71 conference articles, 114 research reports (of the participating organisations),and 56 other publications (theses, reports of other organisations, other publications).

The average number of publications in the research projects was 4.6 per person-year, and the average number of scientific journal articles was 0.8 per person-year. There were clear differences in the number of publications between the projects. Some projects focused more on writing research reports and less scientific and conference articles were written in 2015.

Table 3.1. Publications in the SAFIR2018 projects in 2015.

Project acronym	Volume (p- years)	Research reports	Scientific journal articles	Conference articles	Others	Total
CORE	3.5	4	1	11	1	17
EXWE	3.5	6	9	10	2	27
MAPS	2.2	2	5	6	0	13
PRAMEA	3.2	12	1	1	2	16
SAUNA	4.2	7	1	7	12	27
CASA	2.3	5	2	1	2	10
CATFIS	2.0	3	4	6	2	15
COVA	2.4	6	0	0	0	6
INSTAB	1.7	4	1	1	1	7
INTEGRA	2.6	3	1	1	0	5
KATVE	2.1	4	2	1	3	10
MONSOON	1.2	1	4	0	1	6
NEPAL15	1.0	0	6	0	2	8
NURESA	1.8	8	0	2	1	11
PANCHO	2.8	6	1	4	6	17
SADE	1.4	2	1	2	3	8
USVA	2.2	0	3	2	1	6
ESPIACS	0.3	1	1	1	0	3
FIRED	1.9	3	1	1	1	6
FOUND	3.7	9	0	2	4	15
LOST	0.5	1	1	0	1	3
MOCCA	0.6	3	2	1	0	6
NEST	2.0	2	1	4	2	9
THELMA	2.5	3	1	3	6	13
WANDA	2.1	6	0	1	0	7
INFRAL	2.2	1	0	2	0	3
JHR	0.2	2	0	0	0	2
REHOT	5.8	8	0	1	1	10
ADMIRE	1.1	2	0	0	2	4
TOTAL	**62.9**	**114**	**49**	**71**	**56**	**290**

Altogether 12 higher academic degrees were obtained in the research projects in 2015: seven Doctoral degrees and five Master's degrees (Table 3.2). The academic degrees are listed in Appendix 3.

Table 3.2. Academic degrees obtained in the projects in 2015.

Project acronym	Doctor	Master
EXWE	2	1
CASA	1	
CATFIS	1	
KATVE		1
MONSOON	1	
NURESA		1
PANCHO	1	
FOUND		2
THELMA	1	
TOTAL	**7**	**5**

4. Programme management

The organisation of SAFIR2018 is shown in Figure 4.1 and its function described in detail in the Operational management handbook ([4], available on SAFIR2018 website).

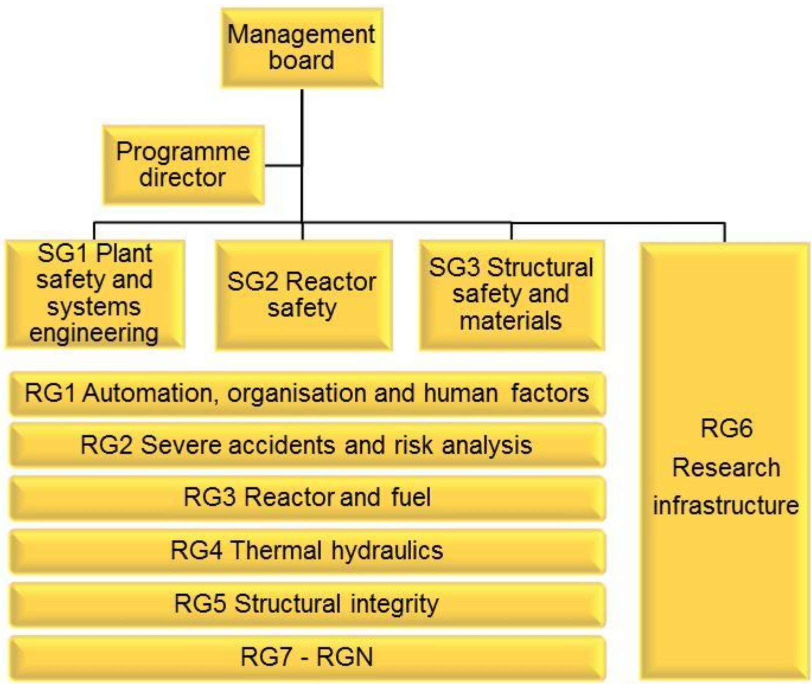


Figure 4.1. Structure of SAFIR2018 organisation. In 2015 each project belonged to one research area Steering Group (SG) and one Reference Group (RG). RG6 "Research infrastructure" has a special role of a steering and reference group [4].

During the administrative period (January 2015 – March 2016) the SAFIR2014 steering group held 4 meetings. Each of the steering groups SG-SG3 had 4 meetings and RG6 as a steering group 3 meetings. The reference groups RG1-RG6 had 3 meetings. The persons involved in the management board (MB) as well as the persons appointed by the MB to the steering and reference groups are listed in Appendix 5. Appendix 5 also shows the staff of the research projects and their main duties.

As a new action in SAFIR programmes, the SAFIR2018 management board can annually initiate small preliminary type studies with the order procedure. Decisions on the small study projects are made after the funding decisions for the actual call for proposals. The study projects support the implementation of the framework plan in topics where actual research projects have not been started. They can also introduce new topics. In 2015 two projects were ordered and carried out: (1) Systems Thinking for Management and Organizations in Nuclear Energy Production – A Feasibility Study (Tampere University of Technology and VTT), and (2) Review on code validation matrices for identification of reproducible test cases (Lappeenranta University of Technology). The projects were formally realised as subcontracting in the administration project (ADMIRE).

The programme director participated in the work of the Euratom Programme Committee (Fission configuration) as an expert member and the three meetings of the national support group were also organised by SAFIR2018.

The information on the research performed in SAFIR2018 was communicated formally via the progress reports of the projects for the reference group meetings, the annual reports of the programme and SAFIR2018 website (public and protected extranet). Additional information was given in seminars organised by the research projects. The detailed scientific results were published as articles in scientific journals, conference papers, and research reports.

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3. Hämäläinen, J. & Suolanen, V. SAFIR2018 Annual Plan 2015. Research Report VTT-R-02813-15. 45 p + 610 app. http://safir2018.vtt.fi/

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Appendix 1

Publications in the projects in 2015

Crafting Operational Resilience (CORE)

Scientific journal articles

Teperi, AM., Puro, V., Ratilainen, H. (2015). Applying a new human factors tool in an nuclear energy industry. Article draft/manuscript.

Conference articles and abstracts

Aaltonen, I., Kuula, T., Wahlström, M., Aikala, M., & Laarni, J. (2015) Training needs in NPP automation maintenance. *Proceedings of ANS NPIC&HMIT 2015.*

Koskinen, H., Laarni, J., Torkkeli, K. & Vesaoja, E. (2015). Pre-validation of a new interactive operating panel system for a nuclear power plant training simulator. *Proceedings of ANS NPIC&HMIT 2015.*

Pakarinen, S., Leinikka, M., Torniainen, J., Henelius, A., Cowley, B., Lukander, K., & Huotilainen, M. (2015). Quantifying mental workload with minimally disruptive measurements of cardiac and electrodermal activity in real-life situations. *9th World Congress of International Brain Research Organization IBRO, Rio de Janeiro, Brazil, July 7-11, 2015.*

Torniainen, J., Cowley, B., Henelius, A., Lukander, K., & Pakarinen, S., “Feasibility of an electrodermal activity ring prototype as a research tool.” *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBC 2015, Milan, Italy August 25-29, 2015.*

Viitanen, K., Axelsson, C., Bisio, R., Oedewald, P., & Skjerve, A. B. (2015). Enhancing Resilience by Introducing a Human Performance Program. Presented at *the 6th REA Symposium, Lisbon, Portugal, June 22-25, 2015.*

Laarni, J., Karvonen, H., Pakarinen, S. & Torniainen, J. (2016) Multitasking and interruption management in control room operator work during simulated accidents. Abstract submitted to *HCI International 2016.*

Liinasuo, M., Koskinen, H., & Porthin, M. (2016) Principles, practises and developmental needs of emergency exercises in Finland. Abstract submitted to *EHPG2016.*

Pakarinen, S., Korpela, J., Torniainen, J., Laarni, J., & Karvonen, H.: Control room operator stress and cardiac activity in simulated incident and accident situations. Abstract submitted to *EHPG2016.*

Teperi, A.-M., Ratilainen, H., & Puro, V. Need for new human factor models and tools in the safety-critical nuclear domain. Abstract submitted to *Safety2016.*

Viitanen, K., Koskinen, H., Axelsson, C., Bisio, R., Liinasuo, M., & Skjerve, A.B. (2016). Learning from successful experiences: An undeveloped potential in the nuclear industry? Abstract submitted to *EHPG2016.*

Wahlström, M. & Kuula, T. (2016). Organizational self-determination and new digital self-study applications as means for developing nuclear power plant operation training. Abstract submitted to *HCI International 2016.*

Research reports

Laarni, J. ‘I am too busy to think’ – Multitasking and interruptions in safety-critical domains. Literature review. VTT-R-03782-15.

Laarni, J. Diagnostic reasoning and troubleshooting in process industry – Literature review. Work in progress. VTT-R-00333-16.

Liinasuo, M., Koskinen, H., & Porthin, M. Principles and practises of emergency exercises. VTT-R-00407-16.

Pakarinen, S. Effects of acute stress on nuclear power plant (NPP) operator performance. Työterveyslaitos.

Others

Viitanen, K., Bisio, R., Axelsson, C., Koskinen, H., Liinasuo, M., & Skjerve, A.B. Learning from successes in nuclear power plant operation. Intermediate Report from the NKS-R LESUN. http://www.nks.org/en/nks_reports/view_document.htm?id=11101021333025

Extreme weather and nuclear power plants (EXWE)

Scientific journal articles

Andreeova, K., E.I. Tanskanen, E. Kilpua, H.E.J. Koskienn. SIR and ICME related IP shock-like pressure pulses: ACE observation 1998-2011, and related storms and substorms, submitted to JGR, in modification, 2016.

Gregow H., P. Poli, H. M. Mäkelä, K. Jylhä, A. K. Kaiser-Weiss, A. Obregon, D. G. H. Tan, S. Kekki and F. Kaspar, 2015: User awareness concerning feedback data and input observations used in reanalysis systems. Adv. Sci. Res., 12, 63–67. doi:10.5194/asr-12-63-2015

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Kämäräinen, M., O. Hyvärinen, A. Vajda, S. Neiglick, H. Gregow, J. Nuottokari, K.Jylhä: Method to estimate freezing rain climatology from ERA-Interim reanalysis over Europe. To be submitted to Natural Hazards and Earth System Sciences (NHESS).

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Tuovinen J-P, J Rauhala & D M Schultz, 2015: Significant-hail-producing storms in Finland: convective-storm environment and mode. Wea. Forecasting, 30, 1064–1076. http://dx.doi.org/10.1175/WAF-D-14-00159.1

Conference articles and abstracts

Gregow E., Pessi A., and Mäkelä A., 2015: Lightning data assimilation for nowcasting applications. . Proceedings for the 2015 EUMETSAT Meteorological Satellite Conference, Session 3, 21-25 September 2015, Toulouse, France.
http://www.eumetsat.int/website/home/News/ConferencesandEvents/DAT_2305526.html

Iwański R., Mäkelä A., Punkka A-J., Poelman D., Wapler K., Grandell J., Stuhlmann R., 2015: Experimental MTG Lightning Imager proxy data at national meteorological services. Proceedings for the 2015 EUMETSAT Meteorological Satellite Conference, Session 3, 21-25 September 2015, Toulouse, France. http://www.eumetsat.int/website/home/News/ConferencesandEvents/DAT_2305526.html

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Karlsen, W., Vilkamo, O., Finland’s old nuclear research reactor to be decommissioned – New Centre for Nuclear Safety under construction. VTT Impulse magazine http://www.vttresearch.com/Impulse/Pages/Finlands-old-nuclear-research-reactor-to-be-decommissioned-new-centre-for-nuclear-safety-under-construction.aspx.

SAFIR2014 Administration and information (ADMIRE):

Hämäläinen, J. & Suolanen, V. (eds), SAFIR2014 – The Finnish Research Programme on Nuclear Power Plant Safety 2011-2014, Final Report. VTT Technology 213, ISBN-978-951-38-8226-6, 2015, 722 p. http://safir2018.vtt.fi/

Operational Management Handbook, SAFIR2018 – The Finnish Research programme for Nuclear Power Plant Safety 2015-2018, SAFIR2018 Management Board, 15 September 2015, 19 p + 26 app. http://safir2018.vtt.fi/

Hämäläinen, J. & Suolanen, V. SAFIR2014 Annual Report 2014. Research Report VTT-R-03998-15, 164 p. + 90 app. http://safir2014.vtt.fi/

Hämäläinen, J. & Suolanen, V. SAFIR2018 Annual Plan 2015. Research Report VTT-R-02813-15. 45 p. + 610 app. http://safir2018.vtt.fi/

Appendix 2

Participation in international projects and networks in 2015

Crafting Operational Resilience (CORE):

NKS project LESUN (Maximizing human performance in maintenance)

OECD/NEA WGHOF (Working Group on Human and Organisational Factors)

OECD/NEA WGHOF Task group on Achieving Reasonable Confidence in Validation Test Results of Integrated System Performance for Nuclear Power Plant Main Control Rooms

NUGENIA (Nuclear Generation II & III Association)

Program Committee Memberships of International Conferences and Workshops: -

Extreme weather and nuclear power plants (EXWE):

FP7 project RAIN (Risk Analysis of Infrastructure Networks in response to extreme weather)

FP7 project CoreClimax (COordinating Earth observation data validation for RE-analysis for CLIMAte ServiceS)

FP7 project CRISMA: Modelling crisis management for improved action and preparedness

FP7 project ToPDAd: The Tool-supported policy development for regional adaptation

AMAP (the Arctic Monitoring and Assessment Program) project AACA-C (Adaptation Actions for a Changing Arctic –part C)

The Nordic Council project ERMOND (Ecosystem resilience for mitigation of natural disasters)

ESSEM COST Action ES1404 “A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction”

EUMETSAT Optical Lightning Imager (LI) Mission Advisory Group (MAG). FMI is an Invited Expert Institute.

Project Coordination in “Enhancing the MTG LI User Readiness in National Meteorological Services” (EUMETSAT funded project. Partner institutes IMGW (Poland), DWD (Germany), RMI (Belgium).

Finnish Nepalese Project (FNEP II), Kathmandu, Nepal. Funded by the Ministry of Foreign Affairs of Finland. EXWE-related thematic “Lightning location data usability in severe weather monitoring and early warning services in developing countries”.

PROMOSERV, Hanoi, Vietnam. Funded by the Ministry of Foreign Affairs of Finland. EXWE-related thematic “Lightning location data usability in severe weather monitoring and early warning services in developing countries”.

Finnish Pacific Project (FINPAC) 2013-2016, Pacific Independent Islands. Funded by the Ministry of Foreign Affairs of Finland. “Lightning location data usability in severe weather monitoring and early warning services in developing countries”.

Nepal World Bank Project 2014-2016, Nepal. Funded by World Bank. EXWE-related thematic “User requirements for a national lightning location network”.

Finnish Bhutanese Project, Bhutan. Funded by the Ministry of Foreign Affairs of Finland. EXWE-related thematic “Lightning location data usability in severe weather monitoring and early warning services in developing countries”.

Membership in the EUMETNET Expert Team Climate

Deputy membership in the Management Committee of the COST Action ES1102 "Validating and Integrating Downscaling Methods for Climate Change Research" (VALUE)

Research visit to Institute of Oceanography and Fisheries, Split, Croatia, 15 Nov - 13 Dec 2015. Collaboration with Croatian meteotsunami experts PhD Jadranka Šepić and Phd Ivica Vilibić on the topic "High-frequency sea-level oscillations on the Finnish coast and their connection to synoptic patterns"

Management Principles and Safety Culture in Complex Projects (MAPS):
Gotcheva, N. International project business workshop, November 2015, Norway.
Gotcheva, N. Resilience Engineering Association, June 2015, Lisbon, Portugal
Ylönen, Marja. Society for Risk Analysis, Nordic Chapter, President elected
Ylönen, Marja. International Sociological Association RC24 (Research Committee of Environment and Society), Board Member.

Probabilistic risk assessment method development and applications (PRAMEA):

NKS project L3PSA (Addressing off-site consequence criteria using Level 3 PSA)

Cooperation with Nordic PSA Group project on HRA dependences in Task 2.3 HRA Dependencies

FinPSA End User Group

OECD/NEA WGRISK (Working Group on Risk Assessment)

- Submission of CAPS activity proposal on Human Reliability Analysis for digitalized control rooms.
- Participation in the activities on Status of Practice for Level 3 Probabilistic Safety Assessment and Status of Site Level PSA (Including Multi-unit PSA developments)

ETSON (European Technical Safety Organizations Network), working group on Probabilistic Safety Assessment

- Participation in group activities by email and meeting,

ISCH COST Action IS1304, Ahti Salo management committee member

Program Committee Memberships of International Conferences and Workshops:

- 27th European Conference on Operational Research, 12-15 July 2015, Glasgow (Ahti Salo)

Integrated safety assessment and justification of nuclear power plant automation (SAUNA):

NKS project MODIG (MOdelling of DIGital I&C)

NKS project PLANS (Planning Safety Demonstration)

OECD/NEA Working Group on Risk Assessment (WGRISK)

OECD/NEA WGHOF (Working Group on Human and Organisational Factors)

OECD/NEA WGHOF Task group on Achieving Reasonable Confidence in Validation Test Results of Integrated System Performance for Nuclear Power Plant Main Control Rooms

ISO/IEC JTC1 SC7 Software and systems engineering - WG7 Life cycle management; WG10 Process assessment.

Comprehensive Analysis of Severe Accidents (CASA):

OECD/NEA BSAF-2 (Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station, phase 2)

U.S.NRC CSARP (Co-operative Severe Accident Research Program)

NKS/DECOSE (Debris Coolability and Steam Explosion)

Chemistry and transport of fission products (CATFIS):

OECD/NEA STEM (Source Term Evaluation and Mitigation)

NKS project ATR (Impact of Aerosols on the Transport of Ruthenium in the primary circuit of nuclear power plant), co-operation with Chalmers University of Technology

PhD thesis work in collaboration with Paul Scherrer Institut (PSI), Villingen, Switzerland

NUGENIA TA2.4 Source term area (participation in the coordination group)

Comprehensive and systematic validation of independent safety analysis tools (COVA):

OECD/WGAMA (Working Group on Analysis and Management of Accidents)

OECD/HYMERES (Hydrogen Mitigation Experiments for Reactor Safety)

OECD/PKL-3 (Primary Coolant Loop Test Facility)

OECD/ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation)

FONESYS (The Forum & Network of System Thermal-Hydraulic Codes in Nuclear Reactor Thermal-Hydraulics)

USNRC/CAMP (Code Applications and Maintenance Program)

Couplings and instabilities in reactor systems (INSTAB):

NKS project COPSAR (Containment Pressure Suppression Systems Analysis for Boiling Water Reactors)

NORTHNET (The Nordic Thermal Hydraulics and Nuclear Safety Network) Roadmap 3

NURESAFE (Nuclear Reactor Safety Simulation Platform) (Euratom FP7 project)

Integral and separate effects tests on thermal-hydraulic problems in reactors (INTEGRA):

OECD/NEA PKL Phase 3 project

Nuclear Criticality and Safety Analyses Preparedness at VTT (KATVE):

OECD/NEA NSC (Nuclear Science Committee)

OECD/NEA WPNCS (Working Party on Nuclear Criticality Safety)

OECD/NEA EGUNF (Expert Group on Used Nuclear Fuel)

OECD/NEA EGADSNF (Expert Group on Assay Data of Spent Nuclear Fuel)

AER WG E (Atomic Energy Research, working group E: radwaste, spent fuel and decommissioning)

EWGRD (European Working Group on Reactor Dosimetry)

Development of a Monte Carlo based calculation sequence for reactor core safety analyses (MONSOON):
Collaboration with International Serpent user community (500 users in 150 universities and research organizations in 37 countries worldwide.

Membership in the Executive Committee of American Nuclear Society (ANS) Reactor Physics Division (RPD).

Membership in the Editorial Board of Annals of Nuclear Energy.

Membership in the Technical Program Committee of the PHYSOR 2016 international conference.

Membership in the OECD Nuclear Energy Agency, Working Party on Nuclear Criticality Safety (WPNCS), Expert Group on Advanced Monte Carlo Techniques (EGAMCT).

Membership in the OECD Nuclear Energy Agency, Working Party on Scientific Issues of Reactor Systems (WPRS).

Neutronics, burnup and nuclear fuel (NEPAL15):
Serpent User Group

Development and validation of CFD methods for nuclear reactor safety assessment (NURESA):

OECD/NEA HYMERES Panda HP1_6_2 CFD blind benchmark on the erosion of stratified helium layer.

Nordic Thermal Hydraulic Network (Northnet), Roadmap 1 (OpenFOAM CFD-solver for nuclear reactor safety assessment).

Nordic Thermal Hydraulic Network (Northnet), Roadmap 3 (Containment Pressure Suppression Systems Analysis for Boiling Water Reactors).

NKS project COPSAR (Containment Pressure Suppression Systems Analysis for Boiling Water Reactors).

Physics and chemistry of nuclear fuel (PANCHO):
OECD Halden Reactor Project
OECD/NEA Working Group on Fuel Safety
Halden Programme Group Fuel&Materials

Jules Horowitz Reactor Fuel Working Group

OECD/NEA – IRSN Cabri Water Loop Project, Technical Advisory Group (TAG)

OECD/NEA benchmark UAM (Uncertainty Analysis in Best-Estimate Modelling for Design, Operation and Safety Analysis of LWRs)

OECD/WGFS RIA benchmark Phase II
IAEA Coordinated Research Programme (CRP) Fuel modelling in accident conditions (FUMAC).

Safety analyses for dynamical events (SADE):

OECD/NEA WPRS Working Party on Scientific Issues of Reactor Systems

OECD/NEA EGUAM Expert Group on Uncertainty Analysis in Modelling

OECD/NEA Oskarshamn-2 (O2) BWR Stability Benchmark for Coupled Code Calculations and Uncertainty Analysis in Modelling

AER working group D on VVER safety analysis

Uncertainty and sensitivity analyses for reactor safety (USVA):

OECD Benchmark for Uncertainty Analysis in Best-Estimate Modelling (UAM)

for Design, Operation and Safety Analysis of LWRs

FIre Risk Evaluation and Defence-in-Depth (FIRED):

OECD/NEA PRISME2

Analysis of fatigue and other cumulative ageing to extend lifetime (FOUND):
NUGENIA Association Technical Area 8 (TA8), ENIQ (European Network for

Inspection and Qualification) Task Group Risk (TGR) activities.

Co-operation with the Swedish-Finnish Beräkningsgupp (BG)

European Technical Safety Organization Network (ETSON)

Nugenia+: Project REDUCE (Justification of Risk Reduction through In-service Inspection)

ASME PVP: Informal networking with the main contributors in the field of environmental fatigue.

Long term operation aspects of structural integrity (LOST):

ASTM E08 committee meeting

Mitigation of cracking through advanced water chemistry (MOCCA):

European Co-operation Group on Corrosion Monitoring (ECG-COMON)

International Co-operative Group on Environmentally Assisted Cracking (ICG-EAC)

Numerical methods for external event assessment improving safety (NEST):

Activity leader to NKS project ADGROUND “Modelling as a Tool to Augment Gound Motion Date in Regions of Diffuse Seismicity” financed and approved for 2015/2016 (Ludovic) – partners Aalto University, Helsinki University, ÅF-Consult, Uppsala University and The Geological Survey of Danmark and Greenland (GEUS)

Participation in ERNCIP European Reference Network for Critical Infrastructure Protection, Thematic group Resistance of structures to explosion effects

VERCORS, *Vérification réaliste du confinement des réacteurs,* is a research program focusing on civil work numerical models. VERCORS is organized by the French energy company Électricité de France (EDF). An experimental mockup of a reactor containment building at 1:3 scale is has been built at Renardières, 70 km southeast of Paris in France. The benchmark exercise has been set up by EDF to numerically study the test structure. VTT (Kim Calonius) participated this benchmark in 2015.

Thermal ageing and EAC research for plant life management (THELMA):

Membership in scientific committee for International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, U. Ehrnstén

Steering committee member in ICG-EAC group (International Co-operative Group of Environmentally Assisted Cracking), U. Ehrnstén

Member of EPRI EPRI A690 Expert Panel, H. Hänninen

IFRAM, the International Forum on Reactor Ageing Management (NRC coordinated network)

OECD Halden Reactor Project (characterisation of materials used in the project)

Co-operation with MIT, USA on thermal ageing of stainless steel weld metals

Co-operation with KAPL, USA on thermal ageing of lean duplex stainless steels

Co-operation with KAERI, Korea on ordering in Alloy 690 material

Co-operation with Pål Efsing, Vattenfall, and Martin Bjurman, Studsvik on thermal ageing of cast stainless steel

Nugenia Association, Technical Area 4 (TA4), INCEFA+ project (Increasing Safety in NPPs by Covering Gaps in Environmental Fatigue Assessment)

MICRIN+ project (Mitigation of environmentally assisted crack initiation) under Nugenia+ project

NDE of NPP primary circuit components and concrete infrastructure (WANDA):

International cooperation within U.S. Nuclear Regulatory Commission (NRC) PARENT (Program to Assess the Reliability of Emerging Nondestructive Techniques)

OECD/NEA WGIAGE (Concrete group)

JHR collaboration & Melodie follow-up (JHR):

Jules Horowitz Reactor project:

- 3rd meeting of the Fuel and Material Working Groups, Prague, Czech Republic
- 3rd meeting of the Technology Working Group, CEA Saclay, France
- 5th Technical Seminar on JHR Experimental Capacity, CEA Cadarache, France
- 4th meeting of the Working Groups, Studsvik, Sweden

Appendix 3

Academic degrees obtained in the projects in 2015

Extreme weather and nuclear power plants (EXWE):

Doctor of Philosophy:

Hanna M. Mäkelä: Estimates of past and future forest fire danger in Finland from a climatological viewpoint. University of Helsinki, Department of Physics, February 2015.

Ari-Juhani Punkka: Mesoscale convective systems in Finland. University of Helsinki, Department of Physics, November 2015.

Master of Science in Philosophy:

Peter Ukkonen: Evaluation of thunderstorm predictors in Finland from ECMWF reanalyses and lightning location data. University of Helsinki, Department of Physics, 2015.

Comprehensive Analysis of Severe Accidents (CASA):

Doctor of Technology:

Eveliina Takasuo: Coolability of porous core debris beds: Effects of bed geometry and multi-dimensional flooding. Lappeenranta University of Technology, November 2015.

Chemistry and transport of fission products (CATFIS):

Doctor of Technology:

Jarmo Kalilainen: Fission product transport in the primary circuit and in the containment in severe nuclear accidents. 2015, (Aalto University publication series, DOCTORAL DISSERTATIONS 71/2015, ISBN:978-952-60-6214-3, https://aaltodoc.aalto.fi/ bitstream/handle/123456789/16568/ isbn9789526062143.pdf, 172 p.)

Nuclear Criticality and Safety Analyses Preparedness at VTT (KATVE):

Master of Science in Technology:

Toni Kaltiaisenaho: Implementing a photon physics model in Serpent 2, Aalto University, Department of Applied Physics, spring 2016 (Master's thesis was prepared in KATVE 2015, graduation expected in spring 2016)

Development of a Monte Carlo based calculation sequence for reactor core safety analyses (MONSOON):

Doctor of Technology:

Tuomas Viitanen: Development of a stochastic temperature treatment technique for Monte Carlo neutron tracking, Aalto University, Department of Applied Physics, May 2015.

Development and validation of CFD methods for nuclear reactor safety assessment (NURESA):

Master of Science in Technology:

Cristian Roda Guillem: A Simulation of a Subcooled Nucleate Boiling in a Pipe with OpenFOAM, Aalto University, School of Engineering, June 2015.

Physics and chemistry of nuclear fuel (PANCHO):

Doctor of Technology:

Ville Tulkki: Modelling nuclear fuel behaviour and cladding viscoelastic response. VTT Technical Research Centre of Finland, 2015, (VTT Sciences 109, ISBN 978-951-38-8347-8, http://www.vtt.fi/inf/pdf/science/2015/S109.pdf, 65 p. + app. 56 p)

Analysis of fatigue and other cumulative ageing to extend lifetime (FOUND):

Master of Science in Technology:

Tommi Seppänen: Environmental Effect of Reactor Coolant on Fatigue of Stainless Steel, Aalto University School of Engineering, January 2016

Aapo Ristaniemi: Linearization of piping supports in dynamic analyses, Aalto University School of Engineering, September 2015

Thermal ageing and EAC research for plant life management (THELMA):

Doctor of Technology:

Matias Ahonen: Effect of microstructure on low temperature hydrogen induced cracking behaviour of nickel-based alloy weld metals. VTT SCIENCE 105, 2015.

Appendix 4

International travels in the projects in 2015

Crafting Operational Resilience (CORE):

Laarni, J., ANS NPIC&HMIT /OECD-NEA WGHOF ISV, February 19-26 2015, Charlotte, USA.

Viitanen, K., Oedewald, P., LESUN Project team meeting. May, 26-27 2015, Halden, Norway.

Viitanen, K., Wahlström, M., The 6th REA Symposium, June 22-25, 2015, Lisbon, Portugal.

Torniainen, J., The Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBC 2015, August 25-29, 2015, Milan, Italy.

Pakarinen, S., The 9th World Congress of International Brain Research Organization IBRO, July 7-11, 2015, Rio de Janeiro, Brazil.

Extreme weather and nuclear power plants (EXWE):

Hynönen, R., E.I. Tanskanen and P. Francia, IUGG meeting in Prague, 22 June-2 July 2015 2015. http://www.iugg2015prague.com/scientific-program.htm

Jylhä, K. Mistra Arctic Sustainable Development (MASD) workshop: Uncertain Futures: The Changing Global Context of the European Arctic, Pajala, Sweden, 9-10 March 2015.

Jylhä, K. 12th Urban Environment Symposium, Oslo, Norway, 1-3 June 1-3 2015. http://hues.se

Jylhä, K. Workshop om klimaendringer i Nordland & AACA Barents region writeshop for Future narratives chapter, Bodø, 25-26 August 2015.

Kämäräinen, M., The 15th Annual Meeting of the European Meteorological Society & 12th European Conference on Applications of Meteorology (ECAM), Sofia, Bulgaria, 7-11 September 2015. http://www.ems2015.eu/home.html

Leijala, U. 10th Baltic Sea Science Congress, Riga, Latvia, 15-19 June 2015. http://www.bssc2015.lv/

Peitso, P., E.I. Tanskanen. EGU meeting in Vienna, 12-17 April 2015. http://meetingorganizer.copernicus.org/EGU2015/orals/17999

Pellikka, H. Workshop on Global and Regional Sea Level Variability and Change, Palma de Mallorca, Spain, 10-12 June 2015. https://slrmallorca.wordpress.com/

Pellikka, H. Research visit to Institute of Oceanography and Fisheries, Split, Croatia, 15 Nov - 13 Dec 2015.

Tanskanen, E.I., Space Climate Connections, Kiel, 16-19 March 2015. http://scc.geomar.de/frontend/index.php

Tanskanen, E.I., “Ionospheric space weather and its drivers” and “Hands-on-session”, ERCA School, Grenoble, 25.-28 January 2015.

Tanskanen, E.I., Ground-based magnetometers in ESPAS, ESPAS School, Warsaw, 19.-20 October 2015.

Tanskanen, E.I., Polar magnetospheric substorms AGF-345 in University Centre in Svalbard, November 2015.

Tanskanen, E.I. miniGEM, San Francisco, 13 December 2015. http://www.cpe.vt.edu/gem-mini/

Ukkonen, P. The 8th European Conference on Severe Storms (ECSS2015), 14-18 September 2015. http://www.essl.org/cms/european-conferences-on-severe-storms/ecss-2015/

Vajda A. Copernicus Climate Projections Workshop, Reading, UK, 20-21 April 2015

Management Principles and Safety Culture in Complex Projects (MAPS):

Gotcheva, N. Participation at the 6th International Project Business Workshop, 19-20 November, 2015, Trondheim, Norway.

Gotcheva, N. Participation at the 6th Symposium on Resilience Engineering, June 22-25, 2015, Lisbon, Portugal (presentation and full paper submission)

Gotcheva, N. Participation at the NoFS2015, the 21st Nordic Research Conference on Safety, 25-27 August, Helsinki, Finland.

Ylönen, M. Cultural Characteristics of Finnish nuclear safety regulation, Society for Risk Analysis (SRA-Europe) conference 15-17, June 2015, Maastricht, Netherlands.

Ylönen, M. European Sociological Association’s Conference, 25-28 of August 2015, Prague, Czech Republic

Ylönen, M. International Sociological Association’s RC24 workshop, 22-25 September, Örebro, Sweden

Ylönen, M. Trading Zones in Technological Societies. Session Nuclear Energy and Safety.15-16 October, Liège, Belgium

Ylönen, M. Society for Risk Analysis, Nordic Chapter, 16-17 November, Lund, Sweden

Ylönen, M. Preparations for the benchmarking Norwegian oil and gas, 12-17 January, Stavanger, Norway.

Probabilistic risk assessment method development and applications (PRAMEA):

Karanta, I. NPSAG/NKS level 3 PSA seminar, January 28th 2016, Solna, Sweden.

Karanta, I., Kling, T., Liinasuo, M., Tyrväinen, T. PSA Castle meeting, September 8-10, 2015, Haikko Manor, Finland.

Björkman, K. International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2015, 26 - 30 April 2015, Sun Valley, ID, USA.

Porthin, M. EXAM-HRA Seminar 22 January, 2015, Stockholm.

Porthin, M. OECD/NEA WGRISK (Working Group on Risk Assessment) annual meeting, 4-6 March, 2015, Paris.

Porthin, M. ETSON (European Technical Safety Organizations Network), working group on Probabilistic Safety Assessment, meeting, 4 November, 2015, Brussels.

Porthin, M. HRA Society Master Class 17-18 May, 2015, Clamart, France.

A. Mancuso, A. Salo. Safety and Reliability of Complex Engineered Systems: ESREL 2015, September 7-10, 2016, Zürich, Switzerland.

Holmberg, J.-E., Porthin, M. PSA Castle meeting & HRA dependences subtask stakeholders meeting, September 8-10, 2015, Haikko Manor, Finland.

Holmberg, J.-E., Jacobsson, M., Porthin, M. Dependencies in HRA – Kick-off meeting with stakeholders, February 11, 2015, Sundbyberg, Sweden.

Holmberg, J.-E., Jacobsson, M., Porthin, M. Dependencies in HRA - Stockholm Seminar, December 3, 2015, Sundbyberg, Sweden.

Integrated safety assessment and justification of nuclear power plant automation (SAUNA):

Koskela, M., NKS-R DIGREL final seminar, January 15, 2015, Stockholm, Sweden.

Papakonstantinou, N., 2015 Annual Reliability and Maintainability Symposium (RAMS), January 26-29, 2015, Palm Harbor, FL, USA.

Laarni, J., ANS NPIC&HMIT / OECD-NEA WGHOF ISV, February 19-26, 2015, Charlotte, NC, USA.

Björkman, K., Holmberg, J.-E., International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2015), April 26-30, 2015, Sun Valley, ID, USA.

Porthin, M., 16th Annual Meeting of the CSNI Working Group on Risk Assessment (WGRISK), March 4-6, 2015, Paris, France.

Pakonen, A., Automaatio XXI seminaari, March 17-18, 2015, Helsinki, Finland.

Valkonen, J., NKS-R PLANS kick-off meeting, March 23, 2015, Stockholm, Sweden.

Valkonen, J., Tommila, T., NKS-R PLANS workshop on safety demonstration and planning in Nordic NPP digital I&C projects, May 12, 2015, Stockholm, Sweden.

Tyrväinen, T., Porthin, M. NKS-R MODIG project internal workshop, June 11, 2015, Stockholm, Sweden.

Uusitalo, E., 23rd IEEE International Requirements Engineering Conference (IEEE RE'15), August 24-28 2015, Ottawa, Canada.

Helminen, A., Holmberg, J.-E., Porthin, M., Tyrväinen, T., Nordic PSA Castle Meeting 2015, Haikko Manor, September 8–10, 2015, Porvoo, Finland.

Linnosmaa, J., International Conference on Computer Safety, Reliability and Security (SAFECOMP 2015), September 22-25, Delft, the Netherlands.

Varkoi, T., 22nd EuroAsiaSPI Conference, September 30 – October 2, 2015, Ankara, Turkey.

Pakonen, A., The 8th International Workshop on Application of Field Programmable Gate Arrays in Nuclear Power Plant, October 13-16, 2015, Shanghai, China.

Vyatkin, V., Discussion on modelling of nuclear automation systems at DIAL (University of Cambridge), during the 5th Workshop on Service Orientation in Holonic and Multi-Agent Manufacturing (SOHOMA 2015), November 5–6, 2015, Cambridge, UK.

Vyatkin, V., Pang, C., 41st Annual Conference of the IEEE Industrial Electronics Society (IECON 2015), November 9–12, Yokohama, Japan.

Pang, C., Regular meeting of MDE research collaborative group at TU Munich. November 26–27, 2015, Munich, Germany.

Vyatkin, V., Seminar on user-friendly specification methods at ITMO University, December 21, St. Petersburg, Russia.

Holmberg, J.-E., Nordic perspectives of Fukushima: Where are we now and where do we go?
Joint NKS-R and NKS-B Seminar, 12–13 January 2016, Stockholm, Sweden.

Comprehensive Analysis of Severe Accidents (CASA):

Takasuo, Eveliina. NKS/DECOSE project meeting. 9-10 February 2015. Stockholm, Sweden.

Sevón, Tuomo. 1st OECD BSAF-2 meeting. 22-26 June 2015. Tokyo, Japan.

Strandberg, Magnus. Course on Severe Accident Phenomenology. 6-10 July 2015. Stockholm, Sweden.

Sevón, Tuomo. CSARP/MCAP meeting. 14-18 September 2015. Albuquerque, New Mexico.

Strandberg, Magnus. MC3D intensive training. 30 November - 4 December 2015. Aix-en-Provence, France.

Sevón, Tuomo. 2nd OECD BSAF-2 meeting. 7-10 December 2015. Paris, France.

Chemistry and transport of fission products (CATFIS):

Kärkelä, T., Gouëllo, M., 7th ERMSAR Conference, European Review Meeting on Severe Accident Research 2015 (ERMSAR2015), 24 - 26 March 2015, Marseille, France.

Kärkelä, T., Gouëllo, M., Auvinen, A., International OECD-NEA/NUGENIA-SARNET Workshop on the "Progress in Iodine Behaviour for NPP Accident Analysis and Management", 30 March - April 1, 2015, Marseille, France.

Kärkelä, T., Auvinen, A., The first NUGENIA-TA2/SARNET Workshop on Source Term, 1-2 April 2015, Marseille, France.

Gouëllo, M., CLADS Decommissioning Workshop - International Collaboration Toward Advanced Decommissioning of Fukushima-Daiichi NPP, 9 - 13 November 2015, Tokai-mura, Japan.

Kärkelä, T., Gouëllo, M., Aerosol Technology 2015 (AT2015), 15 - 17 June, Tampere, Finland.

Kärkelä, T., XVII Conference of the NSFS, 24 - 27 August 2015, Roskilde, Denmark.

Kärkelä, T., Auvinen A., 6th Meeting of the Programme Review Group and Management Board of the OECD/NEA STEM Project, 22-23 June 2015, Paris, France.

Comprehensive and systematic validation of independent safety analysis tools (COVA):

Hillberg S. USNRC/CAMP meeting, 2.11.-7.11.2015, Gettysburg, USA.

Karppinen I. OECD/HYMERES programme review group meeting, 16.11.-19.11.2015, Villigen, Switzerland.

Karppinen I. OECD/PKL3 Programme Review Group meeting, 9.11.-12.11.2015, Madrid, Spain.

Karppinen I. OECD/WGAMA meeting, 22.9.-25.9.2015, Paris, France.

Karppinen I. OECD/PKL3 Project Review Group meeting, 6.7.-8.7.2015, Brussels, Belgium.

Kolehmainen J. Analytical Workshop (16 and 17 June 2015) preceding the OECD/HYMERES PRG5/MB5 project meetings, 15.6.-18.6.2015, Villigen, Switzerland.

Kolehmainen J. 32nd Short Courses on Multiphase flow, 8.2.-13.2.2015, Zurich, Switzerland.

Kurki J. OECD/ATLAS PRG meeting, 18.10.-23.10.2015, Daejeon, South Korea.

Kurki J. FONESYS workshop, 2.2.-5.2.2015, Paris, France.

Couplings and instabilities in reactor systems (INSTAB):

Tanskanen, V., Patel, G., NURETH-16, 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, August 30 – September 4, Chicago, USA.

Puustinen, M., Purhonen, H., NORTHNET RM3 Meeting, October 1, 2015, Stockholm, Sweden.

Tanskanen, V., NURESAFE 2nd Open Seminar, SP3 Meeting, GB Meeting, November 2-6, 2015, Brussels, Belgium.

Integral and separate effects tests on thermal-hydraulic problems in reactors (INTEGRA):

Heikki Purhonen, Juhani Hyvärinen, The Programme Review Group and Management Board meetings of the OECD/NEA PKL Phase 3 Project, Brussels Belgium, 7th-8th July 2015.

Heikki Purhonen, Vesa Riikonen, The Programme Review Group and Management Board meetings of the OECD/NEA PKL Phase 3 Project, Madrid Spain, 10th-11th November 2015.

Nuclear Criticality and Safety Analyses Preparedness at VTT (KATVE):

Räty, A., SCALE Criticality Safety and Radiation Shielding Course (Oak Ridge National Laboratory), 2-6th March, NEA Headquarters, Issy-les-Moulineaux, France

Kotiluoto, P., OECD NEA Nuclear Science Committee and Data Bank Executive Group meetings, 10-12th June, NEA Headquarters, Issy-les-Moulineaux, France

Rantamäki, K., OECD NEA Working Party on Nuclear Reactor Safety (WPNCS) meetings: Expert Group of Assay Data of Spent Nuclear Fuel (EGADSNF), Expert Group on Used Nuclear Fuel (EGUNG) and WPNCS, 5-8th July, NEA Headquarters, Issy-les-Moulineaux, France

Rantamäki, K., International Conference on Nuclear Criticality Safety ICNC2015, 13-17th September, Omni Charlotte Hotel, Charlotte, USA

Kaltiaisenaho, T., 5th International Serpent User Group Meeting, 13-16th October, University of Tennessee, Knoxville, Tennessee, USA

Viitanen, T., Meeting of the European Working Group on Reactor Dosimetry (EWGRD), 8th December, Warsaw, Poland

Development of a Monte Carlo based calculation sequence for reactor core safety analyses (MONSOON):

Leppänen, J. June 7-11, 2015, San Antonio, TX, USA – ANS Annual Meeting and Reactor Physics Division Executive Committee Meeting.

Leppänen, J., Pusa, M., Viitanen, T., Valtavirta, V. and Kaltiaisenaho, T. October 13-16, 2015, Knoxville, TN, USA – 5th International Serpent User Group meeting.

Leppänen, J., Pusa, M., Viitanen, T., and Valtavirta, V. October 21, 2015, Ottawa, ON, Canada – Serpent workshop at the 7th International Conference on Modeling and Simulation in Nuclear Science and Engineering.

Leppänen, J., Viitanen, T. and Valtavirta, V. October 22, 2015, Chalk River, ON, Canada – Serpent workshop at CNL.

Leppänen, J. November 8-12, 2015. Washington, DC, USA – ANS Winter Meeting and Reactor Physics Division Executive Committee Meeting.

Leppänen, J. December 7, 2015, Massachusetts Institute of Technology, Invited seminar.

Neutronics, burnup and nuclear fuel (NEPAL15):

Isotalo, A., visiting scientist at Oak Ridge National Laboratory from June 2, 2014 to December 23, 2015 (8 months in SAFIR14 + 11 months in SAFIR2018)

Development and validation of CFD methods for nuclear reactor safety assessment (NURESA):

Huhtanen, R., 6th Meeting of the Programme Review Group of the OECD HYMERES Project, Paul Scherrer Institute, Villigen, Switzerland, 16–17 June, 2015.

Pättikangas, T., Nordic Thermal Hydraulic Network (Northnet), Roadmap 1 Reference Group Meeting, 29 May, 2015, KTH, AlbaNova, Stockholm, Sweden.

Pättikangas, T., Nordic Thermal Hydraulic Network (Northnet), Roadmap 3 Reference Group Meeting, 1 October, 2015, KTH, AlbaNova, Stockholm, Sweden.

Peltola, J., Nordic Thermal Hydraulic Network (Northnet), Roadmap 1 Reference Group Meeting, 26 November, 2015, KTH, AlbaNova, Stockholm, Sweden.

Physics and chemistry of nuclear fuel (PANCHO):

Arkoma, A., 2nd meeting of OECD/WGFS Task Group on RIA fuel rod code benchmark phase II, 20.-22.4.2015, Belgium .

Arkoma, A., 3rd meeting of OECD/WGFS Task Group on RIA fuel rod code benchmark phase II, 28.-30.9.2015, France.

Ikonen, T., Topfuel2015, 13.-18.9.2015, Switzerland.

Ikonen, T., OECD/WGFS meeting, 29.9.-2.10.2015, France.

Kättö, J., WGFS/HRP LOCA workshop, 19.-22.5.2015, France.

Kättö, J., VVER conference, 27.9.-4.10.2015, Bulgaria.

Loukusa, H., Halden Summer School 2015, 23.-27.8.2015, Norway.

Loukusa, H., NUFUEL workshop, 15.-19.11.2015, Germany.

Tulkki, V., Halden Summer School 2015 (lecturer), 25.-26.8.2015, Norway.

Tulkki, V., Halden Programme Group Meeting, 3.-5.11.2015, Norway.

Safety analyses for dynamical events (SADE):

Syrjälahti E., Meetings of OECD/NEA Working Party on Scientific Issues of Reactor Systems (WPRS) and Expert Group on Uncertainty Analysis in Modelling (EGUAM-05) , February 19-20, 2015, Issy-les-Moulineaux, France.

Syrjälahti E., AER working group D and OECD/NEA O2-4 workshop, May 18-19, 2015, Madrid, Spain.

Uncertainty and sensitivity analyses for reactor safety (USVA):

Pusa, M., Ikonen, T. and Syrjälahti E., OECD Benchmark for Uncertainty Analysis in Best-Estimate Modelling (UAM) for Design, Operation and Safety Analysis of LWRs, Ninth workshop (UAM-9), May 20-22, 2015, Madrid, Spain.

Ikonen, T. TopFuel 2015, September 13 – 17, 2015, Zurich, Switzerland.

Experimental Studies on Projectile Impacts Against Concrete Structures (ESPIACS):

Vepsä, A., The 23rd International Conference on Structural Mechanics in Reactor Technology (SMiRT23), 10-14 August 2015, Manchester, United Kingdom

FIre Risk Evaluation and Defence-in-Depth (FIRED):

Sikanen, T. 2nd IAFSS European Symposium of Fire Safety Science, 16-18.6.2015 Nicosia, Cyprus.

Matala, A. and Hostikka S. PRISME 2 meeting, April 14.-16, 2015, Aix-en-Provence, France.

Sikanen T. and Hostikka S. PRISME 2 meeting, November 17.-19, 2015, Aix-en-Provence, France.

Analysis of fatigue and other cumulative ageing to extend lifetime (FOUND):

Cronvall, O. Swedish-Finnish plant operators Beräkningssgrupp (BG) meeting in Stockholm 10th June 2015

Cronvall, O. Kärnteknik 2015 – Nordic nuclear technology symposium, November 11-12 2015, Stockholm, Sweden

Cronvall, O. and Alhainen, J., Fourth International Conference on Fatigue of Nuclear Reactor Components" 28 September – 1 October, 2015, Sevilla, Spain.

Cronvall, O., NUGENIA TA8: ENIQ - Sub-Area Risk (SAR) meeting, 12th March 2015, Madrid, Spain

Cronvall, O., NUGENIA TA8: ENIQ - Sub-Area Risk (SAR) meeting, 22nd October 2015, Rez, Czech Republic

Long term operation aspects of structural integrity (LOST):

Wallin, K. ASTM E08 committee meeting, May, 17-22, 2015, Anaheim, California, USA.

Wallin, K. ASTM E08 and A01 committee meetings, November, 16-18, 2015, Tampa, Florida, USA.

Mitigation of cracking through advanced water chemistry (MOCCA):

Sipilä, K., 16th Nordic Corrosion Congress in May 20-22, 2015, Stavanger, Norway

Saario, T., International Cooperation Group on Environmentally Assisted Cracking of Water Reactor Materials (ICG-EAC) meeting, May 17-22, 2015, Ann Arbor, Michigan, USA

Sipilä, K., European Co-operative Group on Corrosion Monitoring (ECG-COMON) meeting, June 14-16, 2015, Prague, Czech Republic

Sipilä, K., seminar on "Instrumental Methods on Electrochemistry" at Southampton University, UK, June 21-26, 2015.

Numerical methods for external event assessment improving safety (NEST):

Calonius K., Jussila V. and Saarenheimo A. Structural Mechanics in reactor Technology SMiRT-23 conference, 10-14 August 2014, Manchester (UK),

Jussila V., Fülöp L. Co-Organized the workshop "Potential of numerical methods to supplement empirical earthquake observations" with the Geological Survey of Denmark and Greenland (GEUS), 15 December 2015, Copenhagen

Fülöp L. Presentation at the seminar "Nordic perspectives of Fukushima: Where are we now and where do we go?" organized by NKS, 12-13 January 2016, Stockholm.

Thermal ageing and EAC research for plant life management (THELMA):

Ehrnstén, U. Nugenia Forum and MICRIN+ kick-off meeting, Ljubljana 14-16.4.2015.

Hänninen, H. Meeting with prof. M. Short on thermally aged stainless steels, MIT, Boston USA. 14.5. – 17.5.2015

Ehrnstén, U. ICG-EAC meeting (International Co-operative Group for Environmentally Assisted Cracking), Ann Arbor, Michigan, USA, 16-23.5.2015.

Ahonen, M., Mouginot, R. and Ehrnstén, U. 17th International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, Ottawa, Ontario, Canada, August 9-12, 2015.

Ehrnstén, U. Nugenia TA4 meeting, Renardie, Paris, France, 20-21.10.2015.

Ahonen, M. Kärnteknik 2015, Stockholm, Sweden, 11-12.11.2015.

NDE of NPP primary circuit components and concrete infrastructure (WANDA):

Bohner, E., Kraftindustrins Betongdag, Energiforsk and Vattenfall, 22nd - 23rd April 2015, Älvkarleby, Sweden

Ferreira, M., OECD/NEA-WGIAGE Concrete Group Meeting, 23rd - 24th March 2015, Paris

Ferreira, M (VTT) & Al-Neshawy, F (Aalto), *Structural Mechanics in Reactor Technologies 2015*(*SMiRT-23)* International conference, 10 – 14.08.2015, Manchester

Ferreira, M., ASCET CAPS meeting, NIST, Gaithersburg, 27.6. -2.7.2015

Koskinen, A., 11th international conference on Non Destructive Evaluation in relation to structural integrity for nuclear and pressurized components, 19st -21st May 2015, Jeju Island, Korea.

Leskelä, E., US-NRC PARENT-10 program meeting, 25th – 28th May 2015, Tokio, Japan.

Leskelä, E., US-NRC PARENT-10 program meeting, 26th -29th Nov. 2015, PNNL, Richland, USA

Development of thermal-hydraulic infrastructure at LUT (INFRAL):

Hyvärinen, J. 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-16, 30 August – 4 September 2015, Chicago, U.S.

JHR collaboration & Melodie follow-up (JHR):

Huotilainen, S., Kinnunen, P., Ikonen, T., 3rd Meeting of the JHR Fuel and Material Working Groups, 21-22 January 2015, Prague, Czech Republic

Huotilainen, S., Preliminary testing of the Melodie experimental setup and preparations for in-core experiment, 18-20 February 2015, CEA Saclay, France

Kinnunen, P., 3rd Meeting of the JHR Technology Working Group, 27 February 2015, CEA Saclay, France

Huotilainen, S., Tulkki, V., 5th Technical Seminar on JHR Experimental Capacity, 16-17 April 2015, CEA Cadarache, France

Huotilainen, S., Kinnunen, P., Tulkki, V., 4th Meeting of the JHR Working Groups, 6-7 October 2015, Studsvik, Sweden

Huotilainen, S., Follow-up of the Melodie in-core experiment, 8-10 December 2015, CEA Saclay, France

Renewal of Hot Cell Infrastructure (REHOT):

Myllykylä, E., Nuclear safeguards training, 23 March 2015 Luxemburg.

Tähtinen, S., Karlsen. W., Kukkonen, A., hot cell design insights, Aquila Ltd., 30-31 March 2015, Birmingham, England.

Tähtinen, S., Karlsen. W., hot cell design meeting, ITD GmbH, 6-8 July 2015, Dresden, Germany.

Lydman, J., Jokipii, M., hot cell utilization topical schooling “MAI Materials Degradation Course for Engrs in the Nuclear Industry”, 21-25 September 2015, Fontainebleau, France.

Tapper, U., Ivanchenko, M., electron microscope technology assessment, 28-30 September 2015, Eindhoven, Netherlands.

Karlsen, W., HOTLAB 2015 Conference, 28-30 September 2015, Leuven, Belgium

Tähtinen, S., Palosuo, I., Lyytikainen, T., textExpo mechanical testing equipment show, 11-13 October 2015, Ulm, Germany.

Tähtinen, S., Karlsen. W., Kukkonen, A., hot cell design meeting, ITD GmbH, 14-16 December 2015, Dresden, Germany.

Appendix 5

The management board, the steering groups, the reference groups and the scientific staff of the projects in 2015

SAFIR2018 Management Board - MB

Organisation	Member	Vice member
STUK	Marja-Leena Järvinen (Chair)	Risto Sairanen
STUK	Risto Sairanen (Vice chair)	Tomi Routamo
Aalto	Filip Tuomisto	Eila Järvenpää
Fennovoima	Hanna Virlander	Ilkka Männistö
Fortum	Kristiina Söderholm	Matti Kattainen
LUT	Juhani Hyvärinen	Heikki Purhonen
MEE	Jorma Aurela	Jaana Avolahti
SSM	Eva Simic	
Tekes	Arto Kotipelto	Reijo Munther
TVO	Liisa Heikinheimo	Risto Himanen
VTT	Eija Karita Puska	Petri Kinnunen
SAFIR2018 (Secretary)	Jari Hämäläinen	Vesa Suolanen

SAFIR2018 Steering Groups:

(November 2015)

SG1 – Plant safety and systems engineering

Organisation	Member	Vice member
STUK	Tomi Routamo (Chair)	Eero Virtanen
Fennovoima	Pekka Viitanen	Juho Helander
Fortum	Leena Salo	
TVO	Jari Pesonen	Mikko Lemmetty
SAFIR2018 (Secretary)	Jari Hämäläinen	Vesa Suolanen

SG2 – Reactor safety

Organisation	Member	Vice member
STUK	Risto Sairanen (Chair)	Antti Daavittila
Fennovoima	Pekka Nurmilaukas	Juha Luukka
Fortum	Satu Sipola	Timo Toppila
TVO	Juha Poikolainen (Vice chair)	Matti Paajanen
SAFIR2018 (Secretary)	Jari Hämäläinen	Vesa Suolanen

SG3 – Structural safety and materials

Organisation	Member	Vice member
STUK	Martti Vilpas (Chair)	Pekka Välikangas
Fennovoima	Erkki Pulkkinen	Pasi Lindroth
Fortum	Ritva Korhonen	Ossi Hietanen
TVO	Timo Kukkola (Vice chair)	Paul Smeekes
SAFIR2018 (Secretary)	Jari Hämäläinen	Vesa Suolanen

SAFIR2018 – Reference Groups and Projects:

(October 2015)

Reference Group	Projects	Comments
RG1 Automation, organisation and human factors	CORE (SG1), MAPS (SG1), SAUNA (SG1)	SG1 area
RG2 Severe accidents and risk analysis	EXWE (SG1), PRAMEA (SG1), CASA (SG2), CATFIS (SG2), ESPIACS (SG3), FIRED (SG3), NEST (SG3)	SG1, SG2 and SG3 areas
RG3 Reactor and fuel	KATVE (SG2), MONSOON (SG2), NEPAL15 (SG2), PANCHO (SG2), SADE (SG2)	SG2 area
RG4 Thermal hydraulics	COVA (SG2), INSTAB (SG2), INTEGRA (SG2), NURESA (SG2), USVA (SG2)	SG2 area
RG5 Structural integrity	FOUND (SG3), LOST (SG3), MOCCA (SG3), THELMA (SG3), WANDA (SG3)	SG3 area
RG6 Research infrastructure	INFRAL, JHR, REHOT	A special role

RG1 – Automation, organisation and human factors

Organisation	Member	Vice member
Aalto	Jarmo Ala-Heikkilä	N/A
Fennovoima	Tomi Lankinen, Liisa Sallinen	Janne Peltonen
Fortum	Juha Lamminen, Sami Matinaho, Leena Salo	Ville Nurmilaukas
LUT	Anne Jordan, Eetu Kotro	N/A
STUK	Mika Johansson, Ann-Mari Sunabacka-Starck	Mika Kaijanen, Hanna Kuivalainen, Heimo Takala
TVO	Mauri Viitasalo (Chair), Petri Koistinen	Lauri Tuominen
VTT	Paula Savioja, Tommi Karhela, Heli Talja	N/A

RG2 – Severe accidents and risk analysis

Organisation	Member	Vice member
Aalto	Ahti Salo	N/A
Fennovoima	Juho Helander (Vice chair), Antti Paajanen, Leena Torpo	Niina Miettinen
FMI	Heikki Tuomenvirta	Hilppa Gregow
Fortum	Calle Korhonen, Tapani Kukkola, Sami Siren	Tommi Purho
LUT	Jani Laine	N/A
STUK	Ellen Hakala, Ilkka Niemelä, Pekka Välikangas	Lauri Pöllänen
TVO	Antti Tarkiainen (Chair), Timo Kukkola, Lasse Tunturivuori	Maria Palomäki
VTT	Ilona Lindholm, Tony Rosqvist, Kim Wallin	N/A

RG3 – Reactor and fuel

Organisation	Member	Vice member
Aalto	Pertti Aarnio	N/A
Fennovoima	Libor Klecka, Jukka Rintala, Lauri Rintala	N/A
Fortum	Simo Saarinen, Laura Kekkonen	Jaakko Kuopanportti
LUT	Ville Rintala, Heikki Suikkanen	N/A
STUK	Antti Daavittila (Chair), Ulla Vuorio, Lena Hansson-Lyyra	N/A
TVO	Arttu Knuutila (Vice chair), Anssu Ranta-aho	Kari Ranta-Puska
VTT	Joona Kurki, Sami Penttilä	N/A

RG4 – Thermal hydraulics

Organisation	Member	Vice member
Aalto	Timo Siikonen	N/A
Fennovoima	Juha Luukka	Leena Torpo
Fortum	Timo Toppila (Vice chair), Aino Ahonen, Tapani Raunio	Tommi Rämä
LUT	Juhani Vihavainen, Lauri Pyy, Otso-Pekka Kauppinen	N/A
STUK	Eero Virtanen (Chair), Miikka Lehtinen	N/A
TVO	Janne Wahlman, Matti Paajanen	Timo Virtanen
VTT	Mikko Ilvonen, Anitta Hämäläinen, Jaakko Leppänen	N/A

RG5 – Structural integrity

Organisation	Member	Vice member
Aalto	Simo-Pekka Hannula	N/A
Fennovoima	Mika Helin, Juha Rinta-Seppälä, Pasi Lindroth	Cem Ecevitoglu
Fortum	Ossi Hietanen (Vice chair), Sanna Ala-Kleme, Alpo Neuvonen	Ritva Korhonen
LUT	Vesa Tanskanen	N/A
STUK	Mika Bäckström, Mirka Schild, Jari Louhivirta	Jukka Härkölä
TVO	Erkki Muttilainen (Chair), Paul Smeekes, Vesa Hiltunen	Kimmo Tompuri
VTT	Kim Wallin, Aki Toivonen, Pertti Auerkari	N/A

RG6 – Research infrastructure

Organisation	Member	Vice member
STUK	Martti Vilpas (Vice chair)	Dina Solatie
Fennovoima	Hanna Virlander	Ilkka Männistö
Fortum	Jyrki Kohopää (Chair)	Kristiina Söderholm
MEE	Jorma Aurela	N/A
TVO	Liisa Heikinheimo	Esa Mannola
Aalto	Mikko Alava	Filip Tuomisto
LUT	Heikki Purhonen	Juhani Hyvärinen
VTT	Petri Kinnunen	Timo Vanttola

Project personnel

Crafting Operational Resilience (CORE)

Research organisation: VTT, TTL
Project manager: Jari Laarni, VTT

Person	Org.	Tasks
Jari Laarni, PhD	VTT	Project manager, Human factors engineering, Work design, Cognitive modelling, Cognitive psychology
Hannu Karvonen, MA	VTT	Human factors, Functional situation modelling
Hanna Koskinen, MA	VTT	Human factors, Learning from successes, Emergency management
Timo Kuula, MA	VTT	Work-based learning, Work design
Marja Liinasuo, PhD	VTT	Human factors, Learning from successes, Emergency management
Pia Oedewald	VTT	Safety culture, Learning from successes, Operating experience review
Markus Porthin, MScTech	VTT	Emergency management
Paula Savioja, D.Sc. (Tech.)	VTT	Human factors, Functional situation modelling
Mikael Wahlström, PhD	VTT	Human factors, Work-based learning, Work design
Kaupo Viitanen	VTT	Safety culture, Learning from successes, Operating experience review
Satu Pakarinen, PhD	TTL	Deputy project manager, Psychophysiological methods, Stress management, Biofeedback
Marianne Leinikka, MA	TTL	Psychophysiological methods, Stress management, Biofeedback
Vuokko Puro, MScTech	TTL	Human factors, Safety Management, Operational experience review
Henriikka Ratilainen, MScTech	TTL	Human factors, Safety Management, Operational experience review

Marika Schaupp, MA	TTL	Work-based learning, Work design
Laura Seppänen, PhD	TTL	Work-based learning, Work design
Anna-Maria Teperi, PhD	TTL	Human factors, Safety Management, Operational experience review
Jari Torniainen, MScTech	TTL	Psychophysiological methods, Stress management, Biofeedback

Extreme weather and nuclear power plants (EXWE)

Research organisation: Finnish Meteorological Institute (FMI)
Project manager: Kirsti Jylhä, FMI

Person	**Org.**	**Tasks**
Kirsti Jylhä, Dr	FMI	Project management; WP1 coordination; extreme convective weather; freezing rain
Ari Venäläinen, Dr	FMI	Debyte project manager
Katerina Andréeová-Kähönen, Dr	FMI	Extreme solar wind disturbances
Hanna Boman, MSc	FMI	Meteotsunamis: analysing tide gauge records
Hilppa Gregow, Dr	FMI	Freezing rain: contributing to writing
Harri Hohti, MSc	FMI	Weather radar images of sea-effect snow
Reko Hynönen, MSc	FMI	Waves in solar wind and on ground
Otto Hyvärinen, Dr.	FMI	Freezing rain: optimization methods
Milla Johansson, Dr	FMI	Joint effect of high sea level and waves
Hannu Jokinen	FMI	Meteotsunamis: refraction modeling
Pauli Jokinen, MSc	FMI	Warm-season extreme convective weather
Kimmo Kahma, Prof	FMI	Meteotsunamis, supervision of sea level research
Anu Karjalainen, Ms	FMI	Meteotsunamis: analysing tide gauge records
Ari Karppinen, Dr	FMI	Dispersion modelling: development; WP4 coordination
Matti Kämäräinen, MSc	FMI	Freezing rain; sea-effect snowfall; development of methods
Ilari Lehtonen, MSc	FMI	Synoptic analysis of meteotsunami cases
Ulpu Leijala	FMI	Joint effect of high sea level and waves
Anna Luomaranta, MSc	FMI	Sea-effect snowfall, simulations with HARMONIE
Antti Mäkelä, Dr	FMI	Warm-season extreme convective weather; task 1.3 coordination
Terhi Laurila, BSc	FMI	Weather radar images of sea-effect snow
Pyry Peitso, MSc	FMI	Extreme geomagnetic disturbances
Hilkka Pellikka, MSc	FMI	Meteotsunamis, WP2 coordination

Ari-Juhani Punkka, Dr	FMI	Warm-season extreme convective weather
Jenni Rauhala, MSc	FMI	Warm-season extreme convective weather; task 1.3 coordination
Elena Saltikoff, Dr	FMI	Simulations with HARMONIE
Mikhail Sofiev, Dr	FMI	Dispersion modelling: development
Jani Särkkä, Dr	FMI	Joint effect of high sea level and waves
Eija Tanskanen, Prof	FMI	Extreme magnetic weather, WP3 coordination
Jari Tuovinen, MSc	FMI	Warm-season extreme convective weather, severe hail
Andrea Vajda, Dr	FMI	Freezing rain: contributing to writing
Julius Vira	FMI	Dispersion modelling: development

Management Principles and Safety Culture in Complex Projects (MAPS)

Research organisations: VTT, Aalto University, University of Oulu
Project manager: Nadezhda Gotcheva, VTT

Person	Org.	Tasks
Pia Oedewald, MSc	VTT (till May 2015)	Project management (till May 2015)
Nadezhda Gotcheva, PhD	VTT	Project management (starting end of May 2015), WP3 leader, WP5 leader, WP1 (safety culture expertise, literature review on project complexity, conceptual analysis, qualitative empirical data collection and analysis - interviews at the three power companies, modelling of cultural complexity, internal integration, communication and dissemination of results)
Marja Ylönen, PhD	VTT (from August 2015)	Deputy project management (starting September 2015), WP2 leader (empirical data collection and analysis of the regulator's role in setting constraints and requirements for projects, benchmarking between the nuclear industry and the oil & gas industry-interviews and analysis)
Sampsa Ruutu, PhD student	VTT	WP4 leader (system dynamics modelling literature review)
Pertti Lahdenperä, Principle Scientist	VTT	Scientific support for WP1, construction industry network management
Karlos Artto, Professor	Aalto University	Scientific advisor (project business perspective); analysis of typical project governance models of complex projects from safety point of view

Matilda Starck, Master's student	Aalto University (end of 2015)	Governance models in safety critical projects (WP1) (thesis to be finalized in May 2016)
Jaakko Kujala, Professor	University of Oulu	Project governance models of complex projects from safety point of view (WP1); system dynamics modelling support (WP4)
Kirsi Aaltonen, Assistant Professor	University of Oulu	Project governance models of complex projects from safety point of view (WP1); support for review on project complexity literature (WP1)
Aki Pekuri, Post-doctoral researcher	University of Oulu	Systematic literature review of typical project governance models of complex projects (WP1)

Probabilistic risk assessment method development and applications (PRAMEA)

Research organisation: VTT, Risk Pilot, Aalto
Project manager: Ilkka Karanta, VTT

Person	**Org.**	**Tasks**
Ilkka Karanta, LicTech	VTT	Project management, Level 3 PSA method development and case studies, Level 3 PSA software development, Risk analysis of organizations and operations
Kim Björkman, MScTech	VTT	Multi-unit PRA modelling, method support for level 2 PSA
Terhi Kling, MScTech	VTT	Framework for the HRA of digitalized control rooms
Timo Korhonen, DrTech	VTT	Level 3 PSA method development and case studies
Marja Liinasuo, DrPsych	VTT	Framework for the HRA of digitalized control rooms, Benefits from qualitative analysis
Teemu Mätäsniemi, MScTech	VTT	Method support for level 2 PSA
Markus Porthin, MScTech	VTT	Framework for the HRA of digitalized control rooms, Benefits from qualitative analysis, Dependencies in HRA
Tero Tyrväinen, MScTech	VTT	Multi-unit PRA modelling, IDPSA, method support for level 2 PSA, Level 3 PSA method development and case studies
Jan-Erik Holmberg, DrTech	Risk Pilot	Dependencies in HRA
Magnus Jacobsson, MScTech	Risk Pilot	Dependencies in HRA

Ahti Salo, DrTech, professor	Aalto	Project management, Reliability analysis of defence-in-depth in organizations
Alessandro Mancuso, MScTech	Aalto	Reliability analysis of defence-in-depth in organizations

Integrated safety assessment and justification of nuclear power plant automation (SAUNA)

Research organisation: VTT, Aalto University, Risk Pilot, FiSMA, IntoWorks
Project manager: Antti Pakonen, VTT

Person	**Org.**	**Tasks**
Antti Pakonen, MScTech	VTT	Project management, Closed-loop modelling in formal verification, Requirement editing and refinement for formal verification
Jarmo Alanen	VTT	Systems Engineering Management Plan, Extending DIGREL plant example with functional reference I&C architecture
Kim Björkman, MScTech	VTT	Integration of model checking and PRA, Modelling of digital I&C (MODIG)
Atte Helminen, MScTech	VTT	Description and analysis of the Defence in Depth architecture
Jussi Lahtinen, MScTech	VTT	Structure-based test design, Integration of model checking and PRA, Closed-loop modelling in formal verification
Jari Laarni, PhD	VTT	Assurance methods and practices for documenting and justifying safety
Joonas Linnosmaa	VTT	Assurance methods and practices for documenting and justifying safety, Systems Engineering Management Plan
Jari Lappalainen, LicTech	VTT	Closed-loop modelling in formal verification
Teemu Tommila, MScTech	VTT	Description and analysis of the Defence in Depth architecture, Assurance methods and practices for documenting and justifying safety, Systems Engineering Management Plan
Nikolaos Papakonstantinou, DrTech	VTT	Description and analysis of the Defence in Depth architecture
Markus Porthin, MScTech	VTT	Modelling of digital I&C (MODIG)
Tero Tyrväinen, MScTech	VTT	Modelling of digital I&C (MODIG)
Janne Valkonen, MScTech	VTT	Assurance methods and practices for documenting and justifying safety, Planning safety demonstration – Expert network establishment (PLANS)

Valeriy Vyatkin, PhD	Aalto	Project management, Closed-loop modelling in formal verification, Requirement editing and refinement for formal verification
Igor Buzhinskii, MSc	Aalto	Closed-loop modelling in formal verification, Requirement editing and refinement for formal verification
Cheng Pang, PhD	Aalto	Closed-loop modelling in formal verification, Requirement editing and refinement for formal verification
Sandeep Patil, MSc	Aalto	Closed-loop modelling in formal verification
Jan-Erik Holmberg, DrTech	Risk Pilot	Project management, Modelling of digital I&C (MODIG)
Stefan Authén, MscTech	Risk Pilot	Modelling of digital I&C (MODIG)
Timo Varkoi, LicTech	FiSMA	Project management, Process assessment for systems and safety engineering, Assurance methods and practices for documenting and justifying safety
Risto Nevalainen, LicTech	FiSMA	Process assessment for systems and safety engineering, Assurance methods and practices for documenting and justifying safety
Eero Uusitalo, MScTech	IntoWorks	Project management, Extending DIGREL plant example with functional reference I&C architecture
Mika Koskela, MScTech	IntoWorks	Extending DIGREL plant example with functional reference I&C architecture

Comprehensive Analysis of Severe Accidents (CASA)

Research organisation: VTT
Project manager: Anna Nieminen, VTT

Person	**Org.**	**Tasks**
Tuomo Sevón, , M.Sc. (Tech.)	VTT	OECD BSAF-2 project participation and U.S.NRC CSARP contact, Fukushima accident analyses with MELCOR, WCB-1 experiment analysis.
Eveliina Takasuo, D.Sc. (Tech.)	VTT	Synthesising the results of the COOLOCE experiments on the effect of geometry to the debris bed coolability.
Magnus Strandberg, B.Sc. (Tech.)	VTT	Assessing sensitivity of key input parameters to steam explosion loads.
Anna Nieminen, M.Sc. (Tech.)	VTT	Project management, testing the capabilities of ASTEC to produce dose rates in the containment.
Jukka Rossi, M.Sc. (Tech.)	VTT	Defining probability distributions of

		radiation doses up to 300 km from the source with VALMA.
Mikko Ilvonen, Lic.Sc. (Tech.)	VTT	Analysing VALMA results to evaluate if countermeasures outside the preparedness zone of 20 are needed.

Chemistry and transport of fission products (CATFIS)

Research organisation: VTT
Project manager: Teemu Kärkelä, VTT

Person	Org.	Tasks
Teemu Kärkelä, MScTech	VTT	Project management, Ruthenium, Iodine and HNO_3 experiments, Interpretation of results
Melany Gouello, PhD	VTT	Iodine experiments in primary circuit conditions, HNO_3 formation experiments
Jouni Hokkinen, MScTech	VTT	Iodine experiments in primary circuit conditions, Construction of experimental facilities
Ari Auvinen, MScTech	VTT	Interpretation of results
Karri Penttilä, MScTech	VTT	ChemPool calculations on pool pH
Tommi Kekki, MScTech	VTT	HNO_3 formation experiments
Petri Kotiluoto, PhD	VTT	HNO_3 formation experiments
Emmi Myllykylä, MSc	VTT	Chemical analysis - iodine experiments
Jaana Rantanen, Technician	VTT	Chemical analysis - iodine experiments
Tuula Kajolinna, Engineer	VTT	Analysis of gaseous compounds - iodine experiments

Comprehensive and systematic validation of independent safety analysis tools (COVA)

Research organisation: VTT
Project manager: Seppo Hillberg, VTT

Person	Org.	Tasks
Seppo Hillberg, MScTech	VTT	Project manager, thermal-hydraulic analysis, nuclear power plant modelling, international cooperation/communication through research programmes (USNRC/CAMP)
Ismo Karppinen, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling, international cooperation/communication through research programmes (OECD/WGAMA, PKL3 & HYMERES)
Jarno Kolehmainen, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling, containment modelling,

		international cooperation/communication through research programmes (OECD/HYMERES)
Pekka Urhonen, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling
Ari Silde, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling, containment modelling
Joona Kurki, LicTech	VTT	international cooperation/communication through research programmes (FONESYS & OECD/ATLAS)
Torsti Alku, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling, international cooperation/communication through research programmes (FONESYS)
Joona Leskinen, MScTech	VTT	thermal-hydraulic analysis, nuclear power plant modelling
Sampsa Lauerma, student of technology		Research trainee in the area of nuclear power plant modelling
Dmitry Skripnikov, student of technology	VTT	Research trainee in the area of nuclear power plant modelling
Tatu Hovi, student of technology	VTT	Research trainee in the area of nuclear power plant modelling

Couplings and instabilities in reactor systems (INSTAB)

Research organisation: LUT
Project manager: Markku Puustinen, LUT

Person	**Org.**	**Tasks**
Markku Puustinen, MScTech	LUT	Project manager, Experiment planning and analysis
Jani Laine, MScTech	LUT	Deputy project manager, Experiment analysis, Data conversion
Heikki Purhonen, DrTech	LUT	International tasks, Experiment planning
Vesa Riikonen, MScTech	LUT	Data acquisition, Experiments
Antti Räsänen, MScTech	LUT	Instrumentation, Data acquisition, Data conversion, Visualization, Control systems, Experiments
Vesa Tanskanen, DrTech	LUT	Computer simulations, Experiments
Arto Ylönen, Dr. sc. ETH Zurich	LUT	Assessment of measurement techniques, Experiment analysis
Harri Partanen, Engineer	LUT	Designing of test facilities, Experiments
Hannu Pylkkö, Technician	LUT	Construction, operation and maintenance of test facilities, Experiments
Ilkka Saure, Technician	LUT	Construction, operation and maintenance of test facilities, Experiments

Lauri Pyy, MScTech	LUT	Assessment of measurement techniques, Experiments
Joonas Telkkä, MScTech	LUT	Assessment of measurement techniques, Experiments
Elina Hujala, MScTech	LUT	Pattern recognition, Experiment analysis
Eetu Kotro, MScTech	LUT	Construction, operation and maintenance of test facilities, Instrumentation, Data acquisition, Data conversion, Visualization, Control systems

Integral and separate effects tests on thermal-hydraulic problems in reactors (INTEGRA)

Research organisation: LUT
Project manager: Vesa Riikonen, LUT

Person	Org.	Tasks
Vesa Riikonen, MScTech	LUT	Project manager, experiment planning, analysis and reporting, data acquisition
Markku Puustinen, MScTech	LUT	Deputy project manager
Heikki Purhonen, DTech	LUT	International tasks
Juhani Hyvärinen, DTech	LUT	International tasks
Virpi Kouhia, MScTech	LUT	APROS code modeling and calculations, system planning
Otso-Pekka Kauppinen, MScTech	LUT	TRACE code modeling and calculations
Jani Laine, MScTech	LUT	Internal report reviewer
Antti Räsänen, MScTech	LUT	Instrumentation, data acquisition, process control, experimental work
Harri Partanen, Engineer	LUT	Designing of test facilities
Hannu Pylkkö, Technician	LUT	Construction, operation and maintenance of test facilities, experimental work
Ilkka Saure, Technician	LUT	Construction, operation and maintenance of test facilities, experimental work
Eetu Kotro, MScTech	LUT	Construction, operation and maintenance of test facilities, experimental work

Nuclear Criticality and Safety Analyses Preparedness at VTT (KATVE)

Research organisation: VTT
Project manager: Tuomas Viitanen, VTT

Person	Org.	Tasks
Tuomas Viitanen, D.Sc.(Tech.)	VTT	Project management, Neutron dosimetry, International co-operation, Burnup credit

Pauli Juutilainen, M.Sc.	VTT	Validation package, Burnup credit
Ville Valtavirta, M.Sc.	VTT	Validation package
Toni Kaltiaisenaho, B.Sc.	VTT	Gamma transport in Serpent
Jaakko Leppänen, D.Sc.(Tech.)	VTT	Source terms, Gamma transport in Serpent
Antti Räty, MPhys	VTT	Activation analysis, QA Documentation & scientific publication
Petri Kotiluoto, PhD	VTT	International co-operation, Activation analysis
Risto Huhtanen, Lic.Tech.	VTT	Heat transfer in dry storage cask
Timo Pättikangas, D.Sc.(Tech.)	VTT	Heat transfer in dry storage cask
Juho Peltola, M.Sc.	VTT	Heat transfer in dry storage cask

Development of a Monte Carlo based calculation sequence for reactor core safety analyses (MONSOON)

Research organisation: VTT
Project manager: Jaakko Leppänen, VTT

Person	**Org.**	**Tasks**
Jaakko Leppänen, D.Sc.	VTT	Project manager, head developer of the Serpent code, development of methods for spatial homogenization and automated calculation sequence.
Ville Valtavirta, M.Sc.	VTT	Deputy project managed, Serpent developer, development of methods for assembly burnup calculations with fuel temperature feedback.
Maria Pusa, D.Sc.	VTT	Serpent developer
Tuomas Viitanen, D.Sc.	VTT	Serpent developer
Toni Kaltiaisenaho, B.Sc.	VTT	Serpent developer
Ville Sahlberg, B.Sc.	VTT	Serpent user, group constant generation for TRAB3D reactor simulator code.

Neutronics, burnup and nuclear fuel (NEPAL15)

Research organisations: Aalto University
Project manager: Jarmo Ala-Heikkilä, Aalto

Person	Org.	Tasks
Jarmo Ala-Heikkilä, D.Sc.(Tech.)	Aalto	Project manager
Seppo Sipilä, D.Sc.(Tech.)	Aalto	Deputy project manager
Aarno Isotalo, D.Sc.(Tech.)	Aalto	Computer simulations, analytical methods
Markus Ovaska, M.Sc.	Aalto	Computer simulations, analytical methods
Olli Hyvönen, B.Sc.	Aalto	Computer simulations, analytical methods
Pertti Aarnio, D.Sc.(Tech.)	Aalto	Internal support group
Rainer Salomaa, Prof.Emer.	Aalto	Internal support group
Mikko Alava, Prof.	Aalto	Internal support group
Filip Tuomisto, Prof.	Aalto	Internal support group
Eric Dorval, M.Sc.(Tech.)	Aalto	Internal support group
Risto Vanhanen, M.Sc.(Tech.)	Aalto	Internal support group

Development and validation of CFD methods for nuclear reactor safety assessment (NURESA)

Research organisations: VTT, Aalto, LUT Energy, Fortum
Project manager: Dr Timo Pättikangas, VTT

Person	Org.	Task
Timo Pättikangas, D.Sc.	VTT	Project manager, CFD modelling of sprays
Risto Huhtanen, Lic. Tech.	VTT	CFD modelling of HYMERES stratification experiment
Juho Peltola, M.Sc.	VTT	Two-phase CFD solver and model development for boiling heat transfer and validation
Timo Siikonen, Prof.	Aalto	CFD model development and validation
Juhaveikko Ala-Juusela, M.Sc.	Aalto	CFD modelling of heat transfer in fuel rod bundles
Vesa Tanskanen, D.Sc.	LUT	CFD model development and validation for direct-contact condensation
Giteshkumar Patel, M.Sc.	LUT	CFD model development and validation for direct-contact condensation
Karoliina Ekström, M.Sc.	Fortum	Validation of CFD solver for heat transfer in fuel rod bundles (in-kind contribution)
Timo Toppila, M.Sc.	Fortum	Validation of CFD solver for heat transfer in fuel rod bundles (in-kind contribution)

Physics and chemistry of nuclear fuel (PANCHO)

Research organisation: VTT
Project manager: Ville Tulkki, VTT

Person	Org.	Tasks
Asko Arkoma, MSc (Tech)	VTT	Analysis of reactivity initiated accidents and loss of coolant accidents, implementation and development of SCANAIR code.
Kirsti Helosuo	VTT	Assisting in leaching experiments
Timo Ikonen, D.Sc. (Tech)	VTT	FINIX development
Joonas Kättö, MSc (Tech)	VTT	Improvement of validation database system, FINIX development
Seppo Kelppe, MSc (Tech)	VTT	Senior advisor
Tiina Lavonen, MSc	VTT	Assisting in leaching experiments.
Henri Loukusa, MSc (Tech)	VTT	FINIX mechanical models development
Emmi Myllykylä, MSc	VTT	Leaching experiments on Thoria fuel.
Rami Pohja, MSc (Tech)	VTT	Cladding mechanical models, planning of experimental campaign
Ville Tulkki, D.Sc (Tech)	VTT	Development of cladding creep models, project manager.

Safety analyses for dynamical events (SADE)

Research organisation: VTT
Project manager: Elina Syrjälahti, VTT

Person		Task
Syrjälahti Elina, MSc (Tech)	VTT	Project manager, HEXTRAN-SMABRE, International co-operation
Hovi Tatu, Research trainee	VTT	Auxiliary codes for HEXTRAN-SMABRE
Hovi Ville, MSc (Tech)	VTT	3D thermal hydraulics
Hämäläinen Anitta, DSc (Tech)	VTT	HEXTRAN-SMABRE-PORFLO
Ilvonen Mikko, LicSc (Tech)	VTT	3D thermal hydraulics
Räty Hanna, MSc (Tech)	VTT	Deputy project manager, neutronics, International co-operation
Sahlberg Ville, Research trainee	VTT	Neutronics
Taivassalo Veikko, PhLic (Phys)	VTT	3D thermal hydraulics

Uncertainty and sensitivity analyses for reactor safety (USVA)

Research organization: VTT, Aalto
Project manager: Maria Pusa, VTT

Person	Org.	Tasks
Maria Pusa, D.Sc.	VTT	Project manager starting in October 2015. Uncertainty analysis of reactor physics calculation sequences.
Timo Ikonen, D.Sc.	VTT	Project manager 1/2015-9/2015. Statistical uncertainty and sensitivity analyses, fuel performance calculations.
Asko Arkoma, M.Sc.	VTT	Sensitivity analysis on EPR LBLOCA simulation data
Elina Syrjälahti, M.Sc.	VTT	Uncertainty analysis of reactor dynamical simulations.
Aapo Taavitsainen	Aalto	Uncertainty analysis of multi-physics calculations.
Risto Vanhanen, M.Sc.	Aalto	Supporting role in 2015. Instructor of the special assignment and Master's thesis of Aapo Taavitsainen.

Experimental Studies on Projectile Impacts Against Concrete Structures (ESPIACS)

Research organisation: VTT
Project manager: Ari Vepsä, VTT

Person	Org.	Tasks
Ari Vepsä, MScTech	VTT	Project management, Analysis and reporting of test results
Kalle Raunio, MScTech	VTT	Modification of the data acquiring software
Alexis Fedoroff, Msc. Tech	VTT	Numerical analyses, designing of tests

FIre Risk Evaluation and Defence-in-Depth (FIRED)

Research organisation: VTT, Aalto
Project manager: Topi Sikanen, VTT

Person	Org.	Tasks
Topi Sikanen, MScTech	VTT	Project management, FDS development and validation
Anna Matala, DrTech	VTT	Project management, Pyroplot development, Investigation of cable ageing
Tuula Hakkarainen, DrTech	VTT	Investigation of cable ageing
Antti Paajanen, MSc	VTT	Atomistic simulations of novel flame

		retardants, Pyroplot development
Jukka Vaari, DrTech	VTT	Atomistic simulations of novel flame retardants
Simo Hostikka, DrTech	Aalto	Project management, Barrier performance assessment with Fire-CFD, Interdiciplinary depth of defence
Aisha Ambreen, trainee	Aalto	FEM implementation of 1D-heat conduction
Pekka Huhtala, trainee	Aalto	FEM implementation of reactive 1D heat conduction and validation

Analysis of fatigue and other cumulative ageing to extend lifetime (FOUND)

Research organisation: VTT, Aalto
Project manager: Juha Kuutti, VTT

Person	**Org.**	**Tasks**
Juha Kuutti, M.Sc. Tech.	VTT	Project management; WP4 – Fatigue and crack growth caused by thermal loads
Otso Cronvall, Lic. Tech.	VTT	WP1 – Probabilistic structural safety assessment of NPP piping systems; WP2 – Susceptibility of BWR RPV internals to degradation mechanisms; WP5 – Development of RI-ISI methodologies
Antti Timperi, M.Sc. Tech.	VTT	WP1 – Probabilistic structural safety assessment of NPP piping systems; WP4 – Fatigue and crack growth caused by thermal loads; WP6 – Dynamic loading of NPP piping systems
Jouni Alhainen, M.Sc. Tech.	VTT	WP3 – Fatigue usage of primary circuit
Esko Arilahti, Res. Eng.	VTT	WP3 – Fatigue usage of primary circuit
Tommi Seppänen, M.Sc. Tech	VTT	WP3 – Fatigue usage of primary circuit
Jussi Solin, M.Sc. Tech	VTT	WP3 – Fatigue usage of primary circuit
Tero Tyrväinen, M.Sc. Tech	VTT	WP5 – Development of RI-ISI methodologies
Qais Saifi, M.Sc. Tech	VTT	WP5 – Development of RI-ISI methodologies
Ahti Oinonen, Dr. Tech.	VTT	WP5 – Development of RI-ISI methodologies
Aapo Ristaniemi, M.Sc. Tech	VTT	WP6 – Dynamic loading of NPP piping systems
Iikka Virkkunen, Adj. Prof.	Aalto	WP7 – Residual stress relaxation in BWR NPPs
Harri Toivonen, M.Sc. Tech	Aalto	WP7 – Residual stress relaxation in BWR NPPs

Long term operation aspects of structural integrity (LOST)

Research organisation: VTT
Project manager: Sebastian Lindqvist, VTT

Person	Org.	Tasks
Sebastian Lindqvist, MScTech	VTT	Project management, Report on eta factor, Conference paper about experimental characterisation of dissimilar metal welds interface region
Kim Wallin, Research professor	VTT	Contribution to ASTM Committee E08 Fatigue and Fracture executive committee in May 2015 and November 2015
Päivi Karjalainen-Roikonen, MScTech	VTT	The effect of temperature on ductile tearing resistance

Mitigation of cracking through advanced water chemistry (MOCCA)

Research organisation: VTT, University of Chemical Technology and Metallurgy (BG), Fortum Loviisa NPP
Project manager: Timo Saario, VTT

Person	Org.	Tasks
Timo Saario, D.Sc. (Tech)	VTT	Project management, data analysis, reports, scientific publication writing
Konsta Sipilä, MSc (Tech)	VTT	Experiments on effects of ODA, scientific publication writing
Essi Jäppinen, MSc (Tech)	VTT	Experiments on magnetite surface charge, scientific publication writing
Tiina Ikäläinen, BSc (Tech)	VTT	Water chemistry control, grab sample analysis
Seppo Peltonen, BSc (Tech)	VTT	Experimental design
Martin Bojinov, Prof., D.Sc. (Tech)	UCTM	Corrosion modelling, scientific publication writing
Sari Järvimäki, MSc (Tech)	Fortum	Plant data on N_2H_4 and ODA, scientific publication writing

Numerical methods for external event assessment improving safety (NEST)

Research organisation: VTT
Project manager: Arja Saarenheimo, VTT

Person	Org.	Tasks
Arja Saarenheimo, LicTech	VTT	Task 3. Project management, Task 2.2 Development of modelling and calculation methods for impact loaded reinforced

		concrete structures. Task 2.3 Calculation methods for induced vibrations in rc structures
Vilho Jussila, MScTech	VTT	Task 1.2 Developing the modelling technique and calibration modelling
Ludovic Fülöp, DrTech	VTT	Task 1.3 Scenario modelling for existing locations
Jouni Saari	ÅF consult	Task 1.3 Scenario modelling for existing locations
Marianne Malm	ÅF consult	Task 1.3 Scenario modelling for existing locations
Piritta Varis, MScTech	VTT	Task 2.1 Aircraft impact load simulation
Kim Calonius, MScTech	VTT	Task 2.2 Development of modelling and calculation methods for impact loaded reinforced concrete structures. Task 2.3 Calculation methods for induced vibrations in rc structures Task 2.4. Numerical studies on ageing of pre-stressed rc containment.
Markku Tuomala, prof. emeritus	-	Task 2.2 Development of modelling and calculation methods for impact loaded reinforced concrete structures. Task 2.3 Calculation methods for induced vibrations in rc structures

Thermal ageing and EAC research for plant life management (THELMA)

Research organisation: VTT, Aalto
Project manager: Ulla Ehrnstén, VTT

Person	Org.	Tasks
Ulla Ehrnstén, MScTech	VTT	Project management, International co-operation, mentoring
Mykola Ivanchenko, DrTech	VTT	FEG TEM investigations of thermally aged weld metal and cast SS
Autio Juha-Matti, MSc	VTT	Evaluation of martensite detection methods FEG-SEM investigations on thermally aged materials
Väisänen Pasi, technician	VTT	Autoclave testing
Moilanen Pekka, DrTech	VTT	Design of autoclave parts for testing (MICRIN), supervision of testing
Tapper Unto, MSc	VTT	TEM-investigations of thermally aged Alloy 690
Hurley Caitlin	VTT	INCEFA+ PM at VTT
Mattila Marketta	VTT	Metallography specimen preparation and water chemistry responsible in autoclave tests
Roman Mouginot, M. Sc	Aalto	Investigations on thermal ageing of Alloy

		690, thesis worker
Hannu Hänninen, prof.	Aalto	Knowledge transfer and international co-operation
Risto Ilola	Aalto	Aalto PM

NDE of NPP primary circuit components and concrete infrastructure (WANDA)

Research organisation: VTT, Aalto
Project manager: Tarja Jäppinen, VTT

Person	Org.	Tasks
Tarja Jäppinen, Lic.Sc.(Tech.)	VTT	Project management, Eddy current modelling and testing
Miguel Ferreira, D.Sc.(Tech.)	VTT	Debuty project manager, Concrete infrastructure
Esa Leskelä, M.Sc.(Tech.)	VTT	Ultrasonic applications
Jonne Haapalainen, M.Sc.(Tech.)	VTT	Ultrasonic modelling, POD
Antti Tuhti, B.Sc.(Tech.)	VTT	Ultrasonic applications
Ari Koskinen, M.Sc.(Tech)	VTT	Ultrasonic applications
Kari Lahdenperä, Lic.Sc.(Tech.)	VTT	Eddy current modelling and testing
Tuomas Koskinen, B.Sc.(Tech)	VTT	Ultrasonic applications, modelling, POD
Edgar Bohner, D.Sc.(Tech.)	VTT	Concrete infrastructure
Fahim Al-Neshawy D.Sc.(Tech.)	Aalto	Concrete infrastructure
Esko Sistonen D.Sc.(Tech.)	Aalto	Concrete infrastructure

Development of thermal-hydraulic infrastructure at LUT (INFRAL)

Research organisation: LUT
Project manager: Arto Ylönen, LUT

Person	Org.	Tasks
Arto Ylönen, Dr. sc. ETH Zurich	LUT	Project manager, advanced measuring devices and applications
Heikki Purhonen, DrTech	LUT	Planning and supervising
Antti Räsänen, MScTech	LUT	Instrumentation, data acquisition, process control, experimental work
Lauri Pyy, MScTech	LUT	PIV and WMS applications
Joonas Telkkä, MScTech	LUT	PIV and WMS applications
Elina Hujala, MScTech	LUT	Image recognition, HSC data analysis
Eetu Kotro, MScTech	LUT	Construction, operation and maintenance of test facilities, experimental work
Hannu Pylkkö, Technician	LUT	Construction, operation and maintenance of test facilities, experimental work
Ilkka Saure, Technician	LUT	Construction, operation and maintenance of test facilities, experimental work

Satu Tolvanen	LUT	Assisting in maintenance tasks

JHR collaboration & Melodie follow-up (JHR)

Research organisation: VTT
Project manager: Santtu Huotilainen, VTT

Person	**Org.**	**Tasks**
Santtu Huotilainen, M.Sc. (Tech)	VTT	Project management, participation in the JHR collaboration as a member of the materials working group (MWG), participation in the Melodie follow-up and preliminary data analysis
Petri Kinnunen, D.Sc. (Tech)	VTT	Participation in the JHR collaboration as the convenor of the technology working group (TWG)
Ville Tulkki, D.Sc. (Tech)	VTT	Participation in the JHR collaboration as a member of the fuel working group (FWG)

Renewal of Hot Cell Infrastructure (REHOT)

Research organisation: VTT
Project manager: Wade Karlsen, VTT

Person	**Org.**	**Tasks**
Wade Karlsen, Ph. D.	VTT	Project management
Seppo Tähtinen, MScTech	VTT	Deputy project mgr, hot laboratory design
Petteri Lappalainen, MScTech	VTT	Activated materials transport and waste handling topics; surveillance testing
Arto Kukkonen, Tech	VTT	Activated materials handling topics
Mika Jokipii, TechEng	VTT	Device procurement; remote handling
Ulla Ehrnstén, MScTech	VTT	SEM and failure analysis topics
Juha-Matti Autio, MScTech	VTT	SEM and EBSD procurement
Unto Tapper, MScTech	VTT	TEM and SEM equipment procurement
Mykola Ivanchenko, DrTech	VTT	Microscopy topics
Marketta Mattila, TechEng	VTT	Metallography and hardness testing of activated materials
Tapio Planman, MScTech	VTT	Fracture mechanics of activated materials
Esa Varis, MScTech	VTT	Mechanical testing of materials
Tuomo Lyytikäinen, TechEng	VTT	Mechanical testing of activated materials
Jari Lydman, TechEng	VTT	Mechanical testing of activated materials
Ilkka Palosuo	VTT	Mechanical testing of activated materials
Aki Toivonen, DrTech	VTT	Autoclave equipment for activated materials
Pasi Väisänen, Tech	VTT	Autoclave equipment for activated materials
Santtu Huotilainen, MScTech	VTT	Radioactive waste handling system design

Marko Paasila, Tech	VTT	Materials storage database system
Kimmo Rämö, Tech	VTT	Technical support
Pekka Moilanen, DrTech	VTT	Remote handling design solutions
Tommi Kekki, MScTech	VTT	Centre for Nuclear Safety radiation safety
Ulla Vuorinen, MSc	VTT	Radiochemistry and final repository materials testing facilities
Iiro Auterinen	VTT	Nuclear materials safeguard topics
Emmi Myllykylä, MSc	VTT	Radiochemistry, Clean room and HR-ICP-MS
Perttu Kivelä, MSc	VTT	Radiological monitoring systems
Timo Vanttola, DrTech	VTT	Centre for Nuclear Safety design topics
Irina Aho-Mantila, MScTech	VTT	Financial strategy; Technical writing
Jari Niemi, financial assistant	VTT	Project support services
Åsa Åvall, secretary	VTT	Project support services